CONFIDENTIAL VERSION

Title: Technical Assistance for the Development of a Common Information Model-Based Utility Data Management Strategy and Implementation Plan

Name of Grantee: Provincial Electricity Authority of Thailand

Name of Contractor/ U.S. Firm: Electric Power Research Institute (EPRI)

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ACKNOWLEDGMENTS

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This report describes research sponsored by EPRI

CONTENTS

EXECUTIVE SUMMARY

EPRI and Thailand's Provincial Electricity Authority (PEA) have joined together to transform the delivery of power to more than 20 million customers across Thailand through the development of a Common Information Model (CIM)-Based Utility Data Management Strategy and Implementation Plan. The project result is a plan to modernize PEA's electric grid using a CIM-based model to digitalize the grid. This action will facilitate the integration of advanced technologies to increase energy efficiency, lower costs for consumers, and support the utilization of renewable energy.

A PEA-specific high-level information architecture was developed and refined for effective grid model data management, through utilization and customization of its existing research. Existing data practices were documented to gain insight into problem areas, data management solution requirements and potential solution ideas to Create a 10-Year PEA GMM Vision aligns with the GMM Architecture with tools implemented to support GMM functions acting as the single source-of-truth for Grid Models. The direct implication being that any analytic function across the PEA enterprise which requires a Grid Model to perform any analytical function will rely on the GMM as its key data source. Data is required to be accurate and reliable within the GMM and updates are expected to appear in the GMM as soon as is practicable. Not only will the GMM solution be for the As-Built Grid Model system-of-record but also for historical versions of Grid Models. The GMM will be equipped with many different processing features which can modify Grid Models based on user requirements.

Through a conceptual sequencing of the system design and implementation based on the previously developed vision and IT architectural analysis, a GMM vision was created. The GMM vision describes a single-source-of-truth model-data management system that fundamentally changes a host of business processes within PEA dealing with how planning and operations system models are established and maintained. A general outline of an implementation plan was created which spans the first year of CIM implementation and provides the PEA staff with the tools and knowledge required to successfully undertake similar implementation planning activities in the future for subsequent implementation steps.

In addition to addressing the technical requirements of achieving the GMM vision, a regulatory analysis was performed to identify any relevant regulations that may impact project viability or prognosis to proceed. Examples of such regulations and/or compliance issues are cybersecurity/network security requirements, compliance with Information & Communication Technology infrastructure requirements, and any jurisdictional/operational requirements.

A developmental impact analysis of not only economic benefits to the Provincial Electric Authority of Thailand, but also beneficial impacts on human capacity development, supporting international data management best-practices, physical safety as well as positive social gains.

CHAPTER 1 PEA CIM PROJECT OVERVIEW

Project Purpose

EPRI and Thailand's Provincial Electricity Authority (PEA), through a U.S. Trade and Development Agency (USTDA) grant, have joined together to transform the delivery of power to more than 20 million customers across Thailand through the Development of a Common Information Model (CIM) Based Utility Data Management Strategy and Implementation Plan" (referred to in this report as the "PEA CIM" project). The project will result in plan to modernize PEA's electric grid using a CIM based model to digitalize PEA's grid, enabling the integration of advanced technologies that will increase energy efficiency, lower costs for consumers and support the utilization of renewable energy.

Project Structure

The project team consists of EPRI employees, US-based contractors, Thailand-based contractors, and PEA employees. The project teams are located across the United States and in Bangkok, Thailand. EPRI and its contractors will be providing overall Project Management and Subject Matter Expert (SME) services. The PEA team will provide information regarding current "As Is" processes, data, project support, project review, and Project Management Office (PMO) services. Digital Siam, the Thailand based contractor, will provide on the ground CIM training and support for documentation of PEA's existing data management practices. The end goal of the entire team will be to contribute towards the processes to provide PEA with updated information architecture and a data management strategy.

The work has been divided into 11 Tasks/Milestones. Each of the tasks has associated deliverables.

- Task 1: "Kick-Off" Meeting, Work Plan and Project Organization
- Task 2: PEA Information Architecture
- Task 3: The "As-Is" Technical and Operational Environment
- Task 4: PEA "Vision" Development
- Task 5: System Design and Implementation
- Task 6: Economic Analysis
- Task 7: CIM Deployment
- Task 8: Regulatory Review and Analysis
- Task 9: Development Impact Analysis
- Task 10: U.S. Export Analysis
- Task 11: Final Report

Full details of tasks and related deliverables are in the Appendix – Terms of Reference.

Project Kick-Off, Organization, and Work Plan Kick-off Meeting

The main objective and purpose of Task 1 was to establish a mutual understanding between EPRI, the subcontractors, and PEA. Activities added definition and clarity to the work to be performed under the TA CIM Project. PEA became more familiar with this CIM-based data management improvement initiative.

During February and March 2021, EPRI engaged directly with Digital Siam, the Bangkok-based subcontractor providing project support. EPRI also engaged with all the U.S.-based subcontractors outlined in the Terms of Reference. On-boarding of these subcontractors included the following steps:

- Finalizing subcontracts, including approval of employees not initially listed
- Setting up project software infrastructure and providing security guidelines
- Sorting out how to best accommodate language translation, time zone differences, and contextual/cultural perspectives
- Elaborating on content, tools, and processes available from previous grid model data management projects at EPRI
- Training project team members in how to adapt available tools to the PEA utility context

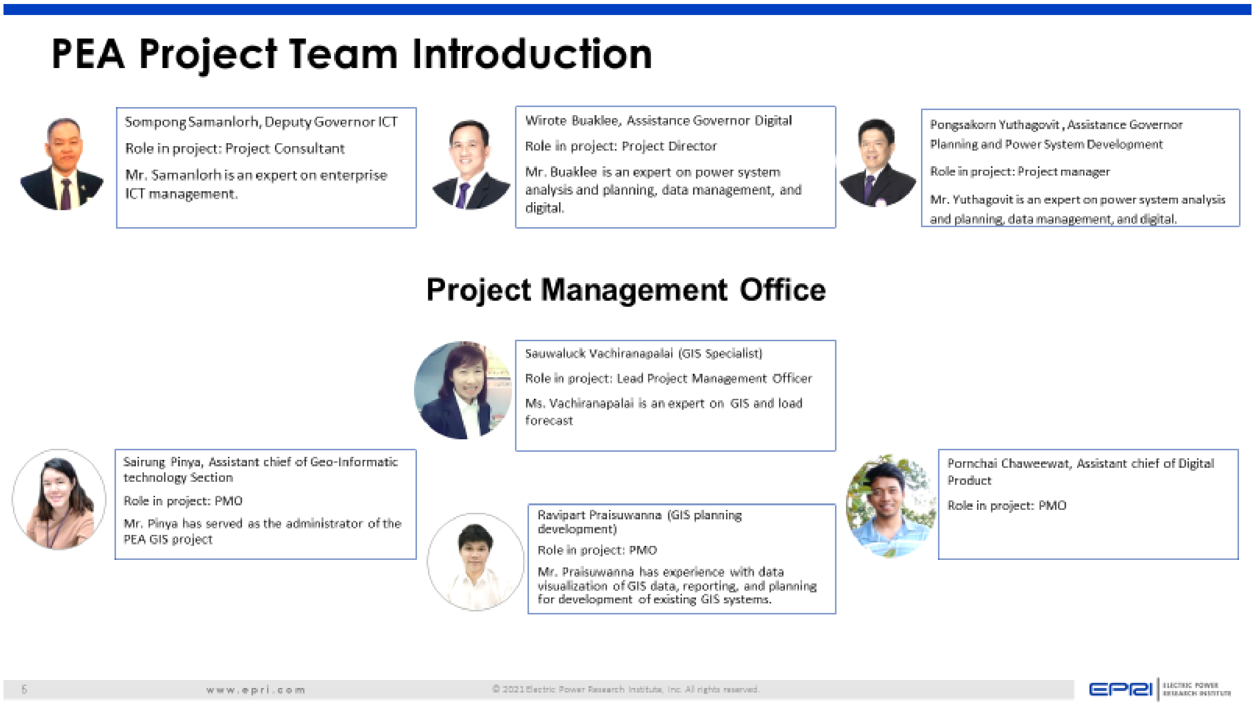
During April 2021 EPRI initiated calls directly with PEA staff, including PEA management and those in the project office. Activities included:

- Explaining the history and background of this research at EPRI.
- Understanding PEA leadership roles and responsibilities
- Getting to know the members of the PEA CIM project office at PEA headquarters
- Identifying PEA viewpoints on project benefits and project challenges
- Adjusting to the volatility of COVID pandemic impacts as PEA employees shifted from home-based work to the office and back

On May 19, 2021 (May 18 in the U.S.) the project kick-off meeting was completed. This 90-minute web conference was designed to provide maximum project understanding given the diversity of attendees and stakeholders at PEA. The following sections describe the key elements of the project kick-off.

Project Team

The kick-off meeting included introduction of PEA team and stakeholders, the EPRI team, Thailand-based subcontractor (Digital Siam), and US-based subcontractors (Britton Consulting, GridOptimize, Strateture, Waterbridge Consulting).


PEA Project Team Introduction
Sompong Samanlorh, Deputy Governor ICT
Role in project: Project Consultant
Mr. Samanlorh is an expert on enterprise ICT management.
Wirote Buaklee, Assistance Governor Digital
Role in project: Project Director
Mr. Buaklee is an expert on power system analysis and planning, data management, and digital.
Pongsakorn Yuthagovit, Assistance Governor Planning and Power System Development
Role in project: Project manager
Mr. Yuthagovit is an expert on power system analysis and planning, data management, and digital.
Project Management Office
Sauwaluck Vachiranapalai (GIS Specialist)
Role in project: Lead Project Management Officer
Ms. Vachiranapalai is an expert on GIS and load forecast
Sairung Pinya, Assistant chief of Geo-Informatic technology Section
Role in project: PMO
Mr. Pinya has served as the administrator of the PEA GIS project
Ravipart Praisuwanna (GIS planning development)
Role in project: PMO
Mr. Praisuwanna has experience with data visualization of GIS data, reporting, and planning for development of existing GIS systems.
Pornchai Chaweewat, Assistant chief of Digital Product
Role in project: PMO
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PEA Project Team Project Review Committee
Pantong Thinsatit, Power System Control and Operation Department Director
Role in project: Chairman of Project Review Committee
Mr. Thinsatit has worked for 29 years at PEA where he has serves as lead of both PEA's SCADA/EMS/DMS project and PEA's Smart Grid Pilot project. He is an expert in Power System Engineering.
Kallaya Srimoung, Manager of Power System Geo-Informatic Division
Role in project: Project Review Committee
Ms. Srimoung is an expert on GIS Data.
Anawat Sonkakul, Information and Communication System Development Planning Department Director
Role in project: Project Support Committee
Peera Rohitabutr, Deputy Manager of Substation Maintenance Division
Role in project: Project Review Committee
Chakphed Madtharad, Manager of Smart Grid Planning Division
Role in project: Project Support Committee
Mr. Madtharad is an expert on Smart Grid.
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PEA Project Team Project Support Committee
Nipont Kiatipuangchai, Digital Product Development Department Director
Role in project: Chairman of Project Support Committee
Mr. Kiatipuangchai is an expert on substation construction and maintenance engineering.
Rapeeporn Bhasabutra, Outage Management System Specialist
Potjana Panitnitinon, System Analysis, Design and Development Management
Ms. Panitnitinon is currently working on Customer Profiles and designing IT systems.
Nattawat Hansapipat, Assistant Manager of Power System Analysis and Planning Division
Mr. Hansapipat is expert on PEA GIS Data and Applications, and is part of the PEA CIM Working Group
Arnond Rotrugsa, Deputy Manager of Power System Maintenance Division
Joon Joongwong, Assistant Manager of System Design/Developer
Parkpoom Chinmai, Chief of Engineering Development Section
Sadet Baimard, Grid Operation Management Enterprise Architecture and performance
Mr. Baimard is an expert on improving of maintenance and decision making on grid operations.
Chaturon Kusonsong, Chief of Advanced Metering Infrastructure Section
Suksit Sripitchayaphan, SCADA Cybersecurity Engineer
Mr. Sripitchayaphan is an aspiring generalist who likes web technology, programming, DevOps, and IT/OT cybersecurity
Pawaphat Sukpadrew, GIS Data Provider (Internal)
Mr. Sukpadrew provides GIS Data across the PEA departments.
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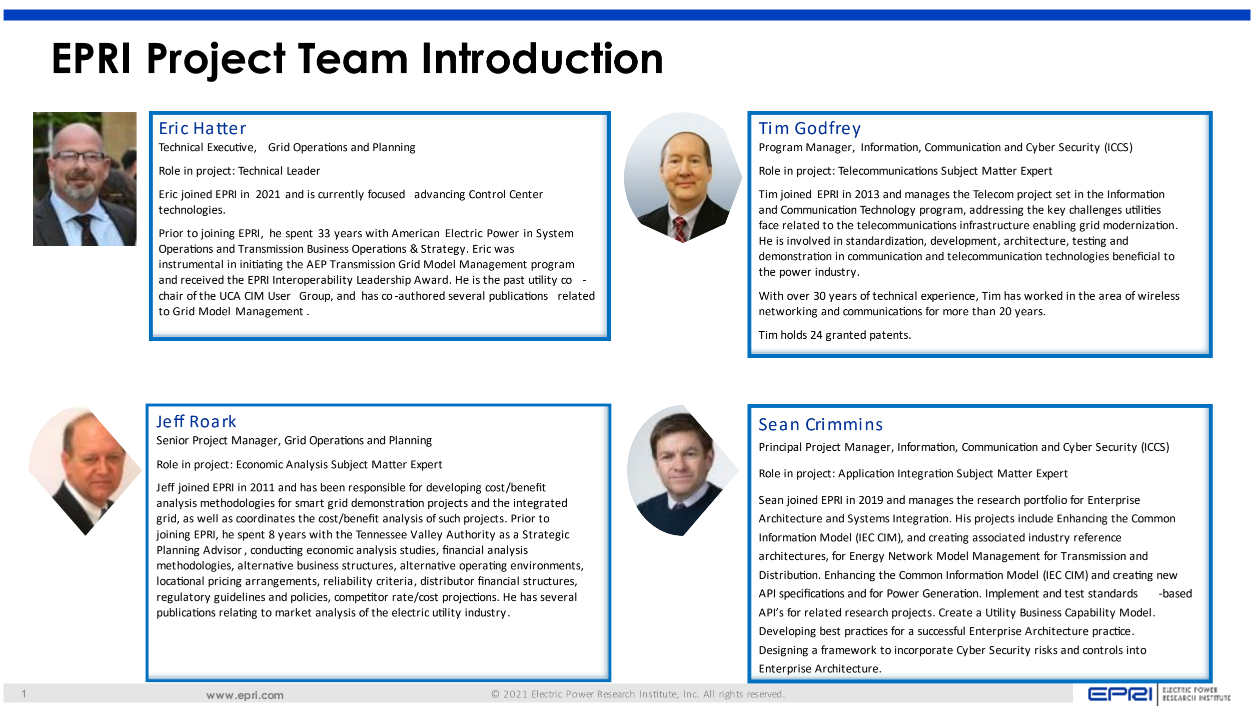
EPRI Project Team Introduction
Eric Hatter
Technical Executive, Grid Operations and Planning
Role in project: Technical Leader
Eric joined EPRI in 2021 and is currently focused advancing Control Center technologies.
Prior to joining EPRI, he spent 33 years with American Electric Power in System Operations and Transmission Business Operations & Strategy. Eric was instrumental in initiating the AEP Transmission Grid Model Management program and received the EPRI Interoperability Leadership Award. He is the past utility co-chair of the UCA CIM User Group, and has co-authored several publications related to Grid Model Management.
Tim Godfrey
Program Manager, Information, Communication and Cyber Security (ICCS)
Role in project: Telecommunications Subject Matter Expert
Tim joined EPRI in 2013 and manages the Telecom project set in the Information and Communication Technology program, addressing the key challenges utilities face related to the telecommunications infrastructure enabling grid modernization. He is involved in standardization, development, architecture, testing and demonstration in communication and telecommunication technologies beneficial to the power industry.
With over 30 years of technical experience, Tim has worked in the area of wireless networking and communications for more than 20 years.
Tim holds 24 granted patents.
Jeff Roark
Senior Project Manager, Grid Operations and Planning
Role in project: Economic Analysis Subject Matter Expert
Jeff joined EPRI in 2011 and has been responsible for developing cost/benefit analysis methodologies for smart grid demonstration projects and the integrated grid, as well as coordinates the cost/benefit analysis of such projects. Prior to joining EPRI, he spent 8 years with the Tennessee Valley Authority as a Strategic Planning Advisor, conducting economic analysis studies, financial analysis methodologies, alternative business structures, alternative operating environments, locational pricing arrangements, reliability criteria, distributor financial structures, regulatory guidelines and policies, competitor rate/cost projections. He has several publications relating to market analysis of the electric utility industry.
Sean Crimmins
Principal Project Manager, Information, Communication and Cyber Security (ICCS)
Role in project: Application Integration Subject Matter Expert
Sean joined EPRI in 2019 and manages the research portfolio for Enterprise Architecture and Systems Integration. His projects include Enhancing the Common Information Model (IEC CIM), and creating associated industry reference architectures, for Energy Network Model Management for Transmission and Distribution. Enhancing the Common Information Model (IEC CIM) and creating new API specifications and for Power Generation. Implement and test standards -based API's for related research projects. Create a Utility Business Capability Model. Developing best practices for a successful Enterprise Architecture practice. Designing a framework to incorporate Cyber Security risks and controls into Enterprise Architecture.
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EPRI Project Team Introduction continued

Matt Rylander, Principal Project Manager, Power System Studies

Role in project: Distribution Operations & Planning Subject Matter Expert

Matt's current research activities focus on utility distribution system issues. Additionally, research activities include the benefits/impacts from advanced inverters and other modern distribution system assets. Matt has several industry publications and jointly holds one patent.

Esther Amullen, Software Engineer/Scientist III, Information, Communication and Cyber Security (ICCS)

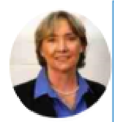
Role in project: Cyber Security Subject Matter Expert

Esther Amullen has a PhD in Computer and Information Systems Engineering. She conducts research and creates tools that support implementation of data driven security metrics and works with utilities to customize EPRI tools and metrics. She also creates guidelines and real-world use cases to enable utilities leverage AI for cyber security. Esther has several publications relating to cyber security.

Daniel Lowe, Engineer/Scientist III, Information, Communication and Cyber Security (ICCS)

Role in project: Interface Developer Subject Matter Expert

Daniel is involved in the software development of various projects related to CIM or DERMS. He also worked on updating IEC 61968-9, the new version of IEC 61968-100, collaborated with NREL on various DERMS projects (ECO-IDEA, FAST-DERMS, RTOPF) involving both CIM and MultiSpeak integration.



Laura McLemore, Project Operations Coordinator, Information, Communication and Cyber Security (ICCS)

Role in project: Project Operations Coordinator

Laura provides administrative and project support for the Director of the Information, Communication, and Cyber Security division. She also provides program operations support to both the Information and Communication Technology program and the Cyber Security for Power Delivery and Utilization program.

Digital Siam Project Team Introduction

Name: Dr. Choompol Boonmee

Role: Project Coordinator

Choompol has been a lecture at faculty of engineering, Thammasat university. He has experience with Interoperability and data standards.

Name: Dr. Chaiyant Boonmee

Role: Power System/CIM standard

Chaiyant has been a lecturer at faculty of engineering, Rajamangala University of Technology Suvarnabhumi. His research interests include power system and data standards.

Name: Mr. Sukarun Rangabpan

Role: IT Management

Sukarun has many years of experiences in information technology management including information system integration and electronic government interoperability framework (e-GIF)

Name: Mr. Kittirit Panchalee

Role: IT Integration

Kittirit has years of experiences in information system integration and electronic government interoperability framework (e-GIF).

Name: Ms. Sunet Boonmee

Role: EXIM & Economic development

Sunet has many years of experiences working around import/export and economic development and also has experiences in performing CIM research at PEA.

Name: Mr. Chaiyaprudi Sasananont

Role: Project Communication

Chaiyaprudi has years of experiences working with projects of information integration and human factor-based problems in interoperability developments

U.S. Subcontractor Project Team Introduction

James Horstman

Role in Project: Data Management Subject Matter Expert

James is working with EPRI on both the Grid Model Data Management project and Network Model Management project. He will be developing a reference architecture for grid model data management while providing architecture and project management services

James has extensive experience with development and implementation of large-scale information systems in areas such as business intelligence, GIS, work, asset and operations management.

Jay Britton

Role in Project: Network Model Management/CIM Subject Matter Expert

Jay will be helping EPRI with standardization of data models and development of the IEC TC57 CIM standards

Jay has several years of experience with various electric utilities with problem-solving and technology development.

Scott Coe

Role in Project: Distribution & Data Management Subject Matter Expert

Scott has worked with EPRI for several years in various projects normalizing international standards.

Scott has decades of experience in data modeling, serves as a board member of Peak Load Management Alliance and an active member of IEC Technical Committee 57. He has worked many organizations and companies around the world.

Mamta Kanzaria

Role in Project: Project Management Resource

Mamta will be helping EPRI with deliverable tracking and other PMO related tasks.

Mamta has several years of experience working with utility companies with deployment planning, test planning, governance, business requirements gathering, research analysis, software customization, and documentation.

Erik Shepard

Role in Project: Network Model Business Integration Subject Matter Expert

Erik has worked with EPRI for several years supporting both Grid Model Data Management and Geospatial Informatics research.

Erik has 20+ years of experience in the utility industry and 30+ years of experience spanning IT, OT and geoinformatics building roadmaps for and deploying OMS, DMS, SCADA, AMI, GIS, graphic work design, work and asset management, supply chain and mobility, as well as tools and processes for building and sustaining grid models.

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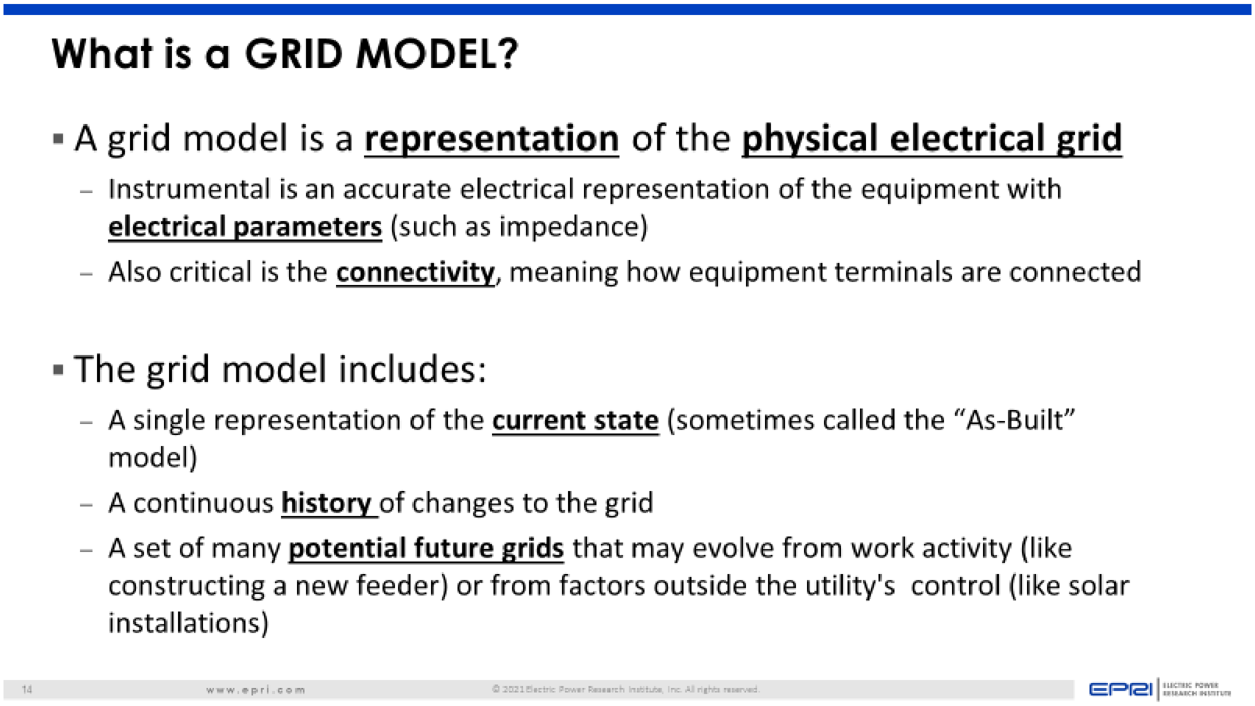
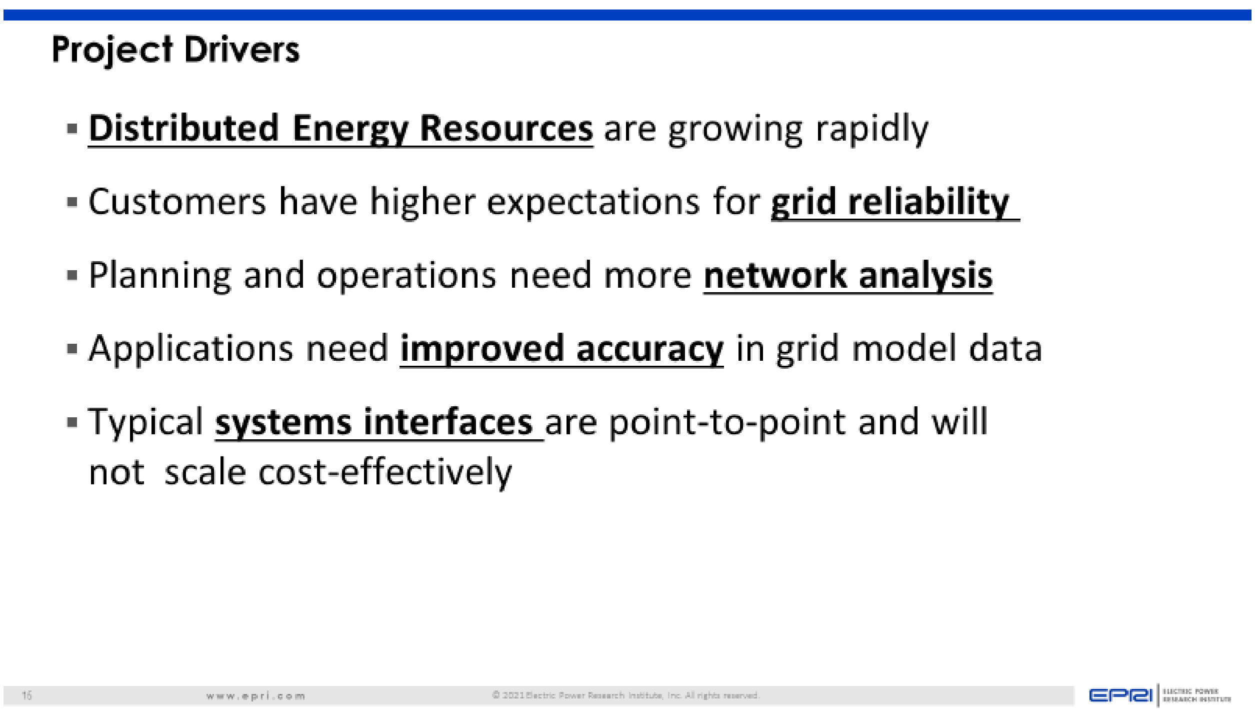
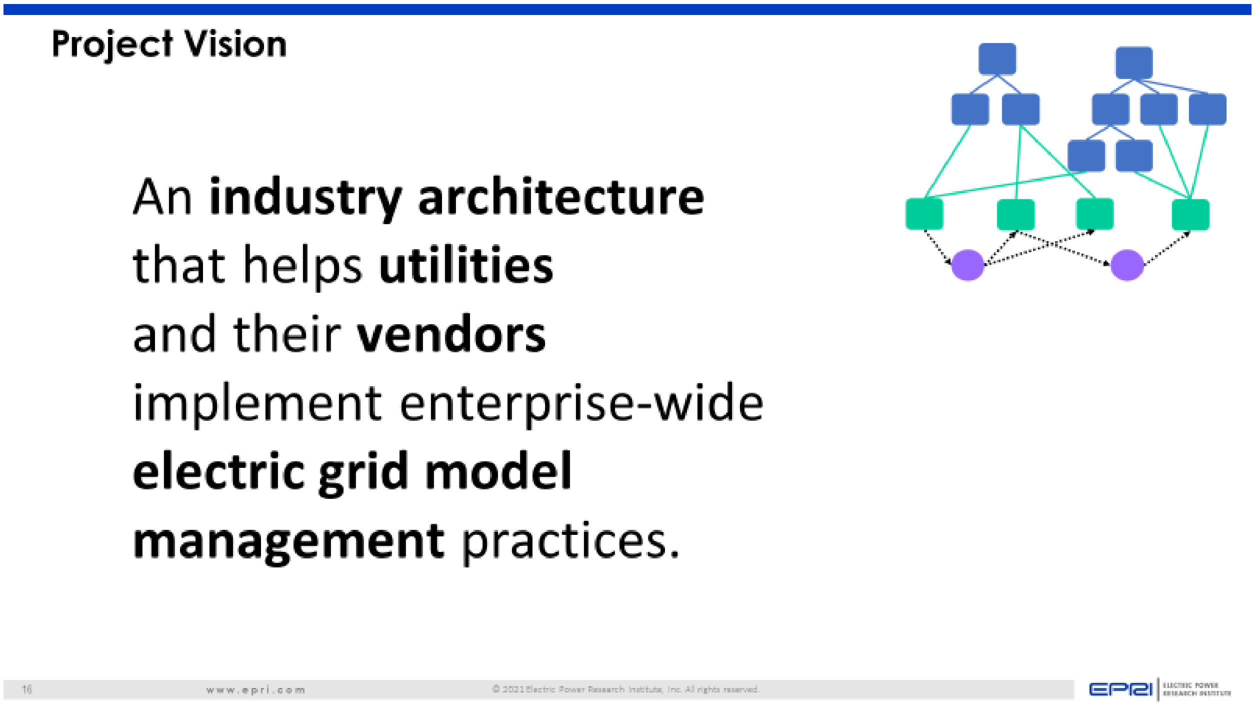
Project Business Drivers and Vision

Scott Coe (GridOptimize) provided more background on why utilities are focusing on grid model data management and the benefits that PEA can expect from the project.






Project Vision
An **industry architecture** that helps **utilities** and their **vendors** implement enterprise-wide **electric grid model management** practices.
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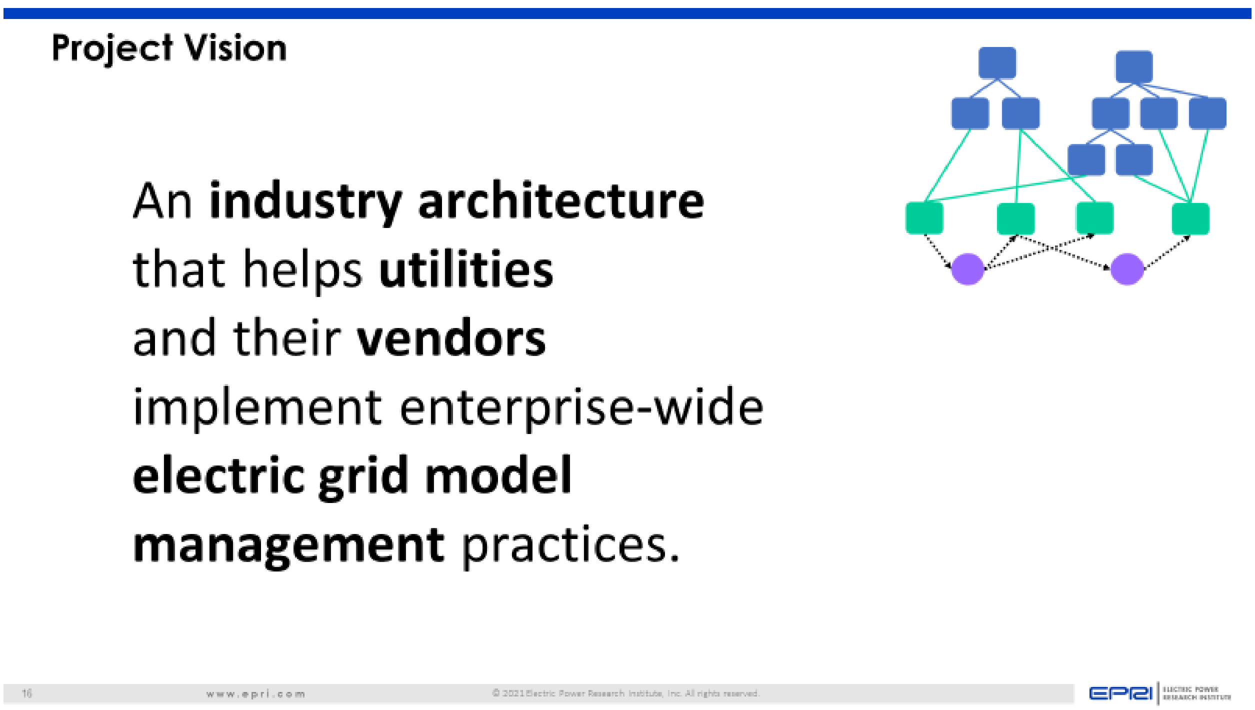
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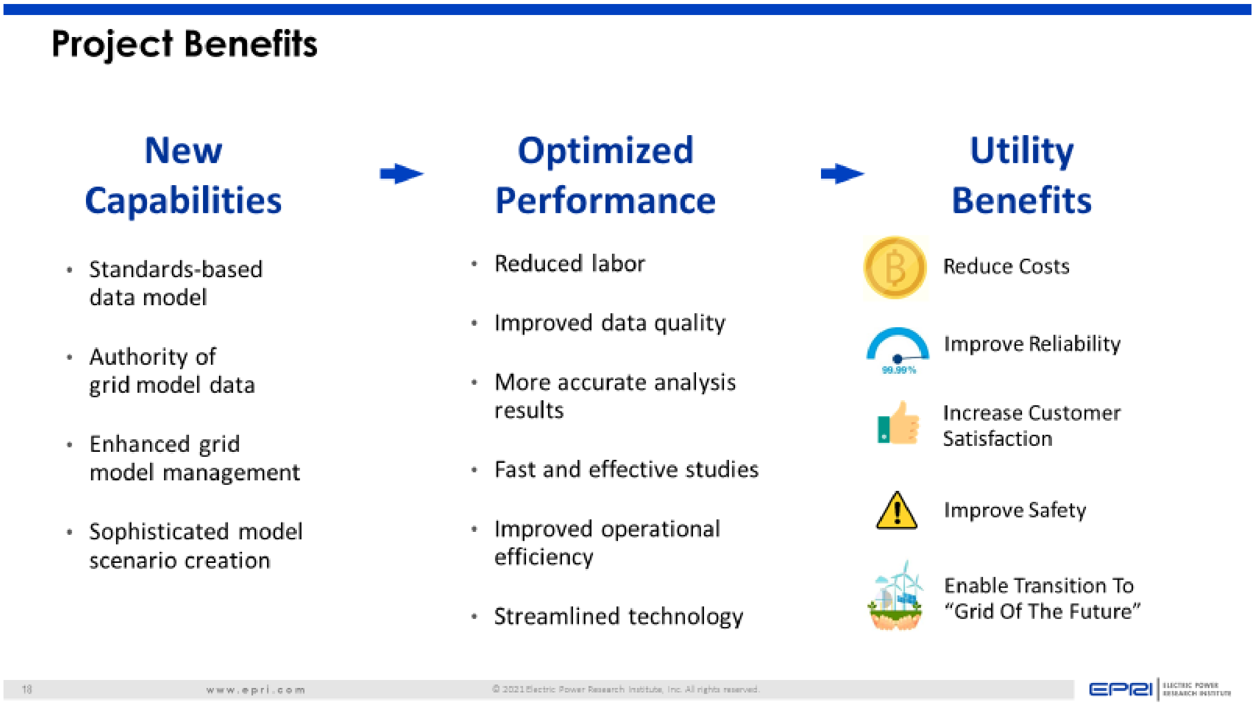
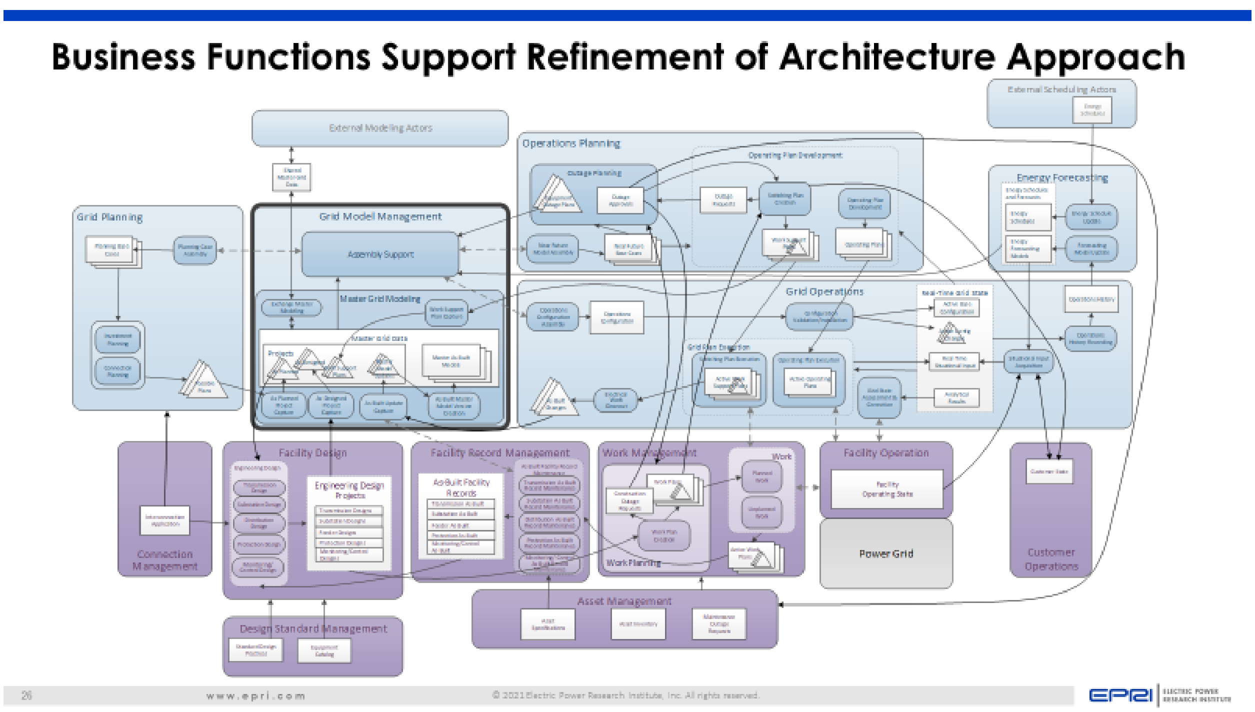


The presentation further highlighted the importance of applying a business function-based approach described in this slide.



Strategy for Review of PEA's Current Processes and Systems

Our Project Will Focus on These Departments

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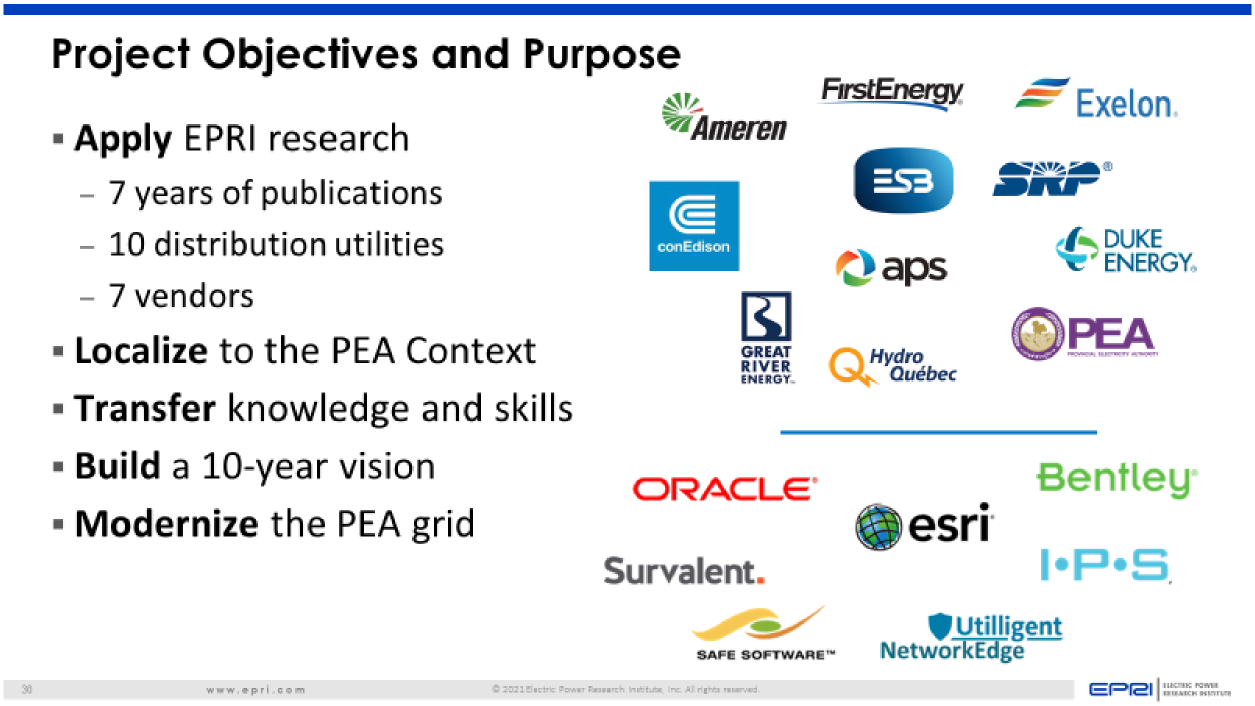
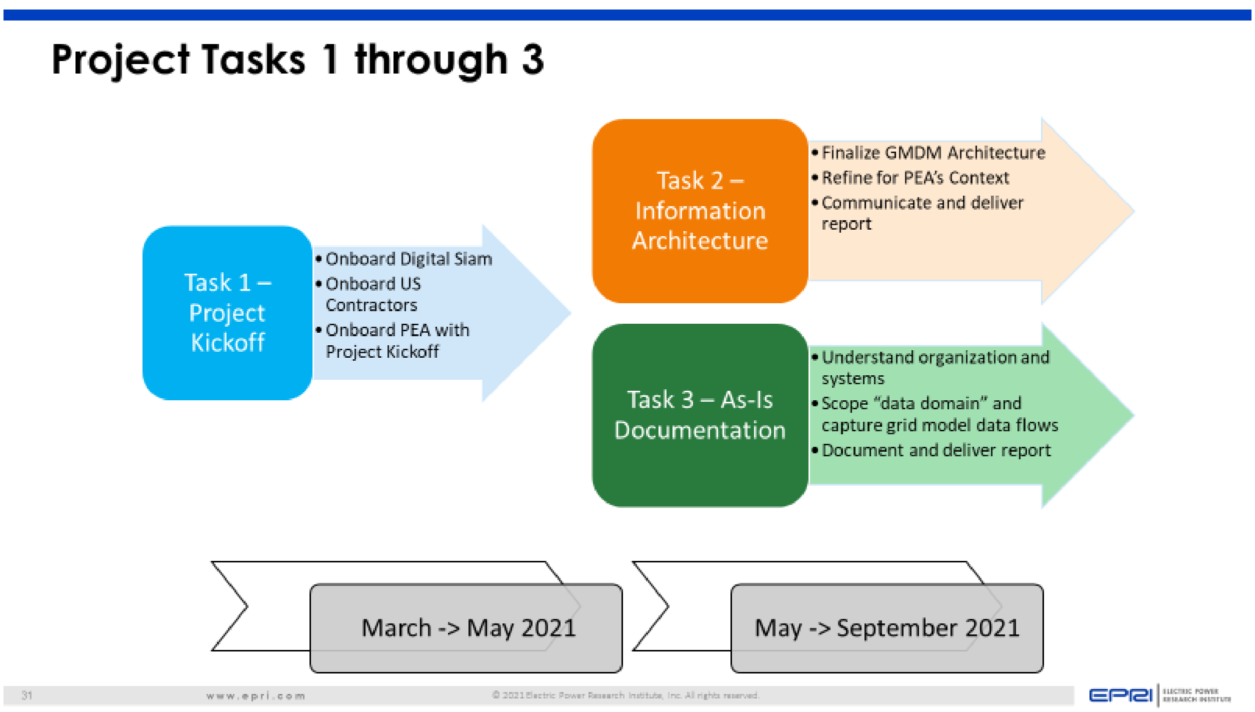
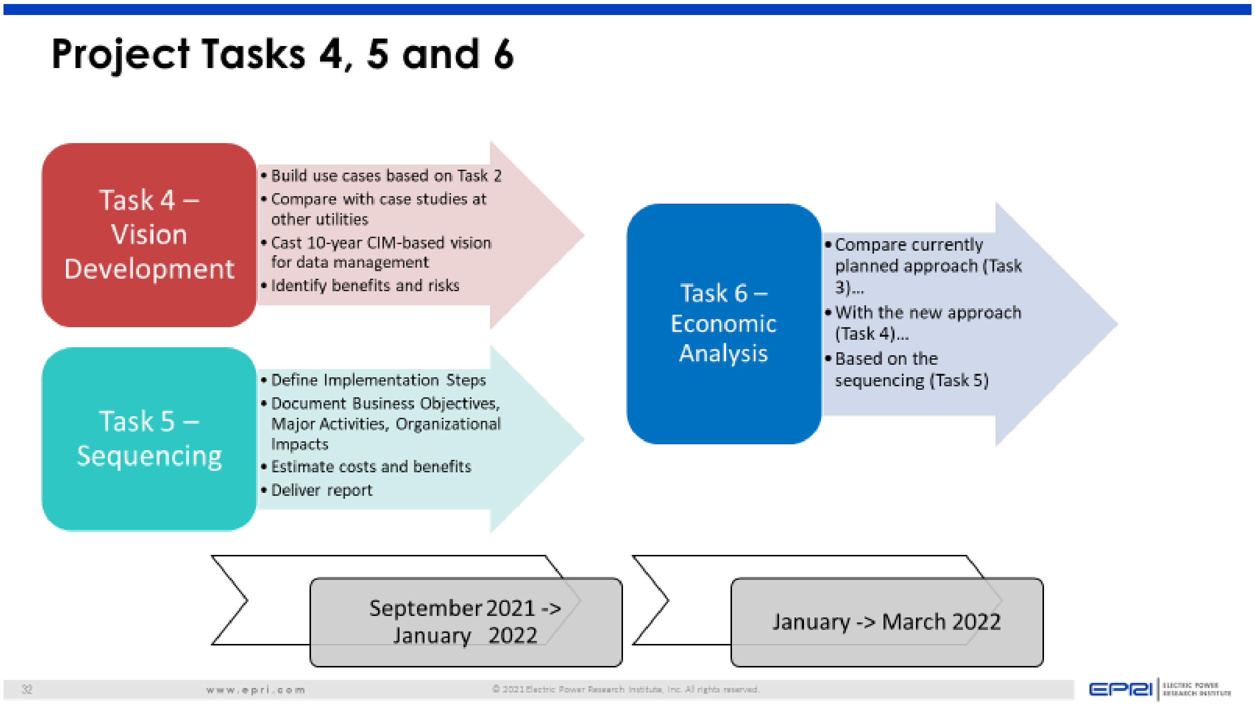
Project Objectives, Purpose and Timeline

Randy Rhodes, Project Manager, described the project objectives and purpose and walked through a high-level summary of tasks.






Project Tasks 4, 5 and 6
Task 4 – Vision Development
• Build use cases based on Task 2
• Compare with case studies at other utilities
• Cast 10-year CIM-based vision for data management
• Identify benefits and risks
Task 5 – Sequencing
• Define Implementation Steps
• Document Business Objectives, Major Activities, Organizational Impacts
• Estimate costs and benefits
• Deliver report
Task 6 – Economic Analysis
• Compare currently planned approach (Task 3)…
• With the new approach (Task 4)…
• Based on the sequencing (Task 5)
September 2021 -> January 2022
January -> March 2022
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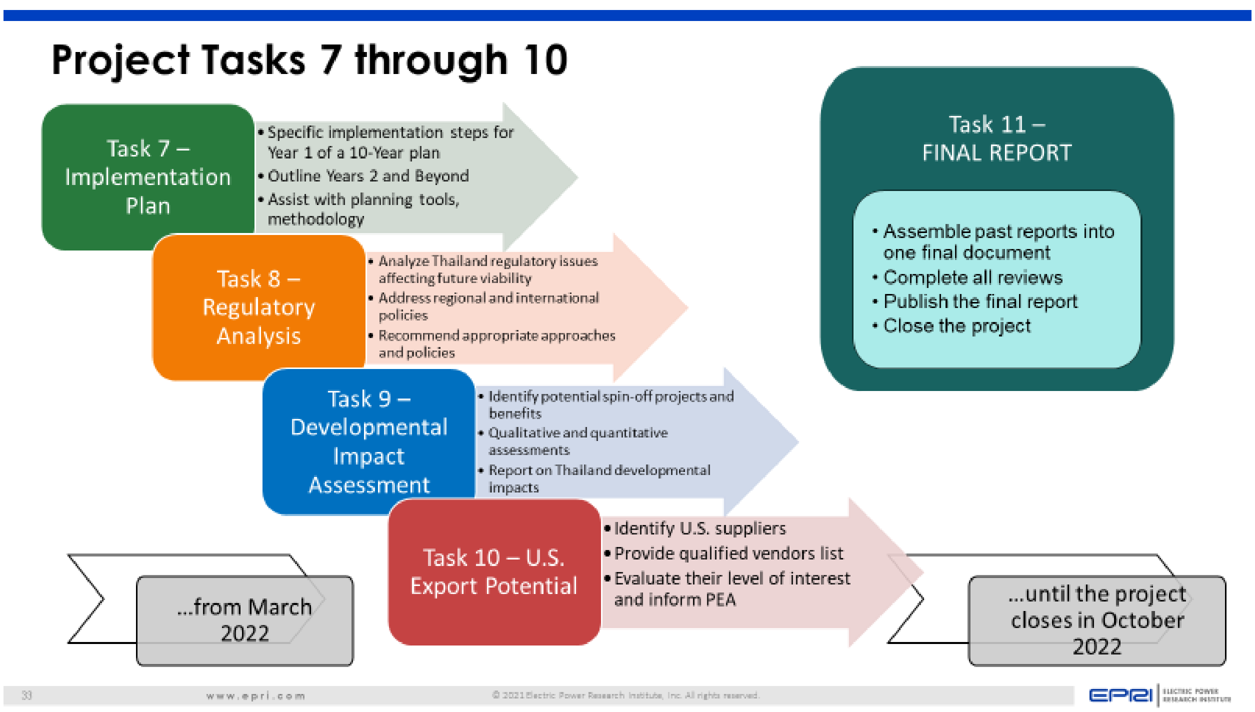
Project Tasks 7 through 10
Task 7 – Implementation Plan
• Specific implementation steps for Year 1 of a 10-Year plan
• Outline Years 2 and Beyond
• Assist with planning tools, methodology
Task 8 – Regulatory Analysis
• Analyze Thailand regulatory issues affecting future viability
• Address regional and international policies
• Recommend appropriate approaches and policies
Task 9 – Developmental Impact Assessment
• Identify potential spin-off projects and benefits
• Qualitative and quantitative assessments
• Report on Thailand developmental impacts
Task 10 – U.S. Export Potential
• Identify U.S. suppliers
• Provide qualified vendors list
• Evaluate their level of interest and inform PEA
Task 11 – FINAL REPORT
• Assemble past reports into one final document
• Complete all reviews
• Publish the final report
• Close the project
…from March 2022
…until the project closes in October 2022
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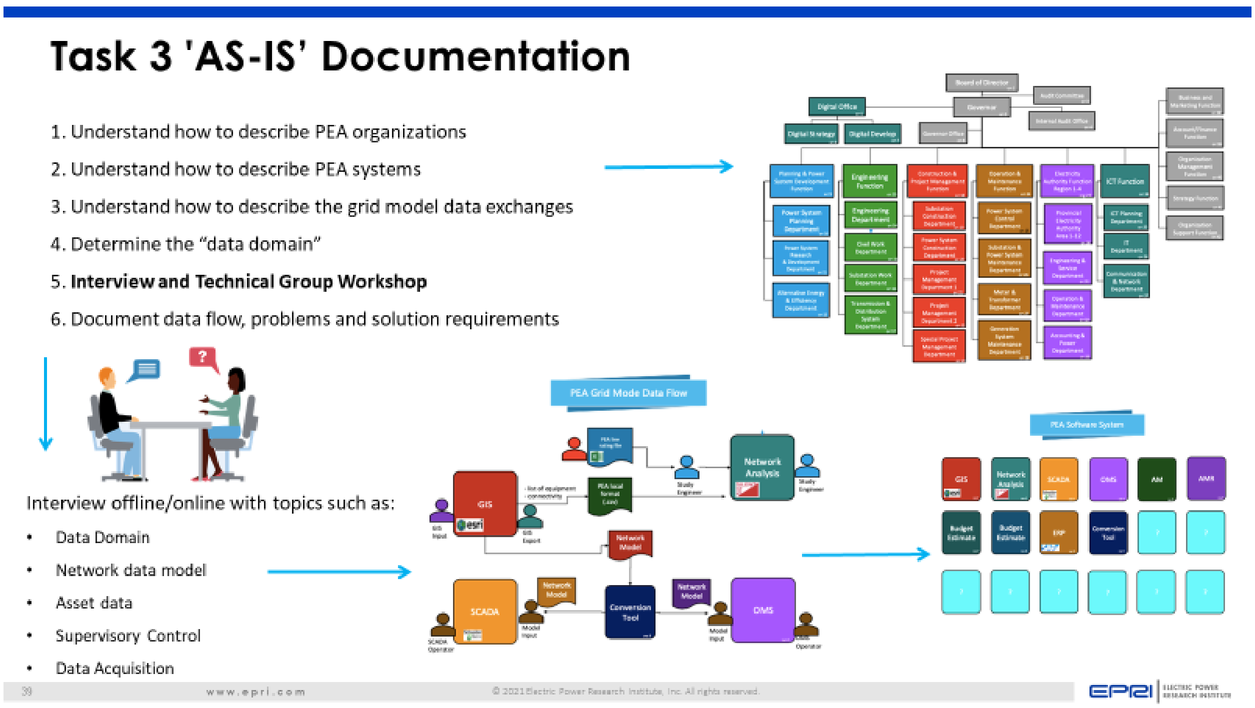
Upcoming Work

Randy Rhodes, EPRI PM, discussed the next phase of the project. Task 3 is critical for the project as it lays the foundation for later analysis. Its execution within the project timeline is critical to project success, therefore it requires particular focus from PEA and Digital Siam.

EPRI and GridOptimize conducted training sessions with Digital Siam staff to ensure their knowledge of the CIM model and the methods previously used by EPRI to obtain this type of information. This approach has been refined through numerous engagements with utilities funding the Grid Model Data Management project.

Dr. Choompol of Digital Siam explained the planned Task 3 approach as follows.

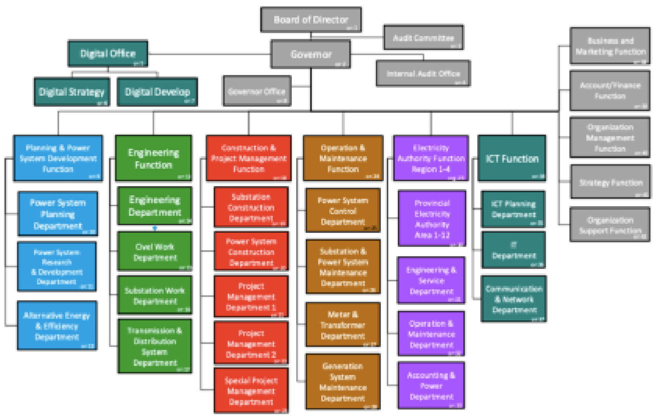


Task 3 Conduct Interviews and Technical Group Workshops

Conduct interviews and technical group workshops with subject matter experts in the various stakeholder work groups across PEA's organization to gather information on data flows and the business processes they enable within the selected "data domain."

1. Appointment-based interviews:
   - Work with PMO to make interview appointments.
2. Technical Group workshops:
   - To discuss and confirm the 'AS-IS' processes.

Planned Duration : June 1st – July 14th 1



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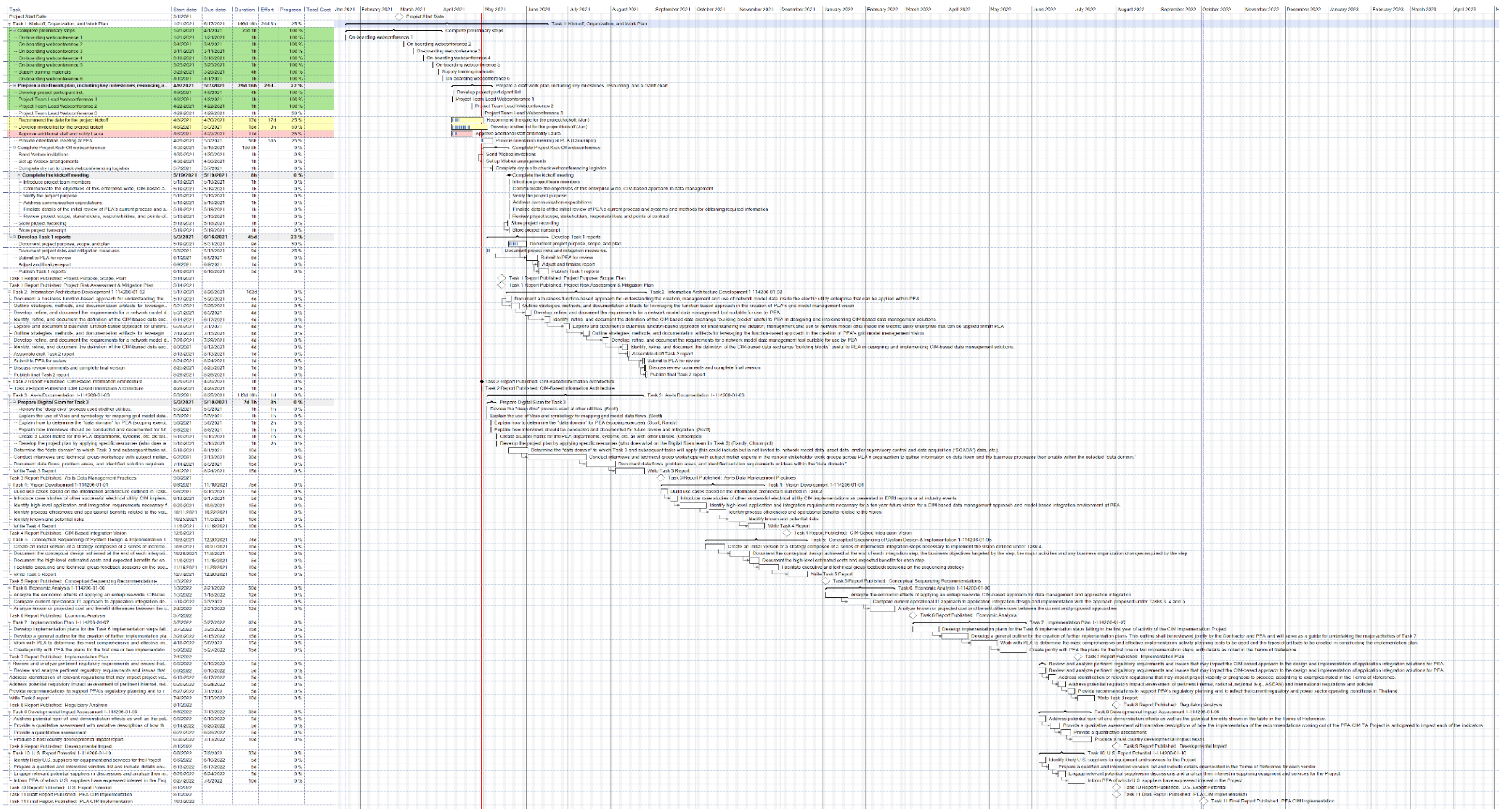
In parallel with Task 3, EPRI and its U.S contractors are working on Task 2. This includes finalizing the formal details of the GMDM Architecture (including Archimate-based model documentation); refining those documents to fit PEA's context; and preparing a Task 2 report. This Task 2 work will be completed during the coming months in parallel with Task 3.

PEA CIM Project Gantt Chart

Following is the initial Gantt chart for the project as discussed with PEA and the project team in mid-May. Estimated durations of each task are based on the forecast in the Terms of Reference, as a baseline. This project schedule will be updated monthly throughout the project.



Project Risk Assessment

The following risk analysis was compiled through discussions with various team members and input from Digital Siam and PEA. Each of the risks has been assigned a Probability and Risk level.

The **Probability Value** is associated with the likelihood of the risk occurring. The values are as follows:

Value	Definition
Not Likely	The chances of this risk occurring are not likely. A mitigation plan is not necessary, however should be discussed.
Likely	There is a fair chance of this risk occurring, however it is not as likely as a risk with a Very Likely probability yet greater than risk with a Not Likely probability. A mitigation plan should be planned to address risk.
Very Likely	There is a high probability that risks at this level this will occur. A mitigation plan should be documented and be ready to execute to ensure risk is addressed.

The **Risk Value** correlates to the amount of impact the particular risk will have on the project and its likelihood of impacting project deadlines. The values are as follows:

Value	Definition
Low	Low, the chances of this risk occurring are not likely. A mitigation plan is not necessary however should be discussed.
Medium	Medium, there is a fair chance of this risk occurring, however it is not as likely as a risk with a High probability yet greater than risk with a Low probability. A mitigation plan should be planned to address risk.
High	High, there is a likely chance that risks at this level this will occur. A mitigation plan should be documented and be ready to execute to ensure risk is addressed.

Currently identified risks along with their assessed values are shown in the table below. Nearly all mitigations are already in place and this assessment will be reevaluated monthly.

Risk 1: Language Barriers	
Description	Communications between EPRI, PEA, and Digital Siam may face challenges due to language barriers which may result in lack of clarity or confusion.
Assessment	Probability: **Very Likely** Risk Impact: **High**
Mitigation	• Mitigate risk with a Thai translator who is experienced with utility terminology. • Utilize translation tools (such as Google Translate, Lingvanex, etc.) to convert important meetings to Thai and vice versa. • Translate important video segments from related workshops, meetings, and forums (such as the GMDM Vendor Forum and the GMDM Perspectives web conference) into Thai for PEA and Digital Siam members to utilize for their tasks.

Risk 2: COVID Travel Restrictions	
Description	Due to COVID-19, travel from Thailand to USA and vice versa for kickoff, workshops, etc. will not happen.
Assessment	Probability: **Very Likely** Risk Impact: **Medium**
Mitigation	Risk can be mitigated via robust communication tools such as: • Web conferencing tools (utilizing video) • Slack for real time communications amongst all team members • Language translation tools for example, Slack has several business partners offering add-in products supporting multilingual translation) • Summary videos to “recap” and elaborate on important technical topics, so that they can be viewed by any team member on demand • Other communication tools used within Thailand, such as the LINE mobile app • Utilization of a shared, secure document repository (Box is the product supported at EPRI)
Risk 3: Time Zone Barriers	
Description	With an 11-hour time difference between EST and ICT, there is a very narrow window of overlap for any workshops, meetings, etc. between EPRI and PEA.
Assessment	Probability: **Very Likely** Risk Impact: **Medium**
Mitigation	• Meetings to be scheduled for EST nighttime or early morning timings. Example with DST: 8:00am EST is 7:00pm ICT or 8:30pm EST is 7:30am ITC
Risk 4: Dependence on Contractors	
Description	Digital Siam will be handling the bulk of Task 3. Future tasks have strong dependence on Task 3 output. If delays occur at PEA and Digital Siam is not able to mitigate the impacts, delays will cascade into later tasks.
Assessment	Probability: **Likely** Risk Impact: **High**
Mitigation	Increased level of communication with teams located in the US and Thailand is necessary. This can be accomplished via following actions: • Schedule regular touchpoint meetings with Digital Siam at least twice a month • Compile weekly status reports from all teams (Digital Siam, EPRI, PEA) to be summarized and shared project wide • Send deliverable drafts at regular intervals to ensure all information needed is sufficiently documented and no gaps exist. • Monitor the project critical path and measure remaining project slack, given the target completion date.
Risk 5: PEA Stakeholder Workgroups Availability	
Description	Communication with client stakeholder groups/executives may be challenging due to other work commitments.
Assessment	Probability: **Likely** Risk Impact: **Medium**
Mitigation	• Schedule meetings, workshops, etc. that are required with stakeholder workgroups as early as possible with time reserved on all calendars. • Conduct regular meetings with the PEA project sponsor to communicate project status and needs.

Risk 6: Security Concerns	
Description	Using unsecure email servers (Such as Yahoo and Gmail) may compromise security and may result in files being accessed by outside parties.
Assessment	Probability: **Likely** Risk Impact: **Medium**
Mitigation	• Users with public domain email accounts should investigate security options and report back to team with findings. • Send links via Box in lieu of sending document attachments with confidential information.
Risk 7: Standardization of Symbology	
Description	Discrepancies may occur in how process steps are documented and/or comprehended without a standardized symbology for Visio process flows.
Assessment	Probability: **Likely** Risk Impact: **Medium**
Mitigation	• Develop and document a standardized symbology key. • Communicate the symbology key to the entire project team early in the project to ensure standardization across all deliverables.
Risk 7: Staff Availability	
Description	If there are not full-time resources dedicated to the project, it may be difficult to allocate time from overloaded schedules
Assessment	Probability: **Likely** Risk Impact: **High**
Mitigation	• Use “project Kanban methods” with a shared taskboard to clearly identify current tasks in progress and resources responsible for completion. • Maintain a calendar of holidays and vacations (for both Thailand and the U.S.) to anticipate periods when staff resources will be unavailable. • Closely monitor the project schedule to determine if additional resources are needed. • If additional time/resources are needed, project leadership should determine if staff can be freed up or if additional help can be onboarded. • Analyze impacts to budget as resources are reassigned.
Risk 8: Project Cost Over-runs	
Description	The USTDA contract is fixed cost. Any project delays that cause additional expenses will result in cost over-run.
Assessment	Probability: **Likely** Risk Impact: **Medium**
Mitigation	• Hold team members accountable for meeting project and task deadlines. • All team members must proactively report potential delays at the earliest sign of issues.

Risk 9: Turnaround Times	
Description	Due to working hours difference in Thailand and United States, it may take longer for turnaround on any items requiring attention
Assessment	Probability: **Likely** Risk Impact: **Low**
Mitigation	• Establish expected response times in initial phase of project. • Document expected and agreed-upon response times and make these accessible to the entire team.
Risk 10: Software Accessibility	
Description	Delays may occur if PEA, Digital Siam, EPRI team members do not have licenses for or access to software (Visio diagrams, spreadsheets, ArchiMate models, etc.), for reviews, approvals, etc.
Assessment	Probability: **Not Likely** Risk Impact: **Low**
Mitigation	• Agreement of software between all teams in early phase of the project.
Risk 11: Lack of Readiness of Existing PEA Software Systems	
Description	As is the case in other countries, existing software systems and tools may not be suited for implementation of CIM data standards. Identifying the best implementation strategy and estimating implementation costs and benefits may be difficult for bespoke systems currently in production status at PEA.
Assessment	Probability: **Highly Likely** Risk Impact: **High**
Mitigation	• Establish early contacts with PEA subject matter experts familiar with the profiles of systems discussed in Task 3. • Engage vendors where necessary to assess when selected PEA systems and tools can realistically be ready for adaptation. • Impacts of above-mentioned investigations need to be reflected in the later project deliverables.
Risk 12: Existing PEA Data Issues	
Description	Applying CIM standard-based methods for managing grid model data at PEA may be a major challenge for certain types of datasets (for example, where manual methods are extensive).
Assessment	Probability: **Highly Likely** Risk Impact: **High**
Mitigation	• Determine best method of how to exchange/share data using new data standards with existing software and data. • Discuss solution method with project SMEs to determine critical path impacts. • Remediation needs to occur early in the project to meet team milestones.

Risk 13: Difficulty of Resolving PEA Data "Siloes"	
Description	Each PEA group/function/department tends to have their own data management protocols. Convincing all to adopt new ways of data treatment may be an issue.
Assessment	Probability: **Highly Likely** Risk Impact: **High**
Mitigation	• Once the project team determines an appropriate data treatment method: ○ PEA project sponsor to communicate updated data treatment method to all PEA teams and departments. ○ Stress the importance of a standardized data treatment as part of communication to PEA departments. ○ If there is resistance, PEA project sponsor should escalate. ○ Thoroughly document data standards with all detail clearly stated. This will serve as a guide to all departments for how data standards will be implemented.
Risk 14: Lack of Flexibility among Product Vendors	
Description	There are a variety of products from different vendors currently in use, each having their own culture. To convince each product team to adapt to a new CIM standard may be a challenge.
Assessment	Probability: **Highly Likely** Risk Impact: **High**
Mitigation	• Clearly document new CIM standards and send to different vendor teams. • PEA vendor contacts should follow up with each vendor the expectations of adapting new CIM standard. • If there is resistance the PEA project sponsor will need to communicate to Project Managers of each vendor team.
Risk 15: Project Management	
Description	Collecting all relevant information from all stakeholders within the project timeline may be difficult, which could result in Project Management challenges.
Assessment	Probability: **Not Likely** Risk Impact: **High**
Mitigation	• Cleary document the status gathering process. • Communicate to all stakeholders the documentation along with expectations of weekly timelines of providing data to Project Management. • Timelines not met will be escalated to project leadership to address with respective stakeholder departments.

Project Glossary

Term/Acronym	Definition
Abstract	If the class in the class hierarchy (i.e., the parent) is not intended to be instantiated then it is considered as an abstract class.
Admittance	A measure of how easily a circuit or device will allow a current to flow.
ADMS	Advanced Distribution Management System, a type of software suite for controlling electrical grids. An ADMS is designed to manage energy output, reduce outages, and regulate electrical demand.
ADT	Abstract Data Type, a mathematical model for data types.
Aggregation	A relationship defines a special kind of association between classes, indicating that one is a container class for the other.
AMI	Advanced Metering Infrastructure, an integrated system of smart meters, communications networks, and data management systems that enables two-way communication between utilities and customers.
API	Application Programming Interface, an interface that defines interactions between multiple software applications or mixed hardware-software intermediaries.
Asset Management	Practice of managing infrastructure capital assets to minimize the total cost of owning and operating these assets while delivering the desired service levels.
Back Office Applications	Application relating to the inner workings of a utility, such as making sure utility customers get the correct paperwork, facilitating payment of customer bills, etc.
Busbar	A metallic strip or bar, typically housed inside switchgear, panel boards, and busway enclosures for local high current power distribution.
Cascading Delete	Details what should happen to a related table when updates are made to a row or rows of a target table.
CCAPI	Control Center Application Programming Interface, an EPRI project with the aim of defining a common definition for components in power systems for use the Energy Management System. It is in this project where CIM was created.
CD	Community Draft, a working draft of the a NWIP standard and circulated to all national committee for comment.
CDM	A design pattern used to communicate between different data formats. Essentially: create a data model which is a superset of all the others ("canonical") and create a "translator" module or layer to/from which all existing modules exchange data with other modules. The individual modules can then be considered endpoints on an intelligent bus; the bus centralizes all the data-translation intelligence.
CDPSM	Common Distribution Power System Model, the distribution equivalent of CPSM, building on the standard balanced network model with additional data used to model low-voltage distribution networks.

Term/Acronym	Definition
CDV	Committee Draft for Vote, updated version of the standard that is issued as CDV and circulated to member countries for a five-month voting period and is considered approved if two thirds of the votes cast are in favor and the number of negative votes does not exceed 25% of the votes cast.
CIM	Common Information Model, an open standard for representing power system components created by EPRI.
CIMSpy	CIMSpy is a software tool which provides data engineering functions and user experience to help understand and analyze CIM-based power system models.
CIMTool	An open source tool that supports the definition of CIM profiles.
CIS	Customer Information Systems, system utilized by customer service representatives for billing and payment.
Class	Represents a specific type of object being modeled. Classes can be abstract or concrete.
Class Hierarchy	An abstract model of a system defining every type of component within a system as a separate class.
Composition	A specialized form of aggregation where the contained object is a fundamental part of the container object.
Conceptual Model for Data Management	Abstract definition that integrates the internal and external model. Ideally the internal and external models are both derived from the conceptual model.
Concrete	If the class is something that may be instantiated, then it is concrete.
Container	A class, a data structure, or an abstract data type (ADT) whose instances are collections of other objects.
CPSM	Common Power System Model used for the exchange of electrical power system node-breaker models. Originally developed to define exchanges between EMSs, it has since grown to encompass the exchanges between multiple systems within the transmission environment.
Data Abstraction	Programming process of creating a data type, usually a class, that hides the details of the data representation to make the data type easier to work with.
Database Schema	Organization and structure of a database.
DEF	Data Exchange Format, language that is domain-independent and can be used for data from any kind of discipline.
DEFLATE	DEFLATE, Dutch Compressed Data Format Specification (currently version 1.3).
DERMs	Distributed Energy Resources Management System, a platform which helps distribution system operators (DSO) manage their grids that are based on distributed energy resources (DER).

Term/Acronym	Definition
DERs	Distributed Energy Resources, physical and virtual assets that are deployed across the distribution grid, typically close to load, and usually behind the meter, which can be used individually or in aggregate to provide value to the grid, individual customers, or both.
DSO	Distribution System Operators, operators who manage the network that ensures energy will be transferred from the high-voltage transmission system to the distribution system and then to the final customer.
DTD	Document Type Definition set of markup declarations that define a document type for a SGML-family markup language. A DTD defines the valid building blocks of an XML document. It defines the document structure with a list of validated elements and attributes. A DTD can be declared inline inside an XML document, or as an external reference.
EAM	Enterprise Asset Management, management of the maintenance of physical assets of an organization throughout each asset's lifecycle.
ELIA	Belgian transmission grid operator.
EMS	Energy Management System, automation systems that collect energy measurement data from the field and making it available to users.
ENTSO-E	European Network of Transmission Systems Operators for Electricity, the association for the cooperation of the European transmission system operators (TSOs).
Enumerations	A complete, ordered listing of all the items in a collection.
ESB	Enterprise service buses, an architectural pattern whereby a centralized software component performs integrations between applications. It performs transformations of data models, handles connectivity, performs message routing, converts communication protocols and potentially manages the composition of multiple requests.
ESPI	Energy Services Providers Interface, concept that has been identified and defined within a number of smart grid domains.
Extensibility	Measure of the ability to extend a system and the level of effort required to implement the extension.
External Model for Data Management	Describes the data that is exposed to the user or will be shared outside of the application. For example, this external model would define the data exposed as part of a user-interface or written to a file.
FDIS	Final Draft International Standard, this is prepared after the working group and addresses any comments that have been received. This is then submitted to the IEC Central Office and circulated to the national committees for a two-month voting period.
Generalization	See "Inheritance."
GUID	Globally Unique Identifier, another term for UUID, refer to UUID for definition.

Term/Acronym	Definition
HES	Head-End System, hardware and software that receives the stream of meter data brought back to the utility through the AMI. Head-end systems may perform a limited amount of data validation before either making the data available for other systems to request or pushing the data out to other systems.
IEC	International Electrotechnical Commission, a global, not-for-profit membership organization serves as a global standards authority, requires the CIM and all related standards to go through a formal standard process before publication.
Impedance	The opposition to power flow in an AC circuit. Also, any device that introduces such opposition in the form of resistance, reactance, or both.
Inheritance	Defines a class as being a subclass of another class. As a sub-class, it inherits all the attributes of its parent, but can also contain its own attributes (also known as Generalization).
Instantiate	To launch or run, in object technology, to create an object of a specific class.
Interface Reference Model	The Interface Reference (IRM) define interfaces for the major elements of an interface architecture for various distributed application components for the utility to manage electrical distribution networks. These capabilities include monitoring and control of equipment for power delivery, management processes to ensure system reliability, voltage management, demand-side management, outage management, work management, network model management, facilities management, and metering.
Internal model	Database schema, which differs from the conceptual model, but can be automatically derived from it.
Internal Model for Data Management	Describes how the application or system stores the data internally, whether within in-memory data structures or a database schema. This data is available to the internal processes and algorithms.
Interoperability	Ability of systems, or components within systems, to interact and exchange services or information with each other, and to operate effectively in an expected way without significant user intervention.
ISO	Independent System Operator, an electric power transmission system operator (TSO) that coordinates, controls, and monitors a multi-state electric grid.
JAR	Sun Microsystem’s Java Archive format.
JMS	Java Messaging Services, JMS was designed to make it easy to develop business applications that asynchronously send and receive business data and events. It defines a common enterprise messaging API that is designed to be easily and efficiently supported by a wide range of enterprise messaging products.
JSON	JavaScript Object Notation, a lightweight, text-based data exchange format. It originated from the programming language after which it was named, JavaScript; however, JSON data can be written in any programming language.

Term/Acronym	Definition
KML	Keyhole Markup Language, a file format used to display geographic data in an Earth browser such as Google Earth. KML uses a tag-based structure with nested elements and attributes and is based on the XML standard.
KMZ	Consists of a main KML file and zero or more supporting files that are packaged using a Zip utility into one unit, called an archive. The KMZ file can then be stored and emailed as a single entity.
Line	Pipes, cables, or other linear conveyance systems used to transport power.
LMP	Locational Marginal Pricing, represents the cost to buy and sell power at different locations within wholesale electricity markets, usually called Independent System Operators (ISOs).
Load	An end-use device or customer that receives power from the electric system.
Map	An artifact which shows the positioning and identification of buried pipes and cables beneath the ground. The procedure involves detecting things like sewers, electric cables, telecoms cables, gas, and water mains. Combine this mapping process with a topographical survey and the results will provide you with a comprehensive detailed map of anything that is hidden underground or directly related to any above ground features.
MDA	Model Driven Architectures, software design approach for the development of software systems. It provides a set of guidelines for the structuring of specifications, which are expressed as models.
MDE	Model-Driven Engineering, an iterative and incremental software development process.
MDMS	Meter Data Management System, suite of software programs that receive and store meter data and support a host of revenue cycle and other functions (e.g., billing, outage management, and distribution engineering).
MDT	Model Driven Transformation, supports the entire life cycle of transformation development using open standard and offering automation resources.
Microgrid	Self-sufficient energy system that serves a discrete geographic footprint, such as a college campus, hospital complex, business center, or neighborhood.
mRID	Master Resource Identifier, a string-based identifier of the measurement, what the measurement of the measuring.
NAESB	The North American Energy Standards Board, serves as an industry forum for the development and promotion of standards which will lead to a seamless marketplace for wholesale and retail natural gas and electricity, as recognized by its customers, business community, participants, and regulatory entities.
Namespace	A set of signs (names) that are used to identify and refer to objects of various kinds. A namespace ensures that all of a given set of objects have unique names so that they can be easily identified.

Term/Acronym	Definition
NWIP	New Work Item Proposal, the first step required the be EIC in creating a new standard. The NWIP is submitted by a working group and is voted on by all member countries
ODF	Open Document Format, an open standard file format for spreadsheets, charts, presentations, and word processing documents using ZIP-compressed XML files.
OMS	Outage Management System, network management software that can restore the network model after an outage.
One-Offs	Instance in which each time a data change is made it starts with the old interface specification. A copy is made of this interface, and then changes to that interface are adapted for the new specification. Finally, changes to the new interface are tested against all the applications that used to old interface (if they are not missed in the test plan) against all the applications the old interface was integrated with.
Ontology	Explicit specification of a conceptualization.
OpenADE	Open Automated Data Exchange (Task Force), group of smart-energy-management vendors, utilities, and government interests developing recommendations toward building interoperable data exchanges that allow customer authorization and sharing of utility consumption information with Third-Party service providers.
OT	Operational Technology - power system-related applications used in planning and operations.
Power System Applications	Applications that deal with power generation, transmission, and distribution sectors.
Procurement	Process of finding and agreeing to terms, and acquiring goods, services, or works from an external source, often via a tendering or competitive bidding process.
Proprietary	Exclusive right to something
PSS/E	A power system analysis tool from Siemens PTI that is widely used in the power industry
PSS/E RAW	Native file format for PSS/E
QVTO	Query/View/Transform Operational, s an Object Management Group specification for model to model transformation with an open-source Eclipse implementation available that runs on top of Java.
RDF	Resource Description Framework, an XML schema used to provide a framework for data in an XML format by allowing relationships to be defined between XML nodes.
RDFS	RDF Schema (also known as RDF Vocabulary Description Language) provides the user with a means of describing specific kinds of resources or classes.
REST	Representational State Transfer, a software architectural style which uses a subset of HTTP.

Term/Acronym	Definition
Reverse Engineering	Process in which software and products are deconstructed to extract design information from them. Often, reverse engineering involves deconstructing individual components of larger products.
RTO	Regional Transmission Organization, an electric power transmission system operator (TSO) that coordinates, controls, and monitors a multi-state electric grid.
SCED	Real Time Markets with Security Constraint Economic Dispatch, determines resources' dispatch MW as well as LMP to minimize the system energy production cost with subject to resources' operational limits and network security constraints.
SCUC	Day Ahead Markets with Security Constraint Unit Commitment, optimization algorithm used for day-ahead planning in restructured electricity markets
Semantic Model	Model which is defined before any software is written or from the perspective of a systems integrator, the model is created before the interfaces are defined at any level of detail.
Serialization	Process of converting a data structure into a format that can be stored and then retrieved later whether it is in a memory buffer, file or transmitted across a network. A file format is an example of a serialization format, where data is written to a file in a set format that can then be read again later, recreating an identical in-memory data structure.
SGML	Standard Generalized Markup Language, a standard for defining generalized markup languages for documents, XML is a subset of SGML
SI	International System of Units
SOAP	Simple Open Access Protocol, a messaging protocol that uses XML for the machine-to-machine message exchange. SOAP web services are contract-based, making use of WSDL files and XSD files to define what messages can be exchanged.
spatial	Relating to or involved in the perception of relationships (as of objects).
Subclasses	A subdivision of a set or class.
Substation	Facility equipment that switches, changes, or regulates electric voltage
Synchronization	Coordination of events to operate a system in unison.
TCO	Total Cost of Ownership, purchase price of an asset plus the costs of operation.
TSO	Transmission System Operator, an entity entrusted with transporting energy in the form of natural gas or electrical power on a national or regional level, using fixed infrastructure. The term is defined by the European Commission.
UML	Unified Modeling Language, modeling and specification language that is used for modeling a wide variety of components within the software development lifecycle including data structures, system interactions, and use cases. The modeling is not tied to one particular implementation technology and can be realized on multiple platforms.

Term/Acronym	Definition
UN/CEFACT	United Nations/Center for Trade Facilitation and E-Business, subsidiary, intergovernmental body of the United Nations Economic Commission for Europe (UNECE) which serves as a focal point within the United Nations Economic and Social Council for trade facilitation recommendations and electronic business standards.
UNECE	United Nations Economic Commission for Europe, one of five regional commissions of the United Nations which aims to promote pan-European economic integration.
URI	Uniform Resource Identifier, a unique sequence of characters that identifies a logical or physical resource used by web technologies.
UUID	Universally Unique Identifier, known in CIM as a Master Resource Identifier (MRID) or Globally Unique Identifier (GUID)
W3C	World Wide Web Consortium, the governing body for web standards.
WG	Working Groups, as related to the CIM, the IEC Technical Committee 57 Working Groups of relevance are 13 (Software Interfaces for Operation and Planning of the Electric Grid), 14 (Enterprise Business Function Interfaces for Utility Operations) and 16 (Markets)
Work Management	Software to plan, track, organize and review the daily flow of information, business processes, and workforce activities. The end goal is to streamline workflow, create operational efficiencies, and improve quality in all areas of the utility.
WSDL	Web Services Description Language, an XML-based interface description language that is used for describing the functionality offered by a web service.
XML	eXtensible Markup Language, a universal format for structured documents and data which is a standard for storing machine-readable data in a structured, extensible format that is accessible over the Internet.
XMLSpy	A commercial XML Editor from Altova.
XMPP	Extensible Messaging and Presence Protocol, a set of open technologies for instant messaging, presence, multi-party chat, voice and video calls, collaboration, lightweight middleware, content syndication, and generalized routing of XML data.
XSD	XML Schema Definition, the current standard schema language for all XML documents and data.

Chapter 1 Appendix

TA CIM Project Terms of Reference (TOR)

These terms of reference ("ToR") set forth the terms, conditions, provisions, and specifications for the performance of the technical assistance ("TA") for the benefit of the Provincial Electricity Authority of Thailand (the "Client"). Electric Power Research Institute, Inc. (the "Contractor") shall perform the TA in accordance with these Terms of Reference pursuant to this Contract between the Contractor and the Client, of which Contract this Annex I is a part.

The Contractor's delivery of the TA must comply with the entirety of these ToR, and any modification of or deviation from these ToR must be approved in writing by USTDA in accordance with the procedures for amendments or other modifications under this Contract. The Contractor acknowledges and agrees that (i) any performance by the Contractor of work not included in, or not in compliance with, these ToR, or any failure by the Contractor to perform any work set forth under these ToR (in compliance with those terms), will be ineligible for approval or payment, absent an amendment or other modification in accordance with such procedures, and (ii) failure to obtain prior written approval from USTDA for any modifications or deviations from these ToR may result in forfeiture of payment for work performed that is not in compliance with these ToR and/or a significant delay in payment of the final invoice.

These ToR detail the scope of work required to facilitate the PEA Common Information Model Technical Assistance ("TA CIM Project") in Thailand. The TA CIM Project aims to establish an information architecture for PEA and then, using the architecture, to assist PEA in designing and planning the implementation of a CIM-based data management solution. The solution implementation, referred to as the "CIM Implementation Project" is a multi-year, multi-million-dollar, PEA-sponsored investment which is enabled by, but outside the scope of, the TA CIM Project. The intent of the CIM Implementation Project is to create a data management foundation at PEA, which facilitates the seamless, reliable, and timely flow of network model-related information across the PEA enterprise. Such a data management foundation can improve the quality of data used in multiple applications vital to the reliable, safe, economic operation of PEA's electric grid. The foundation also enables ongoing software interoperability as application upgrades, replacements and additions occur over time, minimizing the disruption, cost, and effort those activities often cause. The results of the CIM Implementation Project will position PEA to implement and leverage a variety of future sophisticated technology solutions as it faces the challenges of planning, protecting, and operating its increasingly complex future grid.

This ToR is organized by tasks targeted to progressively complete the deliverables of the TA CIM Project for PEA, while employing a method consistent with large information technology- ("IT") and operational technology- ("OT") related integration initiatives. Tasks include outlining an information architecture for PEA, documenting the "as is" data exchange situation at PEA, defining a long-term PEA data management vision, outlining a series of strategic steps toward achieving it, and creating an implementation plan for the first strategic step.

The overall approach is designed to provide maximum interaction with PEA's IT/OT system integration stakeholders, to introduce a Common Information Model ("CIM") implementation approach to them, and to transfer knowledge to enable them to maintain and expand PEA's essential CIM-based data management capabilities following the TA CIM Project's completion.

Detailed plans for each task and its execution and deliverables will be provided in the Contractor's ToR task reports to the Client. The Contractor and its representatives, as appropriate, shall deliver all tasks as defined and described in these ToR.

Any meetings or other actions or work set forth under these Terms of Reference that are indicated to occur in-person, on-site or otherwise in a specified location may, if agreed by both the Grantee and the Contractor (and with advance notice to and written agreement from USTDA), be conducted remotely, including online, by teleconference, by videoconference, or by other means, provided that the Contractor shall clearly document in the corresponding deliverable report the date on which such agreement was reached and approved by USTDA, and shall describe the alternative means of accomplishing the relevant work, along with the rationale for such decision.

Further, if the Grantee and the Contractor propose to apply such a change to any tasks or subtasks in part (i.e., to change portions of a task/subtask from in-person to remote, while maintaining other portions as in-person, including the "breaking up" of a task or subtask in order to separate remote from in-person work), then: (i) the Grantee and/or the Contractor shall notify USTDA in advance of such a proposal, and USTDA may, in its discretion, approve of such proposal and formalize the proposed modification through an implementation letter to the Contract; and (ii) USTDA may, at its discretion, modify the Payment Schedule under the Contract in order to separate such remote and in-person work into separate payments, as appropriate, again through an implementation letter to the Contract. Notwithstanding the foregoing under this paragraph, USTDA reserves the right to make any appropriate adjustments to the total Grant Amount (and therefore the Contract value) that may result from any such modifications.

Task 1: TA Kick-Off, Organization, and Work Plan

The main objective and purpose of this task shall be to establish a mutual understanding between the Contractor and the Client of the work that will be performed under the TA CIM Project, and to familiarize the Client with an industry-validated approach to initiating CIM-based data management improvement initiatives.

A kick-off meeting ("Kick-Off") shall, due to the Coronavirus pandemic, be held virtually instead of on-site. Two weeks in advance of the scheduled Kick-Off, the Contractor shall prepare a detailed agenda for the Kick-Off and a draft work plan for the TA CIM Project.

The Contractor shall prepare a draft work plan for the Client's consideration at the Kick-Off. The work plan will include:

- Key milestones
- Resourcing (staff, time and resource allocation skills required)
- Gantt chart (for scheduling purposes)

The Contractor shall meet with the Client and complete the following activities during the Kick-Off:

- Describe the objectives of an effective enterprise-wide, CIM-based approach to designing, planning, and implementing data management.
- Verify the purpose of the TA CIM Project.
- Introduce the respective teams from the Contractor and Client, and address communications (e.g., conference calls, Skype), methodologies of work and use of standards and collaboration technologies (e.g., Dropbox, One File).
- Finalize the strategy for review of the Client's current processes and systems, and discuss plans to obtain required information; and
- Familiarize the teams with and address any issues relative to constraints, TA CIM Project scope, and stakeholders.

The work plan shall include the TA CIM Project timeline, deliverables, milestones, and roles and responsibilities of the Contractor and Client for successful completion of the TA CIM Project. The work plan shall also discuss how the Contractor will review the Project materials, identify information gaps, and plan for obtaining necessary information. The Client's and Contractor's points of contact and key members of the TA CIM Project team shall be identified and roles and responsibilities of each member established. The Contractor, with assistance from the Client, shall identify the Client organization stakeholders for implementation of the TA CIM Project. The Contractor shall finalize the work plan by incorporating the Client's input, within the Contractor's discretion, and shall prepare and share with the Client a final work plan.

The work plan shall be the basis for assessing the Contractor's monthly progress. During the discussions on the development of the work plan, the Contractor shall establish the Client's desired reporting formats and timing for monthly reporting updates. The Contractor shall prepare and submit a monthly progress report (i.e., 2- to 3-page progress status) to the Client throughout the duration of the TA CIM Project. These monthly reports shall be distributed to appropriate Client technical and executive leadership stakeholders, as documented in the work plan.

In addition to the work plan, the Contractor shall:

1. Write a detailed purpose of the TA CIM Project document to confirm the Client's needs are fully addressed.
2. Prepare a brief TA CIM Project Risk Assessment ("PRA") and risk mitigation plan.

Task 1 Deliverables:

The Contractor shall prepare and deliver to the Client a detailed written report that contains all information collected, work performed, and analysis conducted under Task 1, including, but not limited to, a purpose of study document, a PRA and risk mitigation plan, and a work plan. The results and deliverables of this task shall be included as a stand-alone chapter in the final report.

Task 2: Information Architecture Development

The Contractor shall, through utilization and customization of its existing research, develop and refine a Client-specific information architecture for effective network model data management. The architecture will provide a framework to underpin the work of Tasks 4, 6, and 7 of the TA CIM Project.

The Contractor shall:

- Explore and document a business function-based approach for understanding the creation, management and use of network model data inside the electric utility enterprise that can be applied within the Client's organization.
- Outline strategies, methods, and documentation artifacts for leveraging the function-based approach in the creation of the Client's grid model management vision.
- Develop, refine, and document the requirements for a network model data management tool suitable for use by the Client.
- Identify, refine, and document the definition of the CIM-based data exchange "building blocks" useful to the Client in designing and implementing CIM-based data management solutions.

The Contractor shall prepare and deliver to the Client a report, "A CIM-Based Information Architecture for PEA," summarizing the technical results of the activities undertaken, along with design artifacts (including but not limited to: diagrams, information models) applicable to the Client's data management improvement work. The report will be organized in a format suitable to its role as a reference for future technical tasks under these ToR.

Task 2 Deliverables:

The Contractor shall prepare and deliver to the Client a detailed written report that contains all information collected, work performed, and analysis conducted under Task 2.

The results and deliverables of this task shall be included as a stand-alone chapter in the final report.

Task 3: "As-Is" Documentation

The Contractor shall work with the Client to document the Client's existing data management practices. The activities of this task will examine which data is sourced where, how it moves from application to application, and which applications use which data. Both the data flows and the business processes that are supported by the applications that produce, manage, or consume the data will be explored and documented. The intended outcomes of the task will be:

- Document the Client's "as-is" network model data management practice, which will be useful in future activities under these ToR.
- Develop insight into problem areas, data management solution requirements, and potential solution ideas to be used as input to Task 4 for Client vision development.

Develop a shared understanding, among the Client's stakeholder work groups, of the existing situation and data management challenges. Virtually all departments and divisions of the utility are "stakeholders" in how data flows throughout the business. The areas that are most immediately affected are in distribution, system and operations planning, engineering and network protection design.

The Contractor's activities under this task shall consist of the following:

- Determine the "data domain" to which Task 3 and subsequent tasks will apply (this could include but is not limited to: network model data, asset data, and/or supervisory control and data acquisition ("SCADA") data, etc.).
- Conduct interviews and technical group workshops with subject matter experts in the various stakeholder work groups across the Client's organization to gather information on data flows and the business processes they enable within the selected "data domain." It is anticipated that the Contractor will begin the activities of this 4.5 month task remotely, due to the Coronavirus pandemic, and, if possible, finalize the work during a multi-day, in-person visit to the Client's facilities in Bangkok, Thailand. Multiple conversations to clarify and refine understanding will be held with the Client, either as informal on-site meetings with the Contractor's local representatives or via web conferences.
- Document data flows, problem areas, and identified solution requirements or ideas within the "data domain."

Task 3 Deliverables:

The Contractor shall prepare and deliver to the Client a detailed written report that contains all information collected, work performed, and analysis conducted under Task 3, including but not limited to artifacts documenting the Client's "as-is" data management practices. The results and deliverables of this task shall be included as a stand-alone chapter in the final report.

Task 4: Vision Development

The Contractor shall assist the Client in defining its long-range vision for CIM-based data management. The information architecture outlined in Task 2 will form the foundation for the vision development process. The work of this Task 4 shall leverage the findings from the Task 3 workshops and the Contractor's skills, understanding, and experience to assist Client technical groups in articulating the Client's ten-year future vision for a CIM-based integration environment.

The following considerations shall be incorporated into the visioning process:

- The Client's goal to use a CIM standard infrastructure such as CIM-based data architecture to implement peer-to-peer interaction among systems supporting grid operation.
- The Client's desire to implement an open approach to CIM network modeling for distribution overlaid on land base.
- The Client's need for an approach to system integration and maintenance considering CIM fragments for facility exports to CIM.
- The creation of an initial Network Model Manager (NMM) function to improve efficiency and quality of modelling and to support flexible, maintainable integration design; and
- The Client's desire for a CIM solution supported not only by CIM import/export interfaces on Client vendor-supplied tools, but also by the implementation of flexible software, like modular model-driven transformations of information from one information model to another.

The Contractor shall build use cases based on the architecture outlined in Task 2 and utilize these use cases to facilitate discussion on and development of the Client's vision documentation. Case studies of other successful electrical utility CIM implementations, which have been overviewed in various EPRI reports or at industry events, will also be introduced. Based on the Client vision documented through this process, the Contractor will work with the Client to identify high-level application and integration requirements necessary to implement the defined vision. Process efficiencies and other operational benefits related to the vision shall be identified, as well as potential risks.

The activities of this task are intended to provide a technical target for all future project work and build shared understanding and support for the concept of CIM-based data management among Client technical staff and leadership.

To meet the objectives of Task 4, the Contractor shall perform the following activities as a part of a multi-day visit by the Contractor to the Client's facilities in Bangkok, Thailand:

- Training Client technical staff on the information architecture developed in Task 2.
- Analyzing the Task 3 results.
- Developing and documenting an initial version of the 10-year Client data management vision.
- Identifying and discussing benefits and integration process efficiencies offered by the vision.
- Facilitating at least four feedback sessions with executives and staff of the Client on various facets of the vision during its development, including but not limited to the identification of the Client's strategic requirements, the creation of a business function model for the Client, and the definition of data shared among identified Client business functions.

In addition, the Contractor shall:

- Document, using Visio diagrams, spreadsheets, Archimate models and/or other means agreed upon by the Client and Contractor, the high-level development, integration, and data requirements implied by the long-range vision.
- Create a high-level functional requirement report for any new functions identified through the vision development process.

Task 4 Deliverables:

The Contractor shall prepare and deliver to the Client a detailed written report that contains all information collected, work performed, and analysis conducted under Task 4. The results and deliverables of this task shall be included as a stand-alone chapter in the final report.

Task 5: Conceptual Sequencing of System Design & Implementation

The Contractor shall outline a sequence of incremental implementation steps for achieving the Client's long-range vision articulated in Task 4. The steps will outline a sequence of major increments of work to be undertaken over the next 5 to 10 years by the Client in its CIM Implementation Project as it makes continual progress toward its vision. A typical implementation step will be designed to:

- Take between 6 and 12 months to accomplish
- Deliver a finite set of outcomes that moves the Client closer to its vision
- Result in a stable state where the Client can take time to re-examine and revise its vision and re-adjust the remaining implementation steps.

In Task 5 each incremental step in the initial version of the sequencing will be described in detail: the applications, types of data, and data exchanges added to the Client's CIM-based solution as a result of the step will be considered, and the major activities, staffing requirements and high-level costs/benefits required by the step shall be identified. In developing the implementation steps, the Contractor shall assess the high-level functional and operational capabilities, issues, and concerns for the future Client CIM environment. Existing CIM work already undertaken by the Client shall be factored into the planning of these steps, as will the Client's stated business objectives.

To achieve the objectives of Task 5, the Contractor shall undertake the following key activities:

- Create an initial version of a strategy composed of a series of incremental integration steps necessary to implement the vision defined under Task 4. (Incremental integration steps might include something along the lines of: 1) the deployment of an NMM tool, 2) the integration of the GIS with the NMM, 3) the integration NMM and OMS, 4) the integration of the Asset Management application with the NMM, 5) incorporation of SCADA configuration in NMM, and 6) integration of the Meter Data Management System with NMM).
- Document the conceptual design achieved at the end of each integration step, the business objectives targeted by the step, the major activities and any business organization changes required by the step, and the high-level estimated costs and expected benefits for the step.
- Facilitate executive and technical group feedback sessions on the sequencing strategy.
- A variety of communication techniques will be used in describing the outcomes of the first two bullets above: text, tables, diagrams, and spreadsheets will all be used as appropriate.

It is anticipated that a significant portion of the key activities under this task will be performed as a part of a multi-day visit by the Contractor to the Client's facilities in Bangkok, Thailand.

Task 5 Deliverables:

The Contractor shall prepare and deliver to the Client a detailed written report that contains all information collected, work performed, and analysis conducted under Task 6. The results and deliverables of this task shall be included as a stand-alone chapter in the final report.

Task 6: Economic Analysis

The Contractor shall analyze the economic effects of applying an enterprise-wide, CIM-based approach for data management and application integration to the Client's IT application integration challenges. It is anticipated that completion of the CIM Implementation Project would better optimize performance of the Client's systems and tools. Benefits would derive in the form of reduced labor, more accurate and more frequent study/analysis, improved operational efficiency and streamlined technology. These benefits are anticipated to translate into Client and society impacts in the form of cost reductions, improved distribution system reliability, increased ability to deploy renewable energy technologies, increased customer satisfaction, and improved safety.

The Contractor shall work with the Client to review the current operational IT approach to application integration design and implementation and compare it to the approach proposed under Tasks 3, 4 and 5 of the TA CIM Project. In evaluating the known or projected cost and benefit differences between the current and proposed approaches, the Contractor shall ascertain a preliminary cost estimate for the various components of these approaches.

The Contractor shall provide a Task 6 report, including electronic spreadsheets, describing the economic analysis performed. The report shall fully consider all findings, analysis and recommendations derived from work performed under Tasks 3, 4 and 5.

Task 6 Deliverables:

The Contractor shall prepare and deliver to the Client a detailed written report that contains all information collected, work performed, and analysis conducted under Task 6. The results and deliverables of this task shall be included as a stand-alone chapter in the final report.

Task 7: Implementation Plan

The Contractor shall create implementation plans for the Task 6 implementation steps falling in the first year of activity of the CIM Implementation Project. It is anticipated that one to two implementation steps would fall in the first year of CIM Implementation Project and would therefore have implementation plans created as a part of this Task 7.

The Contractor shall develop and provide to the Client a general outline for the creation of implementation plans. This outline shall be reviewed jointly by the Contractor and Client and will serve as a guide for undertaking the major activities of Task 7. The Contractor will work with the Client to determine the most comprehensive and effective implementation activity planning tools to be used and the types of artifacts to be created in constructing the implementation plan. Examples of tools under consideration could include but are not limited to Microsoft Project, Excel, Word, Enterprise Architect, and Visio.

Taking into consideration the results of work performed in Tasks 1-6, the implementation plan(s) for the first one or two implementation steps shall be created jointly by the Contractor and Client. The following elements, at a minimum, will be addressed by the implementation plan(s):

- Tasks, including:
  - data requirements analysis,
  - detailed solution design,
  - CIM data model and profile development,

  - data population strategies,
  - business process definition,
  - technology procurement and installation,
  - establishing data governance for ongoing solution maintenance,
- Resource requirements, including:
  - staffing, including skills and training,
  - hardware/software and cyber security infrastructure
- Schedule
- Business Case
  - Projected costs and benefits
- Project Management, including:
  - organization change management strategies,
  - development methodologies,
  - project management tooling,
  - risk management.

In support of the objectives of this task the Client shall organize participation by a wide variety of Client work groups in addition to the engineering and IT integration resources required under earlier tasks. Examples of additional stakeholder groups may include but are not limited to: Client's project management office, IT software/hardware and cyber security infrastructure organizations, mid-level leadership from numerous stakeholder groups, and Human Resources.

The Contractor shall provide participating Client staff with the tools and knowledge required to successfully undertake similar implementation planning activities in the future for subsequent implementation steps. This will include providing guidance to the Client on the technical implementation of the CIM solution (CIM information model extensions and profiling, tool selection and training, interface design) as well as guidance on PEA's business organization strategies, data governance approaches, and the evaluation of vendor tools/solutions.

In support of the objectives of this task, the Contractor shall undertake a multi-day visit to the Client's facilities in Bangkok, Thailand, during which time the Contractor shall perform the following key activities:

1. Select the step(s) for which implementation plans are to be developed.
2. Review and revise the planning outline and list of tools to be used in the development of the implementation plan(s).
3. Develop the implementation plan(s).

4. Create the Client CIM implementation plan(s) report covering the elements listed above.
5. Conduct an executive presentation and discussion forum with the goal of securing approval to move ahead with the initial work of the CIM Implementation Project as described in the implementation plan(s)

Task 7 Deliverables:

The Contractor shall prepare and deliver to the Client a detailed written report that contains all information collected, work performed, and analysis conducted under Task 7. The results and deliverables of this task shall be included as a stand-alone chapter in the final report.

Task 8: Regulatory Analysis

The Contractor shall review and analyze pertinent regulatory requirements and issues that may impact the CIM-based approach to the design and implementation of application integration solutions for the Client. The support shall include the following.

- Identification of relevant regulations that may impact project viability or prognosis to proceed. Examples of such regulations and/or compliance issues to be investigated may include but are not limited to: cybersecurity/network security requirements, compliance with ICT infrastructure requirements, rate and/or operating restrictions (that may have an impact on funding available for CIM investment), etc.
- Regulatory impact assessment of pertinent internal, national, regional (e.g., ASEAN) and international regulations and policies

The Contractor shall make recommendations to support the Client's regulatory planning and to reflect the current regulatory and power sector operating conditions in Thailand. For the avoidance of doubt, the Client retains sole responsibility for regulatory compliance and acknowledges that Contractor (including any subcontractors) cannot provide legal or tax advice.

Task 8 Deliverables:

The Contractor shall prepare and deliver to the Client a detailed written report that contains all information collected, work performed, and analysis conducted under Task 8. The results and deliverables of this task shall be included as a stand-alone chapter in the final report.

Task 9: Developmental Impact Assessment

The Contractor shall produce a host country developmental impact report as part of the TA CIM Project. In addition to spin-off and demonstration effects, other benefits may be realized as noted below. Benefit estimates will include the following areas, with possibilities as noted. The Contractor shall focus on the developmental effects when the TA CIM Project is completed, and its recommendations implemented.

The Contractor's analysis of potential impacts of the CIM-based approach to application integration design and deployment project shall be concrete, detailed and based on the data and information collected during the performance of the TA CIM Project. The Contractor shall designate an anticipated timeline and determine how the information shall be measured and collected once the CIM project moves to implementation.

Sector	Category	Indicator	Definition	Measure
Application Systems development	Infrastructure Development and Efficiency Gains	Improved Data Management and Security and productivity	Capacity added, security/ redundancy gained, or reliability improved through implementation of CIM standard, modernized enterprise architecture, a primary and backup data center, and diverse systems and technologies for network operations (e.g. GIS, SCADA, OMS/LMS, CRM)	Y/N
Application Interfaces (AI)	Infrastructure Development and Efficiency Gains	Improved productivity, lower cost, better quality	Efficiency gains and reductions in losses as a result of project implementation, including reduction in time, expense and quality improvements	MWh/year
Skills development	Human Capacity Building	Human Capacity Development through training & workforce development	Training and human capacity development delivered to host country stakeholders over the course of a USTDA activity and into the implementation phase of the project. Implementing standard and capacity development are among the primary goals of the project.	Number of individuals
All	Promoting Effective Markets and Governance	Supporting International Best Practices	USTDA engagement will lead to the adoption of internationally recognized best practices that support positive environmental or social gains, efficiency, transparency, or competition.	Y/N

For the qualitative assessment, the Contractor shall provide narrative descriptions of how the implementation of the recommendations coming out of the TA CIM Project is anticipated to impact each of the above indicators.

For the quantitative assessment, the Contractor shall reassess and reconfirm each baseline measurement above and shall provide the anticipated outcome for each of the above indicators.

Task 9 Deliverables:

The Contractor shall prepare and deliver to the Client a detailed written report that contains all information collected, work performed, and analysis conducted under Task 9. The results and deliverables of this task shall be included as a stand-alone chapter in the final report.

Task 10: U.S. Export Potential

Within its nonprofit parameters as an independent and objective scientific research institute that does not endorse vendors and subject to applicable competition laws, the Contractor shall, based on information reasonably available, provide information for PEA's assessment of potential U.S. vendors.

The Contractor shall identify the likely U.S. suppliers for equipment and services for the Project and prepare a qualified and interested vendors list. The list shall include (i) the potential U.S. sources of supply and services for the Project, (ii) a detailed description of relevant products, solutions and services provided for each potential U.S. supplier or service provider, and (iii) contact information for the party or parties responsible for marketing/sales in the Host Country, including the business name, point of contact, address, telephone number, and e-mail address for each identified party. The Contractor shall engage relevant potential suppliers in discussions and analyze their interest in supplying equipment and services for the Project. The Contractor shall inform the Client of which U.S. suppliers have expressed interest in the Project.

Task 10 Deliverables:

The Contractor shall prepare and deliver to the Client a detailed written report that contains all information collected, work performed, and analysis conducted under Task 10. The results and deliverables of this task shall be included as a stand-alone chapter in the final report.

Task 11: Final Report

The Contractor shall prepare and deliver to the Client and USTDA a substantive and comprehensive final report of all work performed under these ToR, and in conformance with the requirements of the Request for Proposal and Clause I of Annex II of the Grant Agreement.

The Contractor shall prepare and deliver to the Client a draft final report describing all work performed pursuant to these ToR. The Contractor shall incorporate any/all comments/from the Client in the draft final report, identifying, at its discretion, the Client as the source of those comments.

Upon receipt and consideration of the Client's feedback, the Contractor shall prepare and deliver to the Client and USTDA a final report, which shall be organized according to the above tasks and inclusive of all deliverables and documents that have been provided to the Client.

Fifteen (15) days prior to the final report due date, the Contractor will deliver to the Client a draft final report, in the event the Client wishes to offer feedback to the Contractor.

Task 11 Deliverables:

The Contractor shall prepare and deliver to the Client and USTDA a draft final report and final report in English, in the manner specified in these ToR and in accord with the provisions of Clause I of Annex II of the Grant Agreement.

Additionally, the final report shall contain an executive summary, and eight (8) copies must be provided to each of the Client and USTDA on CD-ROM. The CD-ROM version of the final report must include:

- Adobe Acrobat readable copies of all documents (using most recent version)
- Source files for all drawings in AutoCAD or Visio format; and
- Source files for all documents in MS Office 2000 or newer formats.

CHAPTER 2 INFORMATION ARCHITECTURE DEVELOPMENT

Summary

EPRI and Thailand's Provincial Electricity Authority (PEA) – through a U.S. Trade and Development Agency (USTDA) grant – have joined together to transform the delivery of power to more than 20 million customers across Thailand through the development of a Common Information Model (CIM)-Based Utility Data Management Strategy and Implementation Plan. The project will result in a plan to modernize PEA's electric grid using a CIM-based model to digitalize the grid. This action will facilitate the integration of advanced technologies to increase energy efficiency, lower costs for consumers, and support the utilization of renewable energy.

Introduction to Grid Model Management (GMM): A Best Practice Approach

Why Distribution Grid Model Management for PEA?

With a global focus on electrification of heating and transportation, coupled with the transition to and renewable generation source, the electric distribution grid behavior is becoming increasingly complex. As a consequence, distribution utilities such as PEA find they need to execute more frequent, more complex grid simulations requiring higher-quality, more sophisticated grid models. The creation of these models, in turn, demands that utilities implement efficient distribution grid model management that allows grid data to be organized, managed, and shared easily and quickly with applications across the utility enterprise. Providing quality grid models requires coordination of a variety of activities and systems. Current distribution utility solutions, while varying considerably in form and detail, are almost universally limited in their ability to scale to meet the increasing enterprise-wide demand for highly available, highly accurate grid models. The bottom line, is that a new, comprehensive, and enterprise-wide approach to grid model data management is necessary if distribution utilities are to be able to effectively and pro-actively plan, protect and operate the distribution grid of the future.

The Grid Model Management (GMM) Vision

In 2017, EPRI started its Grid Model Data Management (GMDM) research to address the distribution industry's challenge of producing and maintaining accurate, accessible grid models. The research approach was collaborative and was enabled by two projects: one utility-focused and the other vendor-focused. The utility collaborative project built the initial version of the information architecture based on real-world utility insights. The vendor collaborative project is refining and testing the architecture.

EPRI's GMDM research envisions a world where intentional, effective distribution grid model management is practiced at utilities. In this world, a utility enters its grid model data once and leverages it across the enterprise, supplying grid analytics and simulations in planning, operations, and markets with accurate, easily accessible grid models. Data management processes are streamlined, errors are caught and corrected early, simulation results are accurate and can be shared among applications, and the utility is positioned to add new analytics with a minimum of effort and cost.

The vision for improved model management is based around the architectural transition illustrated by Figure 1 and Figure 2. In both figures, enterprise sources for grid model data are shown on the left – sources such as engineering design, facilities records, work, asset management and customer information. Consumers of network models are shown on the right side. These would typically be various grid planning and operations functions. In the middle, grid model information flows between sources and consumers.

Figure 1 illustrates information flows typical at distribution utilities. Between sources and consumers there is a tangle of point-to-point interfaces: some are automated, some are manual, many are inconsistently triggered, and nearly all require some sort of transformation between the structure of data provided by the source and structure required by the consumer.

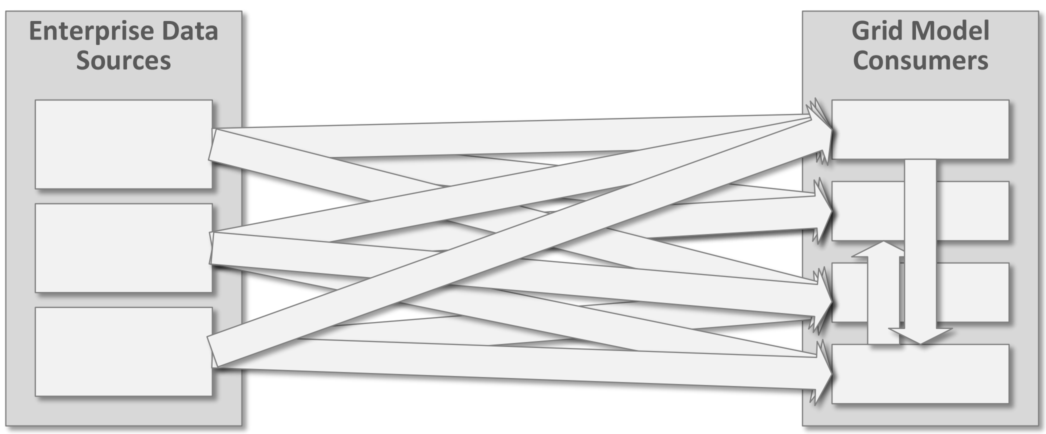


Figure 1. Sample grid model data flows

Figure 1 reflects the approach of the Grid Model Management (GMM) information architecture. Between suppliers and consumers, a Grid Model Management function is introduced. The role of the GMM function is a) to gather source data and maintain a master repository of behavioral grid modeling for the electric distribution system and b) to host a variety of model transformation and assembly activities that create the modeling required by grid model consumers.

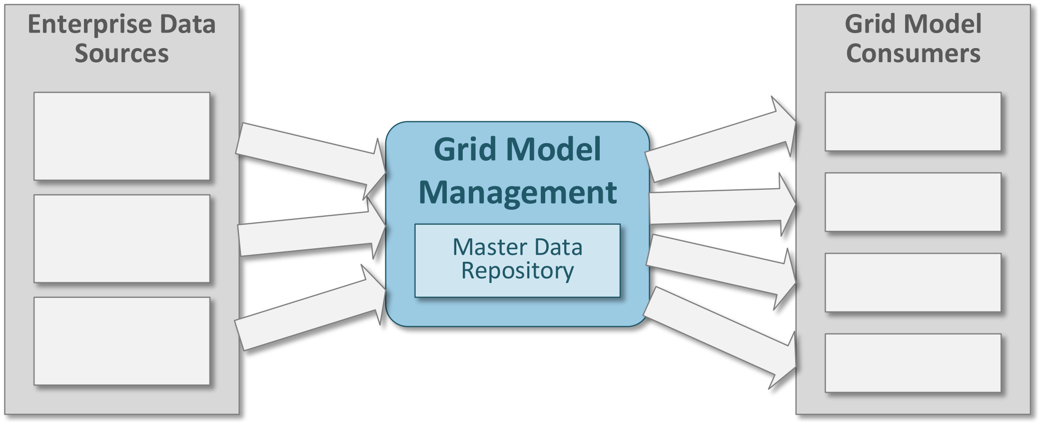


Figure 2. Basic Grid Model Management (GMM) architectural concept

This architectural concept, focused on consistent, enterprise-wide management of network model data, has the potential to help PEA to:

- Reduce labor, as duplicate modeling is eliminated, as work steps are automated, and as time spent synchronizing, validating and correcting data is minimized
- Improve the accuracy of study results and reduce the likelihood of significant errors
- Increase the ability to perform sufficient and sufficiently timely studies
- Improve the ability to compare study inputs and results across tools
- Enable more efficient and effective sharing of modeling with external entities
- Create an environment in which future study applications can be quickly and easily deployed.

In short, the GMM information architecture enables a future world where distribution utilities like PEA, are able to easily and efficiently provide modeling to the growing number of sophisticated simulations and analytics they must use to plan, protect and operate their complex, dynamic grids.

Grid Model Management (GMM) Information Architecture

The GMM information architecture aims to provide a framework, applicable to any electric distribution utility, for designing and implementing enterprise-wide grid model data management. The architecture has been developed using a business function approach and is based on an understanding of common distribution utility requirements. It facilitates best practice solution strategies for designing and building data management solutions based on a set of Common Information Model (CIM)-standard data exchange "building blocks". These data exchange "building blocks" can be utilized by utilities to guide their solution design and by application vendors to implement interfaces on their tools. The architecture is business focused rather than application focused.

A Business Function View

In the GMM information architecture a business function is defined as "a set of business behaviors that 1) delivers an outcome essential to the business and 2) is responsible for an identified type of data". While business functions can be reflected in PEA's organizational structure, they are best understood as groupings of related activities with a collective responsibility for a certain type of utility information. It is this understanding that allows business functions to provide a universal framework for exploring enterprise-wide grid model data management at the industry level. Taking a business function view of the distribution utility activities that produce and consume grid model data allows an understanding of universal processes and data flows to be developed. It lets the discussion occur on a functional level and defers consideration of tool capabilities and implementation particulars until a contextual framework for understanding their roles has been built.

The major business functions involved with grid model data are shown in Figure 3. Blue business functions represent activities that are electric system-focused – they are activities whose concern is some facet of grid-level behavior. Purple business functions are activities with a focus on grid facilities – they are activities whose concern tends to be local. This distinction becomes important as consideration is given to the way business functions structure the data for which they are responsible.

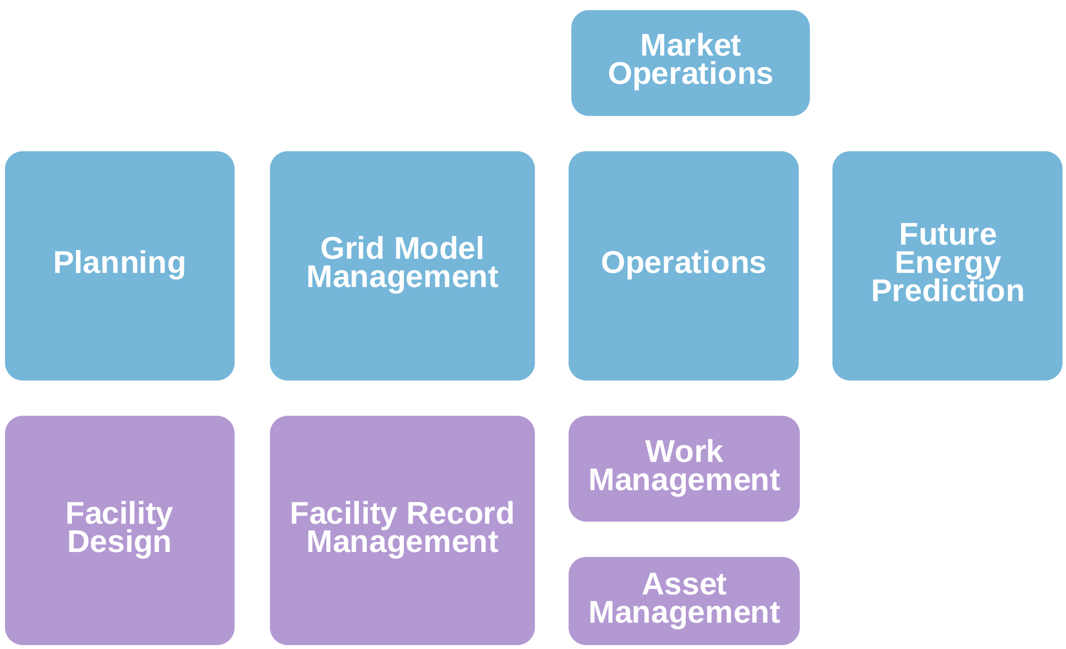


Figure 3. Business functions that source, manage or consume grid model data

One of the identified blue business functions is "Grid Model Management." The GMM information architecture calls out this business function specifically because of its importance. It is indeed "a set of business behaviors that delivers an outcome essential to the business." The source data that are input to a grid model data management business function are distinct from the data produced by it. There are a complex set of data organization and transformation activities required to create the grid modeling supplied to consuming business functions from the data provided by sourcing business functions. It is worth noting that the activities of the Grid Model Management business function themselves are not new. Distribution utilities have been performing and automating those organization and transformation activities for decades. They have just been doing so in multiple locations across the utility with largely uncoordinated and often duplicative processes. The GMM information architecture simply acknowledges those activities as a proper business function and views them as a coordinated whole.

The business function approach supports the definition of an information architecture because the data that one business function is responsible for are often required by other business functions. So, data flow between business functions. The arrows of Figure 4 originate from business functions responsible for a given type of data and point at business functions that require some or all of that information. (Figure 4 also illustrates the fact that business functions can be deconstructed into component business functions in order to gain insight.)

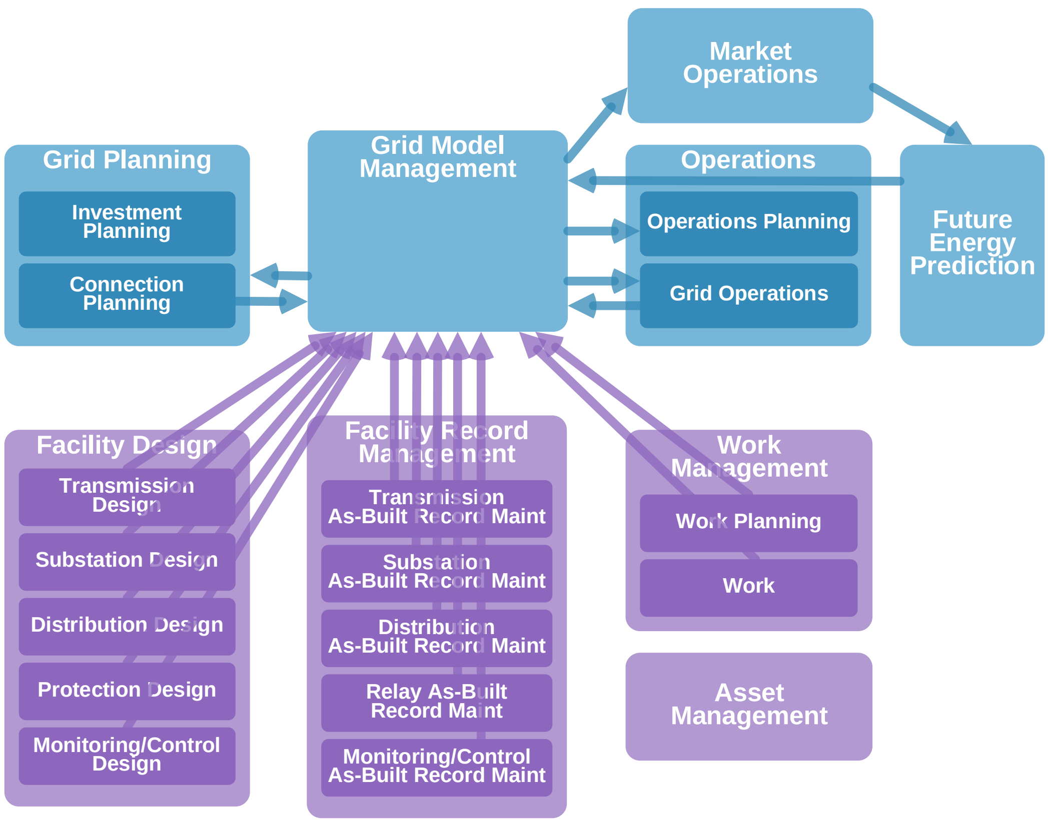


Figure 4. Deconstructed business functions with business objects shown as arrows

This level of detail affords a number of insights into the requirements for managing grid model data at an enterprise level. The first set of insights relates to grid model data consumers. (See Figure 5.) Each consumer requires grid modeling, but the requirements vary:

- **Grid extent**. Sometimes modeling of one part of the grid is needed for a study (for example, a switching study might need two connected feeders) while other studies may require something different (like a non-wires alternative study where a complete substation, its feeders and a portion of the surrounding sub-transmission system would be of interest).
- **Types of data**. Not all types of data are needed for every study. Models for operations will likely include measurement locations, for example, and planning models will often require short circuit parameters.
- **Points in time**. Many studies are run using the current as-built model, some studies require models that reflect a past point in time, but the majority of studies examine a future point in time requiring models that have a select set of projects included in them.

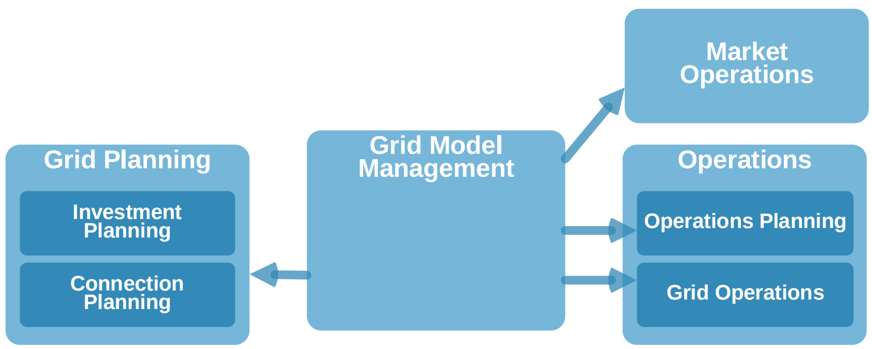


Figure 5. Grid modeling consumers have varying needs

Shifting focus to the business functions that supply grid model data (shown in Figure 6), supplier insights include:

- **Many sources**. Grid model data typically comes from multiple sources. Not only do different sources provide different types of data, but the same type of data can also originate from different business functions. Engineering design data, for example, originates in multiple component business functions and typically is provided in different forms: feeder designs can be expressed differently than substation designs, which are different from protection or monitoring/control designs.
- **Different sources at different stages of grid evolution**. At different stages during the course of a project, different business functions can source the same data element. Device rating data, for example, can be initially specified by Planning, is usually refined by Facility Design, and may be corrected by Work during construction.
- **Transformation of data structure**. The difference between the “local element” view of the world held by purple business functions and the “system” view held by the blue business functions implies that the data which purple business functions are responsible for are likely

to be structured differently than the data of the blue business functions. Purple business functions will likely organize the content of their data from a "civil" (or "structural") perspective, whereas the blue business functions will opt for an "electrical" view. Data that "bridge the gap", flowing between the two are likely going to require structure transformation.

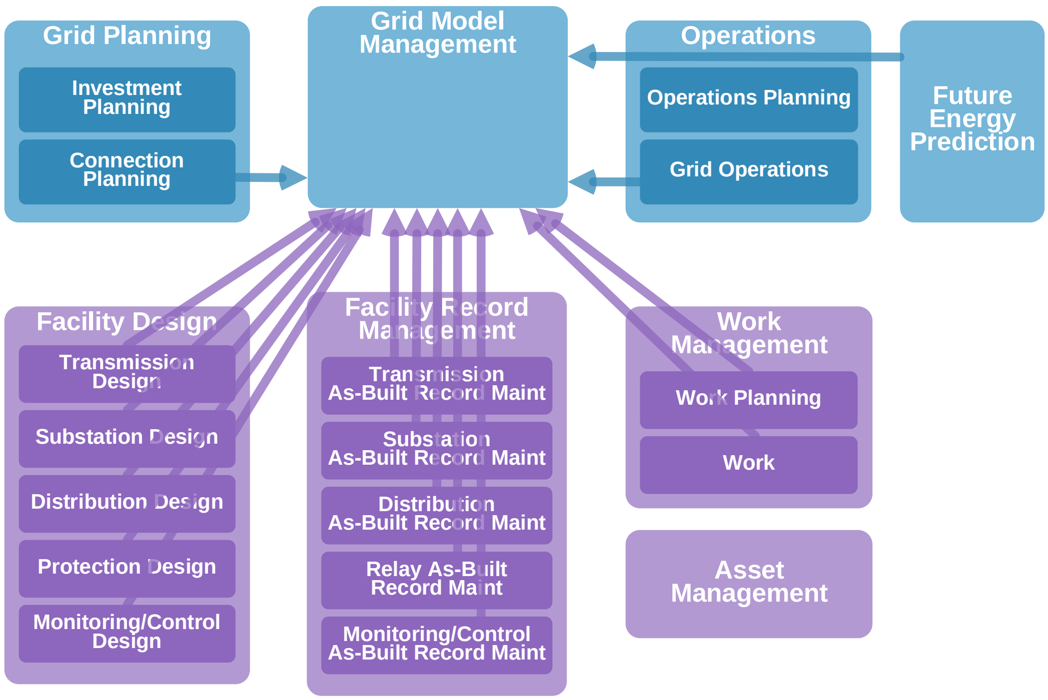


Figure 6. Grid modeling suppliers are many, and contribute at different project lifecycle stages

The Grid Model Management Business Function

The Grid Model Management business function is the workhorse of the GMM information architecture responsible for coordinating the management of grid model data. It can be deconstructed into a variety of smaller component business functions. Two of them, shown in Figure 7, are key:

- **Master Model Maintenance** integrates with engineering detail sources to assure consistency between facility records and the mathematical representation of those facilities in complete "single source of truth" grid modeling. It consolidates and organizes master electrical grid data provided by multiple other business functions in a manner that maintains as-built modeling, future prospective project modeling, and modeling history over time. The master modeling it maintains facilitates the creation of models and cases by the "Assembly Support" component function.
- **Assembly Support** enables the construction of grid models fit for each network analysis purpose. It supplies services for selecting and combining master modeling, simplifying modeling, and maintaining audit trails of assembly actions. The primary business functions

consuming the results of Assembly Support are those related to planning, operations, and markets. While there can be significant overlap in the requirements of various consumers, they are not identical and Assembly Support provides procedures that enable tailored modeling to be created for each consumer.

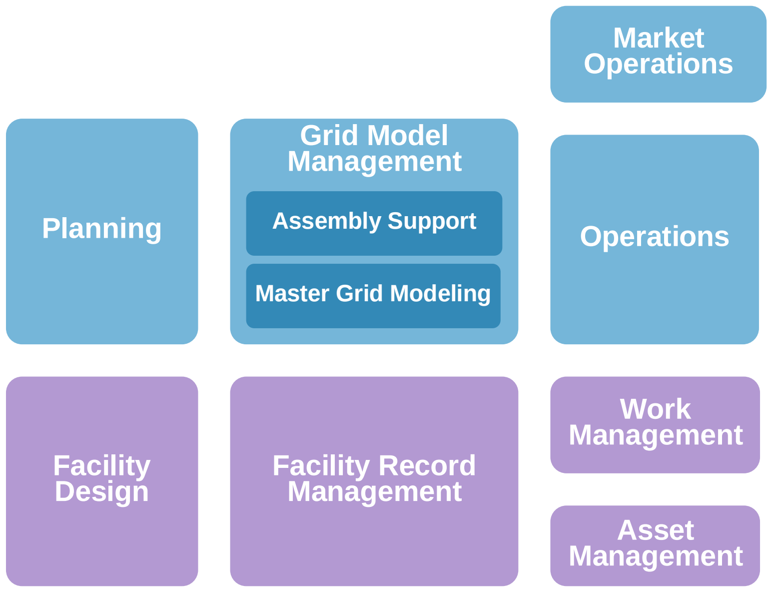


Figure 7. The two major Grid Model Management component business functions: Master Grid Modeling and Assembly Support

The CIM and Grid Model Data Management

The idea of a Grid Model Management business function is made practical today by the CIM grid model standards. The CIM is based around a UML information model that describes the union of all grid modeling data requirements. Without this engineering foundation, developed and tested over 20 years, the notion of enterprise-wide grid model data management would be more a dream than a reality. With it, the internal design requirements for tooling to implement the Grid Model Management business function can be outlined simply by starting with the CIM UML.

How the CIM Organizes Grid Model Data

The CIM has two major types of constructs that support grid model data management:

- “Grid Representation” constructs that model the power system itself
- “Grid Metadata” constructs that enable “building block” organization and management of power system data

They are briefly described below.

CIM “Grid Representation” Constructs

The CIM has a multitude of classes that describe grid equipment, their electrical behavior characteristics, and their connectivity. As shorthand, the GMM information architecture refers to these classes as the “Grid Representation” part of CIM modeling. They enable the creation of network models describing the physical grid in sufficient detail to support a variety of grid simulations and analytics.

At the heart of the CIM ”Grid Representation” modeling are three classes: ConductingEquipment, Terminal and ConnectivityNode, which provide the foundation on which the CIM’s description of a power grid is built. Simply stated, the ConductingEquipment class is used to represent anything with electrical behavior (lines, transformers, breakers, loads, generation, etc.). Every ConductingEquipment has at least one Terminal which is used to “attach” the ConductingEquipment to a ConnectivityNode. Since the Terminals of multiple ConductingEquipments can attach to a single ConnectivityNode, a description of a networked grid can be created. See Figure 8.

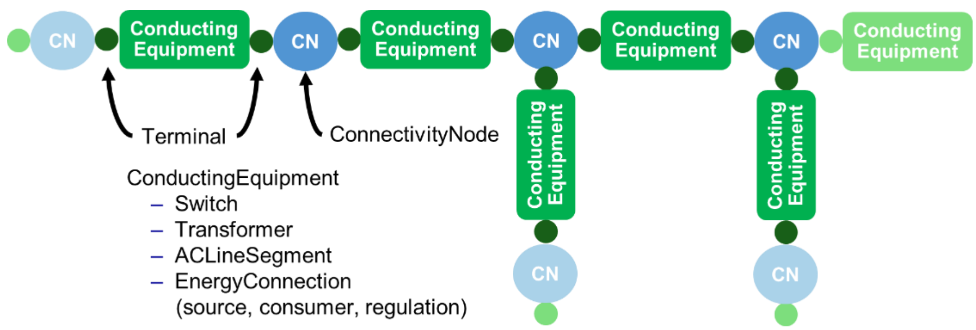


Figure 8. Basic CIM "Grid Representation" power system modeling constructs

CIM ”Grid Metadata” Constructs

The CIM has a set of constructs that enable the “building block” organization and management of power system data. As shorthand, these are referred to as the “"Grid Metadata” part of CIM modeling. These constructs support dividing grid modeling data by type, by grid extent and by changes over time. The CIM Model, Change Model, Frame, Boundary, and Assembly constructs, along with data exchange profiles, enable the organization and effective sharing of grid modeling. Briefly,

- Frames and Boundaries allow the compartmentalization of a grid into multiple, non-overlapping extents (regions).
- Models, containing power system modeling for a portion of the grid, “fit into” Frames and Boundaries.

- Change Models ("projects") define a set of changes that can be applied to a Model.
- Assemblies are collections of Models.
- Data exchange profiles describe a type of grid model data (physical, situational or power flow solution).

Model, Change Model and Assembly are illustrated in Figure 9.

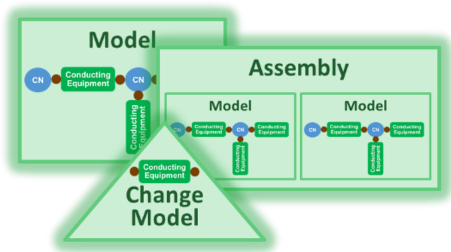


Figure 9. Several of the major CIM "Grid Metadata" constructs: Model, Change Model, Assembly

Leveraging CIM "Grid Metadata" Constructs for Grid Model Management

The two main Grid Model Management component functions and their responsibilities were introduced earlier. Their activities are enabled by and leverage the CIM "Grid Metadata" constructs. This is illustrated in Figure 10, where:

- The Master Model Maintenance subfunction
  - Manages as-built Models that contain master data for parts of the grid
  - Manages Change Models which contain descriptions of prospective future changes to the grid
  - Maintains history of each Model over time
  - Creates new versions of as-built Models by adding the changes described by Change Models to previous as-built Models as projects are commissioned
- The Assembly Support subfunction:
  - Uses Models and Change Models in operations that create new Models
  - Collects Models to create Assemblies (grid models or cases for consumers)

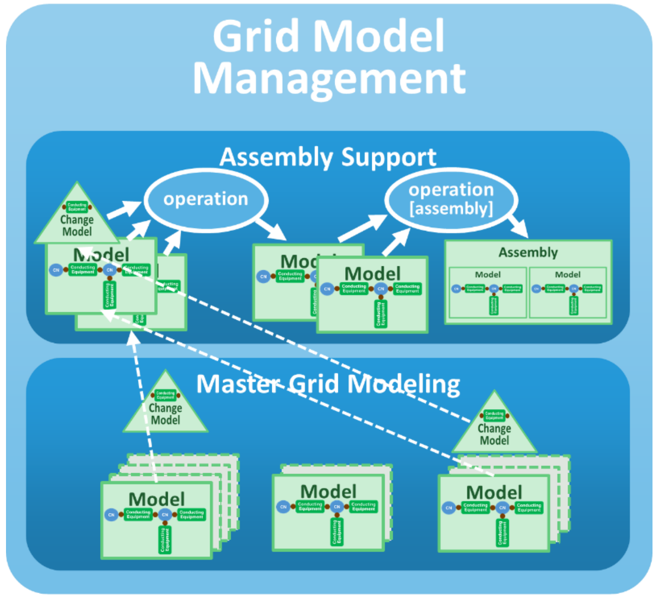


Figure 10. The Master Grid Modeling and Assembly Support component functions use CIM "Grid Metadata" constructs

While all the "macro" constructs contribute to the activities of the Grid Model Management business function, Change Models play a particularly important role:

- They are the means by which the grid model evolves over time. (Completed Change Models ("projects") are added to the previous version of an as-built Model to create the new current Model version.)
- They are the means by which the future is expressed. (The single past is represented as a series of as-built Model versions whereas the future is an infinite number of possible Change Model combinations.)
- They allow modeling to be created for any point in future time to meet the requirements of different studies performed by various consuming applications.

Conclusion

The goal of the GMM information architecture is to enable utilities such as PEA to design comprehensive, enterprise-wide grid model data management solutions that can be implemented using vendor products with standard interfaces. The architecture was developed with input from both utilities and vendors using a business function approach, making it applicable to utilities of all sizes around the world. It leverages CIM-standard data exchange "building blocks" that can both enable high quality solution design and reduce cost and time of deployment. The GMM information architecture enables a best practice approach to building the grid model data management foundation that will allow utilities to meet the challenge of maintaining grid reliability while simultaneously maximizing their contribution to society's carbon reduction goals.

Glossary

Term/Acronym	Definition
Abstract	If the class in the class hierarchy (i.e., the parent) is not intended to be instantiated, then it is considered as an abstract class.
Admittance	A measure of how easily a circuit or device will allow a current to flow.
ADMS	Advanced Distribution Management System, a type of software suite for controlling electrical grids. An ADMS is designed to manage energy output, reduce outages, and regulate electrical demand.
ADT	Abstract Data Type, a mathematical model for data types.
ASEAN	Association of Southeast Asian Nations
Aggregation	A relationship defines a special kind of association between classes, indicating that one is a container class for the other.
AMI	Advanced Metering Infrastructure, an integrated system of smart meters, communications networks, and data management systems that enables two-way communication between utilities and customers.
API	Application Programming Interface, an interface that defines interactions between multiple software applications or mixed hardware-software intermediaries.
Asset Management	Practice of managing infrastructure capital assets to minimize the total cost of owning and operating these assets while delivering the desired service levels.
Back Office Application	Application relating to the inner workings of a utility, such as making sure utility customers receive the correct paperwork and facilitating payment of customer bills.
Busbar	A metallic strip or bar, typically housed inside switchgear, panel boards, and busway enclosures for local high current power distribution.
Cascading Delete	Details what should happen to a related table when updates are made to a row or rows of a target table.
CCAPI	Control Center Application Programming Interface, an EPRI project with the aim of defining a common definition for power system components for use in the Energy Management System. The CIM was created during this project.
CD	Community Draft, a working draft of the New Work Item Proposal (NWIP) standard and circulated to all national committees for comment.
CDM	Canonical Data Model, a design pattern used to communicate between different data formats. Essentially, a data model is created that is a superset of all the others ("canonical"). Also created is a "translator" module or layer to/from which all existing modules exchange data with other modules. The individual modules can then be considered endpoints on an intelligent bus, which centralizes all data translation intelligence.

Term/Acronym	Definition
CDPSM	Common Distribution Power System Model, the distribution equivalent of the Common Power System Model (CPSM), building on the standard balanced network model, with additional data used to model low-voltage distribution networks.
CDV	Committee Draft for Vote, updated version of the standard issued in draft form and circulated to member countries for a five-month voting period. The CDV is considered approved if two-thirds of the votes cast are in favor and the number of negative votes does not exceed 25% of the votes cast.
CIM	Common Information Model, an open standard created by EPRI for representing power system components.
CIMSpy	CIMSpy, a software tool that provides data engineering functions and user experience to help understand and analyze CIM-based power system models.
CIMTool	An open source tool that supports the definition of CIM profiles.
CIS	Customer Information System, system utilized by customer service representatives for billing and payment.
Class	Represents a specific type of object being modeled. Classes can be abstract or concrete.
Class Hierarchy	An abstract model of a system defining every type of component within a system as a separate class.
Composition	A specialized form of aggregation where the contained object is a fundamental part of the container object.
Conceptual Model for Data Management	Abstract definition that integrates the internal and external model. Ideally, the internal and external models are both derived from the conceptual model.
Concrete	If the class is something that may be instantiated, then it is concrete.
Container	A class, a data structure, or an ADT whose instances are collections of other objects.
CPSM	Common Power System Model, used for the exchange of electrical power system node-breaker models. Originally developed to define exchanges between Energy Management Systems (EMSs), it has since grown to encompass the exchanges between multiple systems within the transmission environment.
Data Abstraction	Programming process of creating a data type, usually a class, that hides the details of the data representation to make the data type easier to work with.
Database Schema	Organization and structure of a database.
DEF	Data Exchange Format, language that is domain-independent and can be used for data from any kind of discipline.
DEFLATE	Dutch Compressed Data Format Specification (currently version 1.3).

Term/Acronym	Definition
DERMS	Distributed Energy Resources Management System, a platform which helps distribution system operators (DSOs) manage grids that are based on distributed energy resources (DER).
DER	Distributed Energy Resources, physical and virtual assets that are deployed across the distribution grid, typically close to load, and usually behind the meter, which can be used individually or in aggregate to provide value to the grid, individual customers, or both.
DMS	Distribution Management System
DSO	Distribution System Operator, an operator who manages the network that ensures energy will be transferred from the high-voltage transmission system to the distribution system and then to the final customer.
DTD	Document Type Definition, set of markup declarations that define a document type for a Standard Generalized Markup Language (SGML). A DTD defines the valid building blocks of an eXtensible Markup Language (XML) document as well as the document structure with a list of validated elements and attributes. A DTD can be declared inline inside an XML document or as an external reference.
e-GIF	electronic Government Interoperability Framework
EAM	Enterprise Asset Management, management of the maintenance of physical assets of an organization throughout each asset's life cycle.
EIC	European Innovation Council
ELIA	Belgian transmission grid operator
EMS	Energy Management System, automation systems that collect energy measurement data from the field and make it available to users.
ENTSO-E	European Network of Transmission Systems Operators for Electricity, the association for the cooperation of European transmission system operators (TSOs).
Enumeration	A complete, ordered listing of all the items in a collection.
EPRI	Electric Power Research Institute
ESB	Enterprise Service Bus, an architectural pattern whereby a centralized software component performs integrations between applications. The ESB performs transformations of data models, handles connectivity, routes messages, converts communication protocols, and potentially manages the composition of multiple requests.
ESPI	Energy Services Providers Interface, concept that has been identified and defined within several smart grid domains.
EST	Eastern Standard Time
Extensibility	Measure of the ability to extend a system and the level of effort required to implement the extension.
External Model for Data Management	Describes the data that are exposed to the user or will be shared outside of the application. For example, this external model would define the data exposed as part of a user interface or written to a file.

Term/Acronym	Definition
FDIS	Final Draft International Standard, this is prepared after the working group addresses any comments that have been received. The FDIS is then submitted to the IEC Central Office and circulated to the national committees for a two-month voting period.
Generalization	See "Inheritance" for definition.
GIS	Geographic Information System
GMDM	Grid Model Data Management
GUID	Globally Unique Identifier, another term for Universally Unique Identifier (UUID); refer to UUID for definition.
HES	Head-End System, hardware and software that receives the stream of meter data brought back to the utility through the AMI. Head-end systems may perform a limited amount of data validation before either making the data available for other systems to request or pushing the data out to other systems.
ICCS	Information, Communication and Cyber Security
ICT	Indochina Time
IEC	International Electrotechnical Commission, a global, not-for-profit membership-based organization that serves as a global standards authority. IEC requires that the CIM and all related standards go through a formal standard approval process before publication.
Impedance	The opposition to power flow in an AC circuit. Also, any device that introduces such opposition in the form of resistance, reactance, or both.
Inheritance	Defines a class as being a subclass of another class. As a sub-class, it inherits all the attributes of its parent, but can also contain its own attributes (also known as Generalization).
Instantiate	To launch or run, in object technology, to create an object of a specific class.
IRM	Interface Reference Model, defines interfaces for the major elements of an interface architecture for various distributed application components for the utility to manage electrical distribution networks. These capabilities include monitoring and control of equipment for power delivery, management processes to ensure system reliability, voltage management, demand-side management, outage management, work management, network model management, facilities management, and metering.
Internal Model	Database schema that differs from the conceptual model but can be automatically derived from it.
Internal Model for Data Management	Describes how the application or system stores the data internally, whether within in-memory data structures or a database schema. These data are available to the internal processes and algorithms.
Interoperability	Ability of systems – or components within systems – to interact and exchange services or information with each other and to operate effectively in an expected way without significant user intervention.

Term/Acronym	Definition
ISO	Independent System Operator, an electric power transmission system operator (TSO) that coordinates, controls, and monitors a multistate electric grid.
IT	Information Technology
JAR	Sun Microsystems' Java Archive format
JMS	Java Messaging Services, designed to make it easy to develop business applications that asynchronously send and receive business data and events. JMS defines a common enterprise messaging API designed to be easily and efficiently supported by a wide range of enterprise messaging products.
JSON	JavaScript Object Notation, a lightweight, text-based data exchange format. JSON originated from the programming language after which it was named, JavaScript; however, JSON data can be written in any programming language.
KML	Keyhole Markup Language, a file format used to display geographic data in an Earth browser such as Google Earth. KML uses a tag-based structure with nested elements and attributes and is based on the XML standard.
KMZ	Keyhole Markup language Zipped, consists of a main KML file and zero or more supporting files that are packaged using a ZIP utility into one unit, called an archive. The KMZ file can then be stored and emailed as a single entity.
Line	Pipes, cables, or other linear conveyance systems used to transport power.
LMP	Locational Marginal Pricing, represents the cost to buy and sell power at different locations within wholesale electricity markets, usually involving ISOs.
Load	An end-use device or customer receiving power from the electric system.
Map	A utility map shows the positioning and identification of buried pipes and cables beneath the ground. The mapping procedure involves detecting sewage systems, electric cables, telecom cables, gas mains, water mains, and similar large systems. When this mapping process is combined with a topographical survey, the results provide a comprehensive detailed map of anything hidden underground or directly related to any aboveground features.
MDA	Model Driven Architecture, software design approach for the development of software systems. MDA provides a set of guidelines for the structuring of specifications, which are expressed as models.
MDE	Model-Driven Engineering, an iterative and incremental software development process.
MDMS	Meter Data Management System, suite of software programs that receive and store meter data and support a host of revenue cycle and other functions (e.g., billing, outage management, and distribution engineering).

Term/Acronym	Definition
MDT	Model Driven Transformation, supports the entire life cycle of transformation development using open standards and offering automation resources.
Microgrid	Self-sufficient energy system that serves a discrete geographic footprint, such as a college campus, hospital complex, business center, or neighborhood.
mRID	Master Resource Identifier, a string-based identifier for a measurement.
NAESB	North American Energy Standards Board, serves as an industry forum for the development and promotion of standards designed to lead to a seamless marketplace for wholesale and retail natural gas and electricity, as recognized by customers, business communities, participants, and regulatory entities.
Namespace	A set of signs (names used to identify and refer to objects of various kinds). A namespace ensures that all of a given set of objects have unique names so that they can be easily identified.
NMM	Network Model Management
NREL	National Renewable Energy Laboratory
NWIP	New Work Item Proposal, the first step required by the EIC in creating a new standard. The NWIP is submitted by a working group and is voted on by all member countries.
ODF	Open Document Format, an open standard file format for spreadsheets, charts, presentations, and word processing documents using ZIP-compressed XML files.
OMS	Outage Management System, network management software that can restore the network model after an outage.
One-Offs	Instance in which each time a data change is made it starts with the old interface specification. A copy is made of this interface, and changes to that interface are then adapted for the new specification. Finally, changes to the new interface are tested against all the applications that used the old interface (if they are not missed in the test plan) and against all the applications the old interface was integrated with.
Ontology	Explicit specification of a conceptualization.
OpenADE	Open Automated Data Exchange (Task Force), group of smart-energy-management vendors, utilities, and government interests developing recommendations toward building interoperable data exchanges that allow customer authorization and sharing of utility consumption information with third-party service providers.
OT	Operational Technology, power system-related applications used in planning and operations.
PEA	Thailand’s Provincial Electricity Authority
PMO	PEA Project Management Office

Term/Acronym	Definition
Power System Applications	Applications that deal with power generation, transmission, and distribution sectors.
PRA	Project Risk Assessment
Procurement	Process of finding and agreeing to terms and acquiring goods, services, or works from an external source, often via a tendering or competitive bidding process.
Proprietary	Exclusive right to something.
PSS/E	Power System Simulator for Engineering, a power system analysis tool from Siemens Power Technology International that is widely used in the power industry.
PSS/E RAW	Native file format for PSS/E.
QVTO	Query/View/Transform Operational, an Object Management Group specification for model-to-model transformation with an open-source Eclipse implementation available that runs on top of Java.
RDF	Resource Description Framework, an XML schema used to provide a framework for data in an XML format by allowing relationships to be defined between XML nodes.
RDFS	RDF Schema (also known as RDF Vocabulary Description Language), provides the user with a means of describing specific kinds of resources or classes.
REST	REpresentational State Transfer, a software architectural style that uses a subset of Hypertext Transfer Protocol (HTTP).
Reverse Engineering	Process in which software and products are deconstructed to extract design information from them. Often, reverse engineering involves deconstructing individual components of larger products.
RTO	Regional Transmission Organization, an electric power transmission system operator (TSO) that coordinates, controls, and monitors a multi-state electric grid.
RTOPF	Real-Time Optimal Power Flow
SCADA	Supervisory Control and Data Acquisition
SCED	Real-Time Markets with Security Constrained Economic Dispatch, determines resource dispatch megawatts (MW) as well as LMP to minimize the system energy production cost subject to resource operational limits and network security constraints.
SCUC	Day-Ahead Markets with Security Constrained Unit Commitment, optimization algorithm used for day-ahead planning in restructured electricity markets.
Semantic Model	Model defined before any software is written or from the perspective of a systems integrator. The model is created before the interfaces are defined at any level of detail.

Term/Acronym	Definition
Serialization	Process of converting a data structure into a format that can be stored and then retrieved later, whether it is in a memory buffer, file or transmitted across a network. A file format is an example of a serialization format, where data are written to a file in a set format that can then be read again later, recreating an identical in-memory data structure.
SGML	Standard Generalized Markup Language, a standard for defining generalized markup languages for documents. XML is a subset of SGML.
SI	International System of Units
SME	Subject Matter Expert
SOAP	Simple Open Access Protocol, a messaging protocol that uses XML for the machine-to-machine message exchange. SOAP web services are contract-based, making use of Web Services Description Language (WSDL) files and XML Schema Definition (XSD) files to define what messages can be exchanged.
spatial	Relating to or involved in the perception of relationships (as of objects).
Subclasses	A subdivision of a set or class.
Substation	Facility equipment that switches, changes, or regulates electric voltage.
Synchronization	Coordination of events to operate a system in unison.
TA	Technical Assistance
TCO	Total Cost of Ownership, purchase price of an asset plus the costs of operation.
ToR	Terms of Reference, set forth the TA terms, conditions, provisions, and specifications for the benefit of the Provincial Electricity Authority of Thailand.
TSO	Transmission System Operator, an entity entrusted with transporting energy in the form of natural gas or electrical power on a national or regional level, using a fixed infrastructure. The term is defined by the European Commission.
UML	Unified Modeling Language, modeling and specification language used for modeling a wide variety of components within the software development life cycle, including data structures, system interactions, and use cases. The modeling is not tied to one particular implementation technology and can be realized on multiple platforms.
UN/CEFACT	United Nations/Center for Trade Facilitation and E-Business, subsidiary, intergovernmental body of the United Nations Economic Commission for Europe (UNECE), which serves as a focal point within the United Nations Economic and Social Council for trade facilitation recommendations and electronic business standards.
UNECE	United Nations Economic Commission for Europe, one of five regional commissions of the United Nations that aims to promote pan-European economic integration.

Term/Acronym	Definition
URI	Uniform Resource Identifier, a unique sequence of characters that identifies a logical or physical resource used by web technologies.
USTDA	U.S. Trade and Development Agency
UUID	Universally Unique Identifier, known in CIM as a Master Resource Identifier (MRID) or Globally Unique Identifier (GUID).
W3C	World Wide Web Consortium, the governing body for web standards.
WG	Working Group, as related to the CIM. The IEC Technical Committee 57 Working Groups of relevance are 13 (Software Interfaces for Operation and Planning of the Electric Grid), 14 (Enterprise Business Function Interfaces for Utility Operations), and 16 (Markets)
Work Management	Software to plan, track, organize, and review the daily flow of information, business processes, and workforce activities. The end goal is to streamline workflow, create operational efficiencies, and improve quality in all areas of the utility.
WSDL	Web Services Description Language, an XML-based interface description language that is used for describing the functionality offered by a web service.
XML	eXtensible Markup Language, a universal format for structured documents and data, which is a standard for storing machine-readable data in a structured, extensible format that is accessible over the Internet.
XMLSpy	A commercial XML Editor from Altova.
XMPP	Extensible Messaging and Presence Protocol, a set of open technologies for instant messaging, presence, multi-party chat, voice and video calls, collaboration, lightweight middleware, content syndication, and generalized routing of XML data.
XSD	XML Schema Definition, the current standard schema language for all XML documents and data.

Glossary terms curated from numerous Internet sources, including but not limited to: Wikipedia.com, wikimili.com, wikit.thingsandstuff.org, weebly.com, answer.com, scribd.com, webcevforums.com, answers.com, and smartgrid.gov.

A CIM-Base Information Architecture for PEA

The Grid Model Management (GMM) Business Function Model is a depiction of the information flows within an electric utility that support either the building of grid representations or the transfer of those representations to functions which require them to perform their activities. The GMM Business Function Model is a business architecture model rather than an application architecture model. In it, the responsibility for producing critical sets of information is viewed as being associated to a business function, rather than to an organizational unit or to a software system.

Using a business function approach allows grid model information flows to be described in terms that apply universally to all utilities. It doesn't prevent a given utility from 'drilling down' into a lower level (like the application layer), it just allows the broader conversation to occur in an implementation-neutral manner.

In the GMM Business Function Model, Business Functions are responsible for sets of data called Business Objects that can be shared with other Business Functions. A given Business Object is produced by one Business Function but can be consumed by many. Any Business Function which supplies a Business Object is, by definition, responsible for providing the information in as accurate a state as possible and with as much detail is as required by the consumer.

In the GMM Business Function Model diagram:

- Round-cornered colored boxes with a "chevron" icon in the upper right corner indicate Business Functions.
- Rectangular or square boxes with a line across the top indicate Business Objects.
- When a shape is enclosed in another shape, it is a sub-Business Function or sub-Business Object of the enclosing shape.

Arrows indicate what Business Objects are produced by a Business Function and for which it is responsible and what Business Objects a function uses. Arrows indicate direction of information exchange and depict the overall flow of information through the utility enterprise.

In the GMM Business Function Model, there is no indication as to how data is stored or how it is transferred. Such questions are implementation choices and are out of the scope of a business architecture.

Colors are used to group Business Functions and Business Objects and are defined as follows:

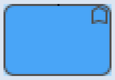
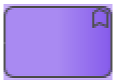
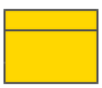
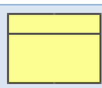
Business Function	Description
	Grid-Focused Business Functions (Blue) have goals which are related to the electric grid as a whole – outcomes that ensure that the grid performs reliably, safely, and efficiently. In general, these Business Functions require a Grid Representation to operate effectively.
	Facility-Focused Business Functions (Purple) have goals which relate to the design and management of the utility's facilities, which include transmission lines, distribution feeders, and substations, along with protection and monitoring/control equipment. In general, these Business Functions operate locally, are not concerned with behavior of the grid as a whole, and do not deal with the entire Grid Representation.
	External Business Function/Actors (Grey) are entities external to the utility which provide or utilize data related to the grid model.
Business Object	**Description**
	Grid Model Business Objects (**Pink**) contain Grid Representation (equipment and connectivity) for a given moment in time (past, present, or future) and a given extent or regional scope.
	Change Model Business Objects (**Orange**) contains changes to Grid Representations, essentially planned additions, updates, and/or deletions of equipment or connectivity.
	Other Business Objects (Yellow) represent Business Objects that are neither Grid Representations nor Change Models.

Figure 11. Business Function/Object Description

When Business Functions or Business Objects are can be deconstructed into sub-Business Functions or sub-Business Objects, different color values (light vs. medium vs. dark) represent different layers in the Object/Function hierarchy as seen in Figure 12.

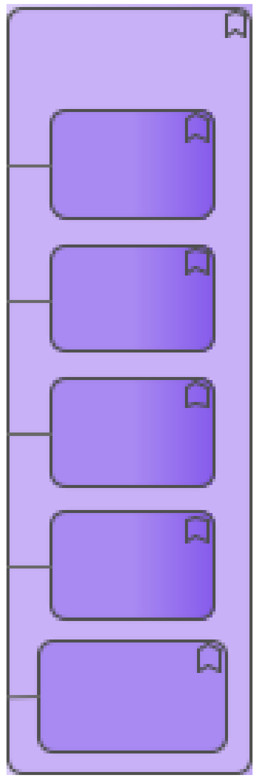


Figure 12. Object/Function Hierarchy Layers

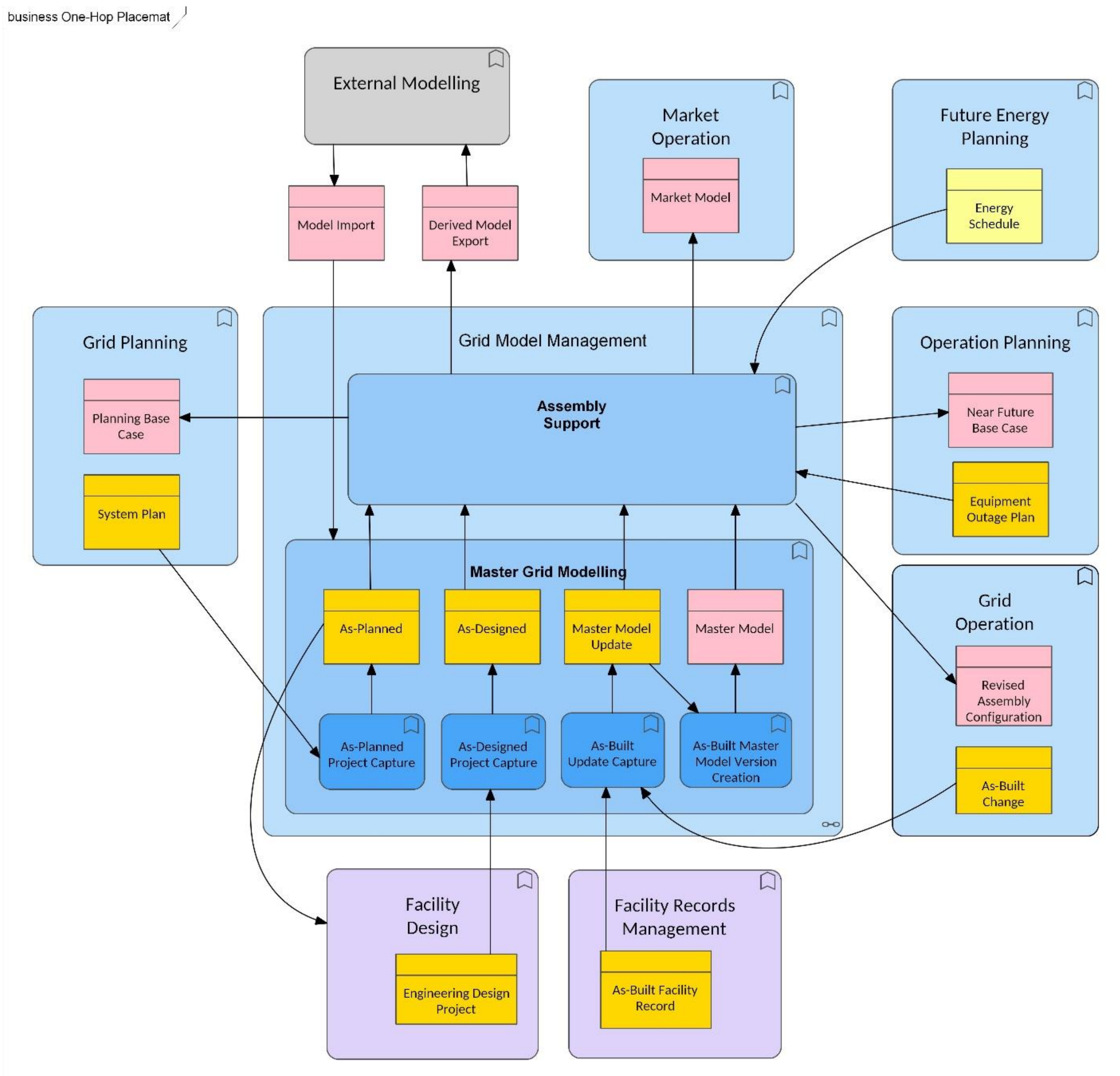


Figure 13. Summary Business Function

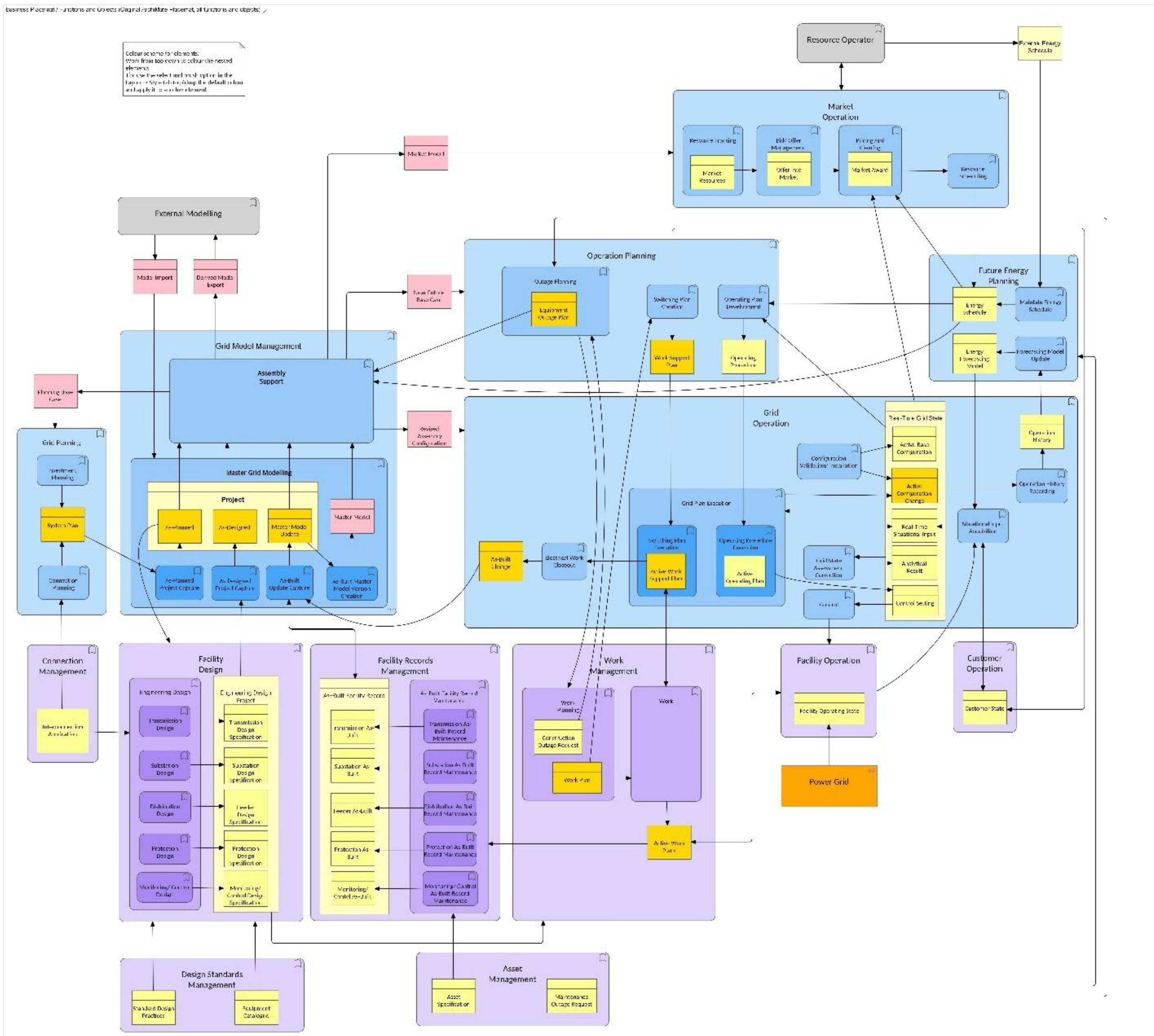


Figure 14. Full Business Function: All Functions and Objects

Grid Model Management Information Architecture Business Functions and Business Object Descriptions

Asset Management (*BusinessFunction)*

Asset Management manages information about a utility's owned assets, generally both electrical assets (like transformers) and non-electrical assets (like poles). Asset management not only tracks the core information about assets which is static, but also dynamic information such as maintenance details and physical location. Asset management may also track assets that are not owned by the utility but are relevant to operating the grid, e.g., DERs

Design Standards Management (*BusinessFunction)*

Design Standard Management develops Standard Design Practices and coordinates with purchasing to maintain inventory of commonly used components (Equipment Catalogue).

External Modelling (*BusinessFunction)*

An External Modelling function is any peer grid modelling entity that a Grid Model Management function may need to cooperate with.

For a distribution utility, the Grid Model Management function of the transmission utility to which the distribution utility connects might play this role. The transmission GMM function could support procedures to develop substation models including source impedance information which would be provided as Imported Modelling to the distribution GMM. And the distribution GMM function might support procedures to develop equivalent feeder models from distribution detail for use in transmission analysis which it would supply as Exported Modelling.

For a transmission utility, External Modelling functions would frequently include the GMM functions of the transmission operators of neighboring territories (in addition to any distribution GMM functions of the sort mentioned above). To support accurate creation of external grid models, each transmission utility GMM business function would provide Exported Modelling to its neighbors' GMMs and would receive Imported Modelling from them.

Facility Operation (*BusinessFunction)*

Facility Operation provides the complete capability for grid monitoring and control. This includes a wide variety of field hardware and software (protective devices, RTUs, smart devices and meters, communication equipment, etc.) which collectively provide Operations with insight into grid conditions (via Situational Input Acquisition) and with the ability to execute grid control actions (via Control). Since many of the field components are configurable, Facility Operation also maintains their configurations, getting input from both Monitoring/Control Design and from Control.

Facility Records Management (*BusinessFunction)*

Facility Record Management maintains the state of constructed facilities.

Facility Design (*BusinessFunction)*

Facility Design creates detailed designs for the construction, upgrade or decommissioning of utility facilities.

Future Energy Planning (*BusinessFunction)*

Future Energy Planning maintains models that can be used to build projections about energy of various categories at future times. In the past, we just worried about load and generation, but now energy is diversifying, and each category requires a means of forecasting. Models for different energy categories and situations differ. The models may be expressed as formulas or lookup tables or logic or any other means of converting a set of model inputs to a set of model outputs.

Grid Planning (*BusinessFunction)*

Grid Planning assesses the need for new grid facilities and/or upgrade of existing facilities, examines alternative solutions typically by means of network analysis, and establishes approved budgeted plans for meeting those needs. Each plan describes the changes to the grid associated with whatever need is being addressed. As planning engineers work on various ideas, each idea is modeled and studied and possible plans are maintained locally by the engineers. Finalized plans are shared outside the Grid Planning business function.

Grid Operation (*BusinessFunction)*

Grid Operations has responsibility for operating the electrical grid. It is a real-time activity, focused on what is, what is about to happen and what has just happened that may require reaction. Concerns include:

- Near-term energy forecast
- Grid reliability
- Power quality
- Crew activity and safety
- Cyber security
- Market or schedule obligations
- Minimal customer outages
- Minimal losses

Understanding of the concerns is often enabled by network analysis.

Market Operation (*BusinessFunction)*

Market Operations negotiates availability and remuneration of controllable energy resources on the grid. Network analysis is a key component of the market processes, which can be performed from months to years ahead of dispatch for capacity-style services, or close to near-real time for services like energy, reserve, and frequency support.

Note: A current industry trend in distribution is toward negotiation via markets designed and operated by the utility, and the information architecture diagram shows a typical outline of market functions. Details of market design are evolving, however, so this should be viewed mainly as a placeholder.

Operation Planning (*BusinessFunction)*

Outage Planning determines how to satisfy a maintenance or new work outage request with minimal negative impact on either grid operation or customer service. Coordination of multiple outage activities is also considered when appropriate.

Protection As-Built Record Maintenance (*BusinessFunction)*

Protection As-Built Record Maintenance keeps the Protection As-Built information accurate, updating it as project work completes.

Resource Operator (*BusinessFunction)*

TBD

Substation As-Built Record Maintenance (*BusinessFunction)*

Substation As-Built Record Maintenance keeps the Substation As-Built information accurate, updating it as project work completes.

Transmission As-Built Record Maintenance (*BusinessFunction)*

Transmission As-Built Record Maintenance keeps the Transmission As-Built information accurate, updating it as project work completes.

Work Management (*BusinessFunction)*

Work Management organizes and carries out work of three main types:
Planned work that executes designed projects.

Unplanned work that responds to problems, such as repairing storm damage and restoring customer service.

Maintenance work

Project (*BusinessObject)*

Projects are prospective changes to the grid. Projects are used by Assembly Support to create modelling for future points in time. Projects are often refined along their lifecycle as reflected by the As-Planned, As-Designed and Master Model Updates business objects.

Grid Model Management (*BusinessFunction)*

Grid Model Management provides a single source of truth for grid modelling. It is responsible for maintaining grid model data quality and for providing grid model data to network analysis consumers in a form useful to each consumer

Assembly Support (*BusinessFunction)*

Assembly Support constructs modeling to meet the needs of each consumer. Consumer functions leverage the capabilities of Assembly Support to produce their required grid modeling . Consumer functions supply procedures to Assembly Support which hosts and facilitates the execution of procedures for the construction of tailored modeling. Procedures utilize the variety of inputs supplied to Assembly Support (As-Built Master Model, Projects, Equipment Outage Plans, Energy Schedules, and External Modelling) and call on a number of services (like selecting and combining As-Built Master Models and Projects, simplifying, calculating additional parameters, defining operating conditions, creating audit trails, and so on) in executing consumer-suppled procedures.

Most assemblies constructed by Assembly Support will be for current or future time frames and will, therefore, typically be built starting with the current version of one or more As-Built Master Models. Then changes represented in relevant Projects are applied to bring the modelling forward to the desired point in time. Reductions and simplifications are commonly performed as appropriate to the kind of study required. Documentation of the assembly process captures both the versions of the As-Built Master Model and Projects used and the Operations performed in the production of the finished product.

Master Grid Modelling (*BusinessFunction)*

Master Grid Modelling encompasses all the activities that maintain master physical modelling, including maintenance of the As-Built Master Model and Projects tracking of grid model history.

As-Built Master Model Version Creation (*BusinessFunction)*

This function takes a set of validated as-built changes or corrections (Master Model Updates) and produces a tested new As-Built Master Model version. Any Projects whose changes were incorporated are then archived.

As-Built Update Capture (*BusinessFunction)*

This function brings in data about completed work or needed as-built corrections and creates Master Model Updates. For completed work already described by an As-Designed project, it will typically update that project to create the Master Model Update. It validates data, cross-checks it as necessary for consistency with facility records and ensures that updates are ready for processing by As-Built Master Model Version Creation.

As-Designed Project Capture (*BusinessFunction)*

As-Designed Project Capture creates an As-Designed project reflecting the impact of a completed Engineering Design Project. It may use an As-Planned project as a basis for the As-Designed project or it may not.

As-Planned Project Capture (*BusinessFunction)*

As-Designed Project Capture creates an As-Designed project reflecting the impact of a completed Engineering Design Project. It may use an As-Planned project as a basis for the As-Designed project or it may not.

As-Designed (*BusinessObject)*

An As-Designed project reflects the expected changes to grid modeling that will result from the facility changes described by an Engineering Design Project.

As-Planned (*BusinessObject)*

An As-planned project is one that has come out of the grid planning process and been finalized but has not yet been engineered. The descriptions of As-Planned projects are typically not detailed.

Master Model (*BusinessObject)*

An (As-Built) Master Model represents the physical plant as it is currently constructed. The grid is usually divided electrically and/or geographically into frames (subsets of the entire grid) which create a ‘framework’ that allows Models to fit together. Each Model is a complete representation of the plant deployed in its frame. Models are updated as changes occur and when a model is changed, a new complete model version is created. As-Built Master Models are derived from detailed facility designs (Engineering Design Projects) and are described in terms that stay as close to the physical nature of the plant as is required by any of the network analysis consumers. Thus, for example, all equipment detail needed to compute operating limits is represented, even though most analysis only requires the limit and does not need to know every component that may have factored into the calculation of the limit.

Master Model Update (*BusinessObject)*

A Master Model Update is a grid model change that is ready to be applied to the As-Built Master Model.

Configuration Validation/ Installation (*BusinessFunction)*

Configuration Validation/Installation rebuilds a base configuration for real-time operations, validates the result and then installs the result. The new Active Base Configuration will contain the official final reckoning of completed changes and those changes will be removed from Active Configuration Changes that are in progress.

Control (*BusinessFunction)*

Control carries out automatic control instructions. These may range from one-time operator driven requests like SCADA control of breakers to ongoing automatic controls like a volt-var optimization scheme. This does not include control by external business functions.

Electrical Work Closeout (*BusinessFunction)*

Electrical Work Closeout summarizes the completion of electrical work a to create a final version of the net impact of the work on grid modelling.

Grid Plan Execution (*BusinessFunction)*

Grid Plan Execution tracks the progress of work and other operational procedures being coordinated or executed by Grid Operations. As field changes are made, the change must be reflected as quickly as possible in the Real-Time Grid State:

- Construction activity that adds or modifies the physical grid or measurement system is reflected as an Active Configuration Change.
- Switching, tags and other situational changes are added to the Real-Time Situational input.

Grid State Assessment Correction (*BusinessFunction)*

Grid State Assessment Correction processes Real-Time Situational Input as it changes producing Analytical Results that evaluate the state of the grid and present the state of the grid to operators.

Operation History Recording (*BusinessFunction)*

Operations History Recording creates a record of all activity that occurs in the grid. The first purpose of the history is to be able to determine exactly what happened in what time sequence in the control room and in the electrical grid

Situational Input Acquisition (*BusinessFunction)*

Situational Input Acquisition provides data about the present operating state that is input to analysis of the present state. This includes:

- Measurements and other data about the present condition of the grid obtained from external sources such as RTUs, smart substations, DER managers, etc.
- Customer state information from metering or from customer calls.
- The state of intelligent controls reported to operations.
- Forecasted supplemental data such as projections of energy at energy connections in the grid.

Active Base Configuration (*BusinessObject)*

The Active Base Configuration is the nominal description of the grid model provided by Grid Model Management. It includes:

- A description of the physical grid currently deployed
- A description of the customer connections to the grid, to the extent needed to enable analysis of the grid
- A description of the agents interacting with the grid (such as aggregators of distributed energy resources or bulk generation operators)
- Configuration of data acquisition and control

Active Base Configuration in general consists of multiple models making up a complete analytical base. For example, in distribution, each feeder may be a separate model. In transmission, each TSO's service territory would likely be a separate model.

Active Configuration Change (*BusinessObject)*

An Active Configuration Change reflects a change made in the field which has not yet been included in the Active Base Configuration. It is a record of change local to Grid Operations.

Analytical Result (*BusinessObject)*

The Analytical Result is a calculated picture of the current grid state. It includes all data produced by processing the Real-Time Situational Input against the current configuration (Active Base Configuration plus Active Configuration Changes):

- The best estimate of complete state, such a state estimation based on network analysis
- Assessments of reliability from real-time contingency analysis
- Energy category summaries and projections

- Abnormal situation summaries
- Event and alarm conditions

Operation History (*BusinessObject)*

The Operations History encompasses different stores for different kinds of information. History data includes:

- Alarm and event logs
- Measurement data (high volume sequences of time values)
- Solved analytical states (complete grid state reconciled for one point in time)

Real-Time Situational Input (*BusinessObject)*

Real-Time Situational Input is real-world information about the present situation of the grid. It is one of the major inputs to Grid State Assessment Correction and is a synthesis of information gathered by Situational Input Acquisition and supplied by Grid Plan Execution and includes data like:

- Field information (grid measurements, the state of customers and customer meters, the Facility Operating State, etc.)
- Forecast energy
- Work in progress / crew locations

Operating Procedure Execution (*BusinessFunction)*

Operating Procedure Execution carries out Operating Procedures other than those related to construction or outage work. It executes changes to Control Settings and coordinates manual field activities. The response to each request is confirmed by observing changes in the Real-Time Grid State. Network analysis studies may be set up and run based on the real-time state in advance of or after requests are executed.

Switching Plan Execution (*BusinessFunction)*

Switching Plan Execution tracks and authorizes steps in work (planned or unplanned) with electrical grid impact. Authorization may include simulation of entire plans based on the present grid state before the plan begins or it might take the form of simulation of the next step prior to authorization during execution. Coordination with Work is done via parallel Active Work Plans (used by Work) and Active Work Support Plans (used by Switching Plan Execution). All actions should be recorded in both models, maintaining consistency between the two views.

Active Work Support Plan (*BusinessObject)*

An Active Work Support Plan is a record of the execution of each step of a Work Support Plan as the activity takes place. Grid changes are maintained in a form that is compatible with the Real-Time Grid State.

Active Operating Plan (*BusinessObject)*

An Active Operating Plan is a record of the execution of an Operating Procedure. The state of each Active Work Support Plan is maintained as activity takes place. Grid changes are maintained in a form that is compatible with the Real-Time Grid State.

Work (*BusinessFunction)*

Work is all field activity carried out by crews. Work modifies the power grid. It also configures operation of grid facilities, which enables communication between the facility and Grid Operations. The execution of work by field crews is coordinated by Grid Operations, who must maintain an accurate reflection of what is going on in the field. Work activity is recorded as Active Work Plans.

Work Planning (*BusinessFunction)*

Work Planning creates Work Plans that describe to work crews how to carry out an activity. It adds schedule and resources (work crews and materials/assets) to an Engineering Design Project. Electrical steps in Work Plans must be cross-checked with the Operations Planning business function. If the work involves an equipment outage or customer outage that requires approval, a Construction Outage Request is created and interaction with Outage Planning is required before completing the Work Plan.

Work Plan (*BusinessObject)*

A Work Plan is a document that directs Work in a manner structured to optimize crew efficiency. Work Plans also provide input to Switching Plan Creation, which develops switching orders and modelling that reflects the anticipated impact on grid models.

As-Built Facility Record Maintenance (*BusinessFunction)*

As-Built Facility Record Maintenance maintains As-Built Facility Records based on completed construction work. Facility records for different types of facilities contain information related to different sorts of real-world objects and are maintained by different work groups using independent processes. In recognition of this, the As-Built Facility Record Maintenance business function is further subdivided.

Feeder As-Built (*BusinessObject)*

A Feeder As-Built is an As-Built Facility Record relating to a lower voltage portion of the grid whose primary purpose is providing electricity to customers

Substation As-Built (*BusinessObject)*

A Substation As-Built is an As-Built Facility Record related to a transmission-connected substation.

Transmission As-Built (*BusinessObject)*

A Transmission As-Built is an As-Built Facility Record relating to the networked, high voltage portion of the grid.

Distribution As-Built Record Maintenance (*BusinessFunction)*

Distribution As-Built Record Maintenance keeps the Feeder As-Built information accurate, updating it as project work completes.

Monitoring/ Control As-Built Record Maintenance (*BusinessFunction)*

Monitoring/Control As-Built Record Maintenance keeps the Monitoring/Control As-Built information accurate, updating it as project work completes.

Protection As-Built (*BusinessObject)*

A Protection As-Built is an As-Built Facility Record related to a collection of coordinated devices that protect the electrical grid.

Facility Operating State (*BusinessObject)*

The Facility Operating State is the current configuration of field monitoring and control hardware and software, including default configurations, current settings, local variables, etc.

Engineering Design (*BusinessFunction)*

Engineering Design generates the detailed engineering specifications (Engineering Design Projects) that Work Management requires to plan and execute grid-related facility improvement or construction work. Designs encompass all aspects of a facility: electrical, civil, communications, and so forth. The designs for different types of facilities describe different sorts of real-world objects and are created with specialized tools by different work groups using their own specialized processes. In recognition of this, the Engineering Design business function is further subdivided.

Engineering Design Project (*BusinessObject)*

TBD

Substation Design Specification (*BusinessObject)*

A Substation Design is an Engineering Design Project related to a transmission-connected substation.

Transmission Design Specification (*BusinessObject)*

A Transmission Design is an Engineering Design Project relating to the networked, high voltage portion of the grid.

Distribution Design (*BusinessFunction)*

Distribution Design covers all activities that create detailed designs of distribution facilities.

Monitoring/ Control Design (*BusinessFunction)*

Monitoring/Control Design covers all activities that create detailed designs of monitoring and control facilities.

Protection Design (*BusinessFunction)*

Protection Design covers all activities that create detailed designs for grid protection

Substation Design (*BusinessFunction)*

Substation Design covers all activities that create detailed designs of substation facilities.

Transmission Design (*BusinessFunction)*

Transmission Design covers all activities that create detailed designs of transmission facilities.

Connection Planning (*BusinessFunction)*

Connection Planning evaluates the ability of the grid to support a customer connection request as reflected in an Interconnection Application. Connection requests may result in the need for improvements on the utility side, so a utility plan may also be created.

Investment Planning (*BusinessFunction)*

Investment Planning evaluates the ability of the grid to meet future needs (as presently projected based on approved plans) and develops plans to address any deficiencies.

Planning Base Case (*BusinessObject)*

A Planning Base Case is a representation of the grid extracted from as-built master modelling and projected forward to some desired point in the mid- to far-term future. Multiple Planning Base Cases, each with the same physical modeling, but with different situational models (e.g. peak load, light load), are often created. Longer term Energy Forecasting Models are used to establish energy patterns in situational models in Planning Base Cases.

System Plan (*BusinessObject)*

A Finalized Plan is a planned grid modification that has achieved level of approval or certainty such that it should be moved into master grid modelling so it becomes visible outside Grid Planning.

Asset Specification (*BusinessObject)*

An Asset Specification is either a manufacturer's datasheet for an asset or test data related to that asset. When real assets are installed in the grid, properties that are important to electrical behavior are sourced from Asset Specifications.

Maintenance Outage Request (*BusinessObject)*

A Maintenance Outage Request is a notification of the need to take a grid-related asset out of service to perform maintenance, testing or inspection. Maintenance Outage Requests typically specify a desired timing and are sent to Outage Planning for coordination with other requests.

Forecasting Model Update (*BusinessFunction)*

Forecasting Model Update maintains and continually refines various Energy Forecasting Models based on a variety of information, including customer information from Customer State and various sorts of historic trend information from Operations History, augmented by weather, demographic, economic and regulatory data.

Maintain Energy Schedule (*BusinessFunction)*

Maintain Energy Schedule is responsible for the collection and tracking of generation and/or load schedules from Market Operations and external sources.

Energy Forecasting Model (*BusinessObject)*

An Energy Forecasting Model describes the algorithms for determining the probable amount of a category of energy given input data such as time or weather. There may be different types of models. Some are schedules of values created from Market Awards. Others are forecasting models developed through statistical processing of historical data. It is common that utilities have unique modelling needs, so this is a placeholder for all such data, put into a form that is consumable by Assembly Support services that need to build an energy hypothesis for a study.

Energy Schedule (*BusinessObject)*

Energy Schedule isa time series of energy values, either consumption or production, that represent the intended pattern of operation. Energy Schedule is usually regular (each interval is the time duration) and cover a market cycle, such as a day or a month.

Connection Management (*BusinessFunction)*

Connection Management receives customer Interconnection Applications to connect to the grid and initiates a process of review and approval.

Customer Operation (*BusinessFunction)*

Customer Operation processes and tracks customer reports of problems and maintains the overall picture of the Customer State. Problem reports are passed to Grid Operation (specifically Situational Input Acquisition) who updates information like expected return to service. Note: For now, we have separated Customer Operation from Facility Operation, but as customer facilities become smarter, this may need to change.

Interconnection Application (*BusinessObject)*

The Interconnection Application describes everything about a proposed customer facility (or proposed change to an existing customer facility) that is significant to the operation of the grid, including physical and behavioral characteristics.

Customer State (*BusinessObject)*

Customer state is the current picture of energization state (and meter communication operations) for all customer meters.

Equipment Catalogue (*BusinessObject)*

The Equipment Catalogue describes the properties of standard equipment types. Usually formatted in the same way as asset datasheets, as these are often nameplate data from catalog items from product vendors.

Standard Design Practices (*BusinessObject)*

Standard Design Practices are documentation of a utility's criteria, practices, procedures and conventions for designing and planning the electric distribution system. Standard Design Practices are captured in a number of forms.

Operating Plan Development (*BusinessFunction)*

Operating Plan Development analyzes the electrical grid to determine operating plans that are designed either to optimize grid operation or to respond to grid events. The resulting plans are instructions to operators that may range from regular daily activities to event-driven responses.

Outage Planning (*BusinessFunction)*

Outage Planning is initiated by requests for equipment outage needed for either maintenance or new work. Outage requests require review to determine how to satisfy the request with minimal negative impact on either grid operation or customer service. Coordination of multiple outage activities is also considered when appropriate. Studies are carried out using analytical tools like power flow beginning from appropriate Near Future Base Cases. This activity is carried out in advance of completing work or switching plans.

The result of Outage Planning is approved Equipment Outage Plans. Approvals are fed back to the requester and models of the plans are available for inclusion in assembling base cases for other purposes.

Switching Plan Creation (*BusinessFunction)*

Switching Plan Creation develops a step-by-step grid model representation (Work Support Plan) of the impact of a work project on the electrical grid. Creating a Work Support Plan consists of breaking down the net impact to reflect work stages, building switching instructions around each stage, and checking the viability of each step with appropriate analysis.

Equipment Outage Plan (*BusinessObject)*

Equipment Outage Plans describe future outages in a form that Assembly Support services can use in the assembly of cases representing a time at which such an outage is occurring.

Near Future Base Case (*BusinessObject)*

A Near Future Base Case is a representation of the grid extracted from as-built master modelling and projected forward to a point of interest in the near-term future. Near term Energy Forecasting Models are used to establish reasonable energy patterns in situational models, which may involve incorporating data such as market outcomes. Normally, a base case in Operations Planning will also incorporate Equipment Outage Plans (whereas a long-term planning case would not). Multiple Near Future Base Cases may be needed for a given business purpose.

Operating Procedure (*BusinessObject)*

An Operating Procedure is a set of instructions to Grid Operations, covering a variety of topics related to day-to-day and emergency operation of the grid. They can take many forms, from text/diagrams whose instructions are implemented manually by operators to a specialized form of data that can be consumed directly software supporting Grid Operations

Work Support Plan (*BusinessObject)*

A Work Support Plan consists of a sequence of change models that describe either switching steps or physical equipment modifications. When work is performed, Grid Operations can use the Work Support Plan in two ways:

- To check each next step with network analysis simulation.
- To update the Real-Time Grid State as each step is performed in the field.

Bid/ Offer Management (*BusinessFunction)*

Pricing and Clearing is responsible for determining the optimal configuration of dispatchable resources that should be used to supply each grid service. Pricing and Clearing performs a least-cost optimization of the available resources for supplying all services, subject to any system constraints, which may be specific to a grid location. The resource-specific clearing results (Market Awards) include energy and/or grid service schedules

Pricing And Clearing (*BusinessFunction)*

Pricing & Clearing is responsible for determining the optimal configuration of dispatchable resources that should be used to supply each grid service. Pricing & Clearing utilizes inputs from the functions listed above, performing a least-cost optimization of the available resources for supplying all services, subject to any system constraints, which may be specific to a grid location. The pricing information is usually made public while clearing is generally a resource-specific notification. The resource-specific clearing results (Market Awards) include energy and/or grid service schedules and are collected by Future Energy Prediction, ultimately processed through Grid Operations for real-time dispatch.

Resource Scheduling (*BusinessFunction)*

A Market Award is the set of data representing the current market outcomes that are the result of a market clearing and represents the partial or complete acceptance of a Market Offer. Market Awards can be made far into the future, by years-ahead capacity markets, or in near-real-time, by processes highly coupled to Grid Operations. Market Awards provide the information used by Resource Scheduling to create Energy Schedules.

Resource Tracking (*BusinessFunction)*

Resource Tracking is responsible for collecting and managing the characteristics of those physical resources which are dispatchable based on market results. Some physical resources, especially those connected to the bulk power system or to medium-voltage circuits have fixed locations and relatively static parameters. However, physical resources connected to the low-voltage grid are highly variable and may transition into and out of resources aggregations, which are also tracked by Resource Tracking.

Market Model (*BusinessObject)*

Market Model is a simplified representation of the electrical grid model, with enough detail to allow for the determination of an economic dispatch of resources.

Market Resources (*BusinessObject)*

Market Resource data describes:

- The characteristics of registered market resources.
- The mapping from market resources to physical resources represented in the Market Model

Offer into Market (*BusinessObject)*

An Offer into Market describes a set proposals for the delivery of one or more market services, generally split into different levels of delivery at different price points

Market Award (*BusinessObject)*

A Market Award is the set of data representing the current market outcomes that are the result of a market clearing and represents the partial or complete acceptance of a Market Offer. Market Awards can be made far into the future, by years-ahead capacity markets, or in near-real-time, by processes highly coupled to Grid Operations. Market Awards provide the information used by Resource Scheduling to create Energy Schedules.

Feeder Design Specification (*BusinessObject)*

A Protection Design is an Engineering Design Project related to a collection of coordinated devices that protect the electrical grid.

Protection Design Specification (*BusinessObject)*

A Protection Design is an Engineering Design Project related to a collection of coordinated devices that protect the electrical grid.

Active Work Plans (*BusinessObject)*

An Active Work Plan documents the state of active work. It begins as a plan and ends as a record of completed work.

As-Built Facility Record (*BusinessObject)*

The As-Built Facility Record represent the current as-built state of the grid-related facilities of the utility. As-Built Facility Record maintain information to support the operation, maintenance, and future modification of the facility.

As-Built Change (*BusinessObject)*

As-Built Changes document the net impact of completed work that modifies the physical construction of the grid. In reflects both planned and unplanned activity. As-Built Changes are fed into the As-Built Update Capture function of Master Grid Modeling, where it is reconciled with similar closure reports from Work and with policy for maintaining master data.

Construction Outage Request (*BusinessObject)*

A Construction Outage Request asks for approval (from Operations Planning) to remove equipment from service or take action that outages customers.

Control Setting (*BusinessObject)*

Control Settings are control targets or configurations that will be sent to field devices by Control. They can be generated by a variety of automated operations functions including Automatic Control, Volt-VAr control, load shed, etc.

Derived Model Export (*BusinessObject)*

Derived Model Export is modelling (like Models, Projects, Cases or parts thereof) sent to an external modelling authority.

External Energy Schedule (*BusinessObject)*

TBD

Model Import (*BusinessObject)*

Model and/or Set of change models received from an external modelling authority

Monitoring/Control Design Specification (*BusinessObject)*

A Monitoring/Control Design is an Engineering Design Project relating to monitoring and control facilities.

Real-Time Grid State (*BusinessObject)*

The Real-Time Grid State represents the present state of the electrical grid and includes a wide range of information related to current physical grid configuration, real-time state inputs, results from grid analysis, and control settings. In transmission, this picture must extend to neighboring areas of the grid that are electrically significant.

Monitoring/Contol As-Built (*BusinessObject)*

A Monitoring/Control As-Built is an As-Built Facility Record relating to the hardware and software supporting Facility Operation.

Common Information Model (CIM) Support for Distribution Grid Model Management

Preface for PEA Audience

While the entirety of the 'Common Information Model (CIM) Support for Distribution Grid Model Management' report should be of interest and value to PEA, there are some sections which may be of greater initial interest to PEA. These include:

What is Distribution Grid Model Management?

The title of the report defines the focus is on distribution; however, this section elucidates that the embedded concepts will apply equally to PEA's high voltage and medium voltage networks.

CIM Grid Representation for Distribution

For those who have not been involved in PEA's current project implementing the use of the CIM for the integration between GIS and Outage Management, the sub-section Basic Equipment and Connectivity provides a good introduction to the grid model aspects of the CIM.

Modeling of Temporary Changes

Keeping track of temporary changes to the grid has been raised as an area of concern to PEA - as it is to many utilities. This section describes how this is addressed in the CIM.

Modeling Frameworks

Currently PEA maintains regional GIS databases of their grid. The Framework concept might be directly applied to this configuration, so this section may be of interest to multiple stakeholders.

Introduction

About this Report

In this report, our goal is to provide a distribution perspective on the use of the Common Information Model (CIM) in support of network analysis functions. The discussion is aimed at informing senior engineers about CIM for distribution modeling for network analysis. CIM implementers may find this report to be a useful introduction but will also require the detailed CIM specifications.

We begin with sections that describe how CIM UML[1] represents an electric grid. After the introduction to grid representation, we discuss modularization of grid data. CIM modularization is a rigorous method of dividing the total set of grid representation data into interlocking parts that can be maintained and used as needed.

All of the CIM modeling is usable for either transmission or distribution but here it is presented from a distribution standpoint.

Related Work

This report is a successor to several other reports EPRI has produced from research into the data management activities required to support high quality network analysis in the power industry. This report adds to previous work, focusing on management of data for distribution analysis.

Reports that preceded this report include:

- **3002002587 Using the Common Information Model for Network Analysis Data Management: A CIM Primer Series Guide[2].** This 2014 report provides a comprehensive description of the Common Information Model (CIM) modeling for network analysis and its intended use in support of data management excellence. It covers the basic UML used to describe the electric grid for analytics and introduces the packaging of that data to facilitate building and exchanging network models for different purposes. While the UML is relevant for both transmission and distribution, the emphasis overall in this report is on design aspects relevant to building models of the interconnected transmission grid.

- **3002003053 Network Model Manager Technical Market Requirements -- The Transmission Perspective[3].** This report, also from 2014, proposes that transmission utilities should consolidate network data management activity and responsibility in a Network Model Management business function. It outlines the way such a function would support the network data management requirements of utilities, eliminating duplication of data and improving quality and efficiency. It includes a set of functional requirements that 1) a utility could use in acquiring a product to automate Network Model Management and 2) a vendor could use to develop a product for transmission utilities. Its primary purpose is to stimulate utility and vendor interest in a data management product.

These reports remain largely accurate, but the reader should of course be aware that work continues in CIM and at EPRI, with consequent changes and additions.

About CIM

CIM, or, more specifically, the portion of the CIM of interest to this report, is a body of engineering work based around a canonical information model for planning, designing, constructing, and operating the electric grid. The information model is expressed in UML (Unified Modeling Language) and maintained in the Sparx Enterprise Architect tool. We often refer to the information model as 'the CIM', but CIM also includes standards derived from the information model, standards for serializing canonical information and methodologies for deriving data exchange specifications. CIM UML[1] is also used by utilities in creating enterprise information architectures and by vendors in creating product architectures.

The concept behind CIM is fairly simple. The best way to get all products and systems to exchange data productively is that they all know one common (i.e. canonical) language for expressing power system information. Data exchanges are always expressed in canonical form. Each party to an exchange must know how to send and receive in canonical form.

While the base concept behind CIM is canonical integration, the ubiquitous requirement to speak CIM also encourages products toward internal data practices that are consistent with CIM.

CIM UML[1] is constantly evolving. The working groups are in continual discussion about how to meet new needs and how to improve existing modeling in light of user experience. The output of this ongoing process is a series of CIM UML[1] releases. At each release, the UML model managers compile a version of the UML that is self-consistent and represents thinking that has reached consensus. The latest release covering grid data is CIM17. As of this writing, work has begun on CIM18, which is planned as a major revision. As it turns out, much of the CIM18 activity is focused on areas of specific interest to distribution (including DER, unbalanced networks, and datasheet templates).

In this report, our approach will be to describe CIM17 modeling, then identify known gaps in that modeling, then speculate about CIM18. Warning: CIM18 discussion is necessarily speculative – check before use!

What is Distribution Grid Model Management?

Grid model management focuses on the data that is required in order to carry out analysis of the electric grid. This set of data is different from the detailed design of grid facilities. Design data concentrates on complete detail of facilities, including electrical, civil, communications, real estate, and so on. Design detail doesn't focus on how the facility functions as part of the complete electrical grid. Grid model management, on the other hand, is about the electrical grid as a complete system and the analysis thereof. Grid model data is obtained by extracting relevant facility information, transforming it as appropriate to support analysis, and combining the results into a complete system analytical representation.

'Distribution' is not a precise term. It is obvious that transmission is mostly higher voltages and distribution is mostly lower voltages but defining a precise voltage dividing line is difficult. In this report we are less interested in distinguishing voltage levels and more interested in the types of use cases.

Distribution and transmission systems both carry power and are made up of similar components (generators, lines, transformers, breakers, etc.). In this important sense they can be modeled using the same classes, and CIM uses the same UML for both. Some modeling features are more important for one or the other, but there are no CIM classes that can only describe transmission or can only describe distribution.

The fact that modeling of the power grid elements is largely the same, however, does not mean the data management processes are the same. Some distinctions include:

- Transmission systems rarely require unbalanced modeling, this is common in distribution.
- Transmission needs to reflect aggregate impact of DER, distribution needs to directly represent individual DER.
- Transmission modeling requires exchange of modeling with many peers, distribution only interacts with a transmission entity.
- The frequency of new construction in transmission is low, while managing distribution field work (construction or repair) is the main focus of distribution operations.

Transmission Data Management Definition

We define the scope of transmission data management to cover that part of grid data where the following is true:

- The grid is operated networked.
- The focus is grid reliability rather than customer outage statistics.
- Analysis requires representation of neighboring utilities (unless you're an island).

This includes parts of the grid that are typically called 'sub-transmission', even though some utilities include sub-transmission under the distribution organization. We include sub-transmission with transmission because the data management requirements are largely the same as for bulk power transmission.

Distribution Data Management Definition

The complementary definition of distribution data management is the part of grid data where the following is true:

- The grid consists primarily of radially operated feeders emanating from a substation source.
- Analysis is primarily concerned with minimizing customer outage time and optimizing feeder operation.
- The grid interconnects with transmission but typically not with other distribution entities.
- Representation of the distribution grid is aggregated to substation loads in transmission studies.
- Operation of the grid is dominated by supervising the electrical impact of ongoing construction and managing storm damage recovery.

Key Goals of Distribution Data Management

A number of goals inform and inspire the activities of grid model management in the distribution domain:

1. Distribution modeling always covers feeder primary voltage but must also allow representation of secondary and consumer premises in whatever degree of detail is appropriate.
2. Distribution data must connect with transmission data to form one continuous set of modularized master data covering the entire electric system.
3. The distribution modeling must have sufficient detail and quality to support future requirements for more sophisticated analysis in both the planning and operating contexts. In particular, it must cover DER installations and any DER control functionality that impacts the way the grid behaves.
4. In the distribution operation control room, analytical capability must be maintained as work is carried out in the field. Any change made to a feeder must be reflected in modeling in real-time – for example, a goal might be set at within 15 minutes of the event.

CIM Grid Representation for Distribution

It should come as no surprise that the majority of CIM UML[1] for grid analysis deals with describing the power system. The heart of the power system description is UML for describing the components of the grid and their electrical connectivity. We refer to this part of the CIM as ‘grid representation’. In this section we give an overview of the grid representation UML from the distribution perspective.

Basic Equipment and Connectivity

This section describes the CIM approach to equipment and connectivity, starting first with a general description, applicable to both balanced and unbalanced modeling.

Conducting Equipment and Terminals

At the heart of CIM grid modeling is the representation of equipment that conducts electricity. All classes representing conducting equipment inherit from the ConductingEquipment class, as shown in Figure 15. As a general rule, CIM tries to follow the basic modeling principle of ‘staying true to the real world’. In that spirit it provides explicit classes for each kind of equipment.

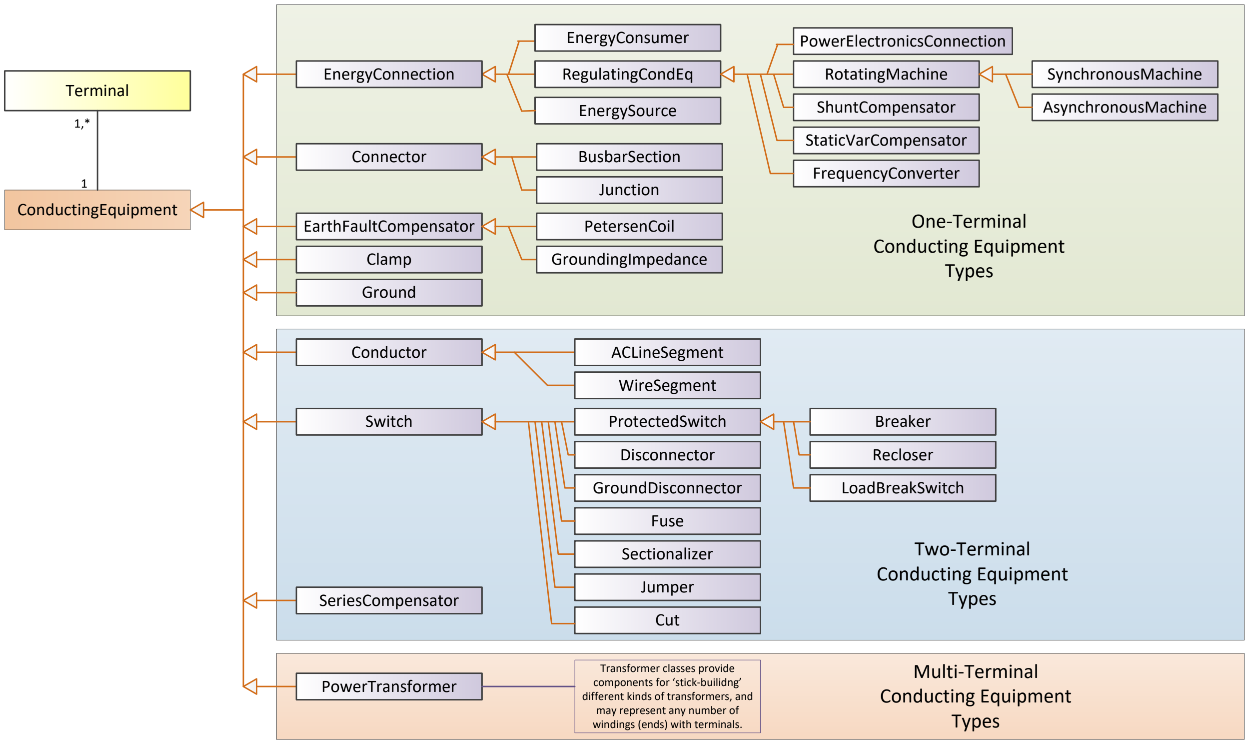


Figure 15. Types of AC conducting equipment represented by CIM ConductingEquipment child classes

In the real world, conducting equipment has terminals and terminals carry power. In the CIM, the ConductingEquipment class has the ConductingEquipment to Terminal association which defines the Terminals of the ConductingEquipment.

Most conducting equipment types have either one or two terminals. Capacitors, customer loads, generators are typical single terminal types. Line segments and switches are typical two-terminal types. Transformers may have more than two terminals. Figure 15 illustrates the number of Terminals for the major types of AC conducting equipment currently defined in CIM.

Alternating current (AC) systems are the primary focus of both the CIM and this report. In CIM17, there is modeling for high-voltage DC transmission components, but inverter-connected DC distributed resources are only represented as a single terminal AC source by the PowerElectronicsConnection class.

In the course of building grid models, each ConductingEquipment object always comes with the appropriate Terminal objects. The Terminals are 'part of' the equipment and cannot be logically disconnected. If you instantiate a ConductingEquipment, you automatically get the Terminals objects. If you delete a ConductingEquipment, the Terminals automatically get deleted.

In analytical solutions, it is almost always the case that the voltage and angle at a Terminal and the real and reactive flows through Terminals are network analysis solution variables. The kind of ConductingEquipment determines the mathematical function that describes the equipment behavior in terms of the solution variables of its Terminals. Each subclass of

ConductingEquipment has the parameters of those mathematical functions, as well as other characteristics of the equipment type. ConductingEquipment objects are wired together by associating their Terminal objects to ConnectivityNode objects, as is explained in the next section.

Connectivity

Regardless of the kind of conducting equipment, the definition of how components are connected together works the same way. The relevant CIM17 classes are shown in Figure 16.

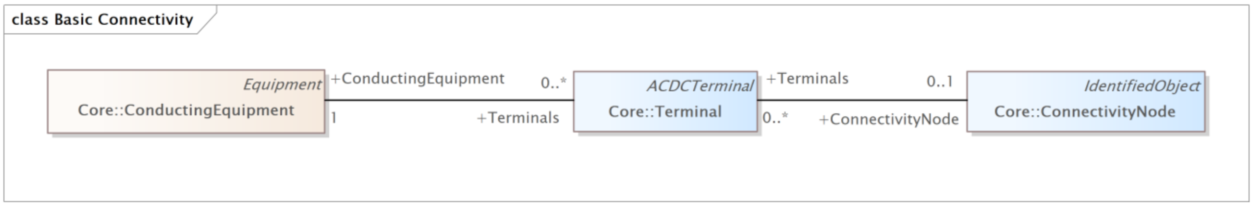


Figure 16. How Terminals are connected together in CIM

Connectivity in network models is defined as follows:

- Each ConductingEquipment child class has a defined number of Terminals. When an instance of a ConductingEquipment child is created, the appropriate number of Terminals is created with it. This mimics physical reality. The actual equipment has terminals, regardless of whether or not it is connected in the field.
- Connections are made by creating a ConnectivityNode object to represent the junction and then creating an association from each Terminal object to the ConnectivityNode object.
- The diagram shows cardinality on the associations. From the view of a Terminal object, there can either be an association to a ConnectivityNode object or not (cardinality of 0..1), depending on whether the Terminal has been connected to something. From the point of view of the ConnectivityNode object, it can connect any number of Terminal objects together (cardinality of 0..*).

In a steady-state analytical solution, the solution variables are voltage and angle at each node and power flow into each node from each conducting equipment – in other words, the power flow through each Terminal. The voltage and angle of each Terminal is the same as the ConnectivityNode to which it is associated.

Base Voltage

In CIM17, a BaseVoltage class represents system base voltages. As shown in Figure 17, it may be referenced from ConductingEquipment, or from TransformerEnd, or from a VoltageLevel container.

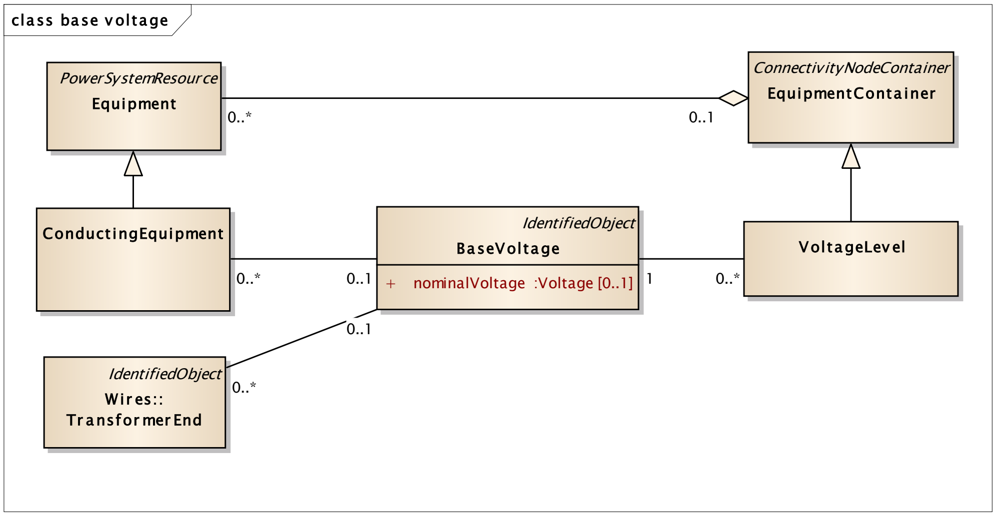


Figure 17. BaseVoltage UML in CIM17

By convention in transmission, substations are organized into voltage level containers and all ConductingEquipment associated with a VoltageLevel takes the base voltage from the VoltageLevel association to BaseVoltage. Transformers are the exception - they are not in a VoltageLevel - so they require a direct association from TransformerEnds to BaseVoltage. Outside substations, ConductingEquipment, such as ACLineSegment, uses the direct association ConductingEquipment.BaseVoltage.

In CIM17 for distribution, the equipment of concern is mainly outside the substation and direct associations from ConductingEquipment to BaseVoltage are necessary.

There have been suggestions that would simplify this modeling, such as replacing what exists in CIM17 with a universal association between ConnectivityNode and BaseVoltage, but it is not clear at this point whether CIM18 will make any changes.

Basic Conducting Equipment Types

The following subsections introduce some basic conducting equipment types. Hands-on use of the CIM will require understanding of the detailed purposes and properties of all these classes. The reader is referred to the CIM UML[1], EPRI's Common Information Model Primer[4], IEC 61970-301[5], IEC 61970-452[6] and/or modeling product guides for this detail. Here, our purpose is to provide an overview.

Simple Switches

The two-Terminal CIM17 Switch class is the parent of a variety of classes, all of which represent SPST switching equipment which can close or open an electric circuits. Child classes of Switch commonly used in distribution include:

- Breaker, to represent feeder breakers
- Fuse, to represent cutouts

- Recloser, to represent reclosers
- Sectionalizer, to represent circuit sectionalizers
- Switch, to represent switches at various locations, including those at normally open points between feeders.

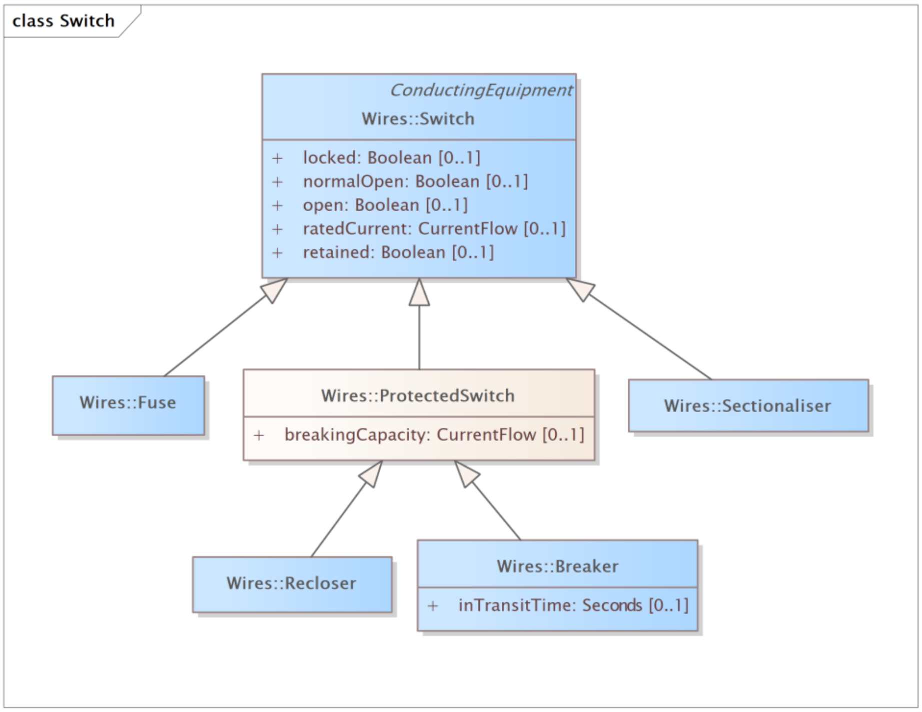


Figure 18. Switch and several of its major child classes

As illustrated in Figure 18, Switch and all its child classes have attributes related to current state, normal state and continuous current rating. Recloser adds an attribute for current breaking capacity and Breaker adds attributes for both current breaking capacity and open-to-close transition time. Figure 19 provides examples, in the form of instance models, of the common types of switches and their attributes.

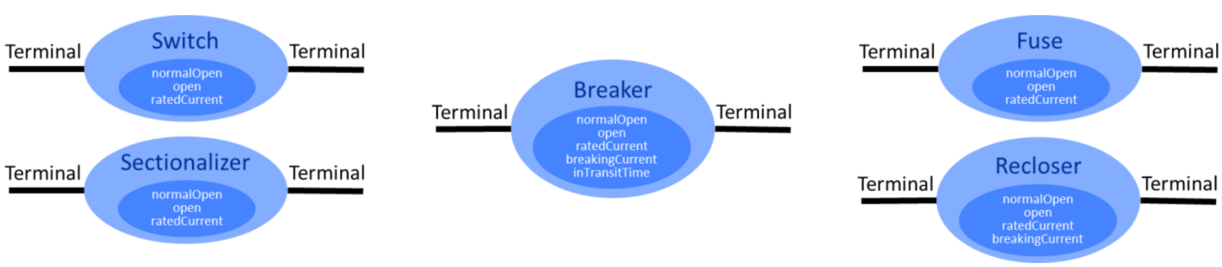


Figure 19. Instance models of different types of switches

No significant changes to Switches are anticipated in CIM18.

Composite Switches

Distribution systems commonly use various types of more complex switches. In CIM17, these are referred composite switches. They are represented as a CompositeSwitch that contains a set of Switches. The contained Switch arrangement is an equivalent representation of the real device built from a pattern of simple Switches. In a modeling application, one would expect to see a capability to define various CompositeSwitch types corresponding to commonly used switching products, each with a pattern of equivalent Switches that offer a net set of external Terminals. Once defined, the application would then allow a CompositeSwitch type to be deployed as a unit into a feeder representation.

A real composite switch will have a limited set of states, each of which would correspond to a pattern of open/close states for the internal equivalent switches, but the equivalent switches cannot be independently controlled. CIM17 does not provide a way to describe this. It is being reviewed but it is too early to speculate whether CIM18 will revise representation of composite switches.

ACLineSegments

The two-Terminal CIM ACLineSegment class is used to represent, according to the CIM class definition, "A wire or combination of wires, with consistent electrical characteristics, building a single electrical system, used to carry alternating current between points in the power system." ACLineSegment is used to represent one span (or many spans) of a line with consistent construction (and therefore consistent electrical characteristics) along its length. The foundational line modeling classes - Conductor, ACLineSegment, and PerLengthImpedance - are shown in Figure 20.

Impedances of line segments are a critical input to network analysis and can be expressed in several ways. Two of those ways reflect balanced modeling of impedances (which are of more relevance in transmission than distribution), the other represents unbalanced phase-to-phase impedances in the form of an impedance matrix. We'll briefly touch on the balanced modeling here and we'll explore the unbalanced situation in more detail below in the Unbalanced Modeling section.

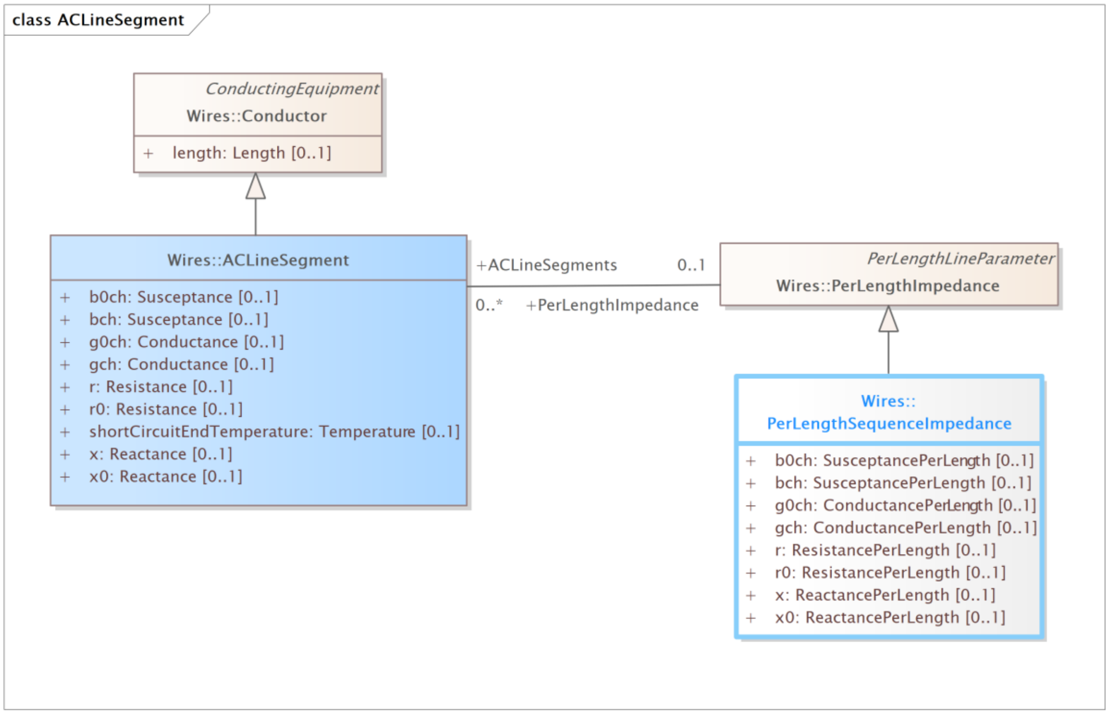


Figure 20. ACLinesSegment and its balanced impedances modeling

Impedances are a collection of values for susceptance, conductance, resistance and reactance and, in balanced line modeling, sequence impedances can be specified in one of two ways:

- as totals for the whole line, using ACLineSegment attributes
- as per length values (contained in the PerLengthSequenceImpedance class) which are then multiplied by the length attribute value (which ACLineSegment inherits from Conductor).

The two styles of balanced impedance modeling are shown in Figure 21.

Figure 21. Two balanced line instance models with impedances expressed different ways

It is not uncommon for two feeders, or two lines of any voltage, to run in the same right-of-way. This situation causes mutual impedances to be created between the line segments. There is a CIM17 approach to modeling balanced mutual impedances, but it is being superseded by more detailed (and more accurate) modeling in CIM 18. This is covered in the Using Datasheet Information section of the report below.

Transformers

Transformers follow a modeling pattern that is different than what simpler equipment, like Switches, use. Whereas more complex Switch variants are modeled by adding additional attributes (via child classes) to the simple switch model, transformer modeling reflects the fact that transformers are made up of a variety of parts in a variety of arrangements. The number of windings vary. The tap configurations vary. Some include phase-shifting. And so on. After a number of initial attempts, CIM modelers elected to provide a set of basic classes for components of transformers that allow users to assemble representations of all the variations of transformers are used in their studies.

The foundational CIM transformer model classes (PowerTransformer, PowerTransformerEnd and the classes representing impedances) are shown in Figure 22. These classes, augmented by the classes used to represent various types of tap changers, are sufficient to cover balanced modeling of all known types of power system transformers, including those doing voltage or phase transformation and those with regular or irregular tap steps.

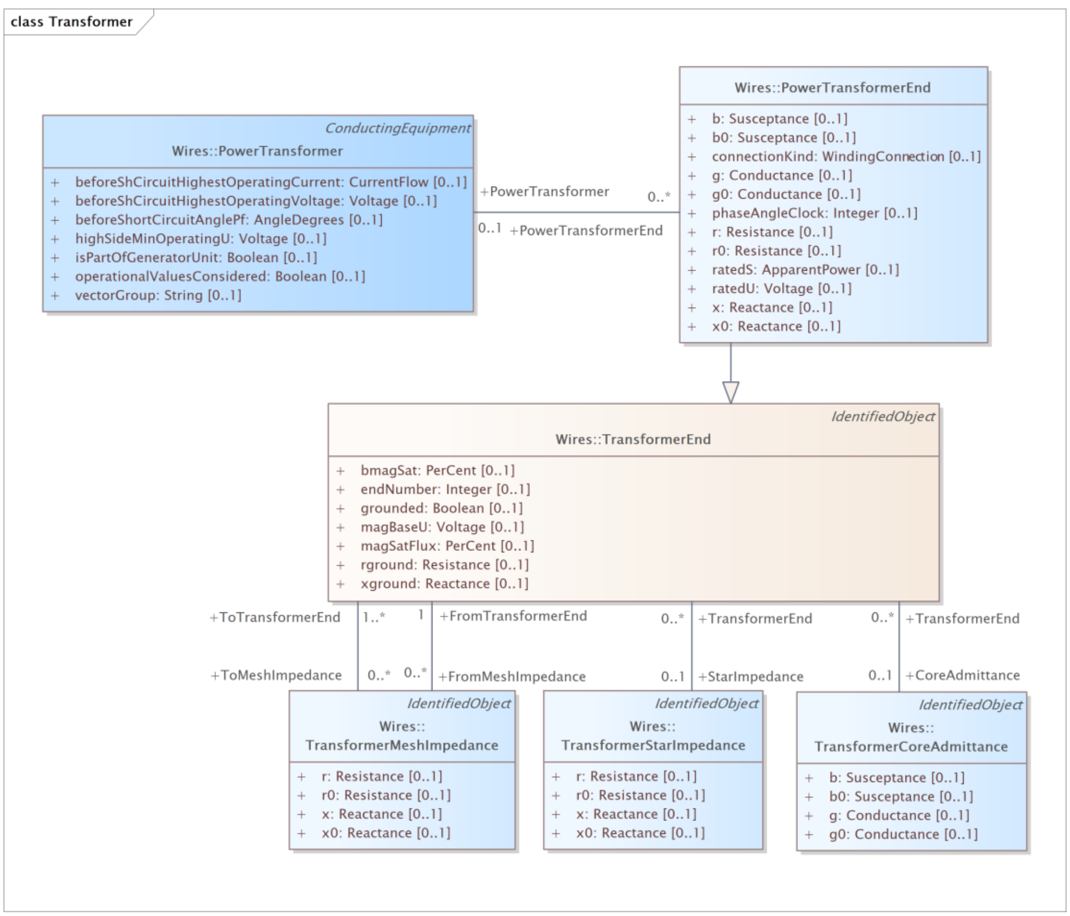


Figure 22. PowerTransformer and its balanced impedances modeling

The components used for modeling a three-phase transformer, in its simplest, balanced form, are:

- One instance of the PowerTransformer class (which is a child of ConductingEquipment and therefore has Terminals associated with it) and
- One instance of the PowerTransformerEnd class for every winding (voltage level connection) of the transformer, each of which also has an association to one of the Terminals.

The normal apparent power rating of a winding is expressed as an attribute of PowerTransformerEnd. Balanced modeling of impedances is typically done using either attributes of the high voltage winding's PowerTransformerEnd instance or by using a combination of one instance of TransformerCoreAdmittance along with one instance of either TransformerStarImpedance or TransformerMeshImpedance. Instance models of the two approaches to impedances modeling are shown in Figure 23.

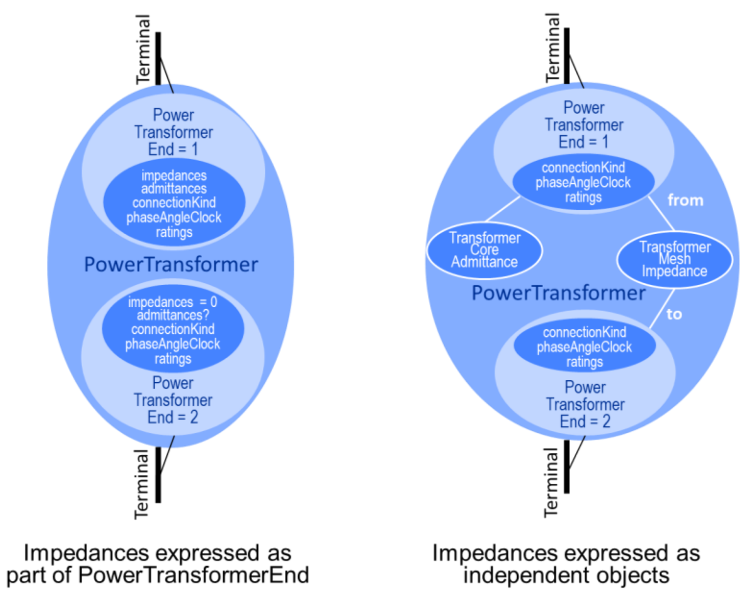


Figure 23. Balanced two-winding power transformer instance models with impedances expressed two different ways

The reader is referred to IEC 61970-301[5], IEC 61970-452[6], and 'Section 5 – UML for CIM' of the EPRI Common Information Model Primer[4] for additional detail on CIM conducting equipment modeling.

Modeling of Temporary Changes

Temporary changes to the grid occur frequently in distribution as field crews carry out planned work or perform system restoration activities. There are several CIM classes intended to support these sorts of non-permanent changes in a way that retains model accuracy without making modifications to the underlying permanent grid modeling that would subsequently need to be 'undone'.

- The single-Terminal Clamp class allows the modeling of a temporary line tap on an ACLineSegment.
- The two-Terminal Cut class describes the temporary splitting of an ACLineSegment and allows the attachment of additional power system modeling to the portions of the ACLineSegment on either side of the cut.
- The two-Terminal Jumper class represents a temporary, manually removable, negligible-impedance section of conductor. Jumpers are often used in conjunction with Cuts, though are also useful by themselves for modeling temporary by-passes.

A detailed explanation of the use of the Clamp, Cut and Jumper classes is provided in IEC 61970-452[3].

Energy Connection

The single-Terminal EnergyConnection class has multiple child classes that represent the presence of different kinds of energy generation or energy consumption at a location on the grid.

CIM17 EnergyConnection modeling covers four main subsets:

- Energy consumers – also known as 'load'
- Rotating machines – AC generation
- Power electronics connection – inverter connected DC components
- Reactive sources – capacitor banks, etc.

This is an area of active development in CIM18 to resolve some inconsistencies and provide better association to energy forecasting and controls. See later sections on consumers, DER, and controls for more detail.

Less Commonly Used ConductingEquipment Classes

The remaining ConductingEquipment child classes shown in Figure 15 are single-Terminal classes and are less commonly used:

- The child classes of EarthFaultCompensator model grounding equipment, including fixed impedance devices (represented by GroundingImpedance) and adjustable devices (represented by PetersenCoil).
- The Ground class simply indicates a point where the system is grounded.

Unbalanced Modeling

Unbalanced three-phase modeling is essential in describing North American distribution grids due to the prevalence of single phase loads which result in an unbalanced power flow on three-phase devices. (This is also true for the lower voltage portions of distribution grids in other parts of the world.) Basic CIM equipment and connectivity modeling as described in preceding sections provides a means to describe balanced three phase networks. The CIM supports unbalanced modeling by augmenting the basic modeling with additional information of two main types:

- An indication of the phases carried by each terminal of a piece of conducting equipment
- A description of the individual characteristics of each phase of the conducting equipment

Both are illustrated in Figure 24 where the .phases attribute of the Terminal class allows the specification of multiple combinations of phases and where ConductingEquipment child classes are shown together with their corresponding xxxPhase classes that supply information about individual phases of equipment. Together these additional sets of information support the description of:

- Equipment able to carry one, two or three phases
- The complete connectivity and electrical behavior of each of the three individual phases of an electrical system

It is worth noting that the CIM phase identification (whether provided by the phases attribute of Terminal or by a xxxPhase class) is ‘nominal’ – in other words, it provides a clear picture of the connected equipment operating as a single phase system. It doesn’t reflect the actual phasing of the energization source.

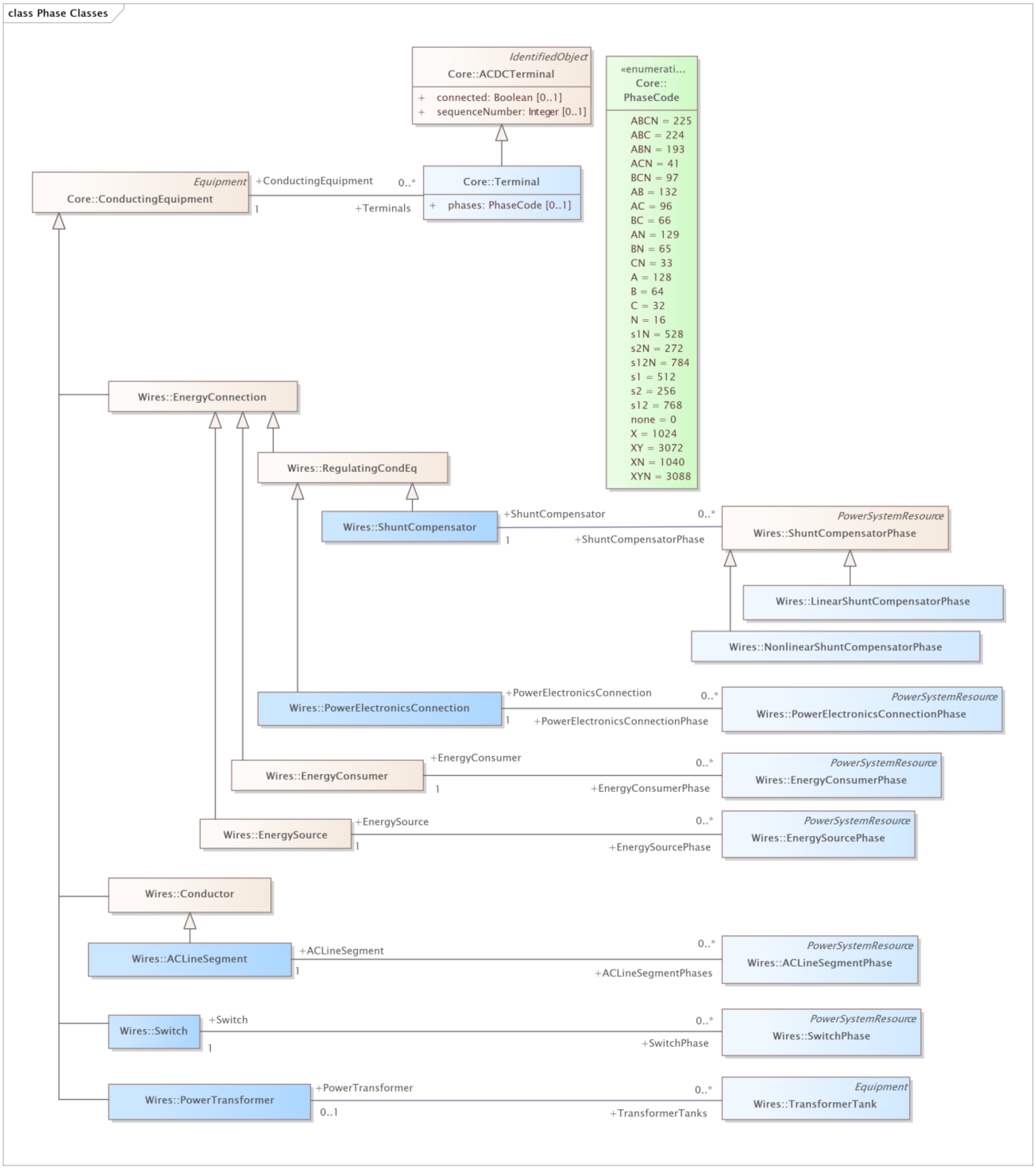


Figure 24. Unbalanced CIM modeling: phases on Terminal and individual phase classes

Terminal.phases

CIM17 provides the .phases attribute on the Terminal class to indicate the phases. The attribute has possible phase connection combinations of ABC, ABCN, AB, BC, CA, A, B, C and so forth. If .phases is left blank, a default of ABC is assumed. (This is a long-standing CIM convention relied on heavily in transmission.) In distribution, best practice is to always specify a value for .phases even if it is ABC. The value of Terminal.phases for a ConductingEquipment child must match the instances of the corresponding xxxPhase classes associated with the ConductingEquipment child.

xxxPhase Classes

As shown in Figure 24, the major ConductingEquipment child classes have corresponding xxxPhase classes. The xxxPhase classes supply information about a specific phase of the equipment. There are typically attributes of the xxxPhase classes that duplicate attributes of their corresponding ConductingEquipment class. The xxxPhase classes of three major types of conducting equipment are described below.

Unbalanced Switch Modeling

Figure 25, which shows the Switch class and its corresponding SwitchPhase class, provides an example of the attribute duplication as the closed, normalOpen and ratedCurrent attributes of Switch are duplicated in SwitchPhase. The attributes of the Switch class are considered the default for any phase identified on the Terminal(s) of the ConductingEquipment class for which no SwitchPhase class instance exists. While this would allow some switches in unbalanced models (conventionally wired ganged ones, for example) to be modeled without the use of any SwitchPhase instances, most distribution modelers prefer, for reasons of clarity, to create a SwitchPhase instance to represent each phase of a switch that exists.

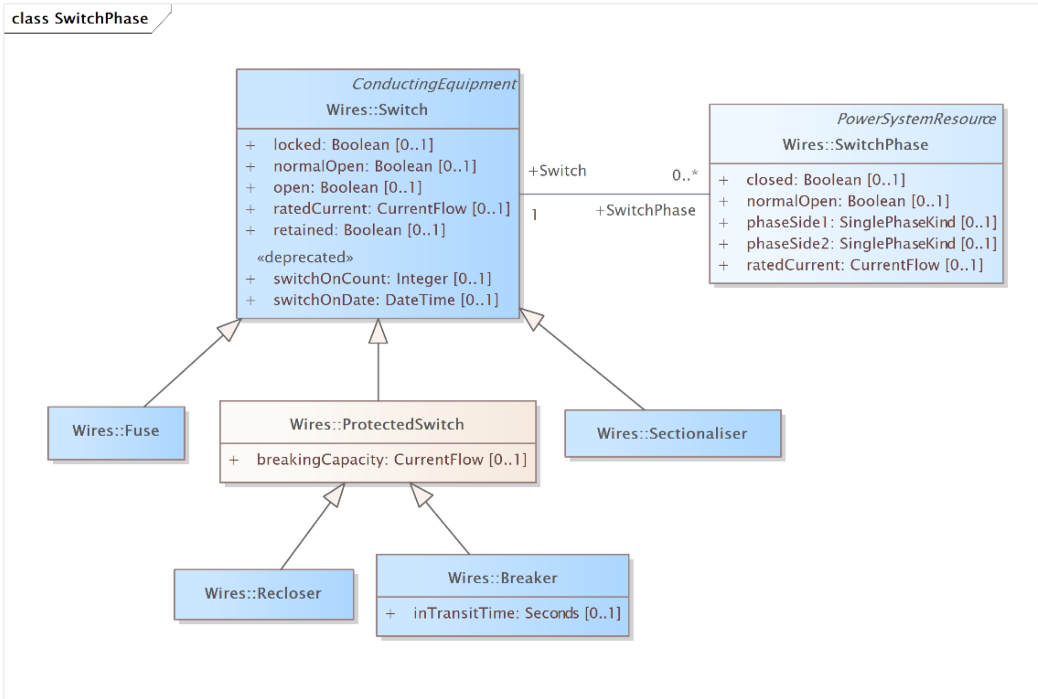


Figure 25. CIM classes for unbalanced switch modeling

The SwitchPhase class, with its .phaseSide1 and .phaseSide2 attributes, allows a Switch to be modeled with a cross-phase connection. (phaseSide1 refers to the ConductingEquipment Terminal with a sequenceNumber of 1 and phaseSide2 to the Terminal with a sequenceNumber of 2.)

Unbalanced ACLineSegment Modeling

Individual phase information is more complex for ACLineSegments and PowerTransformers than it is for Switches because impedance values (both self-impedances and phase-to-phase impedances) need to be described. The classes used for unbalanced modeling of line segments is shown in Figure 26.

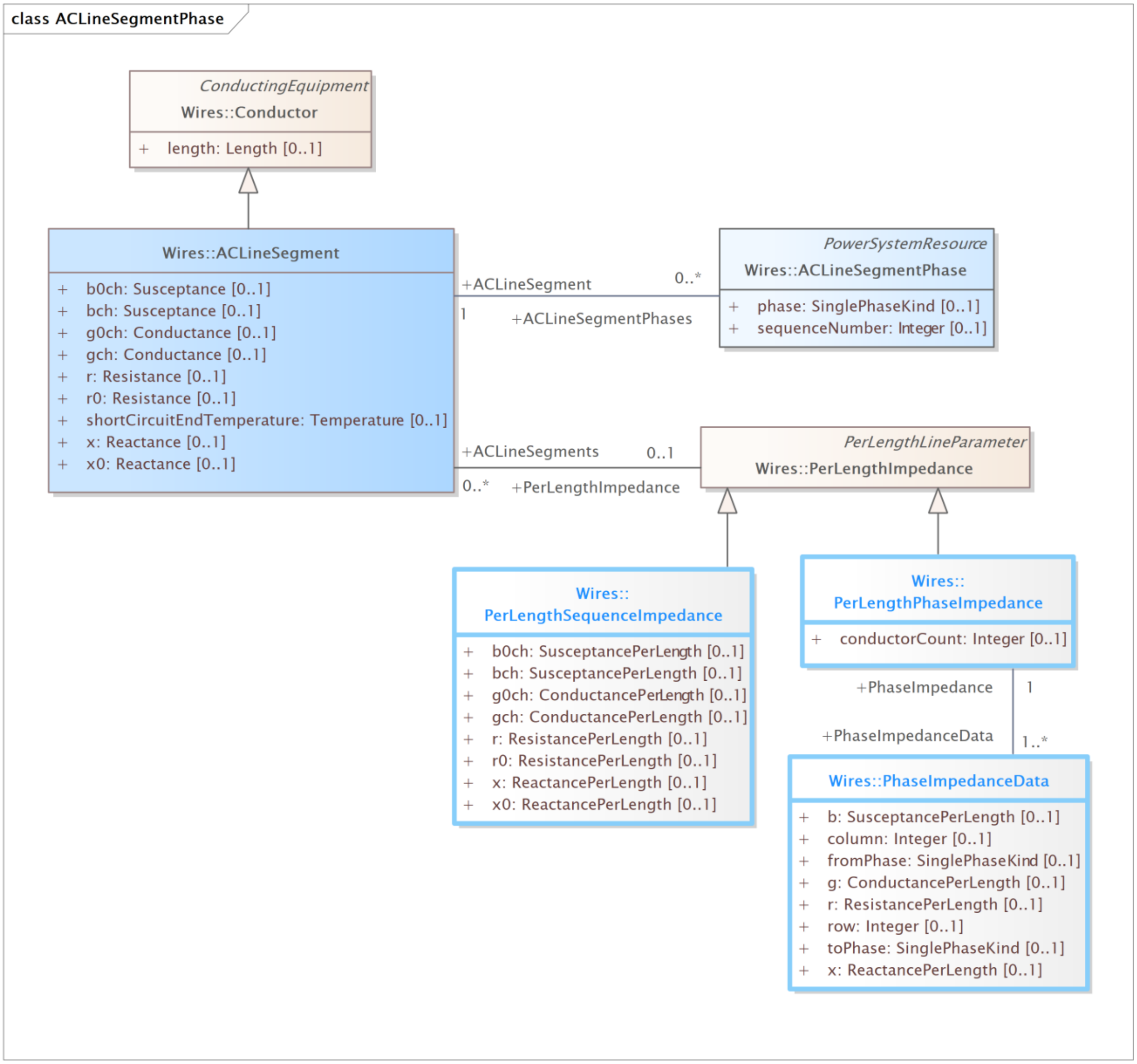


Figure 26. CIM classes for unbalanced line modeling

For ACLineSegments, unbalanced impedances are described in the form of a phase-to-phase impedance matrix where the diagonal terms specify the self-impedance of each phase and the off-diagonal terms specify the mutual impedance between each phase pair. The matrix is represented by the PerLengthPhaseImpedance class and elements of the matrix are represented by the PhaseImpedanceData class. When an ACLineSegment is being described in unbalanced terms, the balanced sequence impedance attributes of ACLineSegment and of PerLengthSequenceImpedance are not used.

Designation of the phases in the matrix can be done either directly in the matrix by using the .fromPhase and .toPhase attributes of PhaseImpedanceData or by creating an instance of ACLineSegmentPhase for each phase of the line segment and using

ACLineSegmentPhase.sequenceNumber to map the ACLineSegmentPhase.phase to the matrix element via the PhaseImpedanceData.row and .column attributes. Examples of both styles are shown in Figure 27.

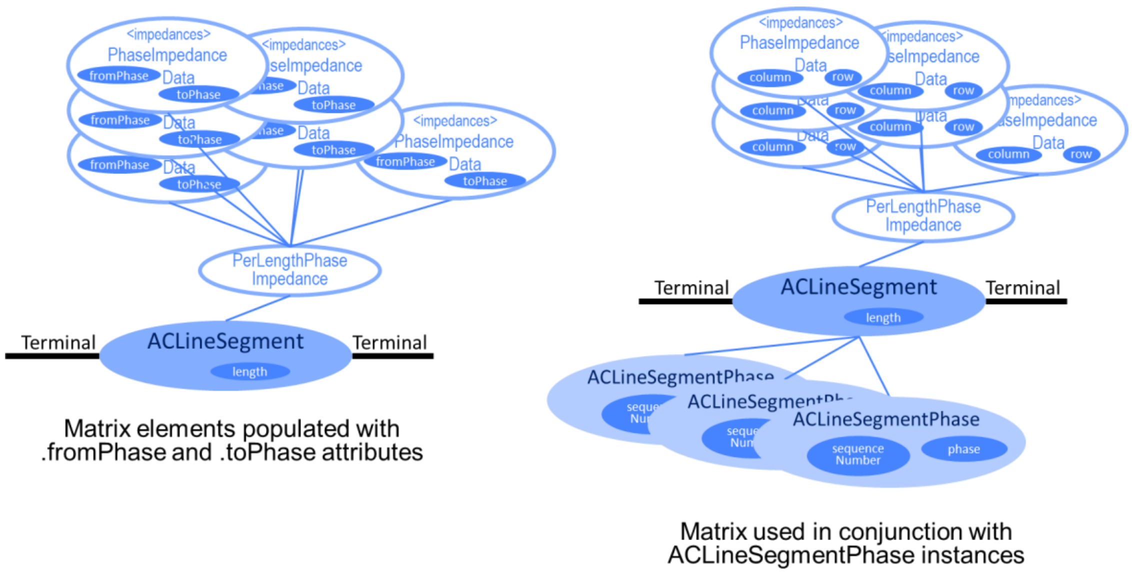


Figure 27. Unbalanced line instance models with two ways to use the phase-to-phase impedance matrix

Unbalanced Transformer Modeling

In unbalanced transformer modeling, each tank (defined as an assembly of two or more coupled windings with a common core operating in the same tank) is represented independently. Up to three tanks (one aligned with each phase) can be associated with a power transformer or 'transformer bank'. Tanks are represented by the TransformerTank class. Each tank can have multiple windings, which are represented by the TransformerTankEnd class. The CIM classes used in unbalanced transformer modeling are illustrated in Figure 28.

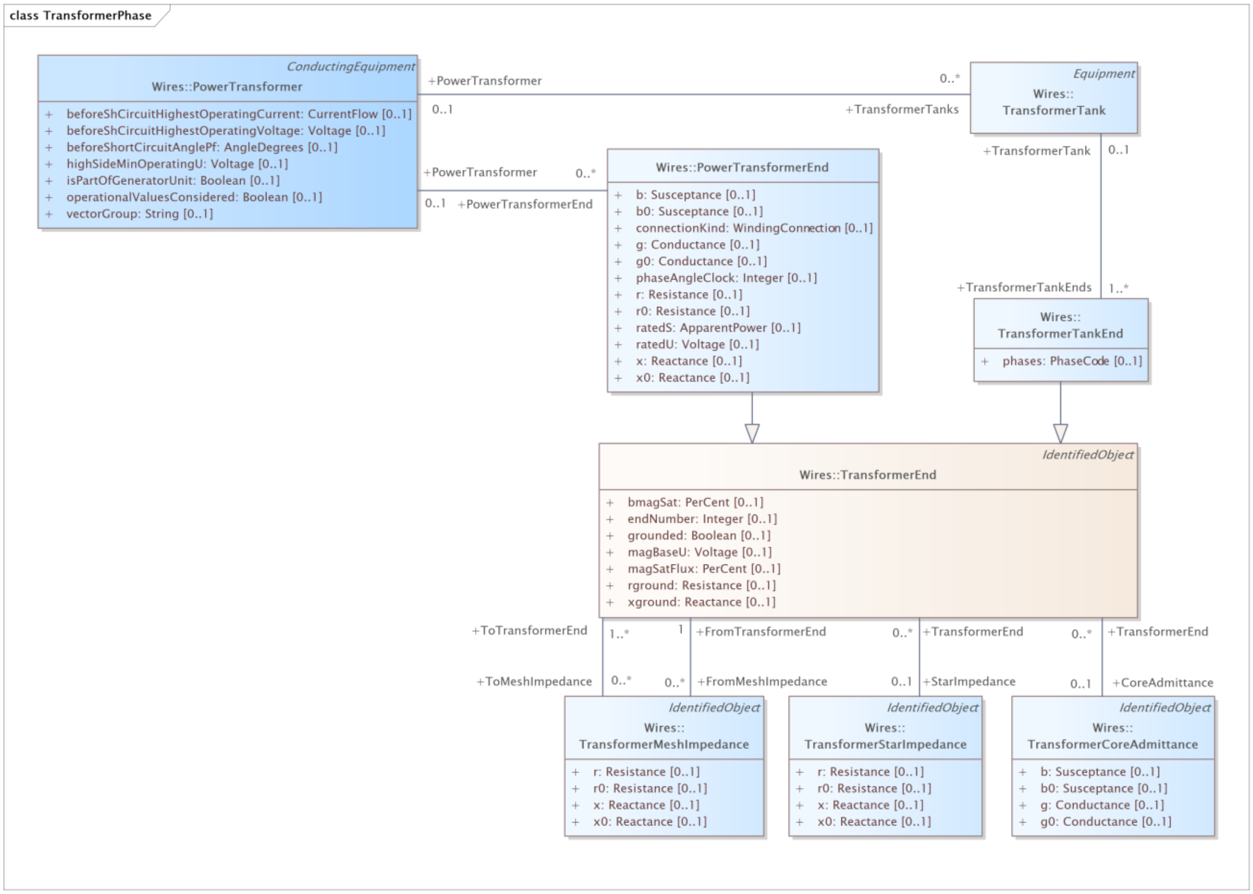


Figure 28. CIM classes for unbalanced transformer modeling

Impedances for tanks are modeled using the same TransformerMeshImpedance and TransformerCoreAdmittance classes as are used for balanced transformer modeling. As opposed to unbalanced impedance modeling, however, the use of those classes is the only option for describing impedances. One instance of TransformerMeshImpedance is used for each pair of ends (windings) associated with the tank along with a single instance of TransformerCoreAdmittance. Associations to Terminals are handled a fashion similar to balanced modeling, with each TransformerTankEnd having an association to the PowerTransformer Terminal representing its winding. An instance model of an unbalanced, two-winding transformer is shown in Figure 29. The additional instances of the TransformerTankInfo and TransformerEndInfo ‘helper’ classes (shown in purple) are required to supply information on the kind of connection (D (delta) or Y (wye), for example), the phase angle (in clock notation) and ratings. In the balanced modeling, this information is part of the PowerTransformerEnd class, but it is not, at least in CIM17, part of the TransformerTankEnd class.

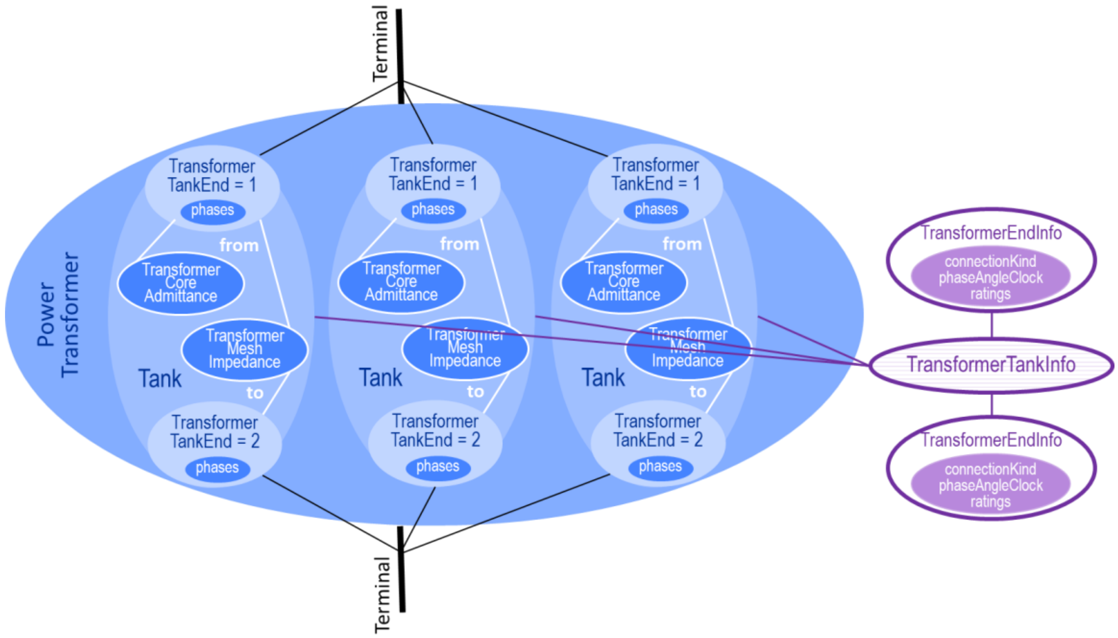


Figure 29. Unbalanced two-winding power transformer instance with "helper" classes

Duplicated Modeling

The existence of both the Terminal.phases attribute and the xxxPhase classes puts unbalanced modeling using CIM17 in a position contrary to the principle of only having one way of describing a given ‘thing’. This situation has been raised as a concern and at least one planning tool vendor has concluded that use of the Terminal.phases attribute was not necessary for its software (as long as xxxPhase instances were always created in a manner that reflected real-world equipment phases). Exploration of the possibility of deprecating Terminal.phases is currently underway and CIM18 is expected to provide improved guidance on the description of phases.

Using Datasheet Information

Distribution has a history of describing its grid model information in more physical terms than does transmission. Whereas impedances would be the information deemed important for lines in transmission, in distribution it is detail like wire position and conductor type that is more common. There are undoubtedly multiple drivers for this difference, but a main one is the prevalence of GIS systems, which ‘speak’ in more physical terms, as the major source of grid model data in distribution. No similar single source of physical information is common in transmission, so transmission engineers focused on network analysis have historically tended to describe their models in electrical terms (after manually translating from the physical descriptions on one-lines or test records). However, over the last 5 or so years, with the growing interest in centralized transmission network model management, there has been a growing interest in physical detail modeling (and automation of electrical parameter derivation) in transmission, as well.

Relevant Datasheet Classes

CIM17 has a set of classes, children of a class called AssetInfo, that describe equipment physical characteristics. The several of these classes, with special relevance to grid modeling, are shown in Figure 30. They include

- One class (SwitchInfo) for switch-related characteristics
- Two classes (TransformerTankInfo and TransformerEndInfo) that have transformer-related physical characteristics (we called them 'helper' classes earlier)
- Five classes (WireInfo, CableInfo, OverheadWireInfo, ConcentricNeutralCableInfo and TapeShieldCableInfo) with line-related characteristics.

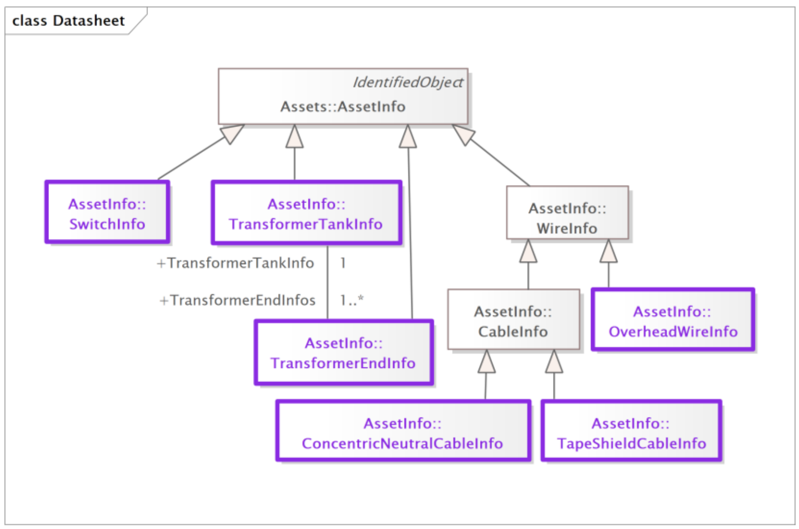


Figure 30. AssetInfochild classes supplying physical characteristics for minor types of conducting equipment

We find it appropriate to describe these AssetInfo child classes as "datasheet" classes. Why? Because each of them is a specification of a set of characteristics that describe the physical attributes and capabilities of a type of equipment. The specification is valid whether it is associated with a particular real-world instance of the equipment (an 'asset' in CIM terms) or not. The specification might be providing a description of what is needed at location in the grid, or what has been designed for a location in the grid, or what is being built or is in-service at a location in the grid. The information in the specification – the datasheet – is relevant and useful in grid modeling regardless. There is discussion in CIM18 of changes in naming to move away from 'asset' terminology for these classes and toward datasheet to more accurately reflect the nature of the information.

How Grid Modeling Can Leverage Datasheet Classes

When the decidedly useful information in datasheet classes is used for grid modeling purposes, there are a couple important concepts to keep in mind.

- From an information modeling "separation of concerns" perspective, datasheet information is distinctly not "owned" by the grid model management business function. Responsibility for information of the datasheet type rests somewhere in engineering design or design standards or assets, but regardless, not in model management. Grid modeling would just like to leverage bits and pieces of the datasheet models maintained by CIM experts in other areas (who know more about the physical characteristic information used by utilities and their equipment manufacturers). The way that grid modeling "leverages" datasheet information is by
  - Creating UML that supports relationships between ConductingEquipment child classes and the datasheet classes
  - Creating profiles (definitions of subsets of data to be exchanged) that contain only that datasheet information which is needed as input to equipment rating or impedance calculations
  - Instantiating grid model-specific instances of the datasheet information for use in grid model data management

  The net effect is that information modeling is streamlined and consistent and, at the same time, data objects with different purposes can be managed independently.
- Datasheets most often represent the physical characteristics of one 'thing' and grid modeling often wants to describe behavior of a collection of 'things'. For example, the engineering standards world will have catalogs describing the physical characteristics of different types of wires, whereas grid modeling needs to know not just about the wire characteristics, but also about their relative positions, how far they are off the ground and how long they are. This means that there are typically classes needed 'between' ConductingEquipment classes and datasheet classes to organize the datasheet information in a useful way.

As illustrated by the ConductingEquipment-related datasheet classes shown in Figure 30, CIM17 has datasheet classes that are useful to grid modeling. CIM17 also has associations (often more than needed) from a number of its ConductingEquipment child classes to the datasheet classes. This means that much of what is needed for the effective use of datasheets is in place. There are CIM18 discussions occurring which are focused on:

- Improving the use of datasheets as templates reflective of industry practice and need
- Removing redundancy and clearly defining instance patterns allowed for exchange to improve interoperability.

Here is sample of what is being considered in CIM18 for datasheet information related to lines. Figure 31 shows the UML, where the datasheet classes are outlined in purple. Also shown are two classes, WireAssembly and WirePosition, that allow the datasheet classes to be referenced by grid modeling.

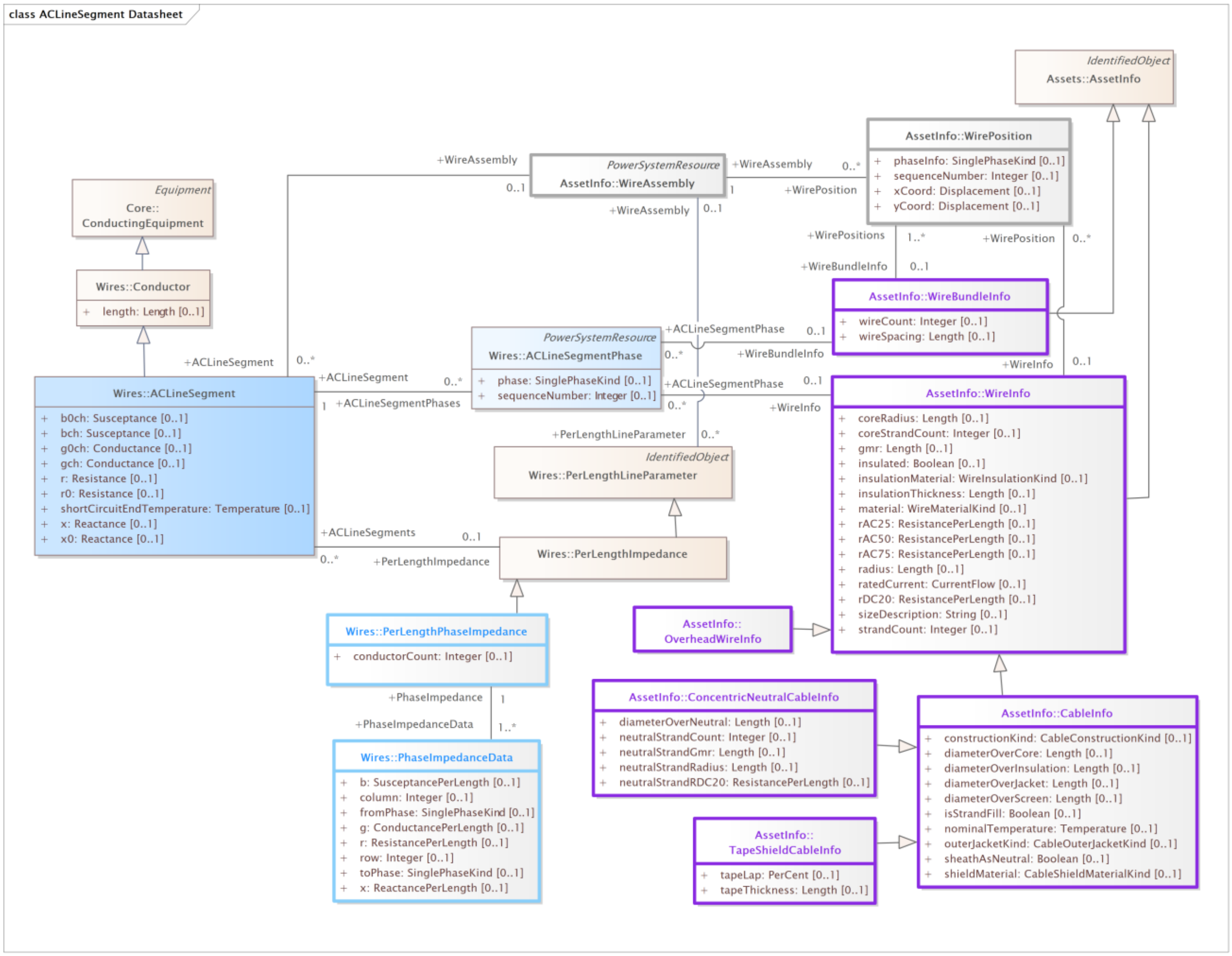


Figure 31. Propose CIM18 UML for ACLineSegment with related datasheet classes

Figure 32 shows one of several possible approaches to using the UML classes to support the exchange of the line detail required for line impedance calculation. In this approach, the WireAssembly class is used to define wire position, wire type and wire bundling. Identification of phase position is done using ACLineSegmentPhase.sequenceNumber to map the ACLineSegmentPhase.phase to the appropriate WirePosition.

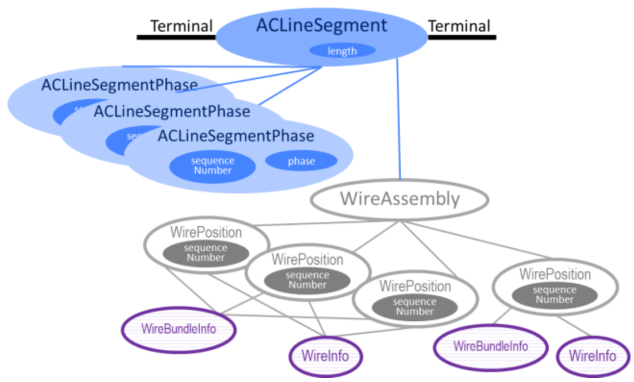


Figure 32. Line instance model referencing position, bundling and wire datasheet information via WireAssembly

Earlier in the report the issue of multiple lines sharing the same right-of-way was mentioned. When lines run close to each other, as happens when they share the same right-of-way, there is a mutual impedance between the lines. CIM17 modeling supports a simplified approach to describing mutual impedances for balanced line segments that is being superseded by more sophisticated (and accurate) modeling in CIM18. The CIM18 modeling is planning to add classes to support line segment grouping and will rely on the ability to define sequenceNumber values across all lines in the group to accurately describe both physical characteristics and the phase-to-phase impedance matrix for the collection of line segments.

Support for Templates

Both the desire to model physical detail and the sheer number of devices to be modeled in distribution raise the need for templates in distribution a way that is not apparent in transmission. Templates are pieces of modeling that supply common detail which can be referenced by multiple instances of classes representing specific detail. In the case of the CIM, the classes representing specific detail are most often ConductingEquipment child classes and the templates reflect some sort of equipment catalog information. The catalog information can be electrical or physical in nature – the value, either way, is that detail can be described once and referenced dozens or hundreds (or thousands) of times in describing a grid model.

So far in this report, we've seen examples of templates in the instance models diagrams of Figure 21, Figure 27, Figure 29, and Figure 32. The instances that are templates in those diagrams are shown as ovals with outlines. The templates in the first two Figures are electrical behavior templates, the template in the last two Figures are physical characteristics templates. Both serve to ease the maintenance burden of network modelers and to improve grid model consistency. An instance model illustrating how the WireAssembly shown in Figure 32.

Figure 33 could be used as a template is given in Figure 33. In this case, three lines have the same physical characteristics (spacings, conductors and bundling) and are represented by three ACLineSegment instances all of which reference the same WireAssembly instance.

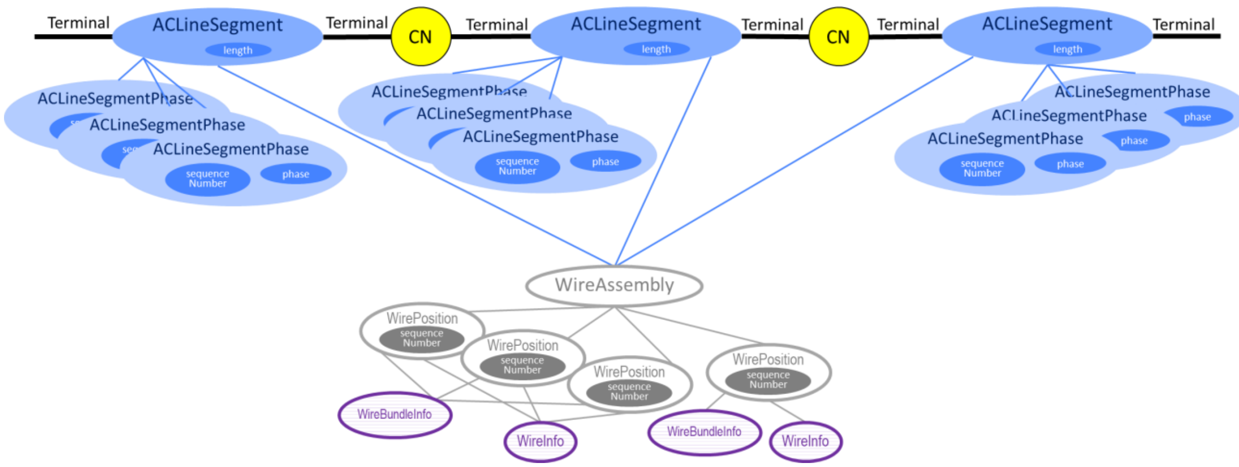


Figure 33. WireAssembly used as a template by multiple ACLineSegments

Being able to leverage CIM modeling to support the use of templates allows the template information (and the benefit of its consistency) to be shared among systems across the enterprise. While CIM17 generally has the classes and attributes necessary to support template-based modeling, the currently defined standard data exchange profiles do not currently support their effective use.

Consumer Representation – aka Load

Load is measured by control area for transmission and by feeder or distribution transformer for distribution. All utilities spend a great deal of effort collecting this data and fitting this data to forecasting models that guide the utility in planning to meet demand. Such forecasts are also fundamental inputs used in setting up network analysis, but in network analysis, the total forecasts must be converted to individual estimates of load at the points in the network where load is connected.

Prior to the advent of DER and tariff-based strategies that influence consumption patterns, these load forecasts translated directly to basic demand that the utility needed to supply. Today's grid requires independent methods of different categories of energy.

One way to understand traditional load forecasting is that it represented 'an aggregate of everything for which we don't have more specific knowledge'.

In CIM, we continue this approach and the EnergyConsumer class is used to represent the aggregate energy that we don't have more specific information about, at a point in the network model. The general idea is that as soon as the utility becomes aware of a DER component, such as a rooftop solar photovoltaics (PV), it should be broken out and represented separately (as will be discussed in a later section on DER). For example, a customer that was supplying all its own needs from PV at a given point in time would show up not as zero load but as +*x* kW from a PV component and -*x* kW from its EnergyConsumer component, so that solar production could be forecasted separately.

CIM17 EnergyConsumers

In CIM17, all load is modeled using the EnergyConsumer class, as shown in Figure 34. EnergyConsumer has a Terminal. In transmission, it is typical that whole feeders are aggregated as an EnergyConsumer instance. In distribution, if secondary is not modeled, EnergyConsumer instances aggregate secondary. In both cases, each EnergyConsumer is associated with load group modeling that describes how a net forecast is distributed among participating EnergyConsumer instances. The modeling is not explicit about the size of grid territory that the net forecast represents, so the same load distribution UML works for both control areas and feeders.

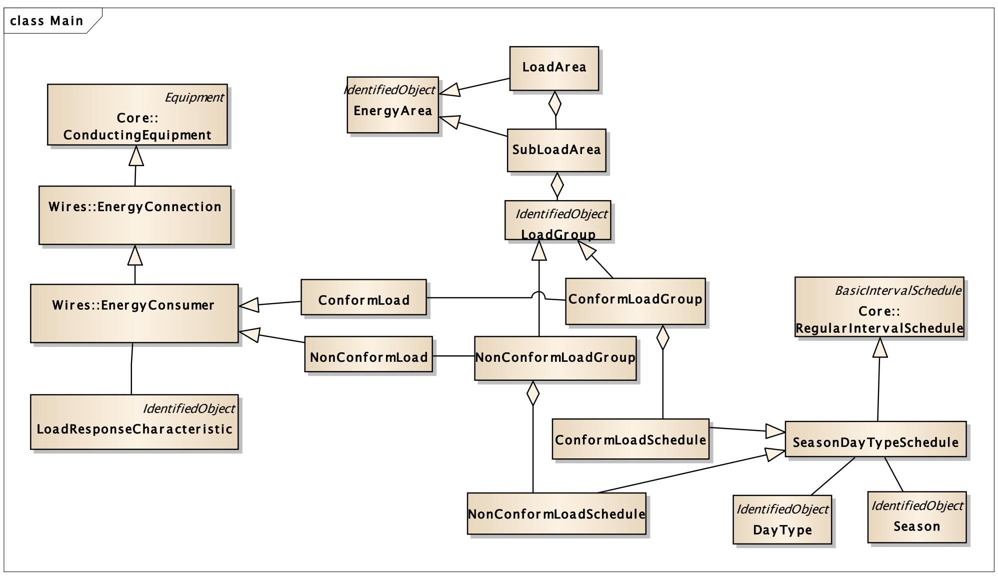


Figure 34. Load modeling in CIM17

The classes in Figure 34 to the right of EnergyConsumer describe how a forecast should be distributed among EnergyConsumers. The simplest distribution pattern assigns a fixed percentage to each EnergyConsumer participating in a given LoadGroup. For a feeder forecast, this would be used if the demand pattern of all the Feeder load was close to uniform, such as ‘all residential’. Where knowledge exists that there are multiple patterns of consumption over time, such as differences between residential consumption and commercial or industrial consumption, these different patterns can be represented, or different forecasts can be supplied.

CIM18 EnergyConsumers

CIM18 goals for improving customer representation include:

- Enable accurate association of meter data with network model Terminals, so that, for example, energization status can easily be incorporated into real-time analysis of distribution network state.
- Assure that distribution modeling may represent details of secondary and customers, without requiring the utility to go any farther than needed to meet its requirements. Consider whether some form of container for customer-owned equipment is desirable.
- Maintain EnergyConsumer classes as associated with general load and load forecasting while breaking out forecasts of other distribution energy components, like batteries, solar, wind, etc.
  - Consider how to represent EVs and EV charging stations.
- Facilitate coordination of a hierarchical relationship between distribution feeder load forecasting and transmission control area load forecasting as part of the goal to support dynamic update of transmission representation of feeders from distribution detail.

Electric Vehicle Charging

There is no explicit modeling in CIM17 covering either electric vehicles or EV charging stations. The best ways to treat EV in CIM17 are as follows:

- Where there is no information available, EV charging or discharging at home will just be hidden within an EnergyConsumer load pattern and if significant, will render forecasting of the base demand less accurate.
- With knowledge that a consumer has an EV, and especially if the consumer has a combined EV – battery – solar installation, the best treatment is to use separate EnergyConsumer instances, one with a conforming load pattern representing base demand and the others with a non-conforming load pattern representing the EV. (Both EnergyConsumers could be behind the same meter or they could be separately metered.)
- With knowledge that a consumer is an EV charging station, represent it as an EnergyConsumer participating in a non-conforming load group designed for charging stations.

Possible extensions to CIM18 include:

- Explicit modeling of an EV charging station as a type of energy connection.
- Appropriate forecasting models for EV charging stations.
- Annotation of EV existence as part of metered home load.
- Explicit metering of home charging / discharging.

Distributed Energy Resources

DER may occur in either transmission or distribution, but their impact on distribution is particularly important because they transform a distribution feeder from a passive downhill supplier of energy to an active component with elements that take independent action in response to various tariffs and markets. This operating behavior must be reflected in distribution models once there is a significant level of penetration of DER elements.

DER modeling is minimal in CIM17, so most of this discussion is focused on future. DER modeling in CIM18 has high priority. The next subsections outline use cases that DER modeling should cover, and then discuss three main aspects of DER modeling requirements going forward:

- The power producing / consuming element and its properties.
- Energy forecasts for DER under various conditions.
- Control modes, such as those described in IEEE1547, and interaction with other intelligent functions.
- Aggregated DER equivalents.

DER Use Cases

Small Rooftop PV

Small PV installations are common. They individually may be small but as their numbers grow, their aggregate impact becomes significant.

In this use case, the scope includes only small DER, such as rooftop PV, that is not communications enabled for control by or interaction with other parties like DERMS or VVO.

Many utilities will be trying to refine their knowledge of customer energy usage. They may not know now whether customers have rooftop PV and so in present state of knowledge this unrecognized PV is part of load (and is probably rendering the load forecast more difficult). Once any PV information becomes known, it is to be modeled separately, participating in a different forecasting structure. And certainly, wherever connection applications are required, every connection, regardless of size, should be recorded in the distribution network modeling.

UML Requirements for PV:

- Must be represented as a type of energy connection separate from typical residential load.
- Is part of a separate energy forecast.
- May either be configured behind the same meter as the EnergyConsumer or may have its own meter.

Participating DER

In this use case, we have a DER that connects into the distribution grid at a single metered 'point of common coupling' and is individually significant to some kinds of analysis due to a combination of size and control capability. Such an installation will have been subject to review and approval from the utility to which it connects and will conform to standards such as IEEE 1547 and meet various regulatory requirements. The review process will require submission of design details sufficient to provide modeling input for analysis.

Such a DER has all the UML requirements of the previous use case, and adds the following:

- If inverter-connected, must represent the dynamic properties of the inverter, such as artificial inertia.
- Must describe the 1547 control mode behavior.
- Has a point of common coupling that is the point at which control targets are defined and is not necessarily the same as its electrical connection.
- Must be able to simulate its behavior interacting with other agents, such as DERMS or VVO, in time-series power flow. (Slow dynamics.)

Complex Campus

The campus use case illustrates a final situation in which the utility supplies a 'campus' that is itself a complex grid with multiple DER. As shown in Figure 35, the campus is assumed to have a campus energy management system, which interacts with the utility DMS /SCADA system. The campus has multiple feeds, even though the norm would be that both feeders are operated radially with an open point determined by the campus management.

This kind of facility can direct its DER components, participate in energy markets or tariffs, and also coordinate in specialized ways with the utility DMS. Of particular interest, though, is that the campus can connect all or parts of itself to either of the main feeders, so that the makeup of the feeders in terms of active controls is dynamically dependent on the configuration of the campus.

This use case adds the following UML requirements to those of the previous use case.

- Must allow multiple campus points of common coupling in addition to the PCCs of the individual DERs.
- Must describe the internal control relationships of DER to Campus Energy Management.
- Must describe the external control relationships of Campus Energy Management to DERMS and/or DMS.
- Probably should annotate the ownership boundary.

- Probably should allow a utility to operate as a peer with a campus modeling system supplying modeling to the utility via CIM interfaces.

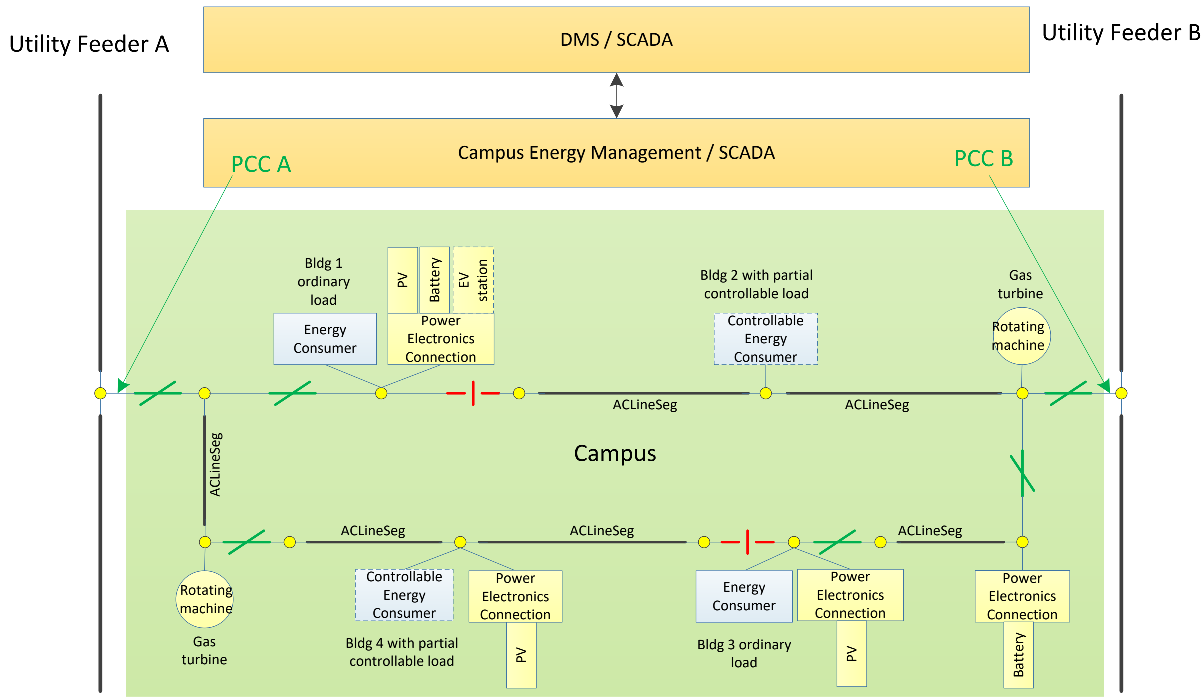


Figure 35. Campus use cases

DER Energy Connection UML

CIM17 supports energy connection modeling that includes DER production components as shown in Figure 22.

- The top of the hierarchy is EnergyConnection, representing any single-Terminal connection that provides energy to or takes energy from the grid. EnergyConnection is a kind of ConductingEquipment, from which it inherits the ability to have Terminals, but it is restricted to a single Terminal.
- Under EnergyConnections there are two classes:
  - EnergyConsumer, representing load.
  - RegulatingCondEq, representing active components which can participate in RegulatingControl. (The RegulatingControl class can describe multiple types of control which is discussed in a later section on Controls.)
- Under RegulatingCondEq there are a number of classes:
  - RotatingMachine represents AC generation connections.
  - PowerElectronicsConnection represents inverter-connected resources.

- Other resources including ShuntCompensators, StaticVarCompensators, FrequencyConverters and equivalent sources represented as ExternalNetworkInjection.

- RotatingMachine has an association to GeneratingUnit, which subtypes into various kinds of AC power plants.
- PowerElectronicsConnection has an association to PowerElectronicsUnit, which subtypes into various kinds of DC energy resources.

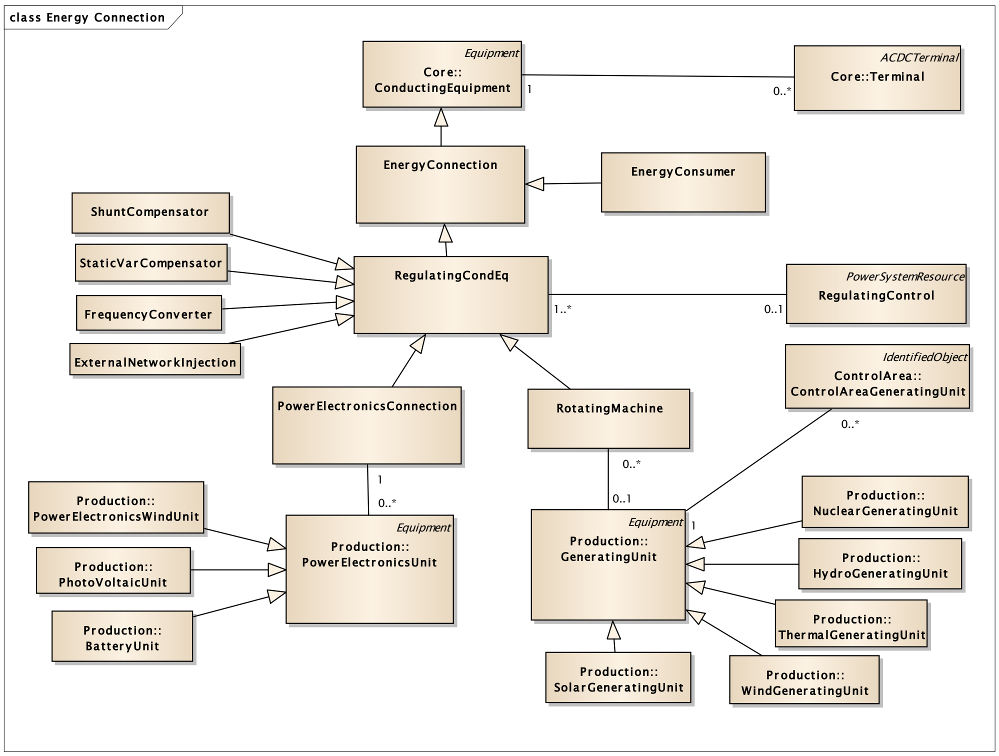


Figure 36. Energy connection modeling in CIM17

This modeling covers both traditional large generating plants and what would fall under the category of DER. However, the classes discriminate the type of production rather than whether it is a DER, which is probably good as DER is not a very well-defined term. In the end, for analytics, it is not important what someone might designate as DER. What is important is a description of its electrical characteristics, its control capabilities, its participation in energy forecasts or schedules, etc.

In CIM17, the modeling describes the component types and their electrical characteristics, but is not sufficient, for example, to describe IEEE 1547 control modes. DER energy connection issues that are being reviewed for CIM18 include:

- The PowerElectronicsConnection class essentially connects DC power with the AC system. There is no explicit inverter class. To associate dynamic behavior with an inverter, the only way to do it in CIM17 is to adopt a policy of using PowerElectronicsConnections to represent an inverter.

- When an inverter has multiple kinds of units behind it, there will only be a single Terminal connecting to the AC system. This means that measurements and meters cannot be located at individual unit Terminals and solution results may not be reported at individual unit Terminals.
- Only GeneratingUnits (not PowerElectronicsUnits) may currently participate in AGC.

DER Energy Forecast UML

CIM17 has no UML for describing energy forecasting other than the distribution of forecast loads among EnergyConsumers.

There is an obvious need to separate forecasting of PV and wind (which are based on weather assumptions and unit capability) from the forecasting of traditional loads. It is not clear, however, whether that requires any new UML.

Other categories of energy pose different problems. How should battery or charging station or home EV energy be estimated for a specified scenario? This is not clear presently. We can say that the UML will identify the kinds of units and their properties. It is likely that utilities will develop local methods of (and custom software for) deriving values for various types of energy connections from a given scenario specification.

DER Controls UML

CIM17 UML allows voltage control by any equipment that inherits from RegulatingCondEq, which includes PowerElectronicsConnections, which means that any DER can be described as participating in control defined by the RegulatingControl class.

There is an active effort in CIM18 to develop UML for covering the full range of IEEE 1547.

Aggregate DER UML

It is common that representation of DER in studies is an aggregate. In transmission studies, an entire feeder's DER will be aggregated. In distribution studies, secondary DER is likely to be aggregated at the primary. But the raw data about DER that the utility receives in a request for interconnection will be about the nameplate of the unit.

CIM will use the same classes to represent DER whether it is a representation of an actual individual unit or an aggregate of units. At a master data level, we encourage modeling that represents each known DER interconnection individually and therefore maintains a 1:1 relationship with applications for interconnection. If, however, the secondary is not represented in detail, an equivalent secondary impedance would be required between the primary and the DER instances, if the DER data reflects nameplate characteristics. At present in CIM17 this would have to be inserted separately as an ACLineSegment or EquivalentBranch. When DER are represented in aggregate in transmission, a similar impedance is required.

CIM18 will be reviewing this to consider whether equivalent impedance should become part of the DER modeling.

Real-time Data Input

The critical centerpiece of the future distribution control center is a comprehensive representation of the real-time state of the distribution grid. This will require all real-time information collected from the field about the present state, regardless of the means of collection, to be integrated into the network model so that it is available to the analysis that develops the steady-state solution that best fits the data (aka state estimation). The UML for the network model must describe, for each real-time datum:

- The electrical grid component and property that the datum represents.
- The means by which an application can acquire the datum from its source. (This assumes that there is an application like a SCADA that acquires this kind of data and serves it to authorized clients.)

Measurements

By measurements in the context of grid modeling, we mean the sampling of real-time grid data by some high-speed system. This data is crucial to assessing the state of the distribution system, just as it is with transmission. Measurements are typically available at substations and increasingly they are becoming available outside the substation and from sources like 61850-based DER. In CIM17 measurements are modeled in typical SCADA style and associated to Terminal (or Equipment in the case of breaker or tap position). This tells an application what network value the measurement is reporting, but the modeling assumes that the application will know how to acquire the data. In other words, the present modeling assumes that the context for use of measurements is the traditional control room, where all measurements were served through a SCADA system that all the applications knew how to access.

Today, both measurement sources and the contexts for use of measurements in network modeling are becoming more diverse and there is a need, which CIM18 is reviewing, to add modeling of the data acquisition paths.

Meter Data

Meter data is needed in distribution network analysis:

- The energization state reported from smart meters is a major clue in assessing customer outages.
- The consumption data recorded through metering is the fundamental statistical input to building better energy forecasting models.

In CIM17, meter data acquisition is represented in the 61968 part of the UML and was designed for traditional meter data management, rather than for use in network analysis. There is a UML path by which meters could be associated to equipment in the 61970 network modeling, but there is general agreement that this is not an acceptable way to use meter-collected data within network analysis, and this is expected to be improved in CIM18.

Controls

CIM17 provides methods of describing controls for steady-state that meet classical power flow requirements. CIM17 also provides methods of describing controls that impact classical forms of dynamic analysis. Unfortunately, there are considerable gaps in modeling a complete set of requirements, and this presents a challenge for CIM18. Details follow in the subsections.

CIM17 Steady-State Control Modeling

Figure 36 shows a summary of the CIM17 UML for steady-state controls, where the classical goal of analysis such as power flow is to find a solution state for basis variables in which no control would act on non-basis variables to move to another state.

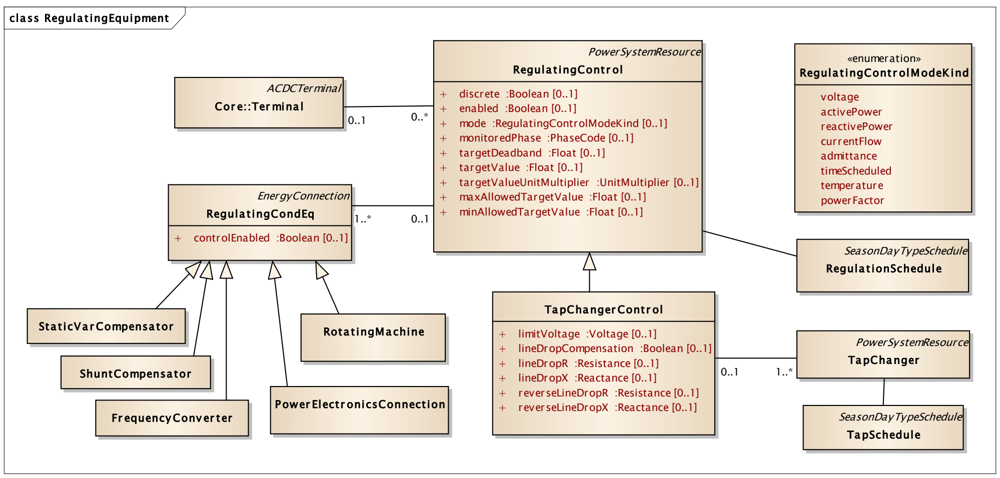


Figure 37. Summary of CIM17 steady-state control UML

The main requirements of any control description are the kind of control, the input to the control, the control logic, and the output of the control. In this CIM17 modeling, the inputs and outputs are always analytical variables associated with the grid. An equivalent way of saying this is that CIM17 controls are 'hardwired' to the grid – they can't be described as getting values from or supplying values to other controls.

The kind of control is indicated by the RegulatingControl class, which has a mode property, whose possible values can be any of the kinds given in the RegulatingControlModeKind enumeration at the right of the diagram. The kind of control, combined with other attributes of RegulatingControl, infers the steady-state behavior of the control, although the precise logic by which an application uses the attributes is left to the application. This means that different power flow applications using the same starting conditions are not guaranteed to find the same solution. (It is common that there are multiple basis solutions that would meet the solution requirements.)

The output of control is the set of values that the control can change. If the set of controllable equipment includes transformer taps, the control will be defined as TapChangerControl; otherwise it is just a RegulatingControl which can associate to any instances of the various RegulatingCondEq subclasses that can be used to achieve the desired control. In general, there may be multiple controllable variables that the control governs.

The input to the control consists of the state of all the controllable equipment plus the Terminal that is controlled – the location of the control's target. Each control instance has only one control target. What is being controlled is determined by the control mode. Most commonly in power flow the target is voltage at a Terminal, although phase shifters may control real power flow and there are other possibilities as well.

CIM17 Dynamic Control Modeling

CIM17 has a large separate package of UML (61970-302) that describes the dynamic behavior of energy connection equipment. The dynamic modeling UML provides the description necessary for simulations of short-term power system dynamics – i.e. the frequency and angle swings that follow when the grid is stimulated by some change.

Dynamic modeling UML is designed to describe the behavior of turbines and their built-in generator controls, and it is based on a collection of connected control function block diagrams. Each set of block diagrams corresponds to an energy connection and draws its sensory input from a grid Terminal. In other words, the functionality of dynamic control models is hardwired to the grid like the steady-state regulating control is hardwired.

Since this dynamic modeling is unnecessary for steady-state (the most common sort of analysis), and since it is also complex, it is maintained as a separate set of data that is only included when needed.

The value of this modeling in distribution is not clear at this point. Dynamic analysis of the transmission will probably need some aggregate representation of DER behavior, but dynamic simulation of feeders is an open question.

CIM18 Controls

Current events in distribution are dominated by the deployment of smart agents:

- Smart meters.
- Intelligent DER with IEEE 1547 control capability.
- Intelligent agents (e.g. DERMS, VVO) that manage other intelligent agents.

Deployment of these smart agents is happening concurrently with widespread experimentation with tariffs that encourage good energy consumption and markets that encourage innovation and, it is hoped, efficiency.

Trying to analyze feeder behavior in the presence of these slow-acting but very important forms of control with traditional power flow is tedious at best. A new, long-term dynamic simulation, sometimes called quasi-static time-series (QSTS) power flow, is necessary because the time constants for actions taken by these smart agents are longer than the time that the grid takes to settle out classical dynamic reactions and return to steady-state. The QSTS power flow is very similar to a classical power flow except that instead of conducting a feasibility search, it steps through time as follows:

- An initial classical power flow provides a starting state.
- At each time step:
  1. Time is incremented.
  2. Load and other external 'events' may be introduced as appropriate for the time.
  3. A power flow basis solution is executed for the condition defined by step 2 and any control actions taken in the previous time step.
  4. Smart control agents are simulated to see if they would react.

CIM18 will propose new modeling for the requirements posed by this form of analysis. High priority areas for distribution include:

- IEEE 1547 control modes
- Function-to-function interfaces suitable for simulating a higher-level function providing settings to a lower-level function.

Very likely, CIM18 will continue the steady-state versus dynamic split in modeling and the new modeling will be added to the steady-state regulation controls part of the UML.

Switching Plans

A fundamental activity in distribution operations is supervising the work steps that impact the electric grid. Operations planning collaborates with work planning to develop 'switching plans' and in real-time, operators track and authorize switching steps. It is common that distribution operations centers include applications that manage switching plans and track their execution, but these applications usually approach this as a data management problem separate from network analysis. These applications typically only represent switching activity and do not represent grid changes resulting from construction activity.

Our view of the future for distribution operations includes these two related requirements:

1. Operations shall maintain network modeling sufficient to support power flow and other network analysis as construction continues in the field. In general, operations shall have a target timeliness, such as "each electrical change that is made in the field shall be reflected in analytical models of real-time within 15 minutes of the event". Normally, failure to model a change will disable the ability to analyze a feeder, but not the whole system, so an

alternative target metric might be accumulated time disabled – e.g. feeder-minutes disabled.

2. Operations shall have the ability to pre-analyze all switching steps prior to execution:
   - Switching plans must include or reference a description of the construction steps that add, modify or remove electrical equipment.
   - All switching step descriptions must refer to the network model so that the descriptions can be used to automate network analysis of each step.

The ability to drive analysis with switching plan steps both provides foreknowledge of what to expect and pre-validates modeling, which serves the first objective. Under normal circumstances, where most activity of any complexity is covered by switching plans, changes get checked out ahead of time and just need to be activated in the real-time modeling. Poorer performance can be expected in storm damage duress, but even there, good user interfaces can probably enable many changes to be reflected in real-time, since operators will want to track what is happening as well as they can.

The 61968 part of CIM17 UML has classes that support the traditional switching plan but not the ability to drive analysis because construction changes are not described.

For some time WG13 has been developing an improved general method of describing changes to a network model – a method that could be incorporated into the description of switching plans and would be able to drive analysis. This is discussed in the later section on Change Models.

Distribution Containment and the Feeder Class

Electric utilities typically talk about grid equipment as being part of a larger grid functional component. In transmission, we typically have substations, transmission lines, sub-transmission lines and generating plants, for example. While these groupings play no part in the definition of power flow equations, they are important to the user interface. They play a key role in naming, in navigating the network, in schematic diagrams, and so on. In CIM, we refer to this generally as the ‘containment’ structure in the UML. Transmission equipment is associated as a ‘part of’ container classes like Substation and Line.

Orientation such as this is also needed in distribution but is not the same.

Network Model Definition of Feeder

The similar need in distribution is to describe a feeder. Feeders are connected at the ‘head end’ to a main substation that would usually be represented in transmission modeling. Feeders are composed of everything that delivers power to consumer premises. This ‘everything’ can be almost any kind of component, including smaller distribution subs where voltage transformation takes place, pole tops, switching cabinets, overhead and underground lines, switches, customer transformers, secondaries, customer meters, and of particular importance these days, distributed energy resources, or DER. The part of 'everything' that is outside the substation is exclusively feeder, but parts of main or distribution substations may be associated with a feeder as well as parts of the substation. Feeders are mostly operated radially, but often have normally open switches connecting to adjacent feeders that provide important load shifting opportunities. There are some (mostly urban) situations where feeders are operated networked and have multiple head-ends.

In grid model management, the term feeder means the electrical components of a feeder. The electric representation contains references to geography, to construction aspects and to the assets that fill electrical roles only to the extent necessary to assure accurate electric representation and present electrical situations to users clearly.

The relationship of feeder components to feeder changes over time as nominal feeder configurations evolve. Normal open points between feeders can change, shifting equipment from one feeder to another. While most such changes are planned, there are circumstances where unplanned response to storm damage persists to the point where it is no longer a temporary change and becomes part of the nominal system configuration. This fluidity means that unlike a substation container where it is logical to compose equipment names with substation names, it is probably better with feeder equipment to use names that are independent of feeders wherever names are desired.

Nominal feeder composition may of course be different at any point in time from what is actually being fed. The real-time composition is determined by the present switching and is always computed by software. So, for any piece of equipment in analysis, real-time source is distinct from nominal source.

CIM17 Nominal Feeder UML

This section describes the UML data structures for describing nominal feeders in CIM17. (We emphasize the version 17 here because distribution grid modeling is an active area of CIM and changes can be expected.)

CIM17 feeder UML is a bit complicated, so the following subsections start with the essentials and then build up.

Feeder and Feeder Head-End

Feeders are created or reconfigured as energy demand increases or changes. Feeder identity is always established by the part of the substation (e.g. a bay) that is its source.

The most important part of a basic feeder description is that a Feeder instance must describe how to trace the customers and grid components that are energized from the feeder source given any current configuration of the grid. We refer to this tracing here as 'topology processing'. This is the only aspect of Feeder that is used in analysis. (Nominal is informational only and doesn't matter in analysis.)

Figure 37 shows the most basic feeder UML. The Feeder class identifies the feeder and the NormalHeadTerminal association to the Terminal class identifies the starting point for topology processing, which searches the electrical connectivity of conducting equipment to determine everything that is energized by that source. The identified Terminal does not need to be precisely the head-end. What matters is that it is a point that will be energized from the substation if anything is energized from the substation, such as a Terminal of the first ACLineSegment of the feeder. Topology processing will start from that Terminal and will collect everything under the feeder until it encounters a designated stop condition in all search directions. (A valuable consequence of selecting a Terminal fully in the Feeder – and not part of the transmission substation - is that it keeps the distribution modeling cleanly separated from the transmission modeling – more on that later when we discuss data modularization.)

The cardinality of the Feeder to Terminal association allows multiple Terminals to be referenced. One rationale for multiple Terminals is a feeder that is operated networked, but there may also be multiple substation source points for a feeder that is operated radially, and the UML is mute about whether this should be reflected as multiple head-end Terminals. If topology processing is conducted to determine the makeup of the feeder, however, the only reason that one would need multiple Terminals is if searches had to be conducted from multiple starting points, which seems to us to be unlikely.

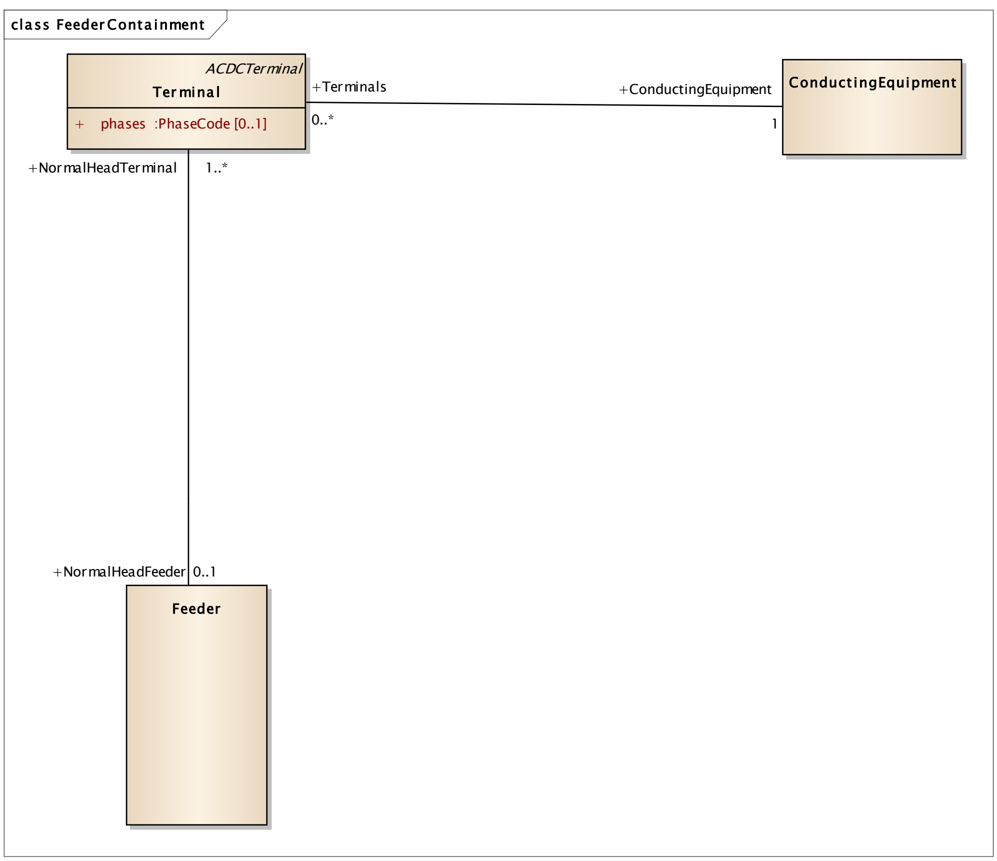


Figure 38. Feeder and Feeder head-end UML

Feeder as a Container

The next step in understanding feeder UML is the containment. This may sound like it should have been the starting point, but the head-end search start is the only information that is truly essential in defining a feeder since everything else about the electrical makeup of the feeder can be determined by software.

The feeder containment UML is meant to describe the nominal configuration of the feeder, not the actual feed based on the switching configuration present in any instance of analysis.

Figure 38 adds containment to our picture of the UML.

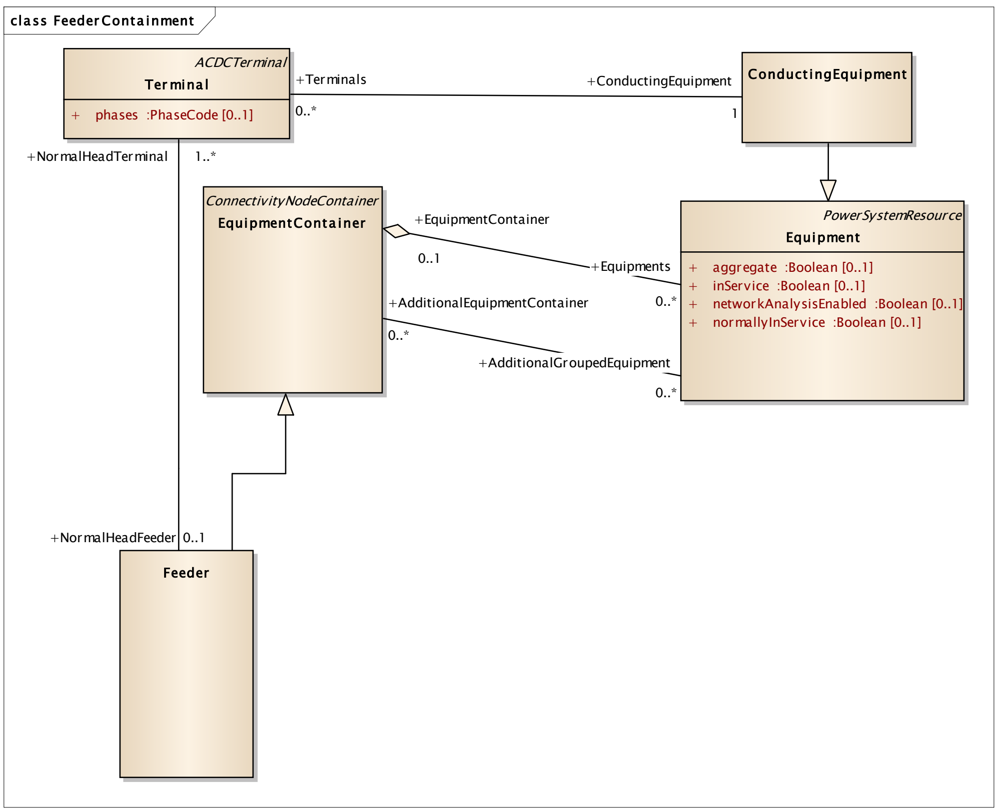


Figure 39. Basic feeder containment UML

The first thing to notice is that the Feeder class inherits from EquipmentContainer, so it is a container just like Substation is a container. Because it is an EquipmentContainer, it may be composed of any number of Equipment instances, which may include any of the many kinds of grid equipment that inherit from Equipment, so this enables all types of equipment to be represented as part of a feeder. Note, however, that the cardinality says that the container need not associate to any equipment.

The other thing to notice is that cardinality on composition association demands exclusive loyalty to one container. This 'feature' in transmission enables a complete name to be composed from the equipment name and substation name, but as mentioned earlier seems less appropriate in the case of feeders. There are, however, several clear examples where equipment belongs in multiple containers:

- A feeder breaker may be considered part of both a feeder and a substation.
- An open disconnect between feeders may be considered part of both feeders.

To cover this situation without destroying the exclusivity idea, an AdditionalGroupedEquipment association is defined, which allows any equipment to be associated with any containment(s). This open-ended relationship could be used to supplement the composition association or could be used to describe complete feeder makeup, ignoring the composition association.

> Note: CIM17 UML taken by itself allows a conflict between the containment description of a feeder and the result of topology processing based on normal switch configuration. We believe that topology processing must take precedence and the containment relationship should be derived.

Distribution Substations

Now we can add the UML that covers the situation where feeders have distribution substations. A little preliminary discussion will help. First of all, we are not talking here about a substation that would show up anywhere in the transmission modeling. Any substation that needs to be represented for use in transmission analysis should be in the transmission modeling and will not be in the distribution modeling. (We don't want any duplication of master data.) Any line feeding such a substation, whether radial or networked, should be modeled as a transmission line rather than distribution feeder. So, by definition, any substation that occurs in the distribution part of the model is a distribution substation.

The more complete UML overview is shown in Figure 39.

Distribution substations use the same Substation class as transmission. It inherits from EquipmentContainer, so it contains equipment, and this allows the modeler to associate equipment specifically with a Substation instance rather than just as part of a feeder.

There are additional associations from Substation to Feeder which are applicable only for distribution substations:

- One association indicates the energizing feeder.
- One association specifies feeders emanating from the distribution substation. New feeders with different identification can sprout from the distribution substation.
- One association can reference a feeder for naming.

> Note: These distribution substation associations are potentially valid description of distribution grids, but their value to application consumers is unclear. They are not required for any analysis.

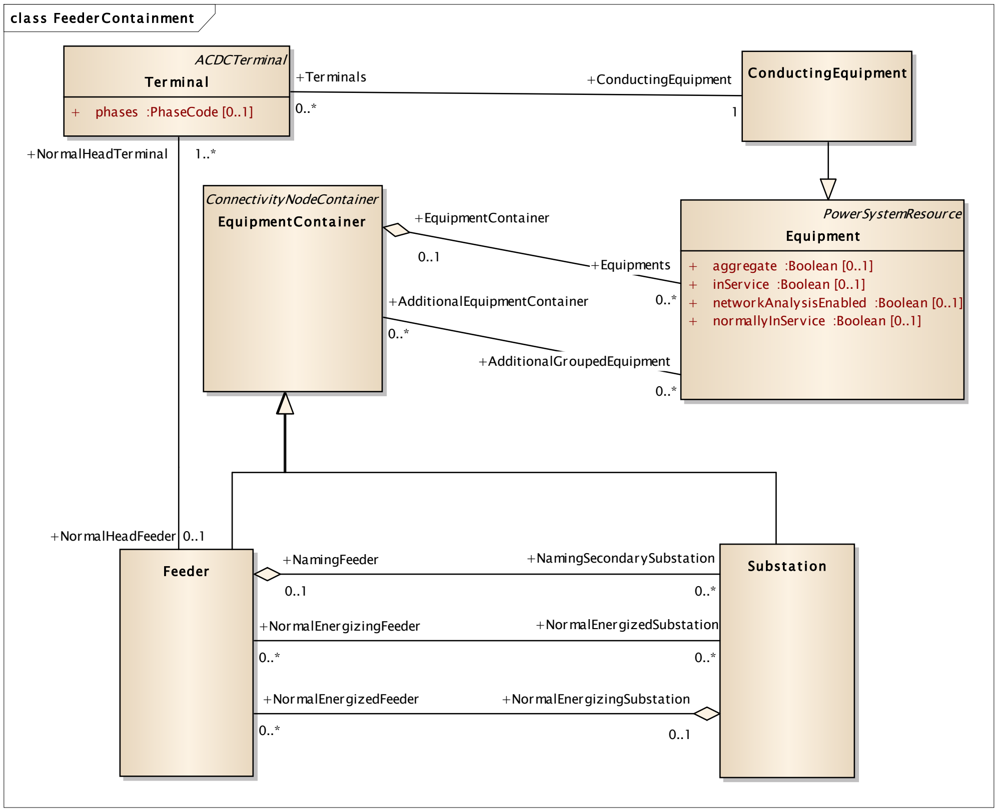


Figure 40. A more complex overview of feeder modeling

How is a real-time energization state described?

If the containment UML describes nominal feeder makeup, how is the actual energized pattern described in any analytical situation?

This information is vital for the entire distribution system in real-time. It is also represented in various extractions of the distribution system for study situations.

Network analysis almost always begins with topology processing. Topology processing in distribution analysis uses the present switch states to determine exactly what is energized from which source and what is de-energized but would connect to a given source.

At present, CIM UML[1] does not provide a standard means to describe the result of topology processing, but the following are simple extensions:

- Add an Energized/De-energized state to Terminal.
- Add an association from each Terminal to its source Feeder to indicate tracing result.

Feeder UML in Standards

When we talk about standardizing, we are talking about CIM profiles that are derived from the canonical UML for use in exchanging data between applications. Conformance to a standard is only defined in terms of conformance to a specific exchange profile.

It should be clear from the previous section that the containment UML for feeders is open to some interpretation as to how it should be used, and especially how it should be used in standards. The next sections review the possible role of the Feeder class in standards.

Standard Exchange of a Distribution Model with Transmission

Transmission studies need models of distribution. These have often simply been static equivalent load at substations, but the future will require the ability to supply real-time equivalents derived in the distribution operations center to the transmission operations center. Such supply is a model of whatever distribution is connected to a given substation point, which will usually be the head-end of a feeder.

The standard for this exchange is, however, no different from any other Model exchange and it is not clear that the Feeder class plays any special role.

Standard Exchange from Modeling Source to Planning or Operating Consumer

For distribution, an important use case is the exchange of modeling data from a modeling source, like a GMM, to either a planning or an operations consumer.

The UML for feeders was conceived with the idea that it is important to describe feeders, rather than just defining the starting point for topology searches. However, if both the starting points and the containments are exchanged from a source to a consumer, what is the consumer going to do about the potential conflict between the two? If a consumer would re-process topology to assure validity of containment, what point is there in sending containment? This is an area that is still being debated. Current versions of the exchange profiles for distribution include all the feeder containment UML discussed in the previous section.

Our proposal is to limit the required standard description of a feeder to the Feeder class and its association to Terminal, for the purpose of models being exchanged from a modeling source to a planning or operating consumer.

Finally, it is common that automated feeds from a source like GIS to a consumer like DMS are partitioned for efficiency. This partitioning has often been based on using the nominal feeder containment as the update partition. We do not recommend this because it complicates the software to detect the relatively common shifting of equipment between feeders that changes containment definitions. A preferred approach is:

- Use CIM change models as the primary means of update. They are more efficient and precise as a method of data update compared to replacement of partitions.

- Define independent stable data modularization governed by Frameworks as necessary for initializing or re-initializing consumer models, as described later in this report.

Standard Exchange of Solutions

The most common use case for exchange of steady-state solutions is to transfer such results between tools. For example, transferring an operating situation captured by an analytical result in an operations center to a planning tools for more study.

In CIM17, there is a set a standard documented in IEC 61968-13[7] for such exchange, but it should be noted that this has had limited usage and is under review in CIM18.

While such solutions are often by feeder, the extent of a solution is usually determined by a network trace and does not conform to a nominal feeder.

Dataset Serialization for Exchange

Dataset exchange is summarized in this section in preparation for later sections on grid data modularization.

Dataset exchange is an important addition to CIM, documented in a new edition of 61970-552 and supported by UML that is currently in the informative section of CIM17. It impacts the way that exchanges are packaged and replaces the network model header with a more flexible for supplying business process data.

> Terminology Note. We use the term ‘grid representation’ data to describe the modeling of the grid discussed in the preceding sections. It is also necessary to supply data that describes the purpose of a set of grid representation data. This we shall call ‘business process’ data because it is typically consumed by business process code rather than grid analysis code.

Why Datasets?

Datasets are an improved alternative to the current standard for serializing and exchanging CIM network model data. They do not change the way that ‘full models’ are serialized but they do change the way that the information in the document header is represented, and they improve the representation of changes (aka the ‘difference model’). They address two particularly important needs:

- The previous header committed the sin of mixing network modeling business process data into an otherwise completely generic serialization method. The dataset approach uses a completely generic header and conveys business process data in the same way as grid representation data.

- The business process data in the previous header was 'one size fits all'. There was only one header structure regardless of the purpose of the exchange and this forced other awkward ways of conveying business process data for different situations.

Dataset Exchanges

Dataset exchanges are very simple in concept:

- An exchange consists of any number of Datasets.
- A Dataset is just a package of logically related content data.
- Each Dataset in the exchange is headed by a single Dataset object.
- Each Dataset has a profile that governs its content.
- Dataset content is serialized in RDF/XML following the same rules as were used for serializing models in the previous 552.
- With Dataset exchanges, the Dataset object at the beginning of each Dataset is very simple and generic. All data that is of interest to a consumer application is just Datasets defined by profiles. Some profiles define grid representation data, and some define business process data. The data previously defined in the model header is conveyed in Datasets rather than as headers.

> Note: Datasets may contain objects that have associations to objects in another Dataset. This allows business process Datasets to be linked to the grid representation Datasets that they describe. It also allows business process Datasets to be interlinked into more complex hierarchies of business process data. And it allows grid representation modules to be interlinked (as is discussed in the next section on grid data modularization).

A Manifest Dataset

It may be useful to create a convention that the first Dataset in an exchange is a Manifest Dataset that identifies the purpose of the exchange and lists the contents. This is under consideration.

CIM Dataset UML

The purpose of a Dataset is to package object data into modules for exchange. Usually, the modularization of data has an important purpose outside the exchange and applications that package or unpackage data are aware of this purpose, but this is not required by the definition of Datasets and it is best to start with a generic understanding of Dataset packaging.

Figure 40 shows the basic UML for Datasets.

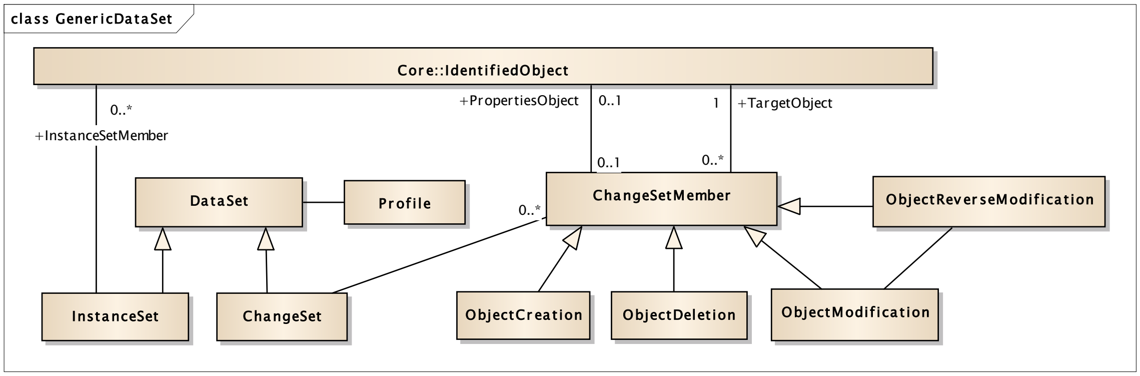


Figure 41. Dataset UML

The Dataset class is a generalization of two subclasses, InstanceSet and ChangeSet, which are the two basic kinds of exchange packages. Both kinds of Datasets share some basic properties, such as the Profile that governs what type of data may be included. A Dataset object (either an InstanceSet or a ChangeSet) heads each Dataset in an exchange.

The Profile class identifies the profile that the exchanged data adheres to. The profile is a separately defined subset of CIM UML[1] that primarily limits the kind of objects and the kind of object properties that are included in the Dataset, so it effectively defines the data type of the Dataset.

InstanceSets

The UML for an InstanceSet is simple. The InstanceSet is just a container for a set of IdentifiedObjects.

- The Dataset Profile describes what classes and properties may be included.
- The association from InstanceSet to IdentifiedObject relates InstanceSet members to the InstanceSet.
- When an InstanceSet is exchanged, it is (by definition) complete, so a receiver may assume that, for whatever purpose this InstanceSet represents, all objects are present. This is the primary aspect of InstanceSet that is different from ChangeSet.

> The way that 61970-552 serializes InstanceSets does not include the membership association – it is implicit that if an object appears in the serialization, then it is a member. In the usual situations where this packaging has meaning outside the exchange, applications must represent this membership in some explicit form to select the right content for packaging or to maintain packaging on receipt.

ChangeSets

ChangeSets are a bit more complex. They describe a set of changes to modeling, rather than just 'here are the objects in a set'. ChangeSets have many possible uses, including:

1. They can express a difference between two sets of data, which is a common way to update a receiver about changes without resending the entire set.
2. They can model a proposed action, where it is left to the receiver to decide how to use the changes.
3. They can convey a transaction – a request for modification of data (but not necessarily of an InstanceSet) that may also require a confirmation.

The ChangeSet itself does not describe its purpose. It is just a set of changes. The purpose of a ChangeSet is known through an accompanying business process InstanceSet that references it. Different business process profiles may be used to convey different kinds of contextual information.

ChangeSet UML describes a set of changes rather than a set of instances, which requires both supplying new data and referencing the objects that are changed. It is presumed that the receiver knows how to interpret the business process data and determine what the ChangeSet is for and how to use it. The only universal requirement for a ChangeSet to be useful is that the user and creator of a ChangeSet have a mutual understanding of object MRIDs.

In the packaging of a ChangeSet, the ChangeSet is made up of ChangeSetMember objects (subclassed as ObjectCreation, ObjectModification and ObjectDeletion):

- All ChangeSetMember objects have a 'target object' association, which identifies an object affected by the change in any set of data to which the change is applied. So, target references do not point to objects in the exchanged ChangeSet but rather point to objects in the receiver's world and this is where mutual understanding of MRIDs is necessary in order to make use of the changes.
  - ObjectCreation target object associations define the MRID of a new object.
  - ObjectModification and ObjectDeletion target objects should already exist in the target data. (Whether failure to exist is an error or just indicates the need to repair some data depends on the context.)
- ObjectCreation and ObjectModification require new object properties to be supplied with the change. They contain an association to 'property objects' that supply the properties.
  - Property objects are included in the ChangeSet serialization.
  - For creation, the property object defines a complete initial state of the new object.
  - For modification, the property object only describes new values for an existing object.
  - A ChangeSet property object has an interim MRID that is different from the MRID of the object to be changed. Once applied, this MRID becomes irrelevant to the target data set.

In some contexts, a ChangeSet is immediately applied to a specific target and absorbed. In other contexts, however, a ChangeSet may have an indefinite lifetime and be applied to multiple target sets of data. For example, if a ChangeSet is used to represent the impact of a future construction project, it is perfectly valid to store the ChangeSet in some sort of repository of future projects that analysts can use selectively when building future states. In such case the ChangeSet is independent of any specific state.

Finally, ChangeSetMembers are unordered. This has consequences:

- A single ChangeSet instance can only capture a net change. It cannot represent an arbitrary sequence of changes.
- ChangeSets are atomic. Partial applications of a ChangeSet have no meaning.
- A ChangeSet should not supply multiple instructions for the same target object.

Modularized Grid Modeling

The central principle of CIM for grid model management is to build the modeling required by all network analysis activities from normalized and effectively organized source data. The processes that build modeling for consumers operate on data modules, combining them and modifying them as necessary in an orderly fashion. The operations can treat modules as complex data types that are arguments of the operations, so the basis of whole idea is to understand the types of modules.

The Product Functionality View of Modularity vs the Standard Exchange Form

Before we get into the modularization discussion, the reader should be warned about the difference between modularization functionality support and conformance with exchange standards. Products are always free to choose their own way of representing data internally. Product conformance to a standard means that a product has demonstrated that it can consume or produce a CIM exchange as defined by a specific version of a CIM profile. This is testable. In our discussion in this section, however, we want products to go farther and support data modularization functionality internally as well as in exchange.

Loosely, we could define two distinct kinds of ‘CIM compliance’:

- An all-in CIM product will support functional modularity internally, which in effect says that it can receive modules, manipulate modules and pass on modules.
- An end-point CIM product may only support receipt or generation of individual modules and can only be a start or end point in a CIM information flow.

All-in products may, for example, choose to store data in a one large data structure, rather than as separate modules. That decision is up to the product, but the product must always know how to create the standard forms for exchange, so there will always be business process data that defines modularization. This business process data about modules is of course used in exporting and created when importing, but in the case of an all-in product like grid model management it is also used to drive automated procedure operations like 'make an assembly of module A with module B'.

The reader should assume that the subsequent text refers to a product's conceptual / functional view except where specifically stated as being about standard exchange forms.

Models and Change Models

Grid model management relies on two basic kinds of data modules:

- A **Model** is a data module that describes a subdivision of the grid data.
- A **Change Model** is a data module that describes changes to a Model.

The Model and Change Model modules are each composed of two distinct parts:

- **Grid Representation** data describes the power grid. This is the information that network analysis algorithms need about the power grid.
- **Business Process** data describes the role and provenance of the Model or Change Model.

Formally in Dataset exchanges,

- A **Model** is conveyed as two InstanceSets, one for grid representation data and one for business process data.
- A **Change Model** is conveyed as one ChangeSet for grid representation changes and one business process InstanceSet to describe the purpose of the change.
- Both Models and Change Models in exchanges may be part of a more complex structure that is described in higher level business process InstanceSets. For example, an exchange may contain a set of Models that make up a power flow solution, or a set of Change Models may be needed to describe all stages of a planned construction activity.

The data contained in Models and Change Models is organized to optimize data management processes. A best practice organization is:

- The present state of the physical grid is represented by a set of master 'as-built' Models.
- As-built Models are organized by a 'Framework' that assures that Models are non-overlapping can be combined without modification.
- Change Models are used to represent planned or hypothetical future changes to the grid.

Usually, a set of modeling for a consumer purpose is assembled by combining as-built Models covering the electrical territory of interest and then moving that view forward in time by adding selected Change Models. More on this in the next sections…

Modeling Frameworks

Modularization by electrical territory is configured by a **Framework**. The purpose of a Framework is to define rigorously the electrical territories that Models will represent. Frameworks allow the modeling contributions of different authorities to be clearly defined and also support the convenient execution of automated procedures that apply to only selected territories.

A Framework consists of Boundaries and Frames. Boundaries are set by mutual agreement and separate Frames.

- Each **Boundary** separates two Frames. A Boundary Model describes objects in the Boundary. Electrically adjacent electrical territories are connected electrically. There must be an agreement about at least some modeling that will only be changed by mutual agreement of the parties responsible for the adjacent territories. In CIM, the mutual modelling is modularized as a separate Boundary Model.
- A **Frame** is a bounded territory into which Frame Models must fit, where 'fit' means that all external associations from objects in the Frame terminate on objects in one of the Frame's Boundaries.

There is no hard and fast rule about what a Boundary Model should contain, although experience with Boundary Models in the transmission domain has indicated that a minimalist approach is typically most flexible. The fewer and simpler the objects in Boundary Models, the easier their maintenance. In practice this looks like populating Boundary Models primarily with a single ConnectivityNode object for each connection across a boundary.

Putting Frameworks to Work

The power grid is a gigantic, connected machine. The network modeling required by any application almost always needs to cover some territory for which the application owner is not the primary source of data. To take some simple examples, transmission operations centers need modeling of neighboring transmission and of distribution load. Distribution operations centers require modeling of transmission substations and sometimes of adjacent distribution divisions.

In common practice modelers get information about external grid parts by any means available and manually put together the best models they can, duplicating (usually with less quality) the modeling work of the primary source. An automated process to get finished modeling directly from the primary source (aka the 'model authority') is a huge improvement and is the CIM objective. There are two basic requirements:

- Data should be available in canonical form (CIM).
- The parties should have territorial agreements about modeling responsibility so that their respective data sets fit together without each party having to extract, merge and manually cross-check data.

CIM Frameworks accomplish the second of these two criteria. A Framework is an agreement among parties in the grid that defines the precise scope of primary modeling responsibility, such that the concatenation of primary models creates a complete grid model.

Any group of modeling authorities may engage in a Framework. All entities do not have to be represented. When some are absent, it simply means that other parties, in their modeling, are acting as proxies for those absent sources. For a common example, if a Framework is solely an agreement among transmission operators, it means that each transmission organization is a proxy for distribution load.

Our clear industry goal, however, should be that all analytical data required anywhere should become governed by compatible Frameworks that allow master data to be prepared once by the logical model authority and all usage derives from those master data sets.

The practical approach to this grand objective is not one single enormous Framework, but rather a hierarchy of compatible Frameworks – a sort of Russian doll approach. The next subsections describe a top-level Framework whose agreement would be orchestrated by an interconnection authority (e.g. NERC or ENTSO-E), followed by a set of second-level sub-Frameworks whose agreement is orchestrated each TSO, followed (if necessary) by another level whose agreement would be orchestrated by each DSO.

A Framework agreement typically requires an orchestrator to bring together the participants, but the hard work is done by participants. This work is carried out in the form of bilateral boundary agreements where each pair of electrically connected entities negotiates the boundary that is their part of the Framework agreement. The orchestrator simply oversees the process.

From the distribution entity perspective, what this means is that it participates in a Framework orchestrated by the TSO and can consider becoming the orchestrator of lower-level Framework if necessary. In the next sections we outline best practice for Frameworks.

Top-Level Frameworks

Interconnected power grids are operated by dividing them into control areas, each of which has responsibility for maintaining frequency and net interchange. Reliable overall grid operation is achieved through analysis of the high voltage part of the grid across the entire grid footprint. Models of each control area are the responsibility of the control area authority, and this modelling should be organized by a top-level Framework in which each control area is a Frame. In most cases, a TSO is the authority for a control area and for simplicity, this discussion is going to assume that and just talk in terms of TSOs. Normally, there will be some sort of governing body for the interconnection that is a logical candidate to be the orchestrator of the top-level Framework, bringing together the TSOs to negotiate the Framework agreement.

Figure 41 illustrates a high voltage Framework consisting of MyTSO plus 8 other TSO Frames defined by 12 Boundaries. To achieve this Framework, the modeling authorities for each Frame have gotten together and agreed on the mutual objects that are to be contained in the

Boundary Models. MyTSO participated in three bilateral boundary agreements, with TSOs G, E and H.

It is important to note that the purpose of this Framework is to govern the exchanges among TSOs. When TSO G sends a Model to MyTSO, MyTSO only needs to see parts of the grid that are significant to its operation. MyTSO does not usually need, for example, detail of sub-transmission in the TSO G footprint. Similarly, when MyTSO prepares a MyTSO model for others, they do not want to see MyTSO sub-transmission modeling.

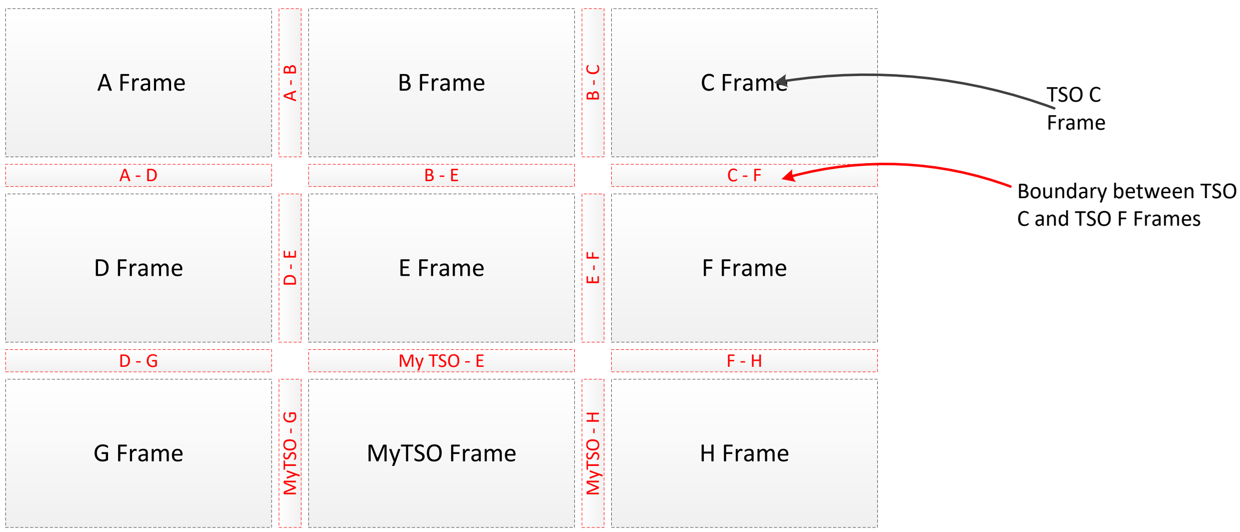


Figure 42. A top-level Framework consisting of MyTSO Frame plus 8 other TSO Frames

Second-Level Frameworks

For our distribution perspective, the preceding top-level Framework is only relevant in that it defines the scope of the next Framework level, but the next level 'down' is directly relevant to distribution. A TSO has two problems to resolve in managing its grid data:

1. TSOs are responsible for contributing representation of their HV (high voltage) grid for bulk power analysis. They are also responsible for performing studies that include their sub-transmission, so they need to modularize so that sometimes they can just use the high voltage while at other times they can include both.
2. There are data sources in the TSO territory that are external to the TSO. These include distribution model authorities and occasionally separate sub-transmission model authorities.

Note in this second category that we say model authority and not company. What matters is that there is a separate source of data, not who owns it. So, some examples of external model authorities might include:

- Separate DSOs (Distribution System Operators).
- Distribution divisions within a large utility.
- A mesh-operated network within a large utility that uses a separate modeling platform.
- Sub-transmission owned by a DSO instead of the TSO.
- A very large customer with a significant internal grid.

Figure 43 then illustrates a general approach to a second-level Framework covering the territory of one TSO.

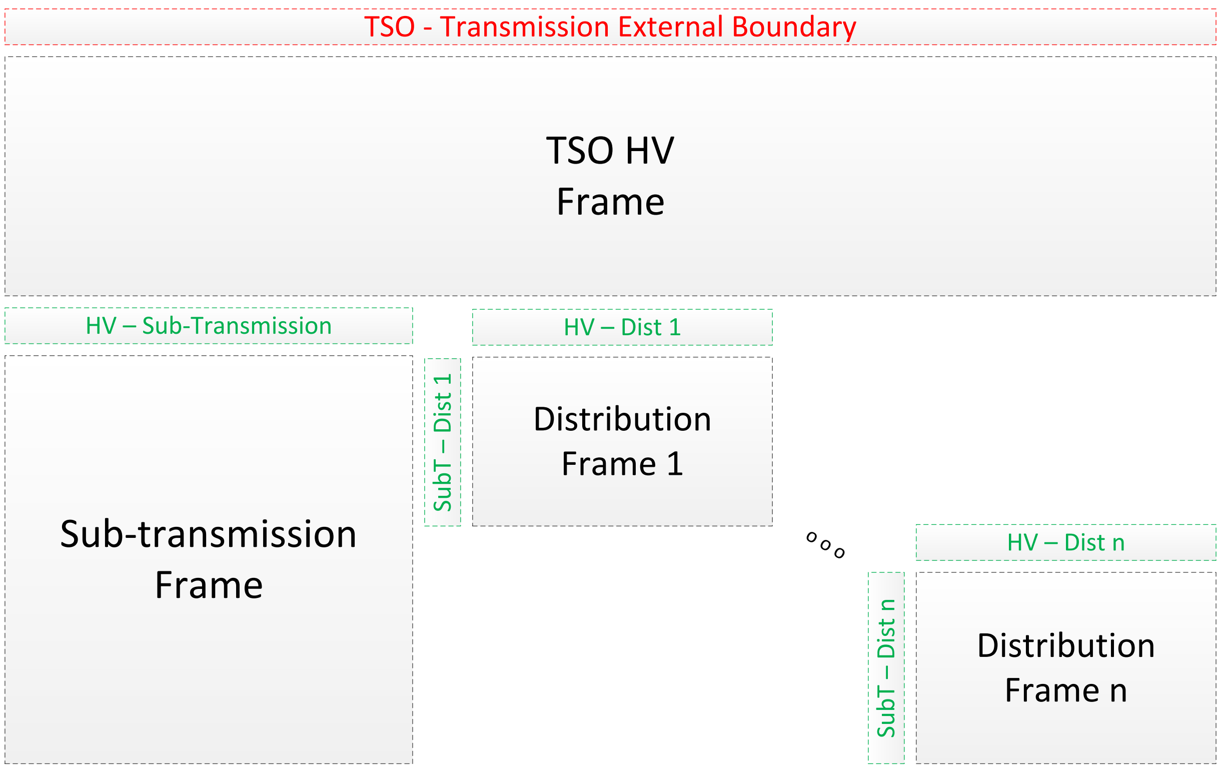


Figure 43. Typical second-level Framework for the territory covered by a TSO

Starting from the top, everything in this second-level Framework must obey the TSO – Transmission External Boundary defined by the top-level Framework – this establishes the Russian doll principle.

Then we define a Frame within the second-level for each model authority, treating sub-transmission and HV transmission as separate Frames even if they are from the same model authority in order to modularize them. Each distribution model authority is a separate Frame with Boundaries (in green) to the HV and sub-transmission Frames. One aspect of this

Framework that is not shown but is also a possibility is that some distribution Frames may need Boundaries between them because they manage feeders that can interconnect.

Is a Third-Level Framework Needed?

Maybe. Sometimes. Eventually. If the distribution situation requires representation of secondary and complex non-owned facilities, it may be desirable to create another Framework level that sub-divides a distribution Frame. In such a case, the distribution entity will be the orchestrator and it may engage grid participants as contributing sources. For example, DER installations are currently required to submit designs for approval to interconnect. Right now, the distribution entity acts as proxy modeler and converts those applications into network modeling as necessary. As time progresses it will become clearer whether a more formalized separation of customer-owned modeling is valuable.

Model Types

Frame data may also be modularized by type. The primary functional types are:

- **Physical** data, which describes the properties of the grid that are inherent its construction – in other words, the electrical properties of equipment and the way the equipment is connected, measured, and controlled.
- **Situation** data, which describes the operating state of the physical grid for some analysis. It includes energy in and out of the grid, control area net interchange, control settings, switch states, and operating limits.
- **Solution** data describes a set of values of steady-state variables (principally voltages and flows) produced by a solution algorithm.

These are usefully modularized because it is common that there are many situations studied for a given physical representation and because situation and solution data originate from different sources than physical data. These functional categories are further subdivided by the IEC data exchange standards, into what the CIM calls profiles, in service of specific use cases for exchange.

Master Physical Data

The origins of physical modeling information are the engineering design functions within the utility or within any grid participants for which the utility serves as the proxy modeler. Data in these design sources will usually be organized primarily to support design, construction, and maintenance of facilities, not network analysis. Transformation of data is usually required to produce analytical modeling of the grid.

Physical Data Import from Engineering

The transformation of data from engineering sources to master physical model data includes a varied collection of activities like:

- Single-line simplification for balanced phase representation.
- Identification of components in the terms used for planning and operating the grid.
- Computation of impedance models for lines and transformers.
- Computation of circuit limits from circuit component details.
- Location and description of grid measurements and controls.
- Representation of grid control functions at the level or levels required by analytical functions.
- Association of energy connection types with energy forecasting and scheduling models.
- Dynamic behavior and harmonic data modeling appropriate to the kinds of analysis to be supported.
- Schematic diagram depiction of the grid.
- Conversion of customer interconnection data to grid model data.
- Other engineering judgment based on needs of analytical tools.

Master Data Representation of Grid Evolution

Master modelling includes representation both of the grid as presently constructed and of planned new construction. The ongoing activity of grid planning, budgeting, constructing, and commissioning facility projects is governed by processes that track the projects through multiple phases of activity. The CIM approach to evolving the grid model over time relies on Change Models that represent such projects. For example, today's as-built becomes tomorrow's as-built by the application of the Change Models that reflect projects that went in service today. (We're not implying here that a daily update increment is preferred, but rather pointing out that Change Models are the only vehicle by which grid updates are accomplished.) Change Models are also used to represent and incorporate changes that result from activities other than construction projects (like emergency restoration activities or even data corrections). Every Change Model, regardless of the event that creates it, has business process data that describes its purpose and context. Business process data for construction projects, for example would identify the project and its status, in service date and other information of consequence to utility processes. Most Change Models will be updated over their lifetime, so they are versioned to allow their use in model creation to be traced and models in which they are present to be updated as necessary when new Change Model versions are created.

Order Dependency of Change Models

The order in which Change Models are applied is important if the Change Models share any common target objects.

In a transmission environment, there are fewer changes, and it is usually very clear from schedules when one project depends on another and must occur before the other.

In distribution environments, major projects with clear interdependencies will also be distinguishable by their schedules, but most projects are small and from a power systems point of view, are independent of one another, which means that the real sequence of activity is determined by crew scheduling, equipment availability, etc. In other words, many projects have independent timetables. However, sometimes even though these projects are independent, their Change Models might share common target objects such that as soon as one Change Model is applied, the other becomes invalid. There are modeling practices that can mitigate this problem, as described in Appendix X.

Maintaining Future Change Models

Master data must be continually updated to reflect the latest engineering and construction activity. Whenever a new plan is initially approved or updated, a new version of the plan must be added to the set of master data. The process for creating the corresponding Change Model content is shown in Figure 44. The main steps and their data interactions are:

Roll model forward to time of plan

1. The latest as-built Model representing the facility is obtained.
2. Existing Change Models representing work that would take place prior to the new plan are added to the as-built to roll the modelling forward to the time of the plan.
3. The 'before' state is recorded, and the definition of the change begins.

Transform facility data, update and validate Change Model

1. If the planned project already has a Change Model, it can be added if the user wants to start from the previous modelling.
2. Facility/asset data is extracted, transformed, and added to the modelling. This can be a manual step or a semi-automated process.
3. The resulting 'after' future Model including the planning project is quality-tested with validation checks (including test power flow runs if appropriate).

'Difference' before Model and after Model

1. The resulting 'after' state is compared to the before state and the differences are recorded as the content of the new Change Model.

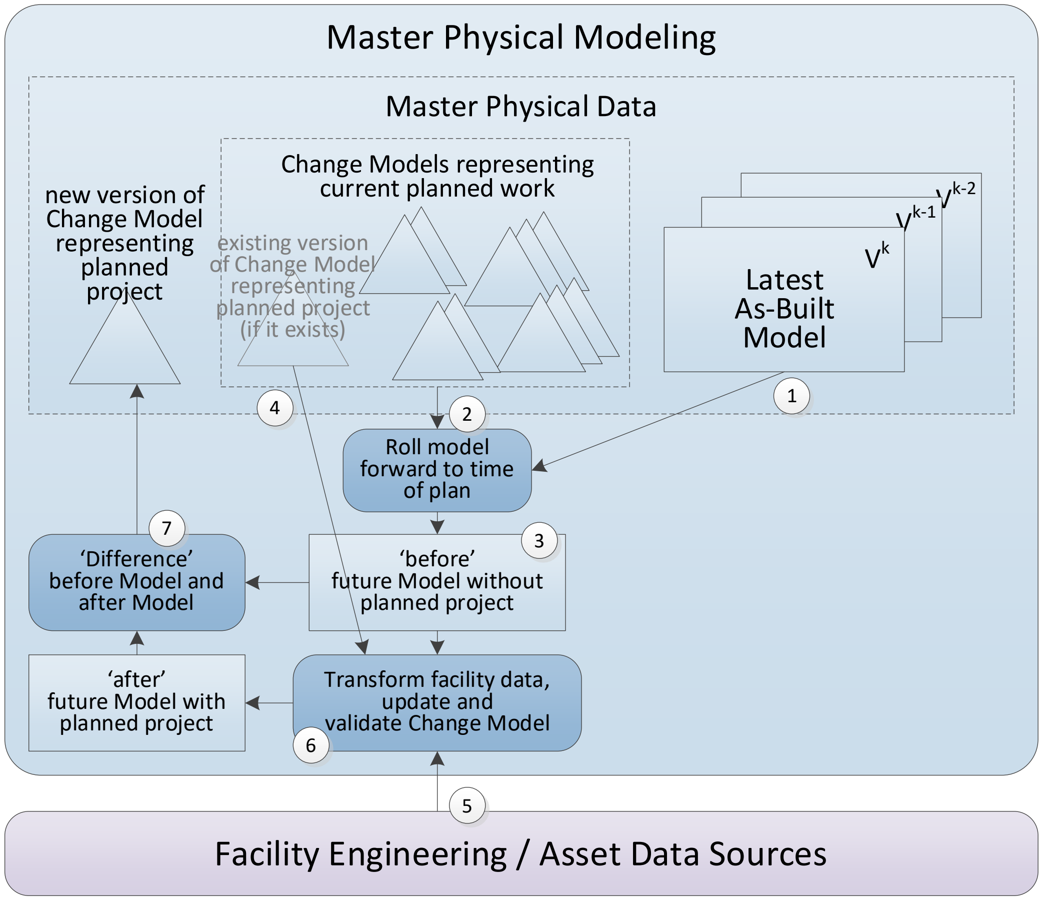


Figure 44. Creating a Change Model representing a new plan

The process of acquisition, transformation/computation and creation of master Change Model data is challenging to automate completely. However, simpler semi-automated implementations can function very effectively if there is a well-designed user interface that includes schematic presentation and editing of power system data.

Maintaining As-built Models

When planned work completes, the formerly prospective changes are added to the as-built modelling, creating a new as-built Model version. This is illustrated in Figure 45.

Here the main step and its data interactions are:

1. The current as-built Model is obtained as a starting point.
2. The Change Models representing completed work are identified and added.
3. The result is saved as the new as-built Model version.
4. The completed Change Models are marked as included and archived.

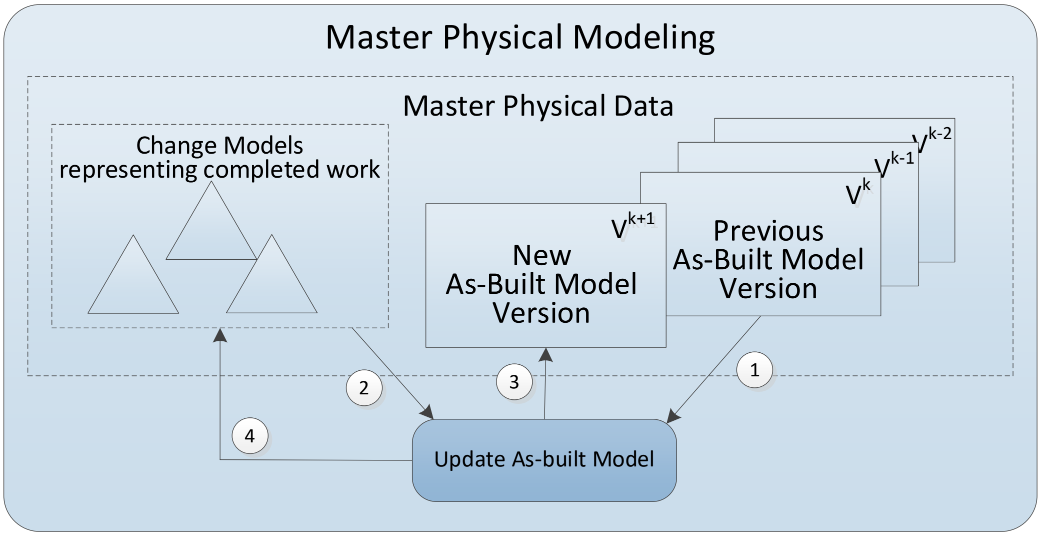


Figure 45. Update of an as-built Model to reflect completed work

Master vs Derived Models

When analysis of future states of the grid is required, ‘derived’ Models of the future state are created by starting from the as-built master Models, selecting the relevant Change Models, and applying the changes sequentially to the as-built starting point. Since analysis of future states is extremely common, this means that modeling provided to consumers is commonly composed of derived rather than master Models. Derived Model business process data will annotate the derivation.

Derived Models are also created by other forms of processing.

- Sometimes processing requires simplification or computation of mathematical equivalents that produce derived Models.
- Most situational and solution Models are derived.

Derived Models have different MRIDs from their source Master Models. Their business process data includes a trail of operations that led to the derivation.

Procedures and Operations

Modularization of source data minimizes data management work and maximizes data quality. A complete architecture, though, also requires the ability to automate common processes, so we need to introduce two more key concepts:

- A **Procedure** is a parameterized code set for producing what network analysis consumers need (which is usually collection of Models called an Assembly).

- An **Operation** is a formal step in a Procedure that accepts arguments such as Models, Change Models, and Assemblies and produces a Model, Change Model, or Assembly as output.

It is likely that CIM will standardize some types of Operations, but for now, the definition of Operations is left to the creativity of grid model management product designers. Many Operations should be universal enough to be routinely implemented in vendor products, but there is also a clear requirement that products allow users to install customized Operations.

One general requirement of Operations is important. Every Operation that modifies a Model, Change Model or Assembly should add a record of its action to the provenance business process data of the modified element. This **Audit Trail** should include the Operation name and the identities of the input arguments.

References

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Chapter 2 Appendix

A Distribution Use Case of Conflicting Change Models

Suppose there is a feeder with a single line segment. Its CIM modeling, as shown in Figure 46, consists of an ACLineSegment (Lseg X) and Terminals on either end of the ACLineSegment (t1 and t2) which are attached, respectively, to ConnectivityNodes (n1 and n2).

Figure 46. The present feeder segment

And now suppose there are two completely independent jobs that will each add a customer transformer at a different point along this segment and they are both requested for the same time period. The most natural way to model these would be as independent changes off the base shown in Figure 46.

Jobs A and B would be as shown in Figure 47 and Figure 48:

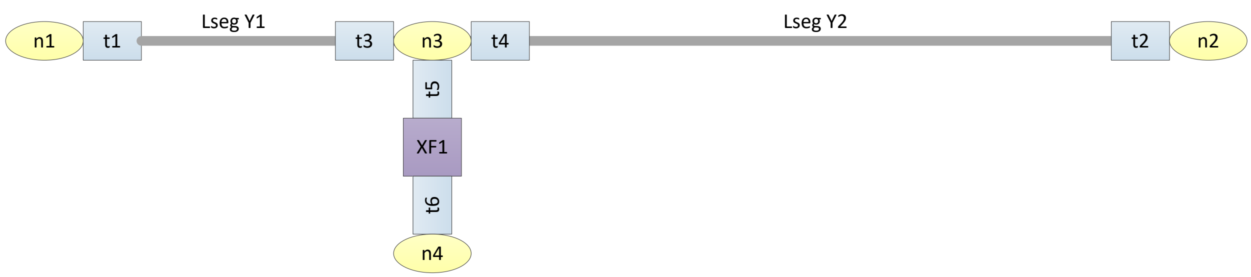


Figure 47. Job A stand-alone

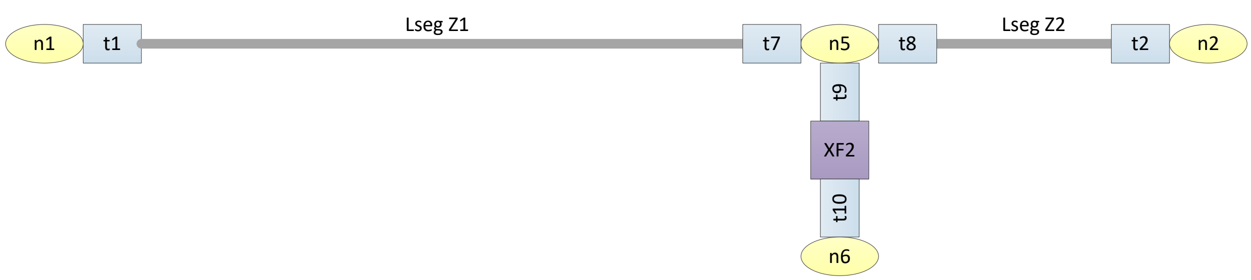


Figure 48. Job B stand-alone

The Change Models for A and B would be as follows:

Job A	Job B
Delete ACLineSegment Lseg X	Delete ACLineSegment Lseg X
Add ConnectivityNode n3	Add ConnectivityNode n5
Add ACLineSegment Lseg Y1 and Terminal t3	Add ACLineSegment Lseg Z1 and Terminal t7
Modify Terminal t1 to point to ACLineSegment Lseg Y1	Modify Terminal t1 to point to ACLineSegment Lseg Z1
Add ACLineSegment Lseg Y2 and Terminal t4	Add ACLineSegment Lseg Z2 and Terminal t8
Modify Terminal t2 to point to ACLineSegment Lseg Y2	Modify Terminal t2 to point to ACLineSegment Lseg Z2
Add ConnectivityNode n4	Add ConnectivityNode n6
Add PowerTransformer XF1 with added Terminals t5 and t6	Add PowerTransformer XF2 with added Terminals t9 and t10

These models present a quantum-like dilemma. They are both individually correct until one of them is implemented, at which point the other one is no longer valid. Either one can happen first with equal likelihood – it's up to the quantum god of work scheduling which goes first. The modeling presents a serious problem, though, if we want to be able to build future states, because the two activities are both planned but the two models cannot be used in the same future assembly.

One way to make the models work in future assemblies is to force these jobs into dependency. After all, the end state after both jobs is as shown in Figure 49, regardless of order.

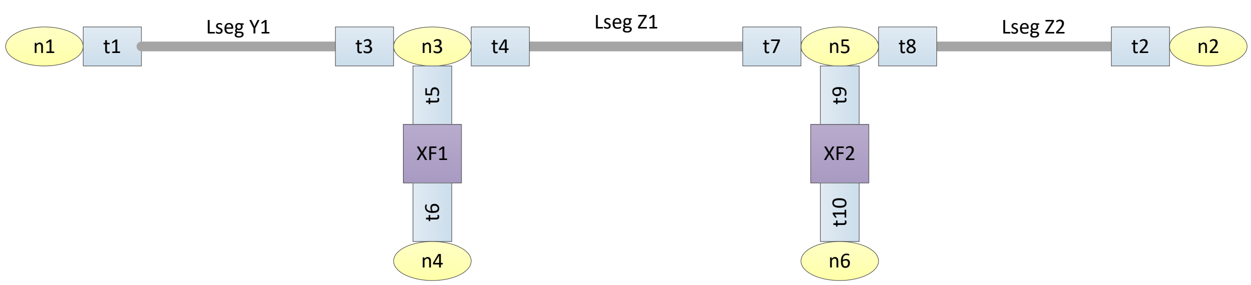


Figure 49. End state after A and B

If we make an arbitrary choice that A is first and B depends on A, then the two Change Models will look like this:

Job A	Job B
Delete ACLineSegment Lseg X	Delete ACLineSegment Lseg Y2
Add ConnectivityNode n3	Add ConnectivityNode n5
Add ACLineSegment Lseg Y1 and Terminal t3	Add ACLineSegment Lseg Z1 and Terminal t7
Modify Terminal t1 to point to ACLineSegment Lseg Y1	Modify Terminal t1 to point to ACLineSegment Lseg Z1
Add ACLineSegment Lseg Y2 and Terminal t4	Add ACLineSegment Lseg Z2 and Terminal t8
Modify Terminal t2 to point to ACLineSegment Lseg Y2	Modify Terminal t2 to point to ACLineSegment Lseg Z2
Add ConnectivityNode n4	Add ConnectivityNode n6
Add PowerTransformer XF1 with added Terminals t5 and t6	Add PowerTransformer XF2 with added Terminals t9 and t10

Now everything is fine if A goes first and everything is wrong if B goes first, but the big win in this is that the net is correct regardless of who is first, so when the Change Models are used to project forward in time, they work correctly.

This is an improvement, but it leaves us with the problem of how to recognize the need to force dependency as well as the need to repair the models when B goes first.

A better approach is to observe that there is an order-independent way to model this by adding a third preparatory change, as shown in Figure 50.

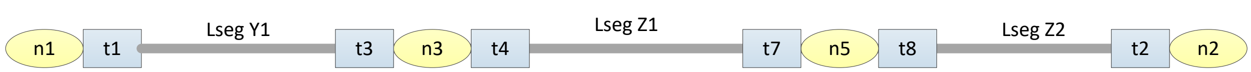


Figure 50. A preliminary change mode to prepare for A and B

The initial preparatory change can be scheduled for immediate effect because it has no impact on the electrical behavior. (Note: 'scheduled for immediate effect' means that the change will always be included in any future build.)

Once the preparatory change is made, job A and B simply add customer transformers and their order does not matter. The resulting Change Models would then be:

Initial Preparatory Change	Job A	Job B
Delete ACLineSegment Lseg X	Add ConnectivityNode n4	Add ConnectivityNode n6
Add ConnectivityNodes n3 and n5	Add PowerTransformer XF1 with added Terminals t5 and t6	Add PowerTransformer XF2 with added Terminals t9 and t10
Add ACLineSegment Lseg Y1 and Terminal t3		
Modify Terminal t1 to point to ACLineSegment Lseg Y1		
Add ACLineSegment Lseg Z1 and Terminals t4 and t7		
Modify Terminal t2 to point to ACLineSegment Lseg Y2		
Add ACLineSegment Lseg Z2 and Terminal t8		
Modify Terminal t2 to point to ACLineSegment Lseg Z2		

The problem that remains, of course, is again how to recognize the conflict and the need for the initial preparatory change if A and B are not aware of one another – and what to do if a third change comes along.

This conflict recognition problem can be eliminated if, procedurally, every job that needs to break a line segment uses a two-step process. Assume that two modelers set out independently to model jobs A and B. One of them, for example A, happens to get there first and locks other modelers out of the affected line. The definition of job A will be as pictured in Figure 47, but will use an initial preparatory Job A Prep Change Model as follows:

Job A Prep	Job A
Delete ACLineSegment Lseg X	Add ConnectivityNode n4
Add ConnectivityNode n3	Add PowerTransformer XF1 with added Terminals t5 and t6
Add ACLineSegment Lseg Y1 and Terminal t3	
Modify Terminal t1 to point to ACLineSegment Lseg Y1	
Add ACLineSegment Lseg Y2 and Terminal t4	
Modify Terminal t2 to point to ACLineSegment Lseg Y2	

As previously, the Prep A Change Model is scheduled for immediate effect so that it is picked up when job B modeling begins. Job B, after the line is unlocked, then 'sees' the Y2 line segment and works from that base as follows:

Job B Prep	Job B
Delete ACLineSegment Lseg Y2	Add ConnectivityNode n6
Add ConnectivityNode n5	Add PowerTransformer XF2 with added Terminals t9 and t10
Add ACLineSegment Lseg Z1 and Terminal t7	
Modify Terminal t4 to point to ACLineSegment Lseg Z1	
Add ACLineSegment Lseg Z2 and Terminal t8	
Modify Terminal t2 to point to ACLineSegment Lseg Z2	

The Job B Prep Change Model is also scheduled for immediate effect. The Job B Prep Change Model is noted as being dependent on the Job A Prep Change Model, so that when applied, they will be applied in order. The preparatory changes (which have no electrical impact) are thus forced into a compatible dependency while the impactful Job A and Job B Change Models are independent.

The same process works regardless of the number of potentially conflicting changes.

An obvious question is whether there are any situations other than lines that create this problem. The unique situation with lines is that they can be cut or tapped, which essentially creates a new Terminal. Other equipment does not have this problem.

Common Information Model Primer, 7th Edition

Network Model
Manager Technical Ma

CHAPTER 3 AS-IS DOCUMENTATION

Summary

This report describes Task 3: As-Is Assessment, which is a continuation of work to assist the Provincial Electricity Authority of Thailand (PEA) with establishing an information architecture, and then use that architecture to assist PEA in designing and planning the implementation of a CIM-based data management solution.

Task 2 documents the existing data management practices. The activities of this task examined which data is sourced where, how data moves from application to application; and which applications use which data. Both the data flows and business processes supported by the applications that produce, manage, or consume the data were explored and documented. The outcomes of the task are:

- Documented the “as-is” network model data management practice.
- Gained insight into problem areas, data management solution requirements, and potential solution ideas.
- Developed a shared understanding of the existing situation and data management challenges.

In Task 3, the team evaluated several different data domains and focused on the following Business Functions and Sub-Functions in the diagrams:

- **Future Energy Planning**
  - Forecasting Model
- **Grid Planning**
  - Investment Planning
  - Connection Planning
- **Design Standards Management**
  - Equipment Catalogue
  - Engineering Design
  - Transmission Design
  - Substation Design
  - Distribution Design
- **Facilities Records Management**
  - Transmission Design

  - Substation Design
  - Distribution Design
- **Grid Operations**
  - Model Configuration
  - Grid State Assessment/Correction
  - Situational Data Acquisition
  - Grid Control
  - Operation History Recording
  - Electrical Work Coloseout

These results will be utilized in Task 4: Vision Development, and the EPRI team, DigitalSiam, GridOptimize, and Strateture continue to work with PEA to develop a long-term CIM-based data management solution.

As-Is Introduction

The "As-Is" collection of diagrams captures the major information exchanges related to managing the electrical representation of the PEA grid. The diagrams serve to document existing PEA practices, provide insight on existing requirements, highlight potential areas for improvement, and perhaps most importantly a common understanding both within PEA and with the larger PEA-EPRI project team.

Each diagram focuses on a specific aspect of a PEA process that creates, manages, and/or consumes grid model data. The diagrams document the systems involved in the process and the flow of grid model data among them. The diagrams contain four primary object types:

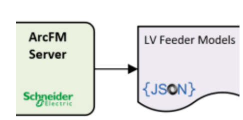
1. **Systems** (applications and tools) are shown as rounded rectangles, generally with a company logo representing the vendor; a PEA logo represents software that is maintained by PEA itself.

Example: ESRI GIS

2. **Data** are shown as document icons (rectangles with curved bottoms), with file format icon representing implementation choice.

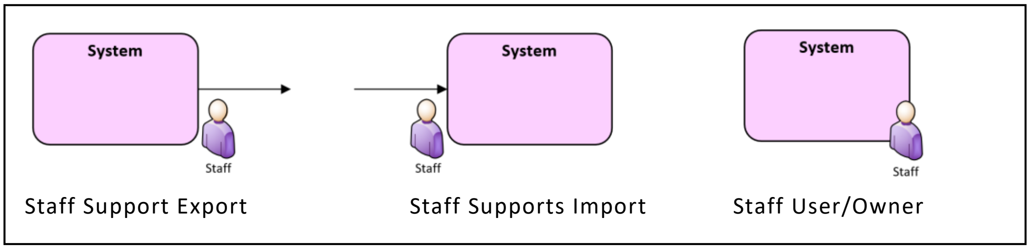
Example: Construction Redline

3. **Information Flows** are shown as arrows between Systems, as either a simple arrow when the exchange is via interfaces or with a Data icon if the information is instantiated as a file.

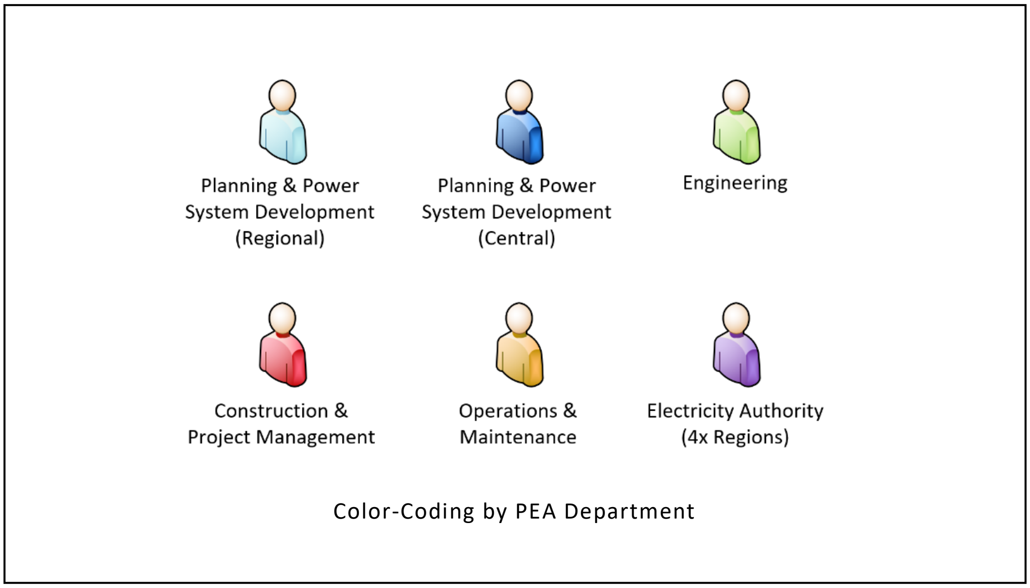


Example: Publish LV Feeder Model

4. **Staff** that assist with information flows are shown as small personnel icons. The position of the personnel icon indicates the nature of assistance: if adjacent to the 'tail' end of an arrow, the staff are supporting the creation of shared data and if at the 'head' of an arrow, the staff is supporting the use of the data. Staff overlapping System icons represent users/owners.



Staff icons are color-coded to represent the department with the group name below the icon.



Observations

PEA operates a grid with a wide range of voltages:

- Low Voltage (LV) at 230/400 V
- Medium Voltage (MV) at 22 kV and some 33 kV
- High Voltage (HV) at 115 kV and some 230 kV

The level of modeling is above average in comprehensiveness, particularly in at lower voltages where a majority of the lines are modeled including the locations of distributed energy generation.

PEA operates a grid which covers a wide geographic area, splitting the management of grid model data into twelve sub-systems. As we shall see, this makes the management of the LV and MV portions of the grid easier, but perhaps more challenging for HV management and for the potential sharing of complete models with neighboring utilities.

The following table illustrates how models are maintained within PEA across different voltages on the vertical axis and across different business units or applications across the horizontal axis. Each box in the table identifies the primary system used to model the grid and how models are partitioned, either as a single PEA-wide model, as models split into each of the twelve areas, or as models created for each localized feeder.

<table>
<tr><th></th><th>GIS</th><th>Planning</th><th>SCADA / DMS</th><th>Outage Management</th></tr>
<tr><th>HV</th><td rowspan="3">ESRI
Model-Per-Area</td><td>DigSILENT
Model-Per-Area</td><td rowspan="2">PSI
Schneider
Model-Per-Area</td><td rowspan="2">eRespond
Single Model</td></tr>
<tr><th>MV</th><td>DigSILENT
Model-Per-Feeder</td></tr>
<tr><th>LV</th><td>OPSA
Model-Per-Feeder</td><td></td><td></td></tr>
</table>

Legend

(orange)	*Model is manually maintained in specific system*
(green)	*Model is derived (at least primarily) from another system*

Observations deduced from this table are:

- **Single MV/LV Modeling.** MV and LV modelling uses a relatively mature technique with a single system (GIS) sourcing models for multiple other business domains.
- **Multiple HV Models.** HV is modeled in two systems independently (GIS and DigSILENT). This indicates some level of duplication of effort and can in some cases lead to divergent models.
- **Partitioned HV Models.** The model for the HV grid elements, which are primarily networked rather than radial, are modeled on a per-area basis in the GIS, in planning tools, and in SCADA/DMS applications. This can (or in the future may) hinder any analysis which would require a broader view of the grid.
- **Planning Voltage Boundaries.** Artificial boundaries are introduced between HV and MV and between MV and LV in the Planning domain. The industry is trending towards removing modelling boundaries between voltage levels. This enables more comprehensive study approaches.

Observations drawn from the diagrams include:

GIS Focus. It is common for distribution utilities to rely heavily on the GIS as a core tool for tracking grid models. PEA appears to be slightly more invested in this option than is typical, with advantages and disadvantages to the approach. On the positive side, much of the data is centrally located, as compared with other utilities who must leverage a GIS with multiple supporting databases. However, since no GIS available on the market today is optimally suited for grid model management, this may not be the best approach in the long-term as the electrical modeling will require more sophistication.

Projects. Projects represent known future changes to the grid model, from small updates to large grid reinforcements. These “anticipated” models are currently stored locally as planned projects in different DIgSILENT schemas or as designs in the various engineering design tools. Models do not become available to the enterprise until the new equipment is energized, updates are made to the GIS model, and those changes are propagated out to other systems. It appears that the current scheme of having the GIS track the as-built without models of near-term future changes also means that short-term analyses, such as validating switching orders or studying planned outages, are not possible or involve a manual process.

EGAT & MEA Modeling. If not already an issue, it is probable that future studies will need more accurate representations of the EGAT model, and perhaps some of the MEA model as well. Certain DIgSILENT models in the planning area likely have equivalent EGAT models, but it is unclear if these models are accurate supported by a standardized, periodic process for updating the models or updated informally.

Some additional, less impactful, observations include:

(HV/MV) Tracking Grid Measurement History. Currently, the GIS is used to track history of the grid with 15-minute snapshots. More commonly a data historian directly on the operational systems (SCADA, DMS, etc.) are used to track changes in state. This method will miss changes on a faster timescale but has the important advantage of tracking measurements and states linked to the grid model.

(HV) GIS Pseudo-Modeling. The use of pseudo-modeling (utilizing circuit breakers to split portions where no physical breaker exists) is not recommended.

(HV/MV) GIS Modeling Consistency. The level of modeling for substations varies by Area GIS, with some systems modeling connectivity within the substation and others with simply a symbol representing the substation.

(HV/MV/LV) Publication Database Processing. The process of creating the Publication Database model from the twelve Area GIS models is highly manual. This process is perhaps made more difficult because of "GIS Pseudo-Modeling" and/or "GIS Modeling Consistency" challenges.

(HV/MV/LV) Enterprise-Wide Equipment Database. The "PEA Main Library" has been established as a single-source for equipment parameters for PEA; however, not all groups leverage this repository.

Chapter 3 Appendix: Diagrams

Diagram 1. GIS

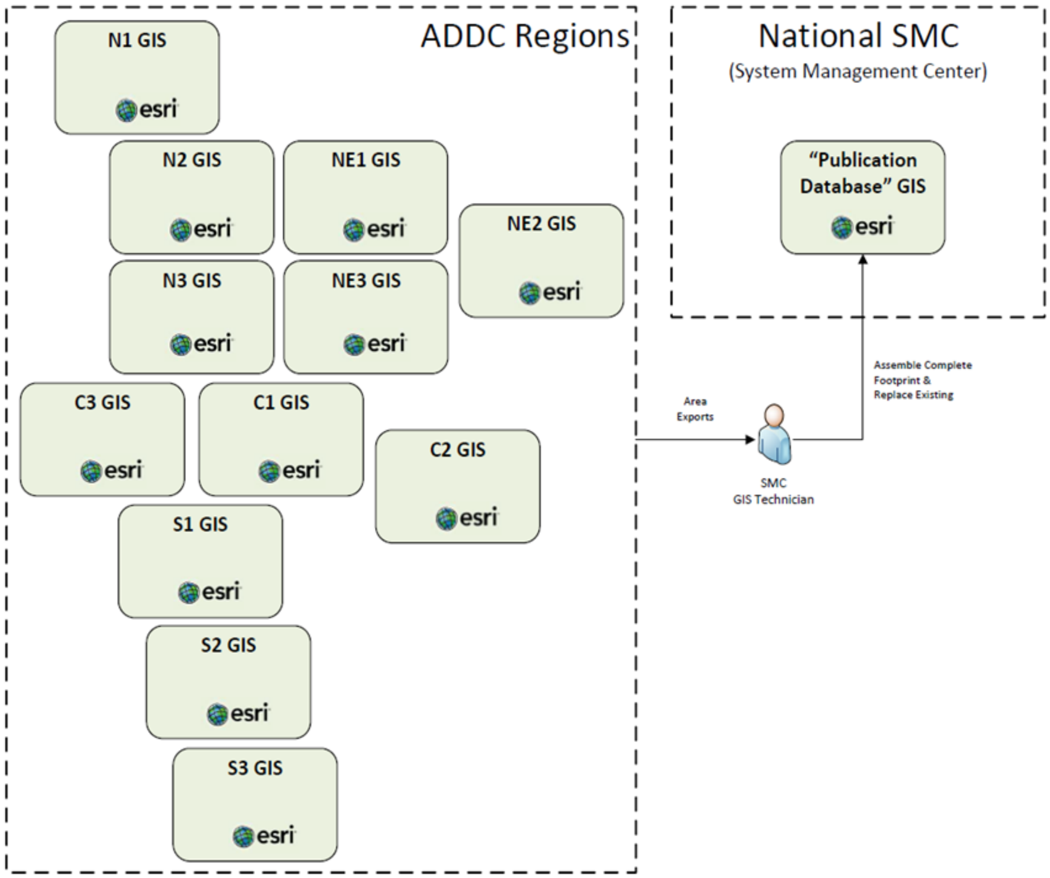


Diagram 2. Load Analysis

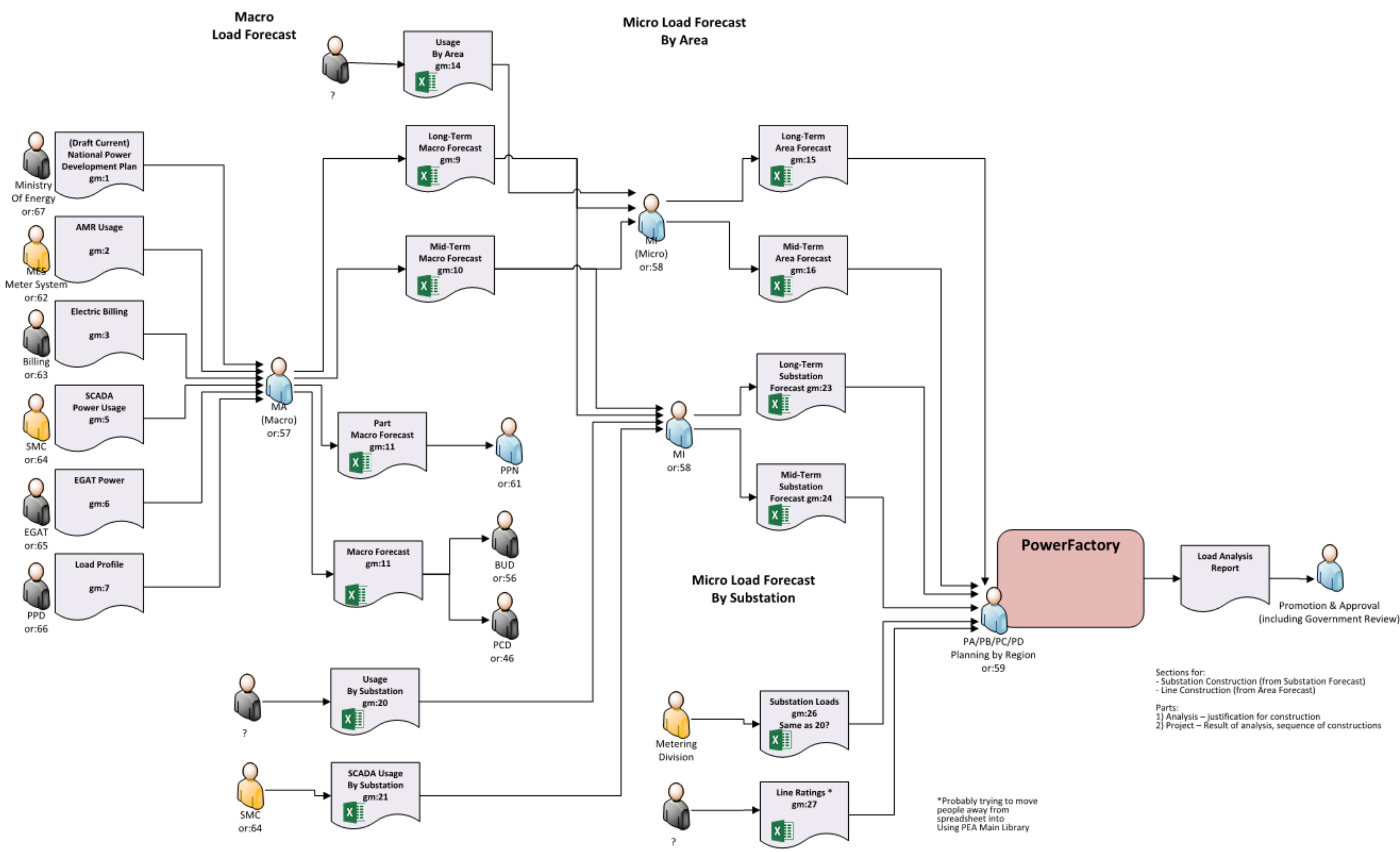


Diagram 3. Planning

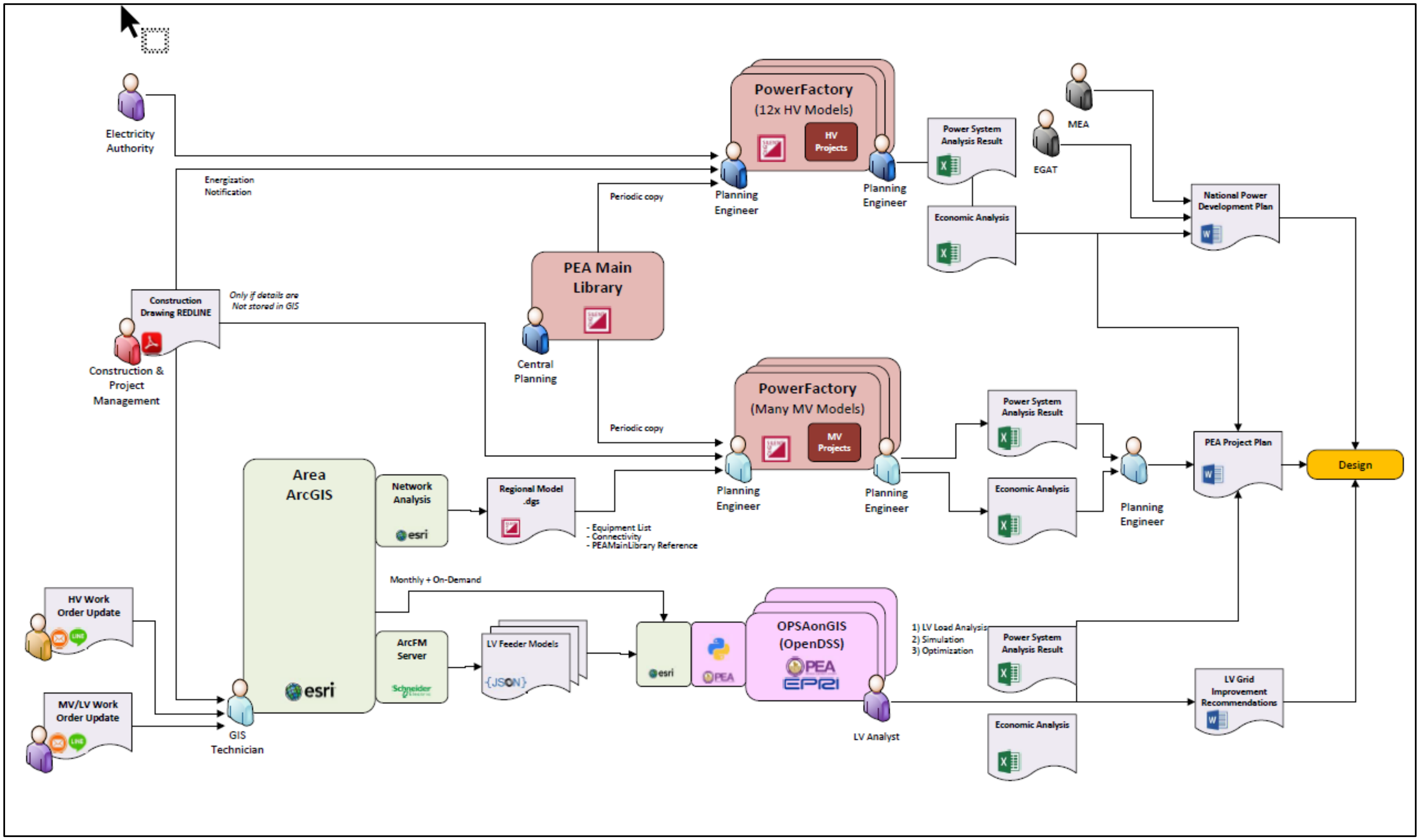


Diagram 4. Design Build

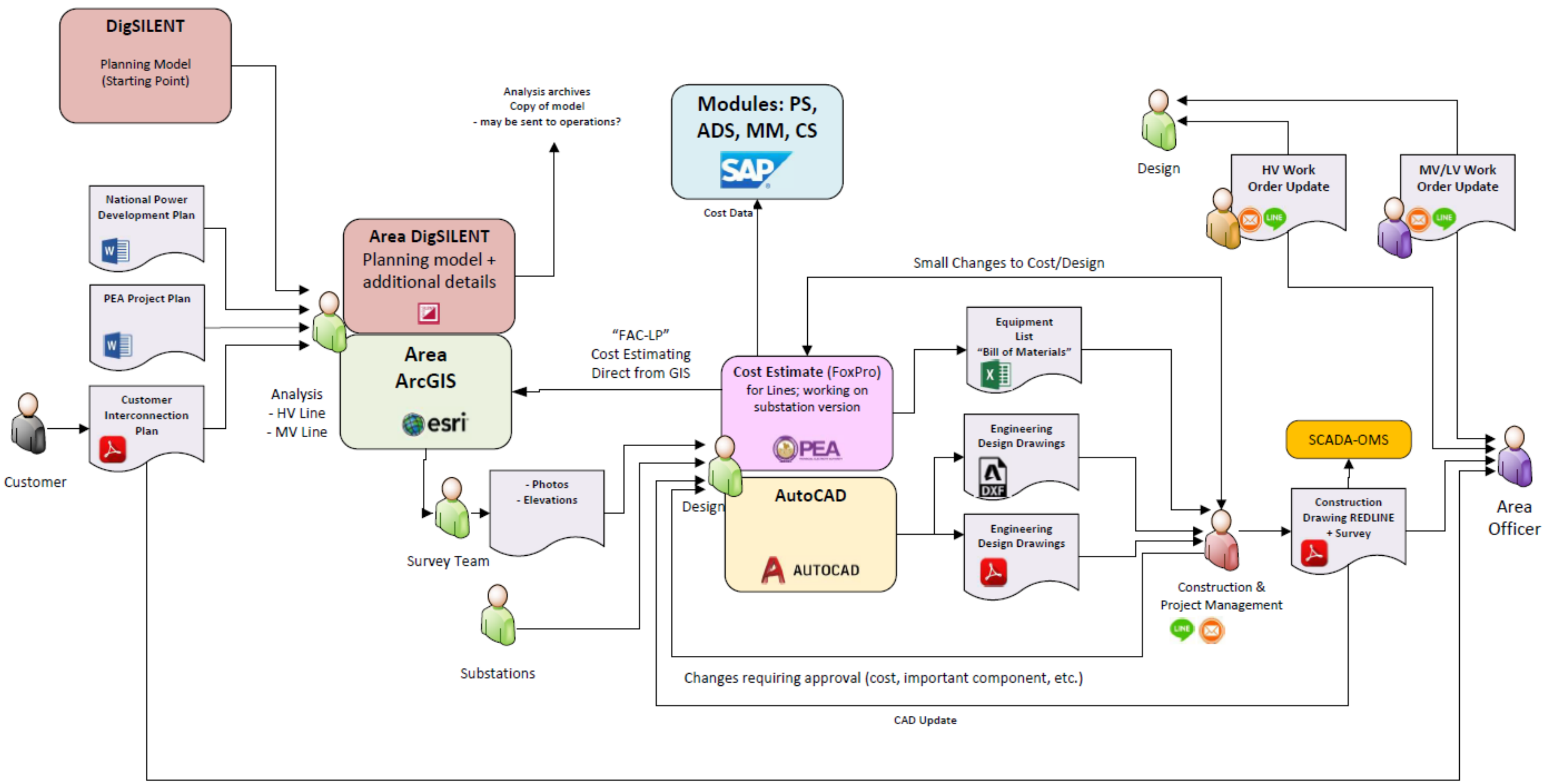
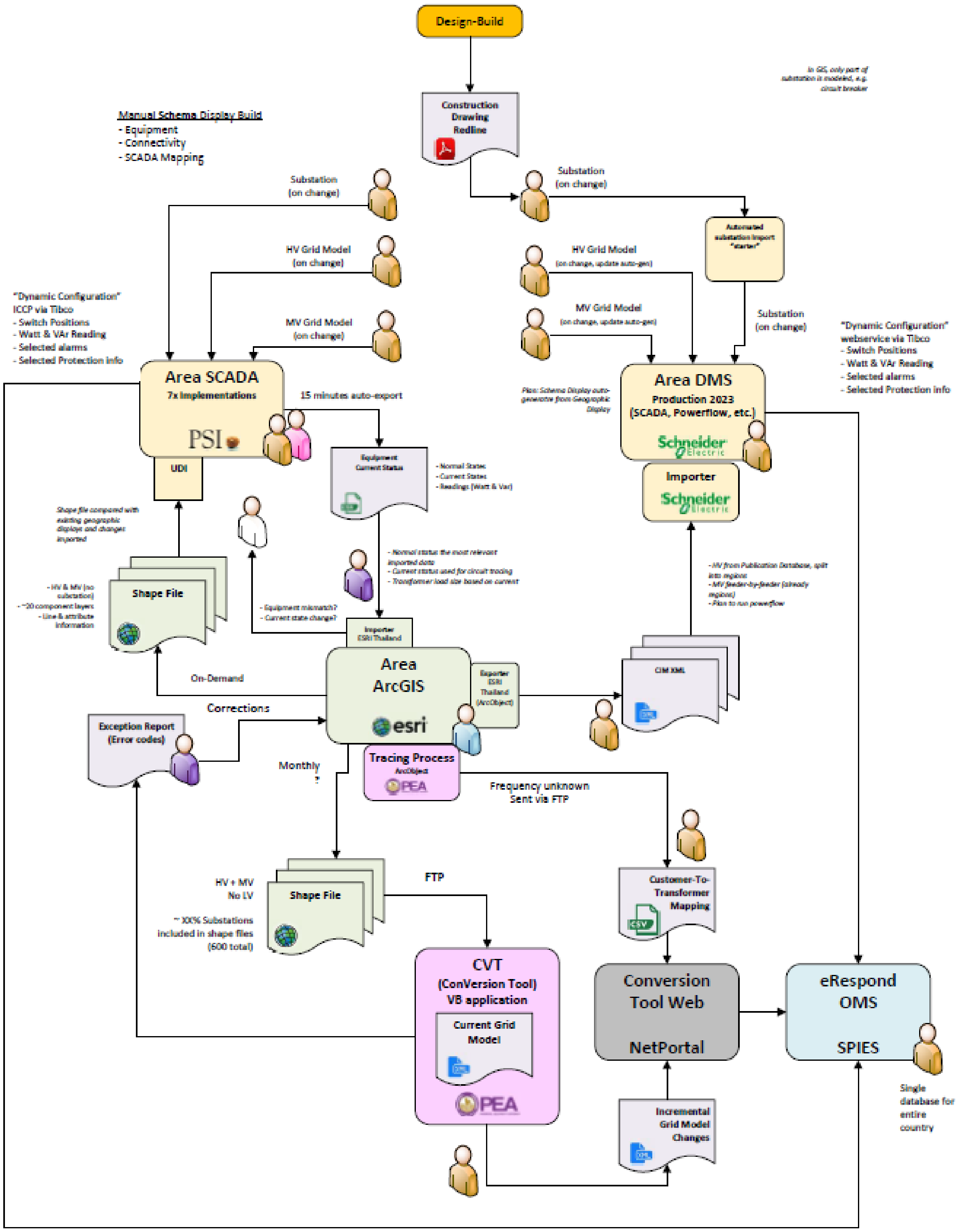


Diagram 5. CADA & OMS



CHAPTER 4 VISION DEVELOPMENT

Summary

Task 4 is a continuation of the work to assist PEA in establishing an information architecture and then, using the architecture, to assist PEA in designing and planning the implementation of a CIM-based data management vision.

Task 4 develops the long-range vision by utilizing the previously developed architecture of Task 2 and building use cases which would replace the existing data management practices. The outcomes of the task are:

- Develop a long-range vision for CIM-based data management.
- Document high-level application and integration requirements.
- Build use-cases based on the architecture outlines in Task 2.
- Document case studies of other successful electric utility CIM implementations.
- Identify and document process efficiencies and operational benefits, as well as potential risks.
- Multi-day visit to PEA in Bangkok, Thailand.

These results will be utilized in Task 5: Conceptual Sequencing of System Design & Implementation as the EPRI team, DigitalSiam, GridOptimize, and Britton Consulting continue to work with PEA to develop a long-term CIM-based data management solution.

CIM Based Data Management: Long Range Vision

The 10-Year PEA GMM Vision aligns with the GMM Architecture with tools implemented to support GMM functions acting as the single source-of-truth for Grid Models. The direct implication is that any analytic function across the PEA enterprise which requires a Grid Model to perform any analytical function will rely on the GMM as its key data source. Data is expected to be accurate and reliable within the GMM and updates are expected to appear in the GMM as soon as is practicable. Not only will the GMM solution be for the As-Built Grid Model system-of-record but also for historical versions of Grid Models.

The GMM will be equipped with many different processing features which can modify Grid Models based on user requirements. The GMM must maintain a library of Project definitions which allow users to construct future Grid Models for various future projections and scenarios. Major changes that occur on the grid when Projects are energized should be published quickly to all consumers, leveraging a coupling between GMM and Operations.

The GMM will also supply and variety of scenarios data sets which can be used as starting points for analyses. Scenarios include snapshots of important event, such a peak load and minimum generation events. Scenario data sets can also include equipment settings, for example switching for planned outages or switching that is planned balance substation seasonal loads.

To attain the 10-Year PEA GMM Vision, there are two major areas of development to consider. The first area is the **Functions** that the GMM solution will need to be capable of performing. See Appendix A. Some requirements are deemed essential while others may or may not be needed at PEA. In Task 5, the team will evaluate the optional features and decide which ones may need to be added to the list of essential functions in the 10-Year Vision.

The second area to consider is the development of GMM **Interfaces**. Some systems will supply Grid Models and Change Models to the GMM. Others will rely upon the specialized Grid Models and Change Models that the GMM will supply to help PEA staff complete their activities. It will not be uncommon for any given application to act in both a supplier and consumer mode.

Application and Integration Requirements

Grid Model Manager Functions

Several vendors have already released grid modelling solutions in the transmission domain. Some of these vendors as well as new vendors have been positioning their tools to meet future GMM requirements for the distribution domain. While EPRI does not endorse any single vendor, our team can provide a list of vendors we understand have tools that may meet many of the core GMM Requirements.

- ABB, Sweden & Switzerland
- Bentley Systems Incorporated, USA[1]
- General Electric (GE) Company, USA
- Intelligent Process Solutions (IPS) GmbH, Germany[1]
- Open Grid Systems, United Kingdom[1]
- Open Systems International (OSI), Inc., USA
- Oracle Corporation, USA[1]
- Schneider Electric, France
- Siemens AG, Germany

[1] Vendor participated in the GMM interoperability event hosted by EPRI and facilitated by the UCAIug in June 2022.

Acquiring a GMM product with core features as soon as possible will make subsequent tasks easier to complete successfully. Short-term success should be balanced with the best chance for long-term goals. Thus, finding a long-term partner that PEA is confident will track with PEA's future requirements should be a key decision factor.

Grid Model Interfaces

The application landscape ten years into the PEA's future is uncertain; however, it is safe to assume that some major platforms will persist – especially those that are deeply embedded in the PEA infrastructure and those that have been recently or will soon be deployed. New applications will appear in the next decade – supplying support to functions that PEA performs manually and where tools have reached their natural upgrade cycle and will likely be reviewed against the current competition. The following sections discuss application integration impacts, making some assumptions about which tools will persist and which are more likely to be new installations. New installations should be coordinated with GMM integration, whereas existing tools will need to be retrofit into the GMM at a logical point; both of these ideas will be explored in more detail in Task 5.

Planning

Within the Planning division, several tools are currently in use for interconnection and grid enhancement planning, namely DIgSILENT's PowerFactory for HV and MV analyses and OPSAonGIS (built on EPRI's OpenDSS) for LV analyses. The GMM Vision enables several things not present today:

- A single source for Planning Grid Models
- The ability to look "across" voltages
- Grid Models with more detailed substation information
- Grid Models with more accurate EGAT and MEA representations
- A Common format enabling easier introduction of new tools

In addition to these goals for consistent As-Built Grid Model analyses, the GMM vision will establish a library of centrally-managed Projects that can be used to create more consistent future Grid Model representations, regardless of tool or voltage. A subset of Projects, for example those which are published in National Power Development Plan or in the PEA Project Plan, will be supplied to the GMM for use by other GMM consumers. This will elevate some of the Planning tools to also be sources for Project definitions.

Engineering Design

In the GMM Vision, Engineering Design plays a key role in the production of new Grid Model data. Today, design is performed in AutoCAD and/or using tools leveraging the ArcGIS data platform. In the future, these tools will provide updates to the GMM whenever new elements are designed and when elements change based on construction and maintenance operations. The GMM may have automated links to these tools (and any newly acquired tools in the Engineering Design realm) so that any change to the grid can be captured promptly and accurately.

Depending on the vendor's GMM capabilities, tools may either supply Change Models that are directly useable by the GMM to update Grid Models or tools may supply updated design fragments which the GMM will use to generate its own internal Change Models. The vision does not anticipate a need for Engineering Design tools to consume Grid Models, but the option is always available should the need manifest.

Construction & Maintenance

Activities in the field – be they planned or unplanned – will have an impact on the Grid Models in GMM. Like Engineering Design, the tools employed for this business function will need to be linked to the GMM to provide updates when they are relevant. Perhaps even more than Engineering Design, mobile workforce enablement technologies are rapidly advancing so that application changes in the Construction & Maintenance business function are likely to appear in greater numbers. This means that there will likely be many more mechanisms to capture changes in the field, implying a larger role for the Enterprise Architecture team to determine optimal integration patterns. In general, these tools should fall into one of two group: (a) tools that communicate directly with the GMM and (b) tools which are better suited to indirect communications, for example via the GIS or through the soon-to-be procured and implemented Asset Management solution. Like Engineering Design, Construction & Maintenance is not anticipated to require Grid Models as a core input, but the option is available here too.

Grid Operations Planning & Grid Operations

The GMM Vision includes a sophisticated relationship between GMM and Operations. On the one hand, GMM will supply the Operations tools with a reliable Grid Model along with Project definitions which are scheduled for energization in the short-term. On the other hand, Operations will also supply GMM with updates to the model, including status changes to equipment with recently energized Projects as well as corrections to the Grid Model which are found during routine operations, both in real-time and during off-line analyses.

PEA is currently implementing the "SCADA Phase 3" project which includes as the primary Operations tool the Schneider ADMS product. In the near team, the ADMS will rely on a Grid Model that is assembled via software developed and deployed by PEA and its integration partners. The base Grid Model must be supplemented by manually entered details not available in the ArcGIS platform, primarily related to details within the substation boundaries. In the GMM Vision, this collection of interface software and manual processes will be discarded in lieu of a fully-automated, and therefore more complete and more reliable, Grid Model assembled by the GMM.[2]

[2] If the GMM Vision is adopted at PEA, serious consideration should be given to ceasing work on the CIM-based ESRI-to-Schneider software development as this interface would not be utilized in the GMM Vision. Assuming a proprietary interface between ESRI and Schneider is available, this would represent potentially better alternative to the CIM-based interface, with CIM-compliant interfaces being adopted after (a) a GMM is

Grid Operations Planning is responsible for the scheduling of Planned Outages for maintenance and construction. Assuming this function is supported by an secondary instance of the ADMS running against the same Grid Model as the on-line instance, for example the QA environment, there is no new requirement for interface development. However, since some Planned Outages will need to be considered by other areas of the PEA business, the Operations Planning instance of the Schneider ADMS will need to be able to publish Planned Outages to the GMM so that other Grid Model consumers can consider these data in their analyses.

Unplanned outages are today managed by a separate application called eRespond. Probably nearing the end-of-life, eRespond will either be upgraded or replaced with another product within the next ten years. The GMM Vision assumes that the new or upgraded system will more tightly coupled to the Schneider ADMS, thereby requiring no dedicated connection between GMM and Outage Management.

Energy Projection

The most recent addition to the GMM Architecture is the Energy Projection business function which focuses on the rapidly evolving areas of forecasting resources on the grid, including load, generation, and storage. Load forecasting is a long-standing activity at every utility that is becoming more difficult as demand curves become less conforming to traditional shapes as more demand response programs are deployed and more customers have flexible demand which can change based on time-differentiated electricity rates. Pure generation – that is generally larger sized generation without co-located load – is also becoming more important to distribution utilities, as the grid interconnections are shifting from higher voltages to lower ones. Moreover, most new generation have renewable energy sources which are both non-dispatchable and highly dependent on both short-term weather forecasts and longer-scale seasonal and climate variations. Finally, the effects from storage come in many variations as well, from utility-controlled to customer-controlled installations and from stationary systems to mobile systems in the form of customer owned and fleet-based electric transportation.

Utilities are expected to require many new tools to support a wide variety of these challenges. In terms of GMM interaction, it is expected that many of these tools will need some level of Grid Model to perform their functions, making them a new group of Grid Model consumers. The results of these tools – alone or more likely combined – will form the basis of different future energy scenarios available through the GMM. Hence, these tools are also expected to be new source Grid Model data.

Use Case Development

Use cases describe either a business perspective or a system perspective. We are focused on the business perspective. A business use case describes "a sequence of actions performed in a business that produces a result of observable value to an individual actor of the business".

installed at PEA and (b) the vendors have commercial CIM interfaces which can be implemented and maintained a substantially lower cost and presumably lower risk of introducing errors.

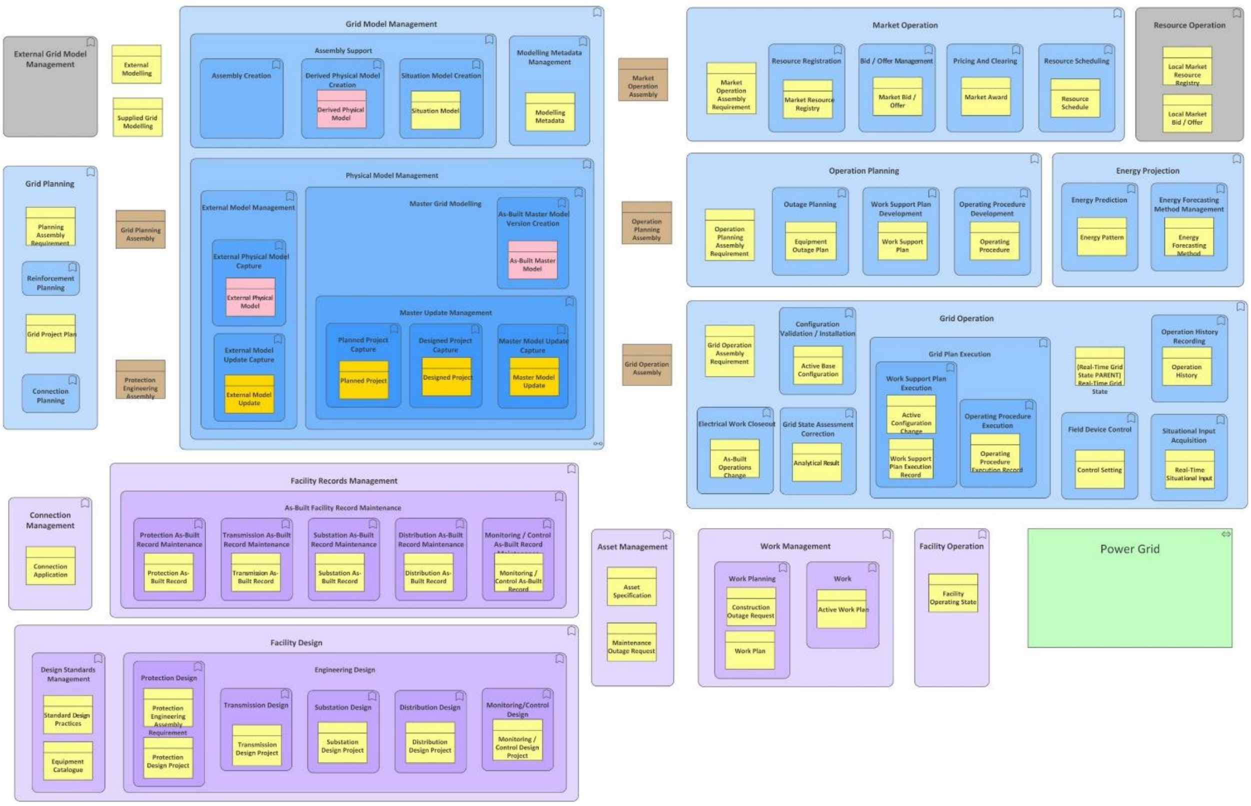
Process flows are a diagrammatic representation of the business processes involved in fulfilling a use case.

The use cases presented in this document represent an As-Is view of various PEA processes related to grid model management (GMM). They will be used to identify GMM functions that are not currently in place at PEA as well as those business functions which are in place and what applications they are served by. This will provide the identification of business functions which are currently supported manually or business functions that are served by multiple, possibly redundant applications. Additionally, this will provide input into the identification of integration requirements relative to the applications.

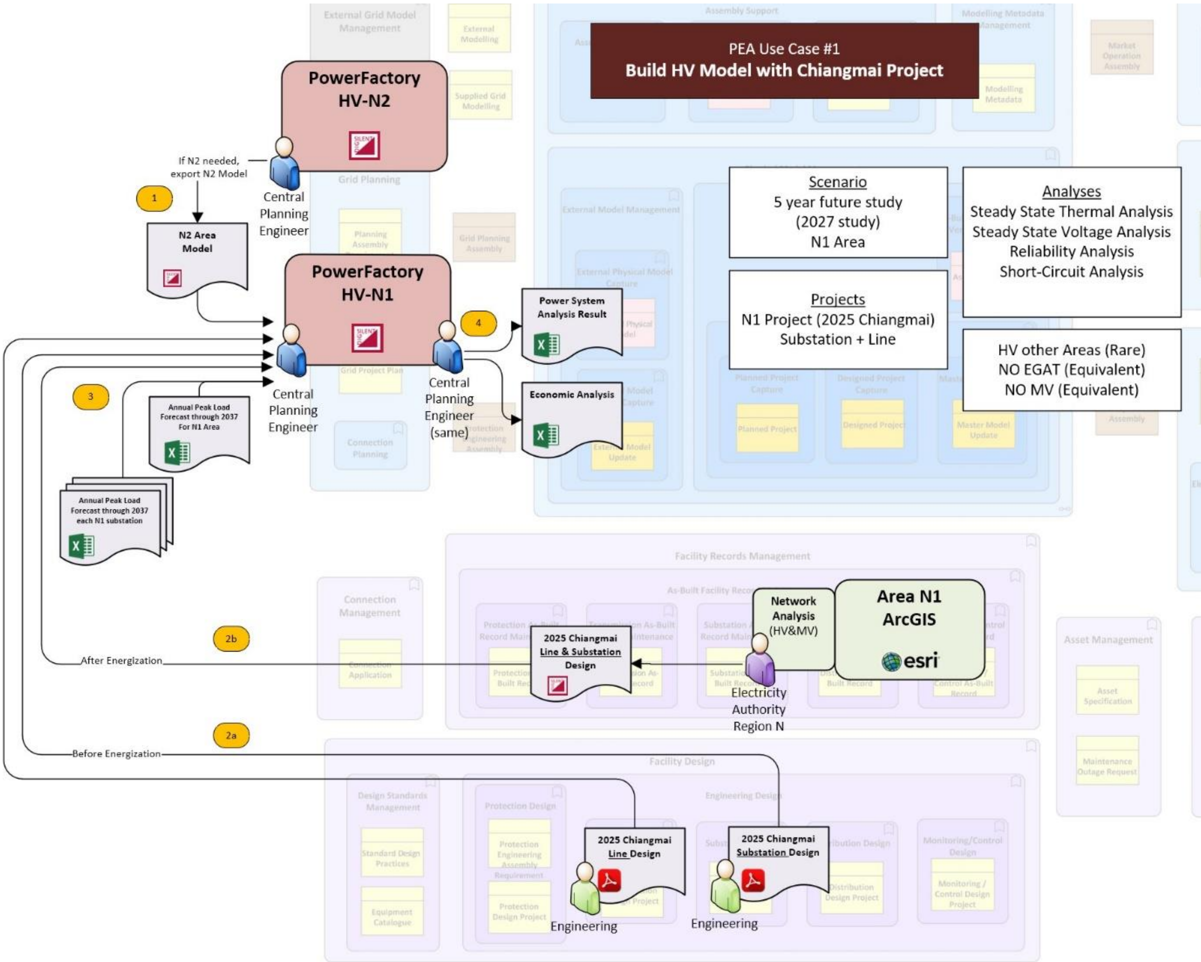
To better assess the current state at PEA with respect to mapping to the GMM business functions, several of the use cases were diagrammed within the Sparx Enterprise Architect tool using the GMM business function architecture. This provides a view of both the relationships among processes in the use cases to the business functions and the current application associations to those business functions. This allows an evaluation of (a) business functions which are not currently fully served at PEA and (b) business functions which are served by multiple processes, typically in different organizations. Additionally, this provides a view of business functions which are not currently served by applications, in other words are manual processes, and those that are served by multiple applications. These Sparx diagrams are in Appendix B.

Use Cases

GMM Functions and Objects



Use Case 1 - Build HV Model With Chiangmai Project



Use case #1 shows the grid model information flow in the case of 115kV high voltage transmission and substation planning. It is necessary as part of a feasibility study for PEA substation and transmission line development project. The diagram illustrates the case for a project in the N1 area.

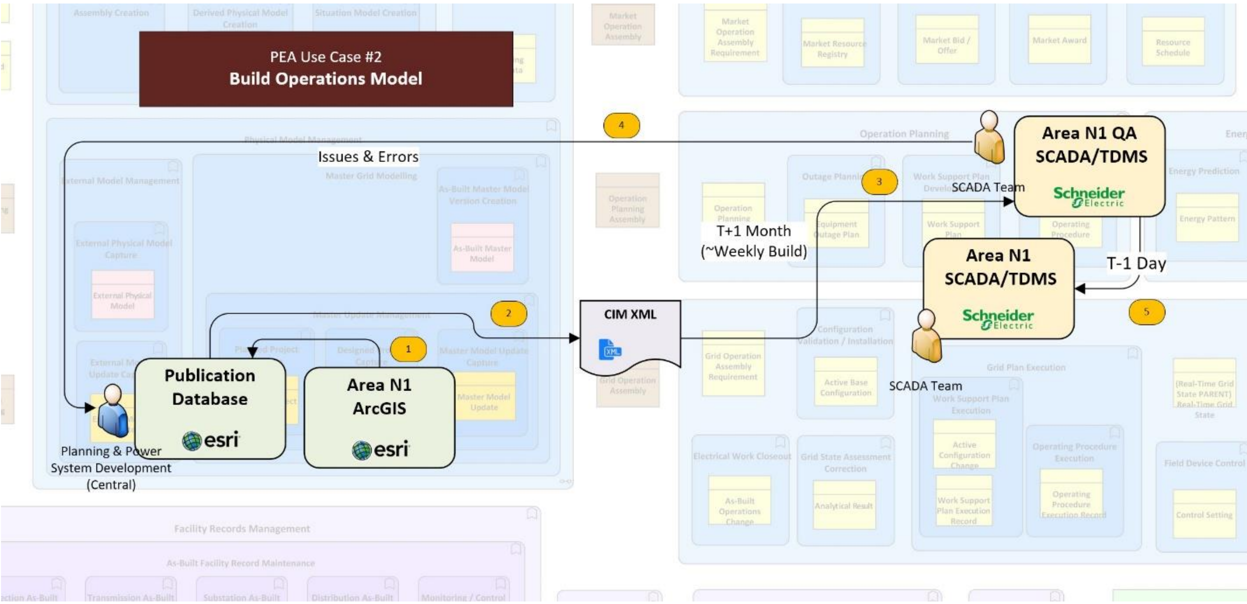
Starting from the box diagram in the middle called 'Power Factory HV N1' which is the grid model of 115kV system in the N1 area, we make the model in DigSILENT, our power grid analysis software. To do the accurate analysis, we need to collect complete network model information. In case that there is a connection across area, for example area N1 connecting with area N2, the grid model of area N2 is also required to complete the N1 model. This is shown in step 1.

First, we need the existing network which has been energized then we also need the future planned network including transmission line in the already approved plan. Not only that but also included are the network in design process and the network under construction and may be in the tendering process as shown in flow 2A in the diagram. However, the constructed as-built model may not necessarily be completely the same as designed nor as planned. For example, the substation location may change. Therefore, we may need to modify the grid model to be consistent with what is really energized, in the diagram this is illustrated by 2A and 2B. This the second process.

In the third process the load forecast of each related substation has to be input into the analyzed model. This includes the load forecast from substation in the area (N1 in this case), other connecting substations in other areas (may be N2 in this case), and load forecast of the big customers who consumes 115kV directly.

After that when input 1,2 and 3 are well prepared, we will be able to run the analysis simulation using DigSILENT to check thermal analysis to determine which equipment we have planned is overloaded and check if the voltage level has error within acceptable standard. Some projects which aim to enhance the stability, not to enhance the capacity, by checking short circuit analysis, the analysis result will indicate problem points for examples overload or voltage is not in acceptable standard range. If problems are found, we need to reconsider the proposed solution scenario choices and repeat similar analysis process again then we will have a grid model for each solution. After that we will do economic analysis to choose the best solution and use it to propose as feasibility study candidates.

Use Case 2 - Build Operations Model



This is one of the more Grid model management focused use cases. It's all about building the operations model used in the SCADA TDMS system.

So, this process is repeated as the network evolves.

The first step in this process is in area number one, and this represents the update of area related GIS information in this case the N1 example area and that is moved into the publication database.

And because we are analyzing the near future state, so we want to capture what the current set of projects will be running in the near future.

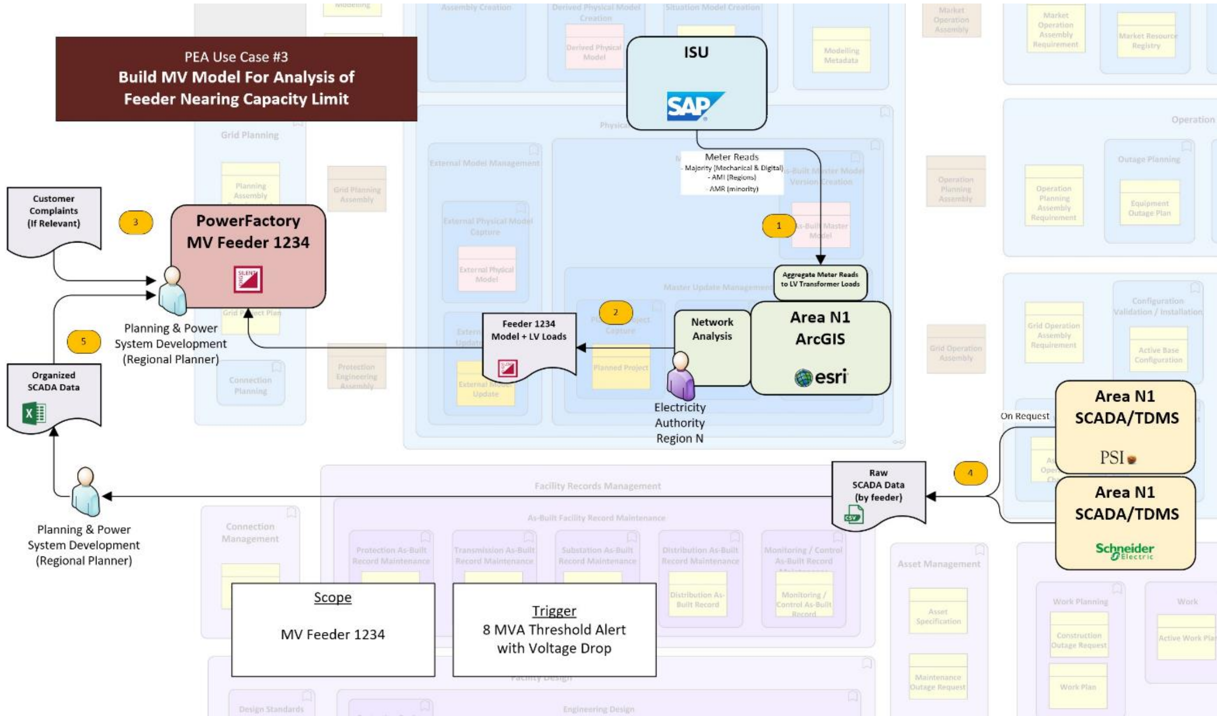
There is the project of course that everyone is aware of now for the new SCADA system. And here we're capturing the publication of a CIM XML, which is a specific format in XML, that is generated out of the publication database or will be generated out of the publication database.

Arrow number three represents the importing of the CIM XML file. The current plan is to do this approximately once every week and the CIM XML file will include changes that will be occurring to the grid roughly within the next month. What's really important to notice about this flow is it's one of the few arrows that we've seen today that is a system to system transfer. There's no team icon on the arrow lines meaning this should be, when it's completed, a fully automated transfer of information.

Arrow number four represents the results of a really important process. As that new model is brought into the new SCADA TDMS Schneider system, the QA environment, the SCADA team will be doing a number of tests to make sure that that model is correct. It'll be running power flow analysis and different kinds of test cases to make sure the model is good. And this serves two purposes. One, of course is to make sure the model is ready for operations to run the grid and energize those new changes. But it also serves a very important grid model management function. And that is the QA process is vetting and is probably the most thorough vetting of the model. And any problems that are found are then sent back to the central planning group who can identify where those problems occurred in the GIS system so they can be resolved. And the grid model is accurate for all the consumers from that point forward.

And finally, step five. If you talk to someone in the operations staff, they'll tell you this is the most important point when you get that new model into the production Operations Control Center. From a grid model management perspective, the hard work is already done because the model has now been validated in the QA system. This represents, if the process works well, a seamless promotion of a well validated model into operations for smooth execution in real time.

Use Case 3 - Build MV Model For Analysis of Feeder Nearing Capacity Limit



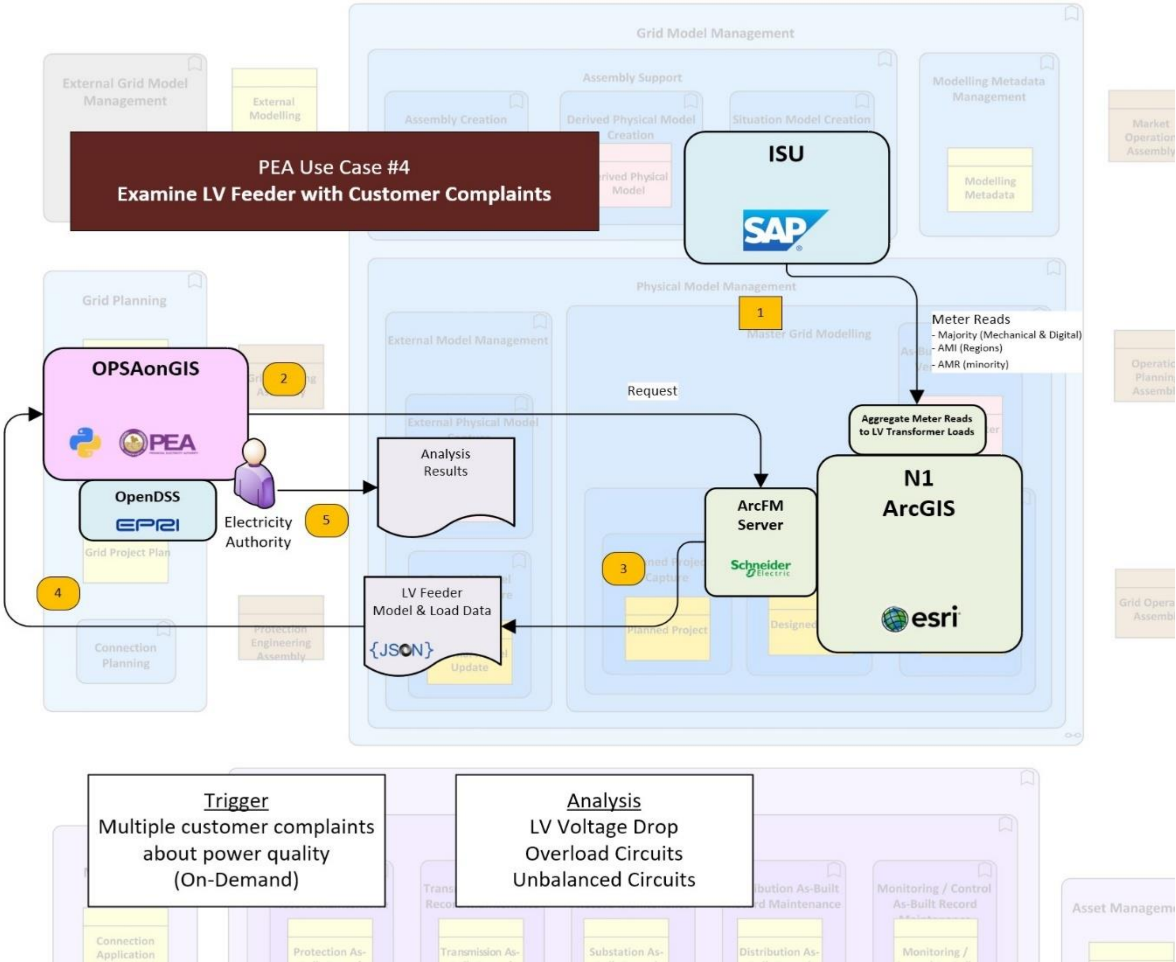
Use Case 3 is about MV system analysis using an example case of area N1. We choose Feeder '1234' as an example to illustrate how we do the job. In this scenario, the trigger is the consuming power is about to exceed the capacity of 8 MVA and seems to have voltage drop problem.

Starting from step 1, the meter reading data is collected to the ISU in SAP and will be used as input to the process. Those meter reading information include data from mechanical rotating disk meters, AMR meter, AMI meter, all of them. After all the meter reading data is collected to the SAP Industry Specific Solution for Utilities Industry (SAP-ISU) then the data will be imported into each individual GIS of the 12 areas. In each GIS system there is a module call 'Network Analysis' which exports the data. The analyst or the planner at the regional area will use the module to export data as illustrated in step 2. In this scenario, he/she will export the information of feeder '1234' together with low voltage consumption from ISU mentioned earlier.

Then we import the exported data into DigSILENT to perform power analysis. Moreover, in step 3, not only the information of grid model and consumption from the feeder, but we also take into account the customers' complaints or voltage drop area. Then in step 4, we also collect information from SCADA measurement including all phases of SCADA systems. (Phase two SCADA is from PSI, Phase Three SCADA is from Schneider.)

The data is in CSV text format. Then the planner will use the CSV text file to transform to a format which can be imported into DigSILENT. Then they will use the tool to analyze the system and solve the problems. The result of analysis may include distribution changes recommendations, adding feeders or even building new substation depending on the area situations.

Use Case 4 – Examine LV Feeder With Customer Complaints

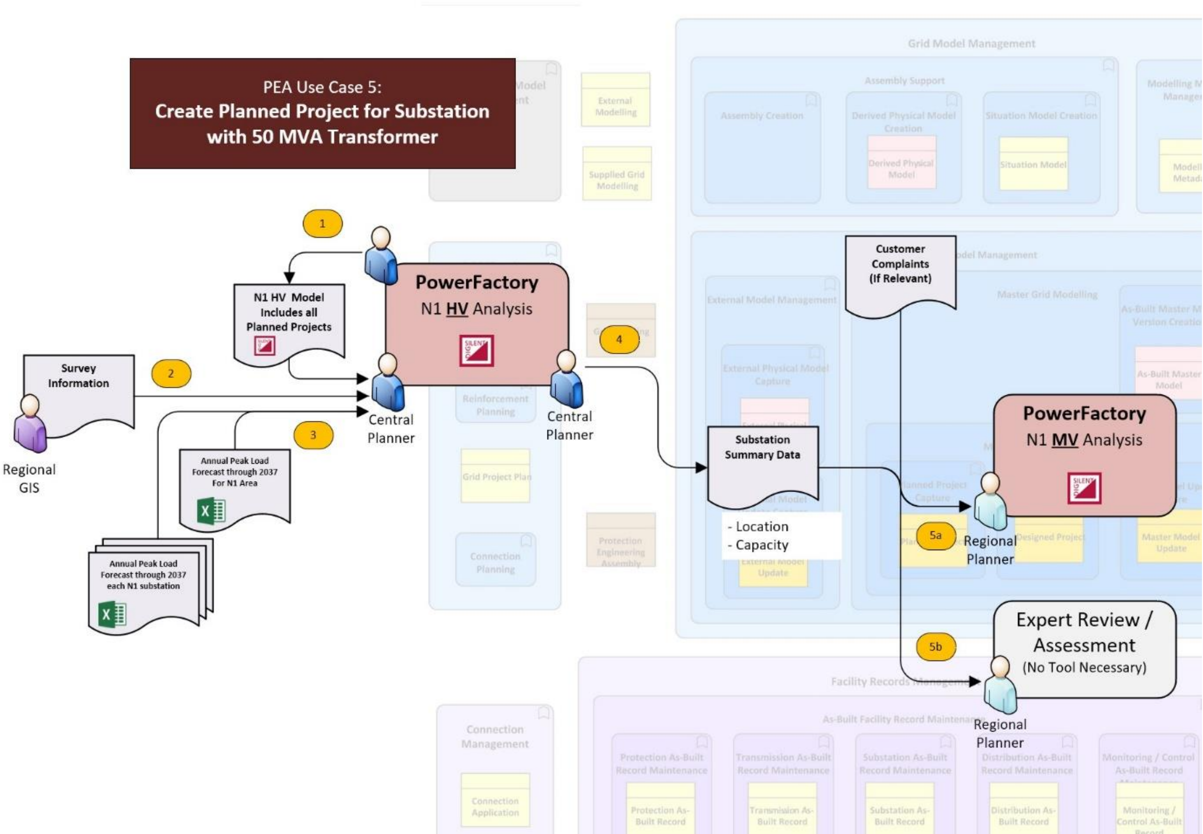


Use Case #4 is about low voltage analysis. This analysis task is triggered by customers' complaints. The complaints include voltage drop or blinking. The flow starts with step one loading meter reading from ISU similar to the case of medium voltage. This case assumes the N1 area so it involves the N1 GIS system. ArcFM GIS-subsystem server is used for doing this part.

In step 2, we have in-house developed software called 'OPSAonGIS' which sits on top of the network analysis software 'OpenDSS' developed by EPRI. In step 2, a request for transformers' load data will be sent to ArcFM. The ArcFM will trace the network under those transformers down to meters then integrate with the exported meter reading data from ISU system to estimate the load on the transformers.

In step 3, the load data will be exported in JSON format. The data includes LV feeder model and the load. After obtaining the data, it will be sent as illustrated in step 4. OPSAonGIS will use the data as input to the DSS to analyze load flow to calculate unbalance state, overload state and then store the analyzed result in the database which can be visualized on OPSA dashboard. The result displayed on the dashboard can also be exported into Excel files. The Excel file can be used in planning and other problem solving tasks as illustrated in step 5.

Use Case 5 – Create Planned Project For Substation With 50 MVA Transformer



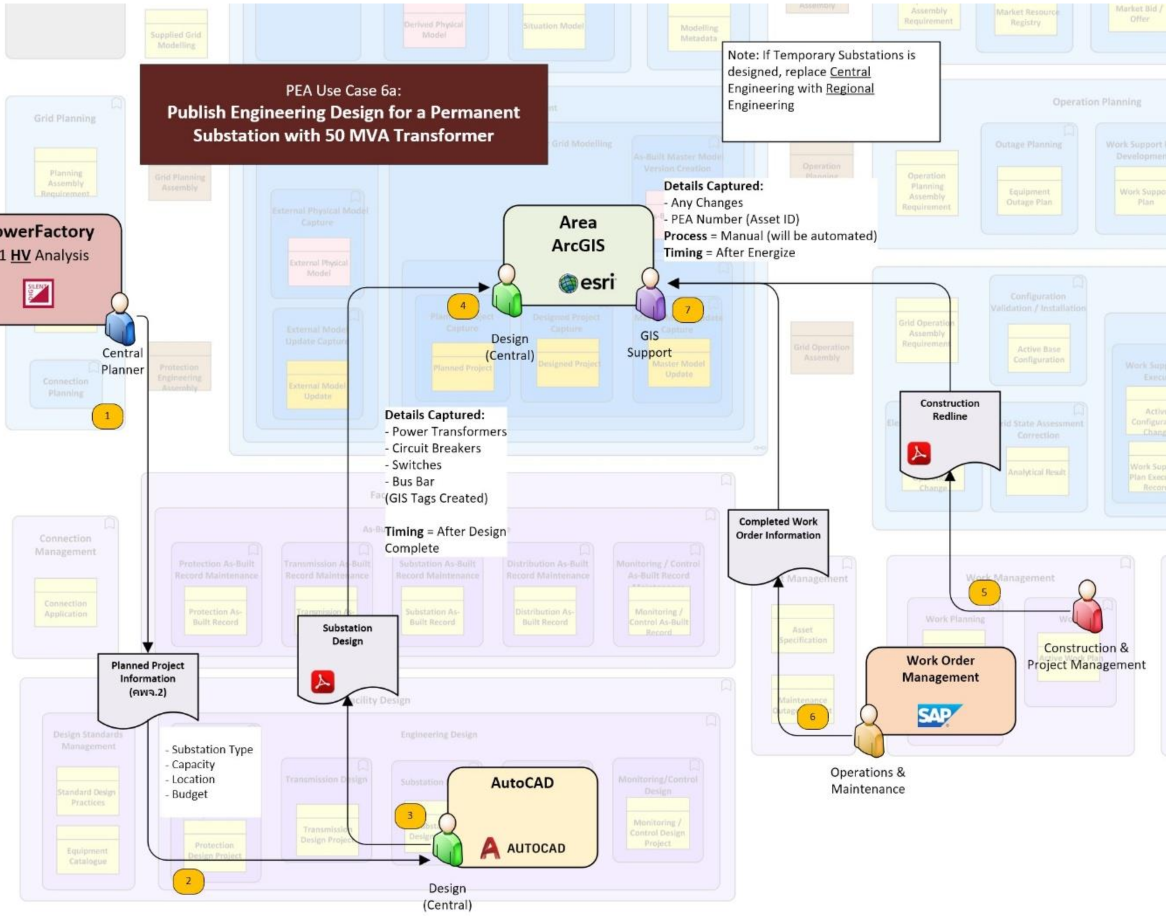
UseCase 5 is mostly about big projects that we are assigned and have been approved by the government (cabinet). Normally project starts from feasibility study (FS) through the government cabinet approval process and takes about one and a half year to two years. Once the project has been approved the construction process will start. The process begins with land procurement for substation construction. Often the procured land is not in the zone or in the area we planned in the first place. It is because either the land is hard to procure or social/economical geographical development grew in an unexpected way different from the plan.

This Use Case begin with collect input data for DigSILENT like UseCase #1. This first step has to take into account the existing grid model and the approved planned grid model data. In step 2, information from the survey will be taken into account and make a proposal into GIS which location should be chosen to build the substation. In step 3, like in UseCase#1, input the load forecast data to power flow analysis in order to check the location and sizing of substation that may have to be changed from existing plan that it still satisfies the expectation and solve problems as proposed adequately. If not, we may need to reconsider the location. However if the relocation still will be able to satisfy or solve the problems and also the capacity still satisfy/solve the problems we will say OK to (approve) the changes.

However, in some cases which are rare, we may take into account customers' complaints as an input. For example, a big customer or groups of customers in the same area have complaints about voltage drop in the area widely. In such cases, we may have to move the location of substation closer to the area to solve the problems and may have to change the capacity. After confirming the (including changed) location and capacity of the substation, we will send the information to the planner in the region (area) to perform the planning for MV parts related to the substation.

The planner in the area will have to make plans to fit well with the planed substation (HV). The area planner may have to do the flow 5a which is optional when they use DigSILENT to do the analysis of MV 22kV and 33kV. Some cases in flow 5b the model is less complicated, and the planner has such experience and knows the situation well enough to make MV plan, review and do assessment directly by hand in single line diagram without software tools. Some planners do both (using software and without software). In other words, the MV planner can do planning in three ways based on their preference; 1. use software, 2. without software and 3. Both do manually then recheck using software tools.

Use Case 6a – Publish Engineering Design For A Permanent Substation With 50 MVA Transformer



Use Case 6a is about the workflow of permanent substation design which is the responsibility of substation design sub-division. First of all, we get plan information from power planning division who performed the feasibility study (FS) of the project. Then we have approval from the government cabinet resulting in getting the project plan document.

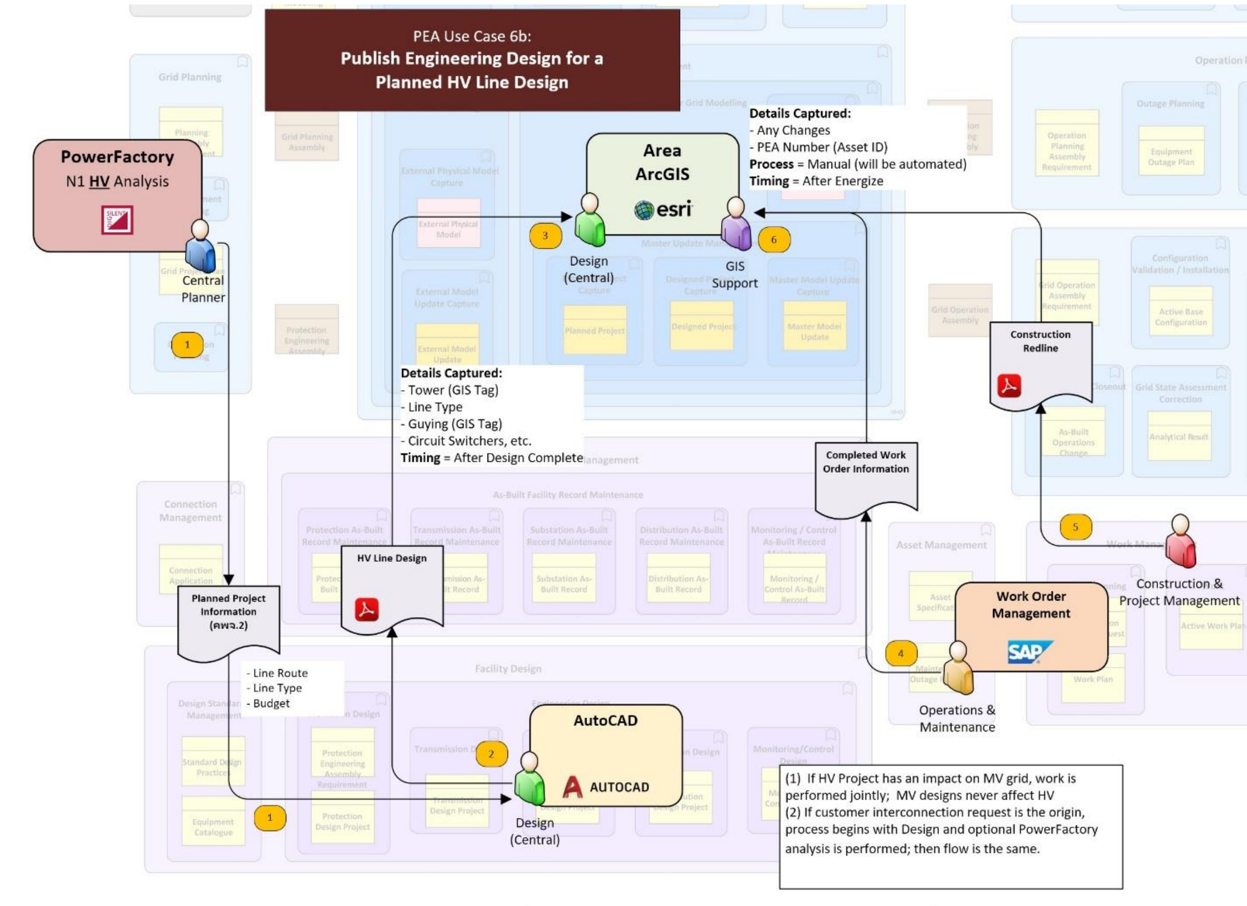
In the project there are details of location, substation name, province, capacity, number of power transformers, substation type with its detail, schematic diagram. We then make yearly plan of activity list based on that information. At the same time, we perform the land procurement for substation construction.

After finishing the land procurement process, we will have land title certificate and its geographical detail to be used in the design process. After that we will survey and design plan and survey activity queue for our staffs to collect all design-required information. We make quarterly plan for both electrical engineering and civil engineering to survey and collect all required information from regional area, for example, line-in, line-out of 115kV and the location of medium volt system; 22kV and 33kV. After that we will get into engineering design process using software AutoCAD and calculate the budget required for the project.

After we have our design document and budget approved, we will then send it to working groups to send the tenders to have a vendor to do the construction. In some case instead of using outside vendor we just perform the construction internally. After completing the construction, the as-built information will be collected in the form of a PDF file. We use the as-built information to input into GIS. The information includes location (lat,long) of the substation and the detailed installation in single-line diagram, number and size of power transformers, circuit breaker, disconnecting switch, bus bar system and also other equipment and its connectivity from HV 115 kV down to 22kV, 33kV system. Our job as substation design division ends there.

When substation construction is completed, construction and project management division which is shown as red shirt in the diagram, will verify from the as-built drawing which is also in PDF format, then send the information to regional staff, the purple shirt in step 4. The regional staffs (purple shirt) will have asset information, for example PEA number treated as PEA asset ID, and input them into the asset management software system SAP.

Use Case 6b – Publish Engineering Design For A Planned HV Line Design



Use case 6 documents the process which takes place after the planning department performs the power system analysis, plans the project and the project has been approved.

In step 1 in this use case, we are talking about the project to develop power transmission system and distribution system part. The project plan must be sent to power system division to elaborate the project detail. The project details include the name of the 115kV transmission line project, the size of the line, the distance/length of the line in kilometer. It is the 115kV HV power line to connect to the substation in the project. After receiving the plans from planning and analysis division we will prioritize those plans. We will pick up a project starting from HV line system in which the connected substation has been constructed already.

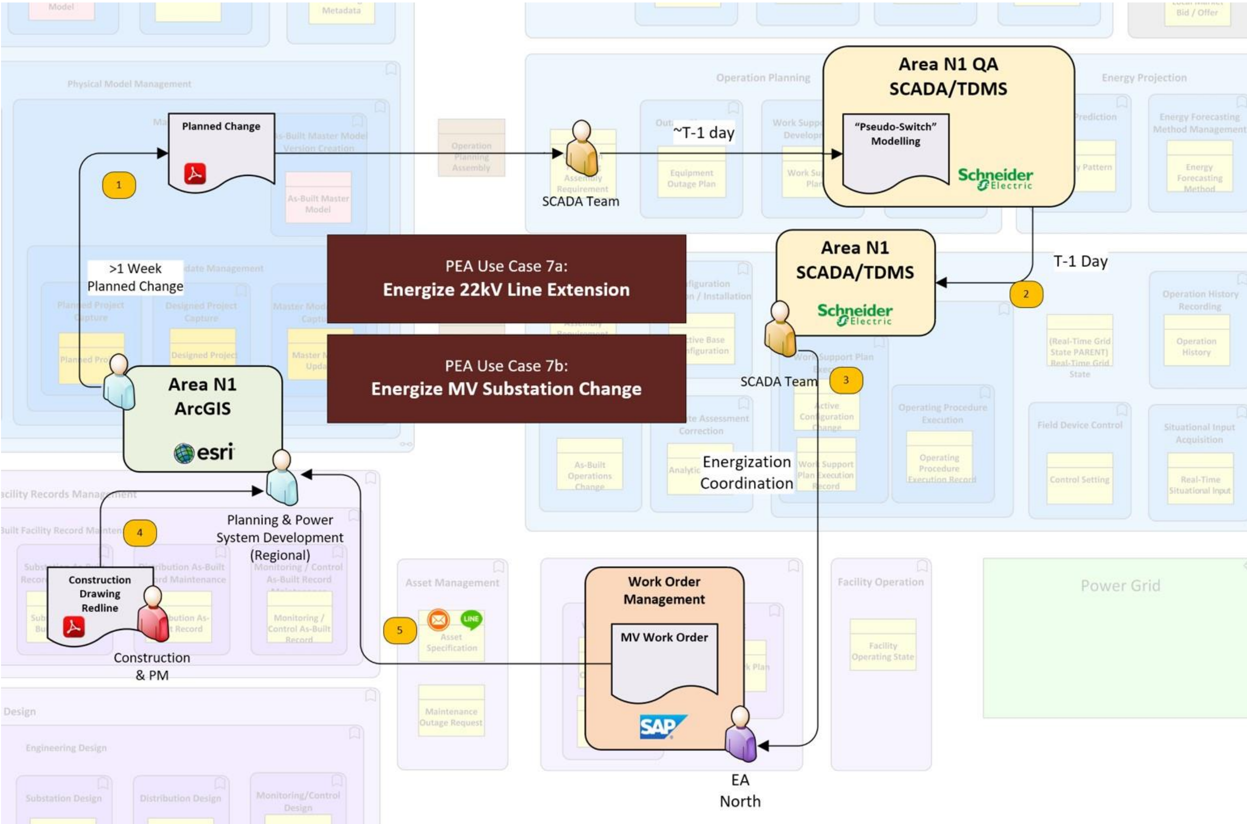
After we choose the plan then we start survey for design the HV line system. Then we do budget calculation. We collaborate with the related regions to identify the route for HV line. We coordinate with the department of highway and other road related organizations with which the design power line has to be coordinated. In step 2, we start the design process using software AutoCad. We survey and calculate project budget using PEA cost estimation software. After that we enter the project approval process. After the approval of the project, we will send the project information in PDF format to the area in charge and other organization units. Then the area will perform the modification and design for the other parts connected under the HV line project.

We send the design to other related organization. There are two types of the following process. One is to hire a vendor to do the HV line construction. The other is for PEA to do the construction internally by itself. In the latter case, we will put the design information in GIS system including concrete tower, steel tower, monopole, guying information, tower foundation structure and other power equipment as designed including circuit

In step 3, after input of the designed information into GIS, when construction and project management division finishes the construction process, either hiring vendor to do the construction or PEA do the construction itself internally, the construction controller/inspector will update the as-built information in GIS system to make the data in GIS up-to-date. The next step, the 6^{th} step in the diagram, the staff at regional area office will inspect the finished construction and make the data in GIS system up to date.

There are cases that the 115kV HV power line design task has not been initiated by PEA internally from planning department, but initiated from customer request typically a big customer. We will include the request in our survey plan in step 2, then we will perform the design process the same way as normal design procedure then input the design into GIS.

Use Case 7ab – Energize 22kV Line Extension/Energize MV Substation Change



Use Case 7a and 7b have very similar workflow so we put them into one diagram. The difference is mainly in step 3 since the workers for each use case are different. In particular, the process of work order management in SAP.

Use Case 7a is about energizing MV 22kV Line extension and Use Case7b is about energizing MV substation change. In use case 7a we need to have MV 22kV line extension information after finishing the construction to perform our operation. The flow begins from the request for operation which must be sent at least seven days before the time of operation. This is the step 1 in the diagram. Other related teams must send their related information to SCADA team. The grid model in GIS system, which includes equipment and its connectivity, must be sent to the SCADA teams at least one day before the operation day as illustrated in the diagram. Then SCADA teams will connect the network which 'hot line' with 'dead line'. SCADA team also must build a pseudo switch model to make the transition smooth in real-time in SCADA PEA TDMS (Transmission Distribution Management System)

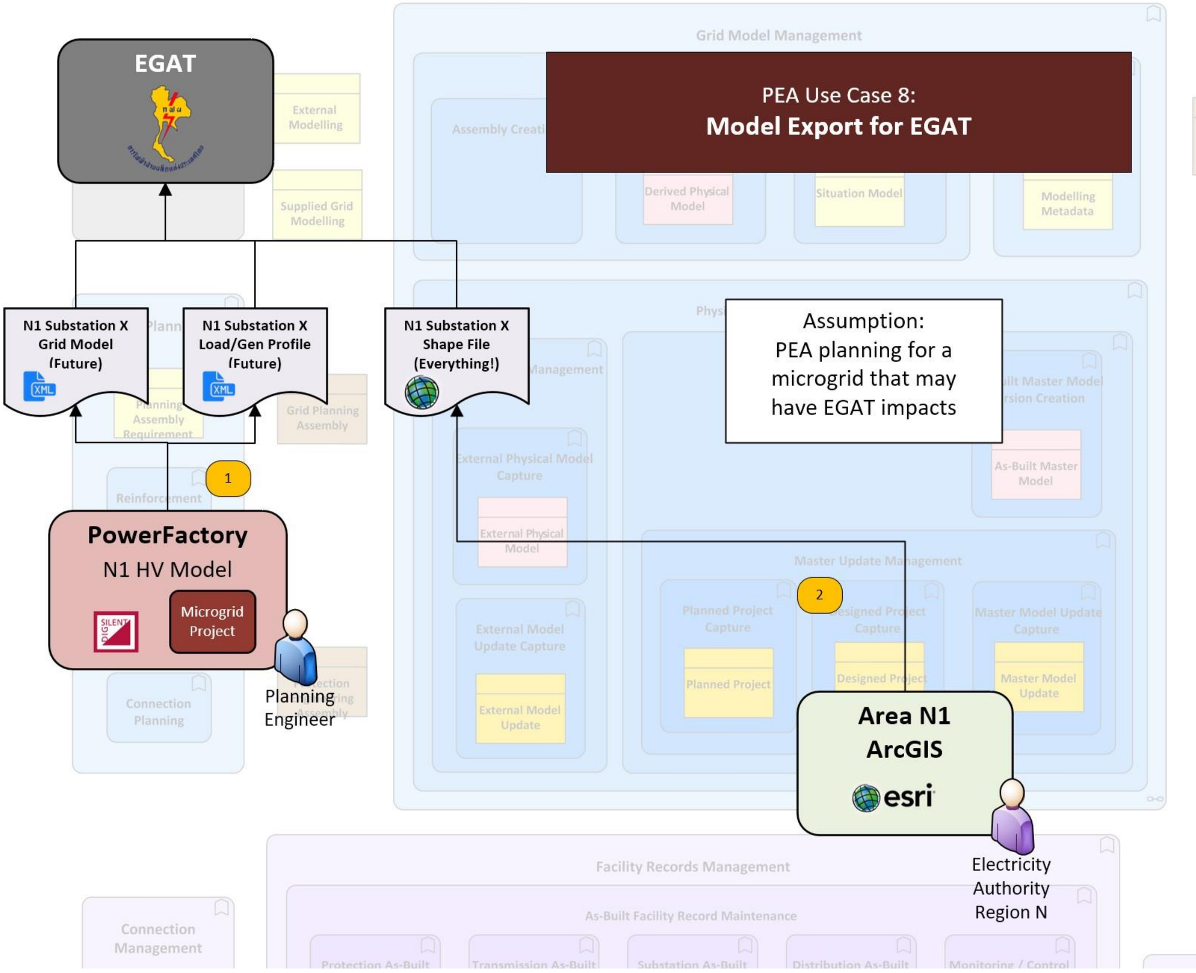
In step 2, the database team will take the modelling then send to the database of users and then in step 3 after the switch order has been approved by management then the operation will be performed. After the operation there will be a team or operation crew responsible to operate on some equipment (manually) which have no control from SCADA system. After that operation completion, information must be input into SAP system, most of which are about the expense (cost) of the operation. After completing the work order then hand over to planning team to verify if it satisfies the planned expectation.

In the step 4, this is the flow connected from Use Case 6b, since there may be need to allow changes effected by the real construction conditions/situation, so the design may have to be modified.

In Use Case 7b there is also a similar workflow, the working staff become regional area staff or the purple shirts. In case of the transformer in a substation, we must design the transformer which mostly may be the same as the existing one. To perform the operation, the request must be sent to SCADA team before the operation at least 7 days. For the power transformer maintenance staff is not the regional staffs but is the staff from central PEA since for power transformer we need a lot of work crews. The flow is almost the same as use case 7a, the data should be sent to SCADA at least seven days before the operation with pseudo switch modelling. To operate with the new power transformer, we need to connect 'hot network' (energized) with 'dead network' (not energized)

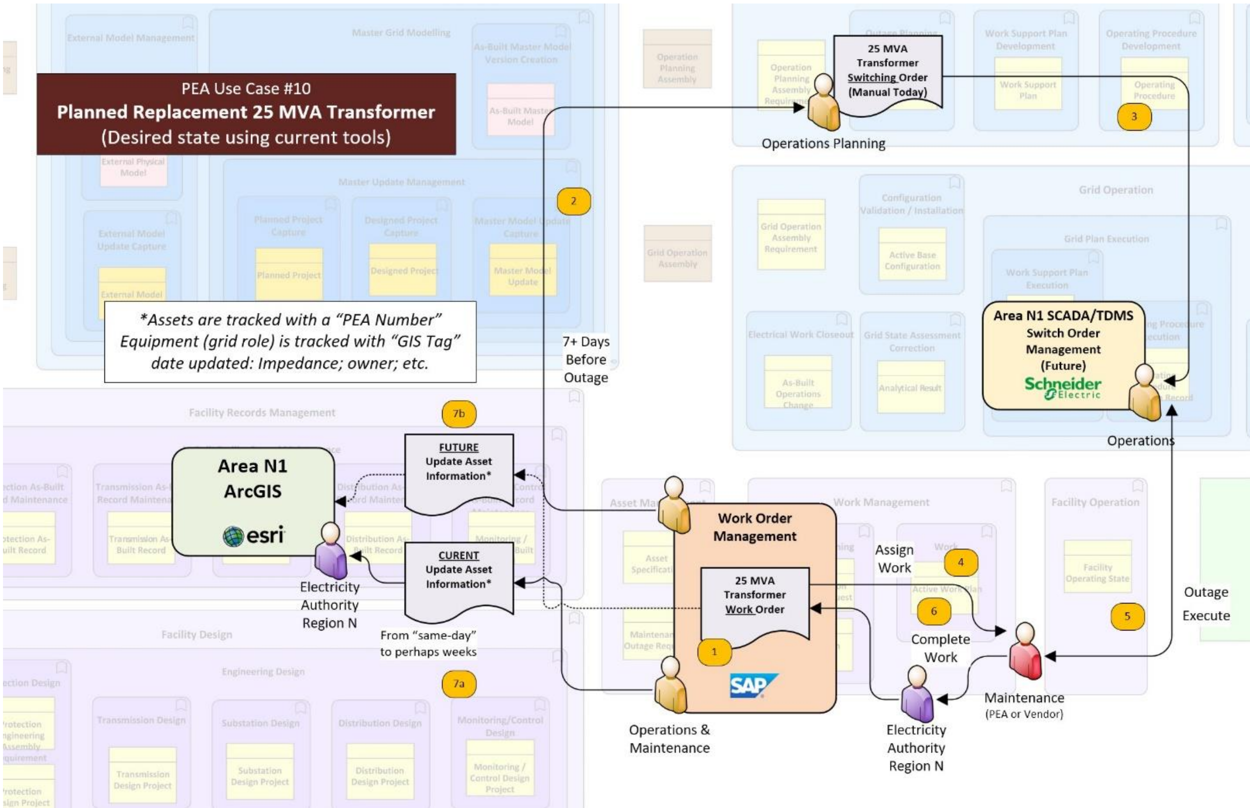
The operation team will prepare the model and switching order at least one day before the operation. Then they will send to the team to make the correspond work order in the SAP system. After finishing the operation, we will let the planning division know for them verify and update the GIS data.

Use Case 8 – Model Export For EGAT



While the previous use cases focused on current processes, use case 8 addresses the potential processes that would be involved in exporting a model to EGAT reflecting the PEA planning for a microgrid in area N1 that may have an impact on EGAT. The first step is the creation of the model reflecting the microgrid from the PowerFactory software by the planning engineer. The second flow is the extract from the Esri GIS to provide the related shape files.

Use Case 10 – Planned Replacement 25 MVA Transformer



Use Case10 is about replacing a 25MVA transformer in a substation in area N1. This activity makes the changes in grid model. Replacing a power transformer affects a number of parts in PEA. There are two reasons to replace a power transformer. One reason is because the capacity of the transformer to supply power. It may be not sufficient for the near future needs of the area. The other reason may be the power transformer is very old and needs to be replaced or its condition is not good enough to be used anymore.

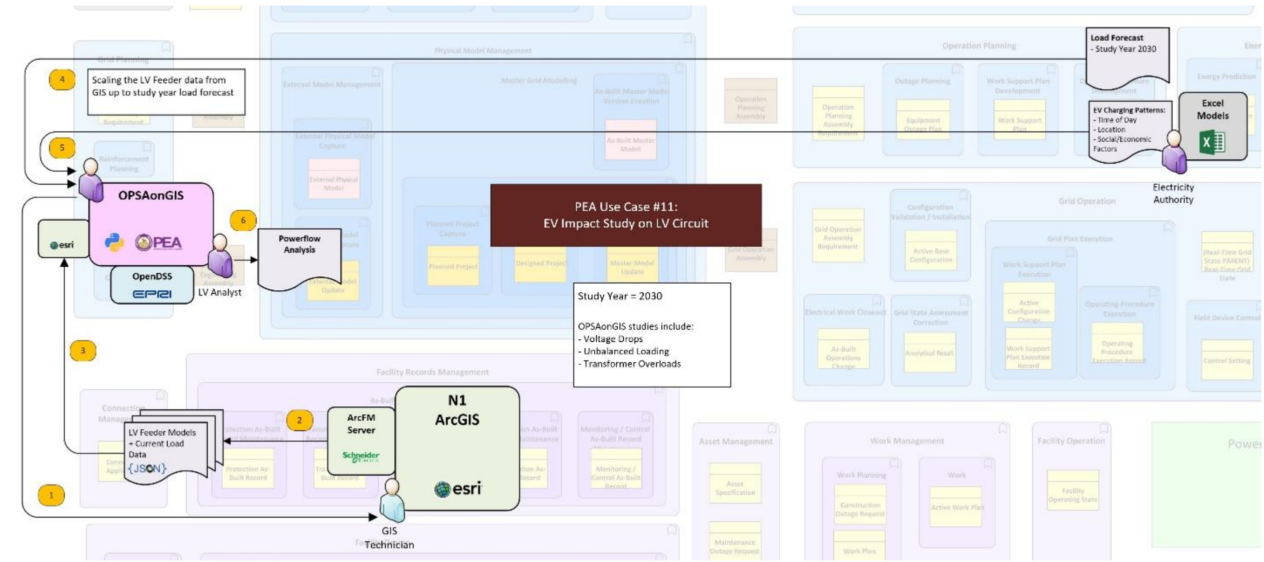
The flow starts from operation and maintenance staffs which include central staffs and regional area staffs collaborating in order to perform the power transformer health/condition check to make replacement decision. When the replacement decision has been made, the document process will be done until the replacement has been approved. There may be variety of ways to do the replacement including purchasing a new power transformer and reusing the existing power transformer. In case there are bigger, 50MVA power transformer in the area or other area and need to be moved, the moving procedure will take place. The procedure is mainly approval process which usually include a number hierarchical higher rank-management approval. It may include purchasing process, transportation process, demolishing process and installation process.

After the approval, there will be a new task in Work order management which is SAP. In case of purchasing a new power transformer a new WBS (work-breakdown-structure) will be created. In case of transformer migration also, we must allocate budget for demolishing, transporting, and installation. Then after the approval, operations will be informed with all project information. They will send the information about the requirement of the replaced 25MV power transformer to operation planning staffs in order to make a planned outage for the replacement operations. This process is performed by regional operation as illustrated by arrow number two. In this case, similar to the previous operation use case (7a/b), this have to be prepared at least seven days before the operations. This early information is due to the required time to make sure that it won't affect much in PEA power distribution services. At the same time the maintenance staffs also must prepare engineering work related to the power transformer replacement, the transport, demolition, and installation as illustrated in arrow number 4. In case that PEA perform the operation internally, the whole operation includes transformer preparation, pick-up, crew budgeting and planning, and so on. In case hired vendor does the job, the operation also include procurement and contract making and control. In this step 5 there will be a lot of information involved. There will be meetings about the operation, action plan, outage planning, time-consumed in the operations, switching order required for power re-allocation to obtain the operation detail consensus.

From step 2 and step 3 there will be a collection of information used to build action plan. After that the action plan with details will be distributed to engineering staff, protection system staff, switching staffs as illustrated in step 5. In the real operation/construction the red shirt guy is supposed to be the person who performs the transformer replacement. During the construction/operation process there will be engineering verification process, acceptance testing process and then they must update the information of the power transformer replacement and send it to regional area staffs. Also, there will be a process to close or complete the job in SAP system.

In the end, operation maintenance guy (yellow) collects all information about the power transformer replacement and sends it to the staff in the regional area to update the information into the GIS system.

Use Case 11 – EV Impact On LV Circuit



The scenario in use case 11 usually required as part of yearly budget planning of PEA to enable PEA to manage EV charger load in the future.

To study the affect, three sources of information are required: 1.Power system from GIS; 2.EV charging pattern; 3. Load Forecast

From step 1, the flow starts from purple box in the middle, the engineer who is responsible for low voltage distribution system analysis will prepare the desired information from GIS by request to GIS technician. Then the technician will send the data in JSON format to be used in program OPSAonGIS which PEA internally developed. After that, regional staffs will use the analyzed information from OPSA by choosing scenario for analysis, choose year to operate on, choose load forecast to work with in the flow number 4. Then they scale-up present load to forecast load in the future year. After determining the load forecast, then we select charging pattern of EV charger which include time of charge, location and other factors, and then calculate the power flow analysis using OPSAonGIS as show in step 6. The calculation result will be some value similar to UseCase 4 which is the low voltage distribution analysis. The result may look like this: 1.Transformer overload; 2.Voltage drop lower than accepted standard; 3. Transformer Load Unbalance.

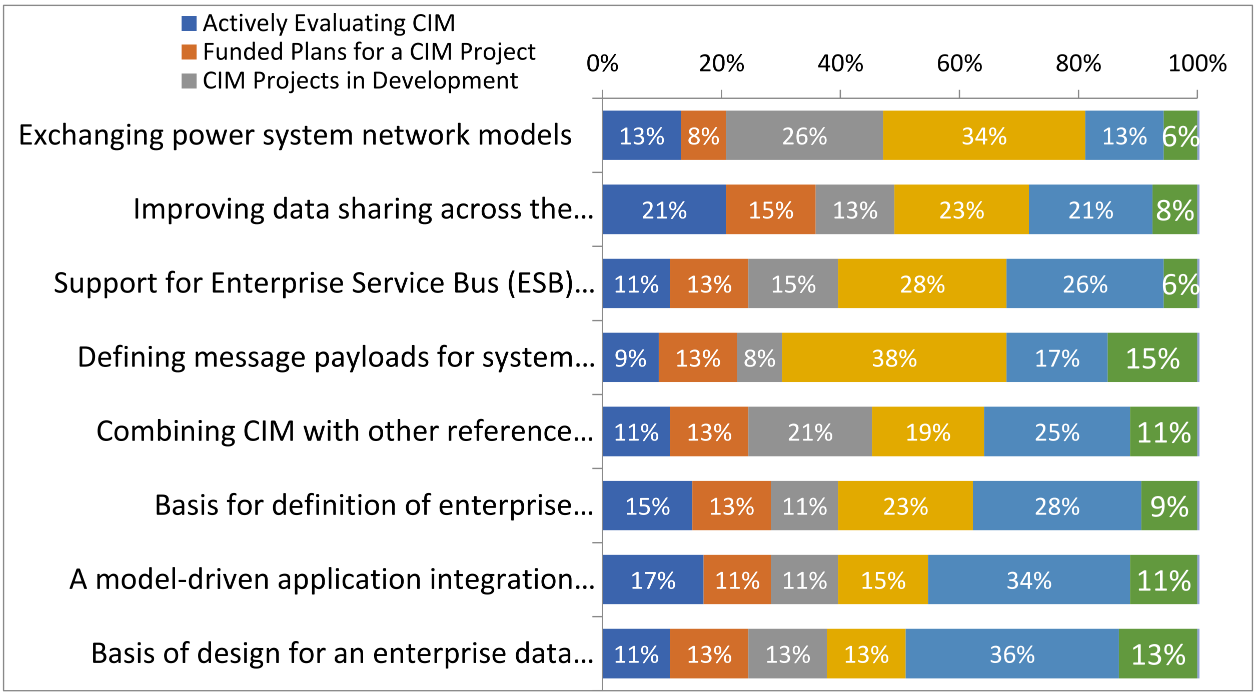
Industry Case Studies

Results from a Recent CIM Survey

The following sections show the results of a survey conducted by Gartner on utility experience with the CIM.

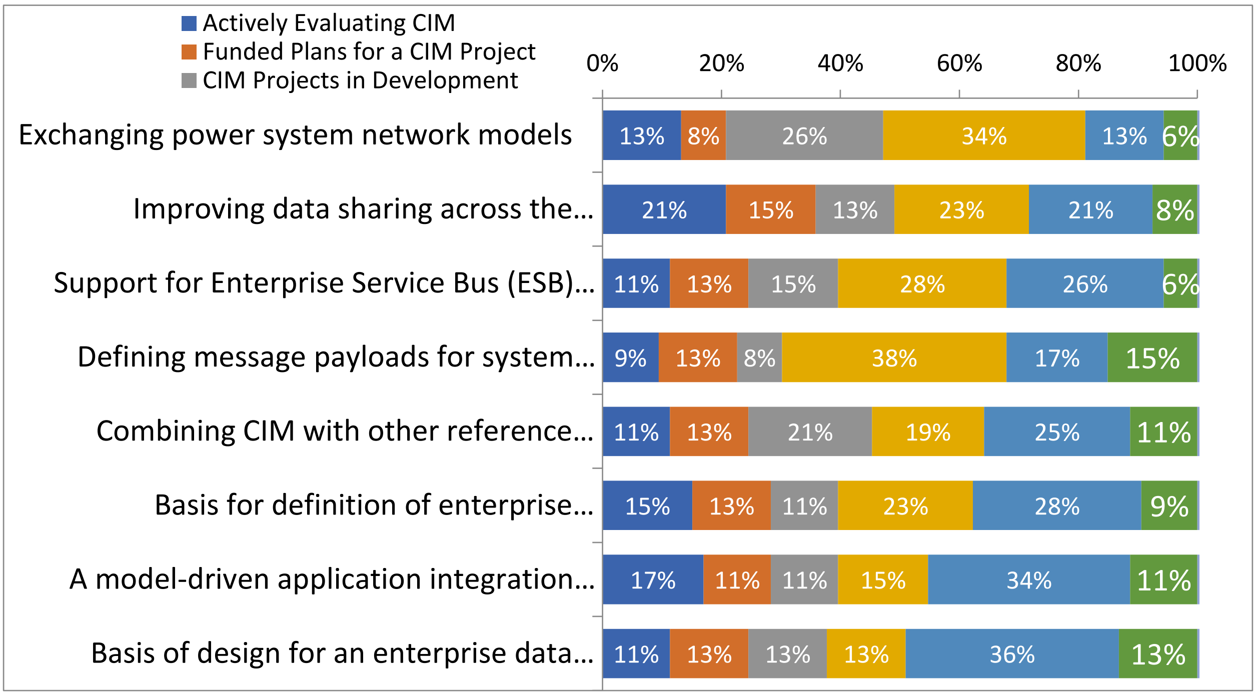
Utility State of CIM Use

For each of the following, please state whether your organization has …



Utility Benefit From CIM Use

Please rank in order of importance the top three business benefits sought from successful CIM implementations in your organization.



Utility CIM Usage and Grid Model Management Examples

TenneT NMM

Summary

- Background
  - Transmission System Operator for Netherlands and part of Germany
- The problem
  - Exchanges with outside world (TSO and DSO) are increasing
  - Processes in System Planning and System Operations need constant adaptation
    - More and more cases are calculated to assess risk level
    - Non-steady-state phenomena increasingly studied
    - Grid models in System Planning and System Operations were diverging
    - Coherent grid security assessment from long-term to real-time
  - People that are knowledgeable in grid model maintenance are scarce
- CIM solution
  - Implemented CIM-based approach for enterprise-wide network model management (NMM) platform
  - Engaged EPRI to assist in creating an NMM Roadmap
  - Started with an NMM component in SCADA/EMS replacement project
- Use cases
  - Asset Management, Energy System Planning and System Operations agreed upon benefits/feasibility of a 'Single Point of Truth' approach

Takeaways

- To get a transformation like this started
  - you need people who think outside their own box (silo)...
  - ... and managers who support that kind of thinking.
- Main benefit from this initial roadmap phase is that you have a direction. Even if you know that direction can change along the way.
- The long-haul development comes with challenges (from the beginning):
  - Keeping momentum.
  - There will be other developments in the company that change the reality you are designing and building against.
- We benefitted from working with EPRI because

  - they have experience what approach works to identify relevant steps for implementing NMM
  - they combine deep knowledge on data management and the power system (i.e. our) business (IT and OT).

2.2 ESB Networks

Summary

- Background
  - Licensed operators of the electricity distribution system in the Republic of Ireland
  - Serves 2.3 million customers
  - Responsible for constructing all the medium and low voltage electricity network infrastructure in the country as well as operating and maintaining this infrastructure.
- The problem
  - Can utilities deploy software to offset the investment in traditional assets
  - Many data sources with many owners
- CIM solution
  - Implemented CIM based data model platform which was used to capture all distribution assets and data into a single model
- Use cases
  - Asset management – load visualization and asset reporting
  - Operations – increased visibility into the low voltage network
  - Capacity optimization – enables DSU participation and investment offset
  - System Services – voltage and frequency control

Messages For Leadership

- The most important message coming out of the GMDM deep dive that we wanted to share with leadership was …
  - Multi-year transformative program
  - Adopting will be a serious undertaking
  - Executive sponsorship is key
  - Shared understanding of the amount of time/cost – length of time
  - Involves significant organizational change
  - Requires a ‘commitment to explore’ not a ‘commitment to execute’

As-Is Findings

- Our processes are working largely as designed

- Knowledgeable, service-oriented, forward -thinking staff
- Modelling efficiency varies dramatically based on the 'grid extent' being modelled
- Like nearly all other utilities of ESBN's size
  - Lots of duplicate modelling, especially HV/MV substations
  - Leveraging of GIS as the source for MV OMS and Planning models
  - Lots of mapping tables
- GIS serving a wide range of needs
  - Data for load forecasting
  - Source impedances
  - Inclusion of HV and Transmission lines
- Mapped out the areas with manual updates, periodic loading of models, not kept in synch

Key Takeaways

- Some valuable takeaways from the GMDM deep-dive are …
  - The mapping of our As-Is process
  - Quantifying the amount of manual entry/duplication
  - Getting people across the organization to share knowledge, problems and ideas
  - Start with requirements, not solutions
  - Focus on the data not the infrastructure
  - Take an enterprise approach by looking at business functions – developed an initial strawman ESBN vision business function model
  - Validate the solution with use cases

Hydro-Quebec

Summary

- Background
  - Public utility that manages the generation, transmission and distribution of electricity in the Canadian province of Quebec, as well as the export of power to portions of the Northeast United States

Hydro-Québec « As Is » network model data management practices

- EPRI made a really nice and summarized representation of our "as is" practices. It was better and expressed a wider reality than the majority of the diagram made internally.
- The most surprising thing we realized about our existing (as-is) network model data management practices was…
  - We knew that Hydro-Québec modeling practices were different than other utilities
  - We've learned that this was a "good different", that HQ practices were in-line with EPRI GMDM vision. That we've already implement most of recommended practices in terms of network model management.
  - We've learned that EPRI was pleased to see all the theoretical approaches/assumptions they had made was actually working/running in a utility.
  - We've learned what good choices HQ had made in the past (Software choices, design choices, business process choices) to enable the current solution.

The way forward: Improvement recommendation

- EPRI identified areas that need improvement in our organisation and made good recommendations on upgrades which would add the most value to our organisation.
- The theoretical approach of the business function expressed by EPRI is making a lot of sense, but hard to materialize
  - We need to take baby step on that one
- The ne tool for GMM also makes a lot of sense. But considering performance, data integrity, all behaviour required by specific department or business function it might be hard to implement.
- The detail of the flow for change management envisioned by EPRI need to be implement and tested with full functionality (ex: auto-schematics generation, high volume of change request) to prove its effectiveness.

Where we are at HQ

- At HQ we are actually in a project (MSCR) to change all our operation software (DX and TX). We ask the vendor (OSI) to meet all the requirement proposed by EPRI regarding NMM functionalities.
- We ask for an Integrated Dx and TX NMM tool because we think this is where the future need to go.
- The solution proposed by OSI is not an NMM as expressed by EPRI. So, we are not reaching our NMM capabilities with MSCR project. We need to revisit our plan for the future on how we will reach that goal because we believe it would add value to Hydro-Québec.
- We hope that EPRI observations on our current solution and future MSCR solution will have a good influence on our management to make the right decision.

Consumers Energy

Summary

- Background
  - Public utility in Michigan that provides natural gas and electricity to 6.7 million of the state's 10 million residents
  - Sub-transmission and distribution
  - Has been adopting IEC CIM standards since 2008
- The Problem
  - How to ensure a consistent Network Model across all aspects of the enterprise
  - New applications to support ADMS functions, addressing the future demand of DER and Enterprise Analytics with respect to the Network Connectivity Model
- CIM Solution
  - Developed CIM based Enterprise Semantic Model (ESM)
  - Establish a Network Connectivity Model utilized by different applications and sources decoupling and minimizing the amount of dependency on specific technology or solutions
- Benefits
  - Eliminating duplicate work on integration
  - Maximizing the reusability of a common data model
  - Lowering the cost on overall integration and support
  - Facilitating the composition and consumption of information across multivendor landscapes
  - Leveraging vendor's CIM-based solutions and SOA approaches for integration

ERCOT

Summary

- Background
  - The Texas Legislature restructured the Texas electric market in 1999 and assigned ERCOT four primary responsibilities
    - System reliability
    - Competitive wholesale market
    - Open access to transmission
    - Competitive retail market
  - ERCOT is a nonprofit organization that is regulated by the Public Utility Commission of Texas, with oversight by the Texas Legislature
  - ERCOT is not a market participant and does not own generation or transmission/distribution wires
- Historic Problems with Grid Data Flow
  - Differences in model topologies, element attributes, and naming conventions
  - Single non-temporal Operations model updated every two weeks –no future case models
  - Large time gap between Operations Model and the most current Planning Models
  - Dynamic cases built from Planning Cases, but used to support decisions made in real-time
  - Market Information was not integrated in Operations Model
  - Future one-lines and contingency files were not available to support Outage studies
  - Multiple interfaces used by Market Participants were inefficient
  - Market Participants had no access or visibility to the any of the multiple model databases
  - Operations Model database and Outage Scheduler had no dynamic link
- Impetus for Change
  - In 2004, ERCOT began a complete system redesign to migrate from a zone-based market model to a node-based market model
  - The new Nodal Protocols contained a requirement for a high-level of model consistency between all applications used to control the grid
  - After consideration, it was agreed that a centralized data warehouse with an all-encompassing model schema to contain, maintain, and deliver consistent model data for all model driven activities was the best solution

- To help solve the communications issues associated with using different vendors for the various ERCOT systems, the Common Information Model (CIM) was adopted as the exchange standard both within ERCOT and to external users

Southern California Edison

Summary

- Background
  - Primary electricity supply company for much of Southern California providing 15 million people with electricity across a service territory of approximately 50,000 square miles
  - Began adopting CIM in 1999
- CIM Solutions
  - Asset data exchange between Work Management Systems (WMS)
  - Asset data exchange between WMS and Outage Management System (OMS)
  - Work Order data to Ledger Accounting System (LAS)
  - Work Order Data exchange for Distribution Service and Pricing System (DSRP)
  - Device status data exchange between Energy Management System (EMS) and OMS
  - SmartGrid standards including grid model (SCEIM)
  - Initiated CIM for Environment standard

Benefits and Risks

Multiple benefits will accrue to PEA with the implementation of the GMM Vision, including:

1. **Improved quality of Grid Models** which are derived from a single source consisting of the most detailed, enterprise-wide representation of the equipment and connectivity, resulting in analyses that:
   - May span across different voltage levels
   - May include Grid Models across multiple PEA areas
   - May include representations of the EGAT and MEA Grid Models
   - More accurate and timely substation data
2. **Reduced staff effort** as the GMM Vision will lead to:
   - Eliminating duplicate data entry process
   - Reducing manual data entry and unnecessary handoffs among divisions
   - Removing the need for model comparisons across different divisions
   - Reducing time requires to track down inconsistences and potential error
3. Reduced software development costs as the GMM Vision will lead to

- Fewer point-to-point (system-to-system) custom interfaces
- Simpler introduction of new and updates tools utilized standard data exchange patterns.

As with any large multi-year effort, there are risks involved, including:

- **Ongoing executive support** for the duration of the implementation is mandatory. Given the multiple-year implementation timeframe, executives may be distracted by other major issues affecting PEA if proper importance is not given to this initiative. On a related not, individual PEA staff must be convinced of the importance of the GMM vision, as it will be essential for support at PEA from top-to-bottom as IT designers and implementors, along will all day-to-day interactions staff have with the GMM solution will need to be nurtured.
- **Significant organizational and process change** will be required. Failure to implement with a well-conceived change management program could result in uncertain areas of responsibility, lack of proper training, and ultimately errors in the data.
- **There is only limited availability of GMM software** at this time, and of those commercially available today, only a subset of the GMM Functional Requirements is implemented in any one tool. Selecting a vendor that does not have a good roadmap is a certain risk; however, waiting for the “perfect” vendor has it’s own potentially more costly impacts.

PEA Site Visit

Representatives from the EPRI team made a six work day on-site visit with PEA in Bangkok, Thailand from July 4 through July 12, 2022. The itinerary and working session topics were designed to fulfill the Task 4 requirements of the ToR.

Training Client staff technical staff on architecture of Task 2

The EPRI representatives met with PEA Executive and members of the Enterprise Architecture organization to review the suggested Task 2 information architecture, and to better understand their role within the PEA organization.

Analyzing Task 3 Results

Over the course of the site visit in Thailand, the EPRI team discussed the Task 3 As-Is documentation as well as the GMM vision and benefits with representatives from the following PEA work groups;

- Planning
- Operation
- Design/Construction
- Asset Management

Developing and documenting the 10-year client data management vision

The PEA Executives and staff facilitated working sessions where they presented their current work on the SCADA upgrade project, as well as their GIS-data roadmap and vision. These discussions were very beneficial in informing the EPRI staff in the further development of the 10-year client data management vision.

Identifying and discussion benefits and integration process efficiencies of the vision

Throughout the working sessions with various PEA groups, very detailed discussions around current business practices and the identification of potential efficiencies of GMM were held.

Facilitate at least four feedback sessions with executives and staff on the various facets of the 10-year vision

These feedback sessions were facilitated throughout the site visit meetings, as well as wrap-up discussions with the executives during the last day of the site visit.

PEA Hosted Pattaya Facilities Site-Visit

The PEA executives hosted an all day site visit to several facilities in the city of Pattaya, Thailand. During the site visit, EPRI staff were able to tour;

- Area Control Center
- Substation
- Area distribution customer service office that also aggregates and analyzes customer AMI meter data.

Chapter 4 Appendix

GMM Functional Requirements

GMM
Requirements.xlsx

SPARX Diagrams

Diagram 6. Use Case 3

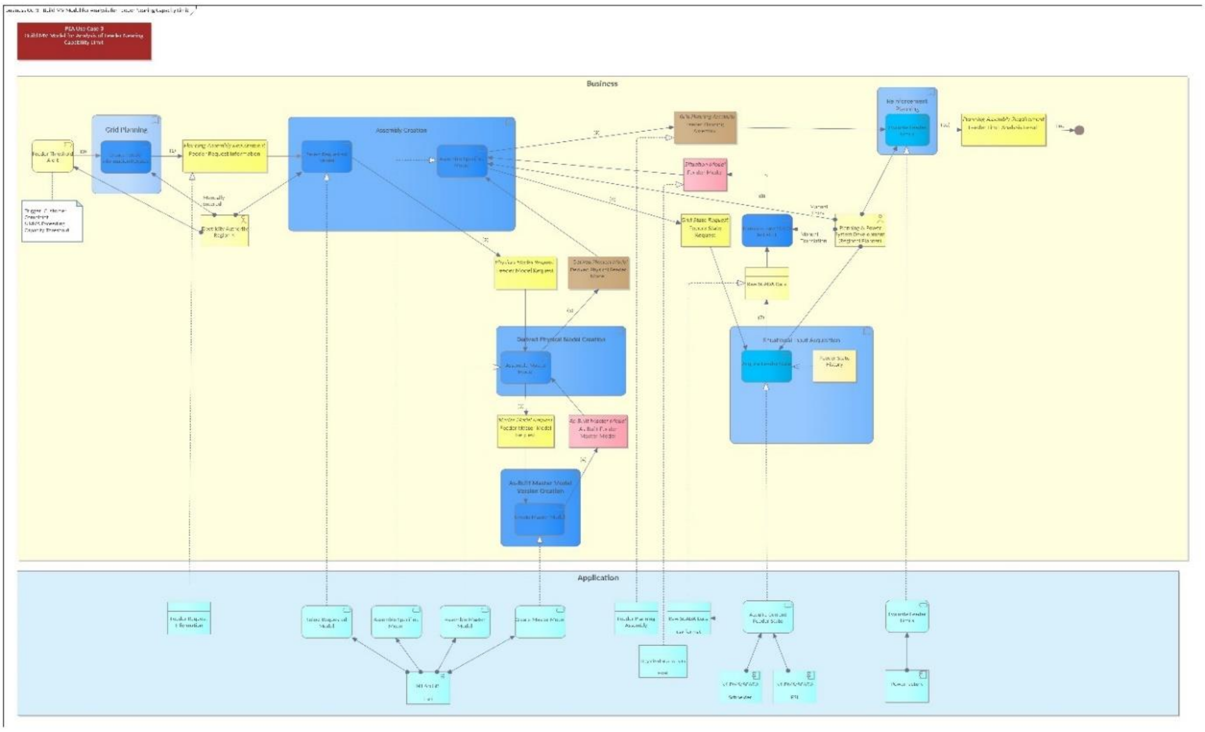


Diagram 7. Use Case 4

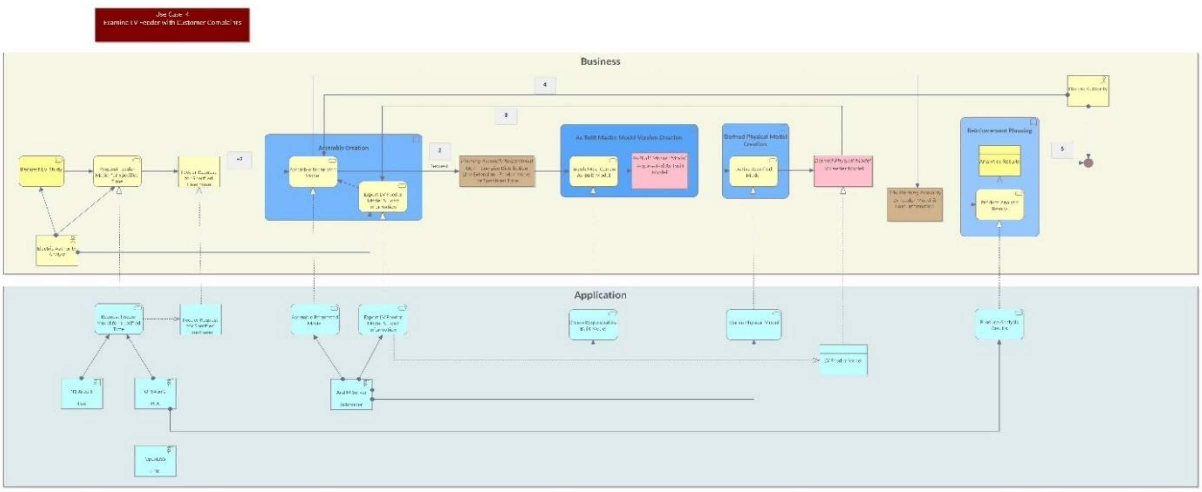


Diagram 8. Use Case 6a

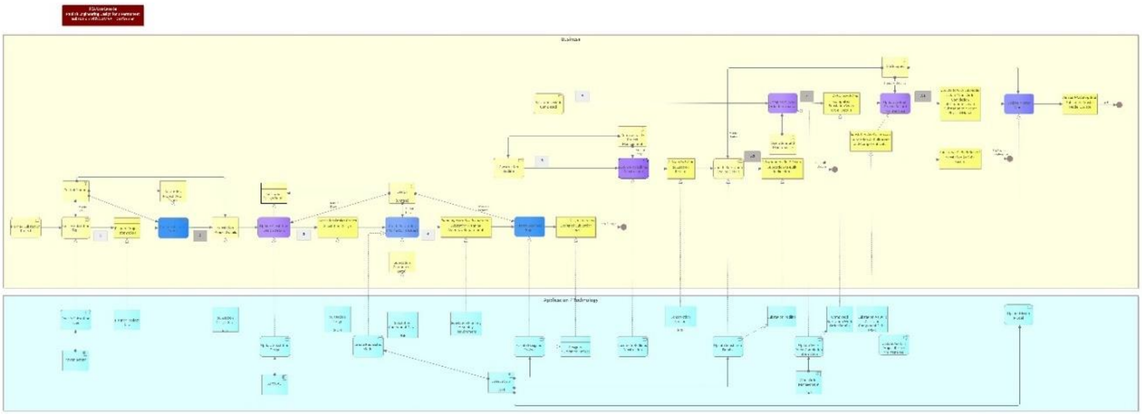


Diagram 9. Use Case 6b

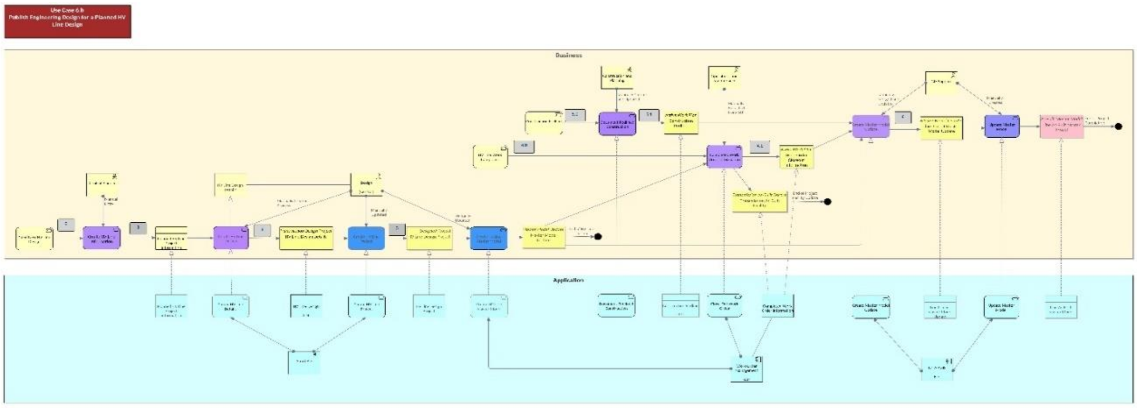
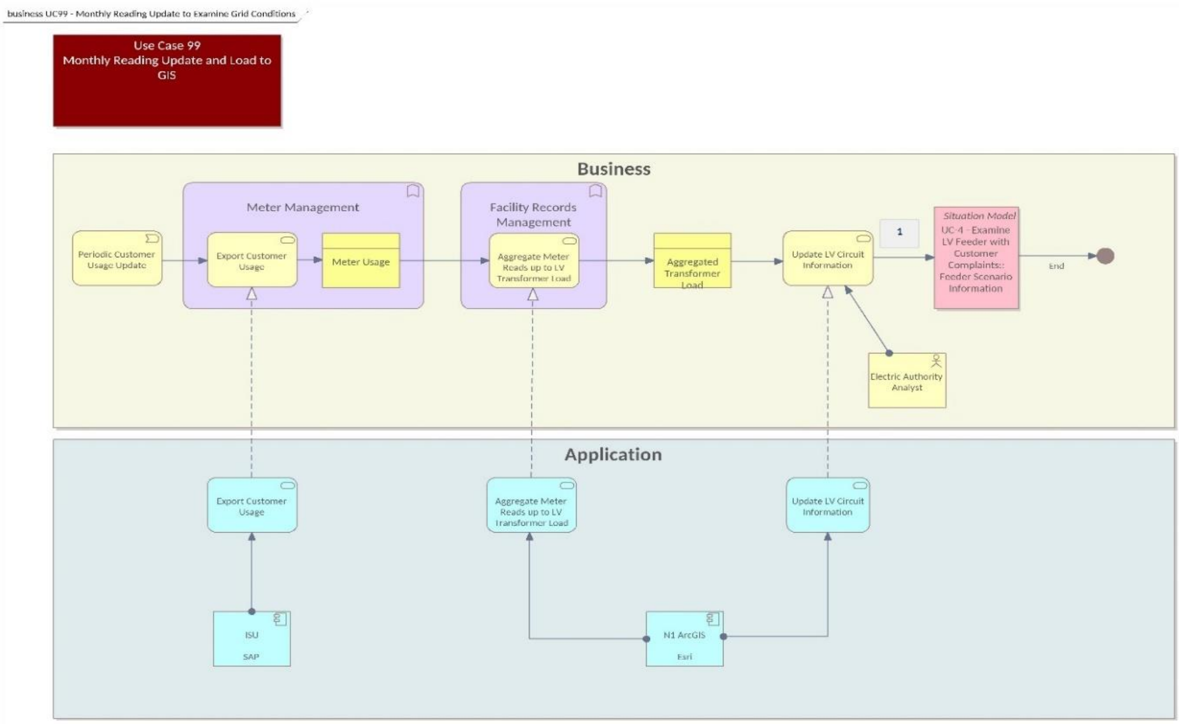


Diagram 10. Use Case 99



CHAPTER 5 CONCEPTUAL SEQUENCING OF SYSTEM DESIGN AND IMPLEMENTATION

Summary

Task 5 is a continuation of the work to assist PEA in establishing an information architecture and then, using that architecture, to assist PEA in designing and planning the implementation of a CIM-based data management vision.

Task 5 develops a conceptual sequencing of the system design and implementation based on the previously developed vision and IT architectural analysis. The outcomes of the task are:

- Create an initial version of a strategy composed of a series of incremental integration steps necessary to implement the vision defined under Task 4
- Document the conceptual design achieved at the end of each integration step, the business objectives targeted by the step, the major activities and any business organization changes required by the step, as the high-level expected costs and benefits for the step.
- Facilitated five (5) executive and technical group feedback sessions on the sequencing strategy. These sessions were held on September 15, 2022, October 10th 18th and 25th, 2022 and November 20, 2022

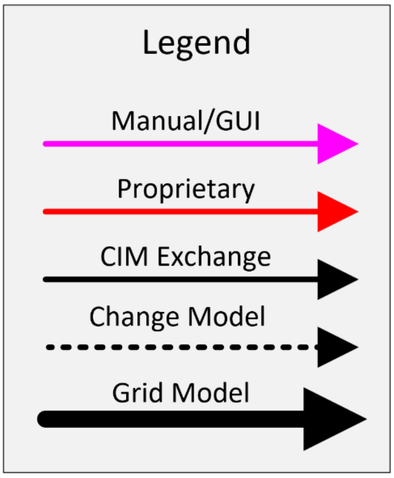
These results will be utilized in Task 5: Conceptual Sequencing of System Design & Implementation as the EPRI team, DigitalSiam, GridOptimize, and Britton Consulting continue to work with PEA to develop a long-term CIM-based data management solution.

Introduction

Task 5 delivers a phased implementation plan for the GMM Architecture at PEA. The phasing plan assuming a competed implementation of SCADA Phase 3 project and considers interactions with several planned future PEA projects, including:

- Project Management Tracking System
- ArcGIS Utility Network Upgrade
- Outage Management System Upgrade

The phasing plan is described visually using similar methods to Task 4’s use case diagrams; here condensed into a single PEA-wide picture of how the GMM might interact with different systems and different users over time. The following legend is utilized:



Each phase of the plan introduces new features in the GMM and new CIM interfaces, over time replacing the Manual/GUI-based exchanges (pink) and proprietary vendor interfaces (red) which are prevalent today for grid model management at PEA. CIM-based exchanges are shown in black, with two variations:

- **Grid Models** (shown with a thick black line) encapsulate representations of some or all of the PEA grid with connectivity and varying degrees of equipment details.
- **Change Models** (shown with a dashed black line) document sets of additions, subtractions, and modifications to equipment and/or connectivity, representing both corrections and updates to the as-built model as well as planned, designed, and constructed but yet-to-be-energized grid improvements.

Grid Modelling Baseline (Phase 0)

Phase 0 describes the modelling environment at PEA as envisioned after the SCADA Phase 3 project is complete, but before GMM activities commence. The SCADA Phase 3 project is focused on upgrading the operational tools at PEA and includes a locally developed CIM XML interface which builds a grid model from information stored in the ArcGIS. SCADA Phase 3 will deliver many new operational features; however, focusing narrowly on grid modelling features, perhaps the most important point is that all twelve PEA areas will be, for the first time in history, operating on the same operations platform. And all environments will leverage the same model building process interface.

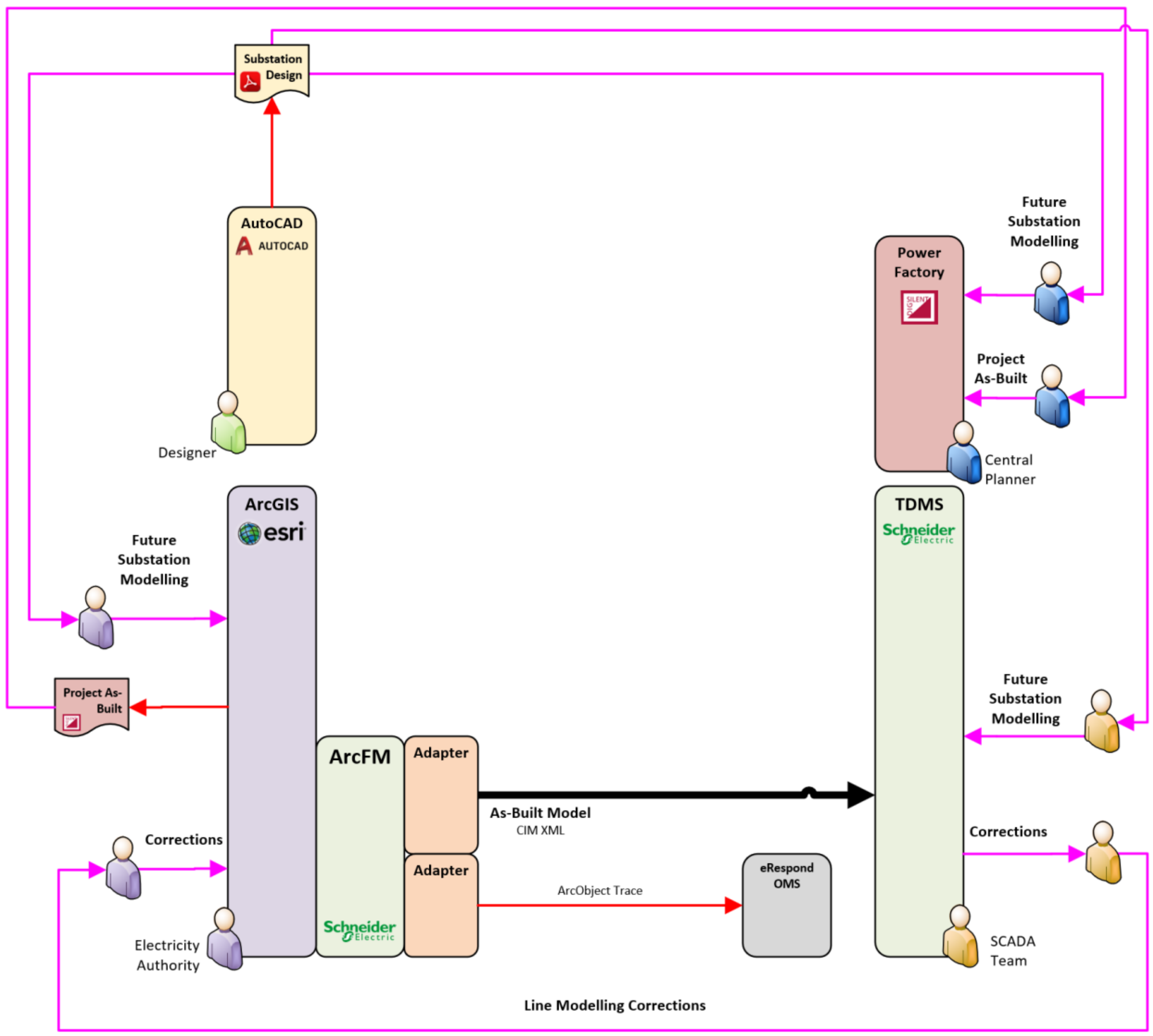


Figure 51. Phase 0 Modelling Environment

While strides have been made in standardizing data sources and modelling processes for line details and connectivity, collecting substation details and connectivity will remain manual. Entering substation design information is repeated for different tools to varying levels of details:

- Into the TDMS environment to support Operations,
- Into the DIgSILENT environment to support Planning, and
- Into the ArcGIS environment for general modelling needs

All of systems require manual data entry from PDF drawings exported from AutoCAD. The current eRespond OMS will not be changed during SCADA Phase 3 and is shown with its internally developed ArcObject model building process interface.

Also shown in the Phase 3 diagram is the planning function supported primarily by DIgSILENT. Other tools are utilized presently, for example OPSAonGIS for analysis of LV circuits, and still others may be introduced in the future. Logically, any number of planning simulation tools may be visualized over the DIgSILENT function block, utilizing similar, if not identical, interfaces. The SCADA Phase 3 has limited impact on the planning functions.

Model corrections are completely manual and symbolized by the Operations-to-Electricity Authority communication path. There are likely corrections which originate from multiple sources today which would look like identical to the human-to-human interactions only with different departments in the chain.

It is important to note that this configuration is a strict “feed-forward” architecture from GIS as the system-of-record to operations. Additionally, the architecture is incomplete, with much of the information operations requires not in the information flow, most notably, details about substations, diagram layouts, and SCADA configuration is all absent. Finally, the profile implemented between the GIS and the DMS is locally developed, so most certainly changes will be requested to all related systems once a formal CIM infrastructure is adopted.

Phase 1: Establish GMM-Enabled As-Built Modelling

Phase 1 introduces a GMM into the PEA environment and centralized both the line modelling (originating on the ArcGIS) and substation modelling (originating in AutoCAD). The focus is on the as-built model with future states of the grid pushed to later GMM phases.

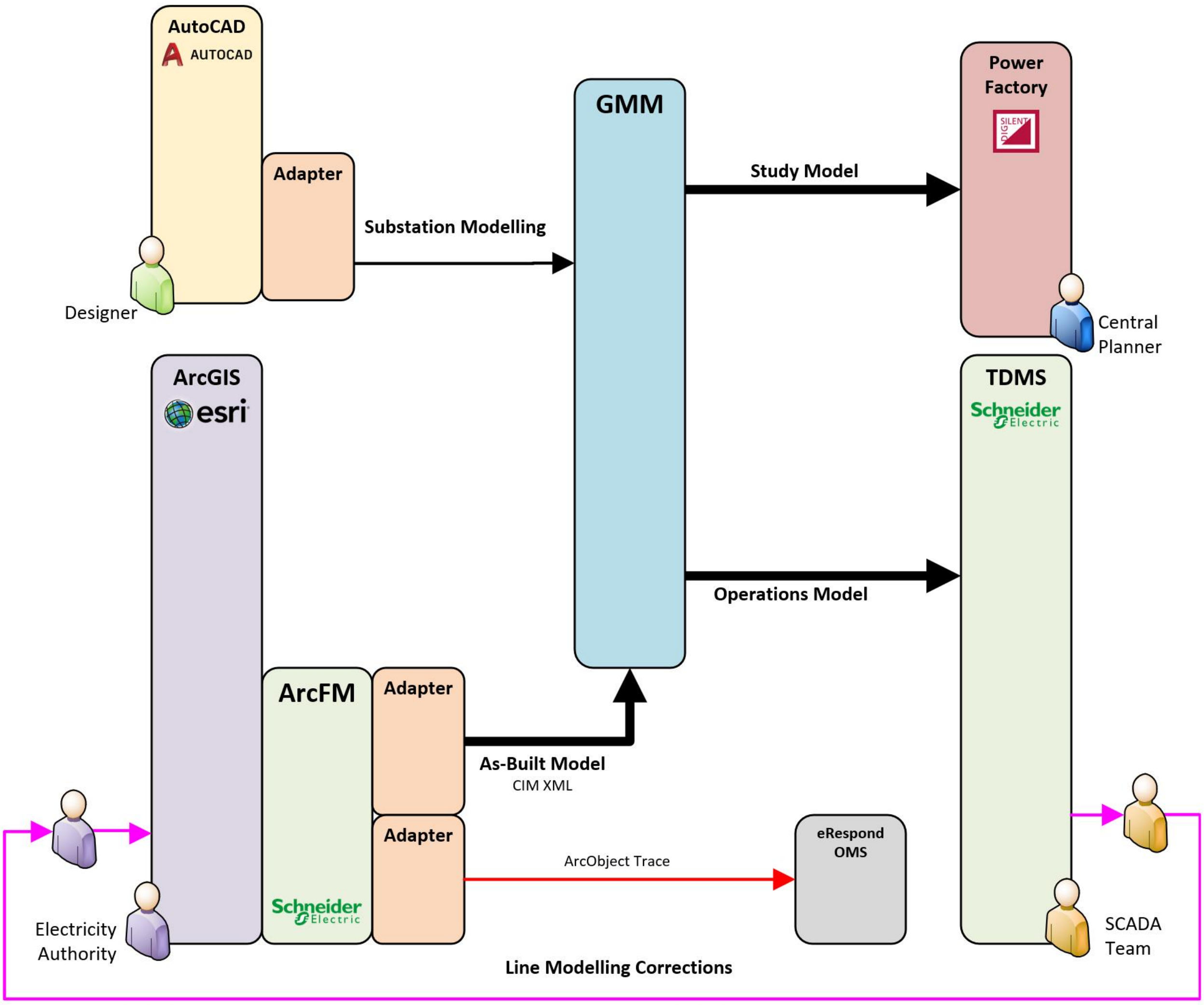
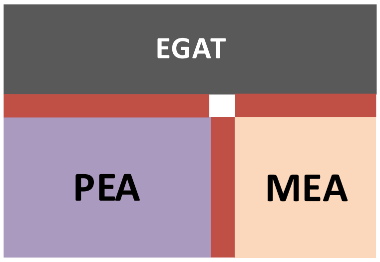


Figure 52. Phase 1 GMM Modelling

1a: GMM Selection

One of the most challenging sub-tasks in the GMM roadmap is the selection of the GMM tool itself. While EPRI has developed functional requirements to help guide utilities select effective solutions, there are currently no products on the market which satisfy all the requirements. Given the timeframe and areas of focus for this initial phase, a GMM which can manage current snapshots (as-builts) for multiple frames is essential. And since the major advancements in modelling for PEA will be in the area of substation modelling, tools which have less experience in MV and LV modelling can be selected, assuming the tool's roadmap for releasing distribution-specific features is aligned with the plan.

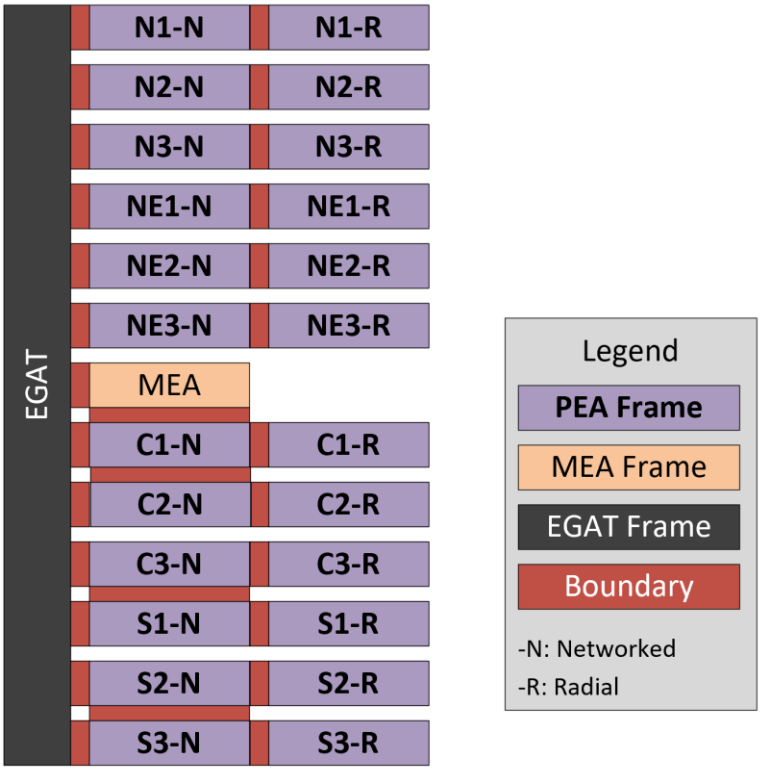
Frames are used to partition grid models into separate but connected regions for two reasons. First, frames should be used when different modelling authorities exist. This is clear when there are different companies; thus, frames for EGAT and MEA are essential. For example a simple framework as shown on the right could be adopted.



However, this is also the case when there are different modelling authorities inside a single company. In PEA there are twelve areas, hence there can be twelve frames to allow each region to manage its own portion of the grid.

Additionally, since the source data for substations is primarily AutoCAD rather than the GIS, we are suggesting splitting each area in half; one noted by "N" containing the networked grid (primarily the HV lines and substations) and another noted by "R" containing the radial portions of the grid (primarily MV and LV circuits). The frames should not be chosen rigidly, for example exactly at a specific voltage; rather as much of the model should be pushed into the "R" frames so long as the modelling is completely sourced from the GIS. The "N" frames should contain all substations and as many of the HV lines as to minimize the crossings stored in the N/R boundaries. A representation of the proposed PEA framework shown on the right:

The second reason to utilize frames is to support different consumers. For example, EGAT might only need PEA's HV frames. MEA might only require the PEA's C1-HV frame. And internally system planners today example the system by area. And when central planners examine the full system, they may wish full details for the N frames, but simplified frames for the R frames. Tools like OPSAonGIS will only require information from the R frames. And so on.



1b: "R" Frame Selection

The CIM XML interface developed to populate models into the TDMS for SCADA Phase 3 will be repurposed to build the twelve "R" frames, and potentially some of the "N" frames. The "R" frame conversion should be relatively simple; however the "N" frames will be more complex (see next section). As noted above, "R" frames should have as a single source the ArcGIS, and therefore since the data is currently available to build the TDMS model, that same data can be used to build the twelve "R" frames.

1c: "N" Frame Selection

The "N" frame populations scheme will be substantially more complex than the "R" frames. That stated, the benefits of a more through modelling of the substations should being major advantages to PEA in the long term. The "N" frames will consist of both HV lines (with the ArcGIS <u>or</u> AutoCAD as the system-of-record) and substations (with AutoCAD as the system-of-record). The line population should be built upon the existing CIM XML ArcGIS-to-TDMS interface. The substation population will be new development.

Options for building substation models are plentiful:

1. AutoCAD itself (most likely through the AutoCAD Electrical package) can publish the substations models directly,
2. A 3rd part tool is added to the AutoCAD environment to automate the building of the substation models,
3. The selected GMM tool will have the capability to "reach into" AutoCAD and extract substation models,
4. PEA will to build its own substation build interface, or
5. No export from AutoCAD; PEA staff will manually create the models in the "N" frames in the GMM based on the AutoCAD design documents

The costs, risks, and benefits should be analyzed all options. And to be clear, some options (like #2 may have different tools which can lead to many more than 5 options). Clearly though, a native solution (either #1 or #3) will have an inherent advanced simply through the benefit of not introducing yet another tool. However, if those solutions are not available or have major issues their inherent functions, then the other options may be more reasonable choices.

Even if option #5 (manual building) is chosen, this should not be seen as a step backward. This one data population task would replace at least three separate model building processes that are currently performed today. So not only will there be a savings in labor costs, but also having a single source of the model when complete will mean the removal of modelling differences which can be found today in different departments. Plus, for initial population leveraging models in the TDMS is a strong option so that merely new changes be manual, and centralized in the GMM.

One other significant issue is deciding how the alignment between line data from GIS and substation data from AutoCAD is made in GMM. One option to consider is that each of the "N" frames will itself be a collection of much smaller frames; specifically, a collection of subframes that hold each of the substations. This granular dissection of the grid from an information organization perspective will likely make the population of data much easier. Each design in AutoCAD will correspond to a single substation frame within the "N" Frame, and the GIS perhaps capable of populating the line details in the super-frame. The advantages and disadvantages of this and other frameworks should be considered before adopting an official approach

1d: MRID Generation

One of the fundamental concepts in GMM is that the definitions for the equipment in the grid and the connectivity among equipment be managed separately from the assets which are installed. We are recommending a CIM-based GMM solution, which means that the equipment identifier should be a Master Record Identifier (MRID). Specifically, each piece of equipment in the grid model is a Power System Resource with and MRID and optionally, one or more human-recognizable names may be associated with the Power System Resource.

Assuming PEA's asset management system leverages a CIM-based model, each individual Asset in the system would itself have a MRID and optional Names. Essential to this modelling is the relation between the Power System Resources and the Assets which allow for common attributes to be shared, for example impedance or current rating.

The lifecycle of the Power System Resource and the Assets are different. For example, consider the following simplified process:

> Step 1: Design engineer specifies and Breaker with parameters specified for current rating and breaking capacity. In the GMM, a Breaker is created with a unique MRID. Note that a Breaker is a type of Protected Switch, which is a type of Switch, which is a type of Conducting Equipment, which is a type of Equipment, which is a type of Power System Resource.
>
> Step 2: The breaker is purchased and logged into the asset management system. A different MRID is generated to track the breaker's lifecycle. Note that the physical breaker may have a current rating and breaking capacity slightly different (but with allowed tolerances) of the designed breaker.
>
> Step 3: The physical breaker is installed. The association between the physical breaker (Asset MRID) and the breaker role in the grid (Power System Resource MRID) is now established. The design parameters may be updated to the actual values of the asset.
>
> Step 4: Some time in the future, the breaker is replaced with a new asset. The new physical breaker has a new Asset MRID; however, the Power System Resource MRID remains unchanged. Only the relationship is updated and, as before, if attributes of the new asset vary, those values may be updated in the grid model.

In the example, the MRID of the Power System Resources exists before the asset is purchased. The MRID of the Asset is created before it is installed and associated with the

Power System Resource. And finally, that relationship is not permanent; as assets and even designs change overtime and the grid is modified.

Regardless of which system stores the mappings between Power System Resources and Assets, it is important to determine the point in time when the MRIDs are generated, and which system generates those numbers. MRIDs must be unique across the utility and a central system (which could be the GMM) will need to generate them for use by any CIM-based system. Non-CIM systems will need to be mapped into these identifiers if those systems to not have the ability to track external identifiers.

All of this is to state that when engineering design is complete and the electrical parameters and equipment connectivity are published to the GMM (in phases 1b and 1c), it is essential that the MRID generation process be established, and those interfaces leverage that process. The engineering design platforms (AutoCAD and ArcGIS) may or may not be aware of the MRIDs. If unaware, there must be a mechanism to examine designs to determine which are new (requiring new MRIDs) and which are updates (leveraging existing or primarily existing MRIDs).

In summary, most of this process is about things that take place outside the GMM. What the GMM “sees” is simply a power system resource that has properties. When plans reach a stage where the asset is known, an import will update the power system resource properties, including importantly the association to a known Asset.

1e: Consumer As-Built Model Creation

Compared with the previous steps in this phase, building an as-built model for either operations support, planning support, or potentially support of any other PEA department, should be relatively easy. The GMM solution chose should be able to combine frames and create models based on requirements. Advanced features which could be established at this point, for example:

- The ability to remove specific equipment types, for example removing breakers
- The ability to simplify frames or even portions of frames, for example aggregating loads below a certain voltage level

More importantly, all of the consumer tools will need to be able to accept a CIM-based model. This should be relatively straightforward for operations, as the the PEA-developed CIM XML interface will already in production. All other consumer tools, e.g. DIgSILENT and OpenDSS, must be capable of reading CIM models natively. As a fallback option, some GMM tools may be able to publish propriety model, e.g. native DIgSILENT or native PSS/E and this option may be reasonable to implement. It is important to note that regress of format and any marketing hype, these processes are almost always more complex than expected with small difference in definitions which need to be resolved in testing.

Finally, once an as-build model is available, this model can be manually published to EGAT and MEA. This may satisfy annual planning processes. Moreover, having this example for these companies which are most likely lagging PEA in their modelling processes will give them good samples with which they can develop new import/export tools.

Phase 2: Add New Grid Model Data Sources & Grid Model Consumers

With the complete as-built PEA system delivered in Phase 1, this phase is focused on leveraging that model for more consumers and enriching the data set with additional data elements. Phase 2 updates can be performed in series or in parallel, as improvements are largely compartmentalized.

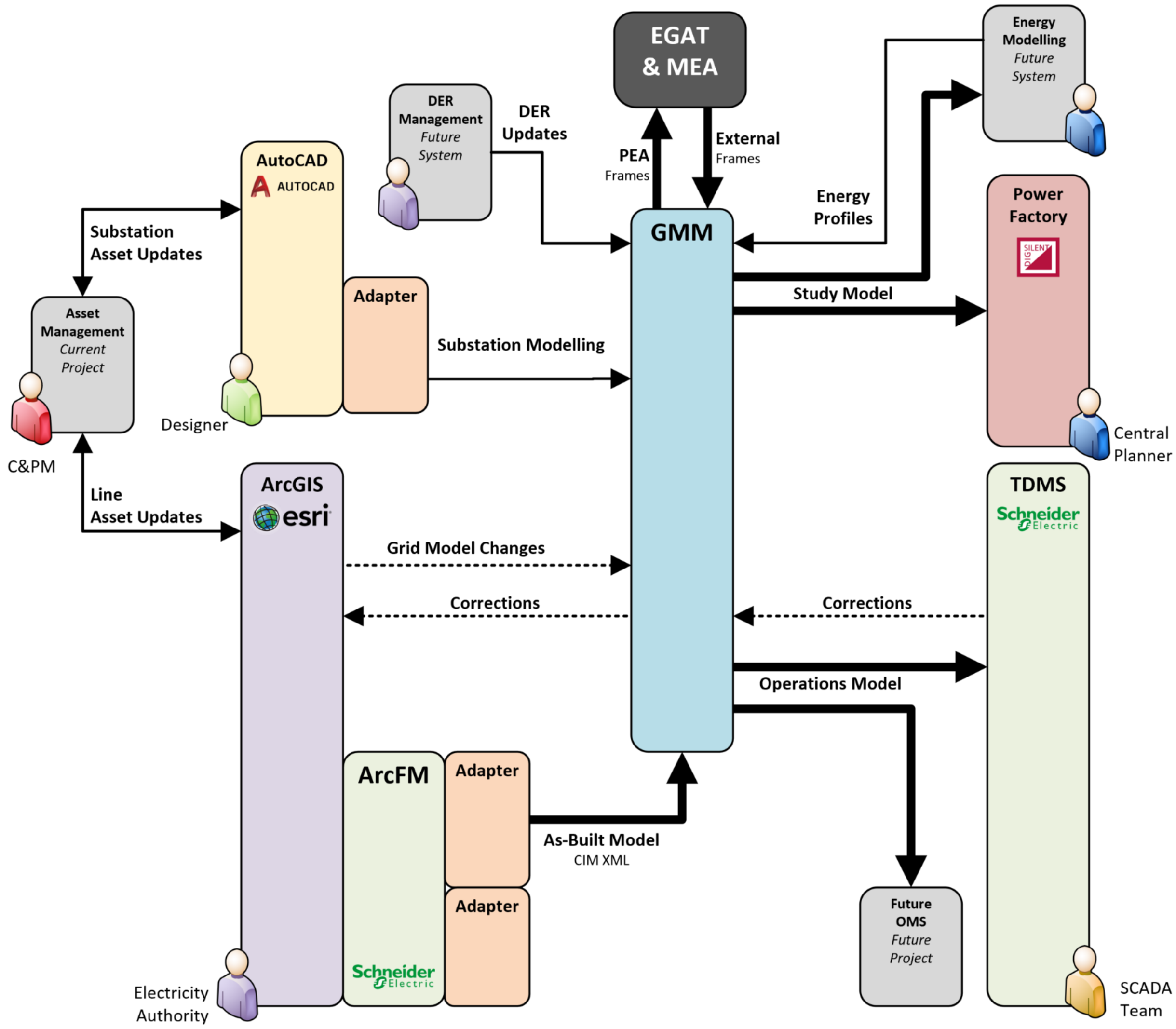


Figure 53. GMM New Sources & Consumers

2a: Asset Management

With the implementation of the PEA-wide asset management solution assumed to be completed by this time, there will likely be improved data sources in that new system which can be leveraged in the GMM. Fundamental to this interface will be a mapping between the invariant equipment identifiers in the GMM (MRIDs) and the identifiers which change when asset changes are made in the field (PEA Numbers).

Asset updates may trigger design updates. And for this reason, it is probably a better idea to push asset updates to the source design systems (ArcGIS and AutoCAD) and then utilize the existing GMM updates interfaces. If this path is chosen for either or both line and substation design, MRID mappings could be stored in those systems. Alternatively, a separate mapping system could be utilized. All options should be examined here before a decision is made for this key step.

2b: DER Management

It is assumed that by Phase 2, PEA will have implemented some sort of DER Management solution. The DER Management solution will track the status of each DER interconnection for proposal though to energization. DER management starts with receiving requests to connect DERs that must be reviewed. For larger DERs, review entails analysis which requires modeling.

Similar to asset management, the MRID for the DER should be generated from the GMM and communicated back to the DER Management solutions. Then, again like the Asset Management solutions, DER parameters can be communicated to the GMM when available.

If grid location is tracked in the DER Management solutions, that platform will require at least a rudimentary grid model which should be supplied by the GMM. On the other hand, if DERs are associated with customer accounts, the DER Management solution may be grid "unaware" and the GMM would be able to "attach" DERs to the model through an interaction with whatever system at PEA maps customer to the LV network, likely either SAP and/or ArcGIS.

Note that the DER Management solution may or may not be closely related to a DERMS component for operations. The DERMS, whether separate or connected to the DER Management system, should operate on the same model upon which the TDMS operates in real-time.

2c: Corrections

Phase 2 also incorporates the first feedback process into the GMM. As new models are vetted by Operations Planning in the staging environment and errors are inevitably found, these corrections to the model can be sent back to the GMM. If necessary, those changes could even be communicated back to the GIS for data that are sourced from that system if the modelling is sourced outside the GMM.

2d: External Models

Similar to the CGMES process in Europe, PEA frames can be periodically published for use by PEA's neighbors: MEA and EGAT. Depending on use, these entities may wish for a full model, similar to what is published for PEA Operations, or may want a simplified model, perhaps more similar to what is published for PEA Planning.

Phase 2 continues to be focused on as-built models. If short-term future components, for example a new substation, are in the model they will appear with "pseudo-switches" that keep them isolated from the existing grid model. Again, depending on purpose, these future grid elements may or may not be included in the published models.

If MEA and/or EGAT has equivalent models available for PEA to utilize, the EGAT and MEA frame elements may be replaced periodically with these models. It is assumed that up to this point, MEA and EGAT frames will be PEA managed models with only a small number of grid elements in those frames represented the traditional view of PEA into its neighbors. More detailed models which are managed by the external entities will likely need simplification for different PEA consumes, so it is important that the GMM is capable of manipulating models in certain frames, for example merging all loads below a certain voltage to an equivalent aggregate load.

2e: Energy Modeling

Several factors have been making the traditional load forecasting process more complicated: more variations in demand including flexible demands like demand response, embedded and often weather-sensitive local generation sources, and increasing number of energy storage solutions which can shift loads seemingly arbitrarily to the utility. To model these new variables, utilities will likely be turning to more advancing load (or more correctly, net load) modelling solutions from software vendors. These solutions will need some level of grid modelling and, ideally, information about the embedded DERS (see Phase 2b).

Once developed these load and embedded generation profiles, together in the GMM architecture we call "Energy Modelling", are useful for daily operations. Moreover, important cases - that is cases that are particularly hard to operate the grid to support - should be saved for future planning and training studies. Because these energy models are valid for a particular model, the GMM at this level of development should be able to manage these unique solutions for use by any GMM consumer.

2f: Outage Management

Today, the eRespond OMS is a stand-alone system with its own model building process coded in ArcObject. As a part of the OMS upgrade project, there should be coordination so that the model used in that new system is tightly aligned with the TMDS Operations platform. The alignment can take one of two forms:

> **Stand-Alone OMS:** If the new OMS is an upgrade to eRespond platform and a new stand-alone system, it should be coded to accept the Operations model. This way the models are identical feeding the two operational systems. This is the option shown in the Phase 2 figure above.
>
> **Integrated OMS:** If the new OMS is an extension of the TDMS, or perhaps a tightly coupled tool which operates closely with the TDMS, there may not be a need to supply a grid model to the OMS at all. Rather this OMS

implementation style would run directly on (or directly from) the grid model in the TDMS.

Phase 3: Enhance GMM with Projects & Future Modelling Features

While Phase 3 has fewer new systems leveraging the GMM infrastructure than other phases, it represents a major conceptual step forward: the management of future grid changes through the concept of Projects. Like corrections and updates to the as-built model, Projects represent collections of additions, subtractions, and modifications to the grid model, but in this case for a future state of the grid. Projects allow for the planning the "unknown", in that any number of future options may be modelled in a library of Projects. As time moves forward, certain Projects will be become more logical options and the less optimal options will be discarded continuing until the point where the best option is selected, constructed, and energized.

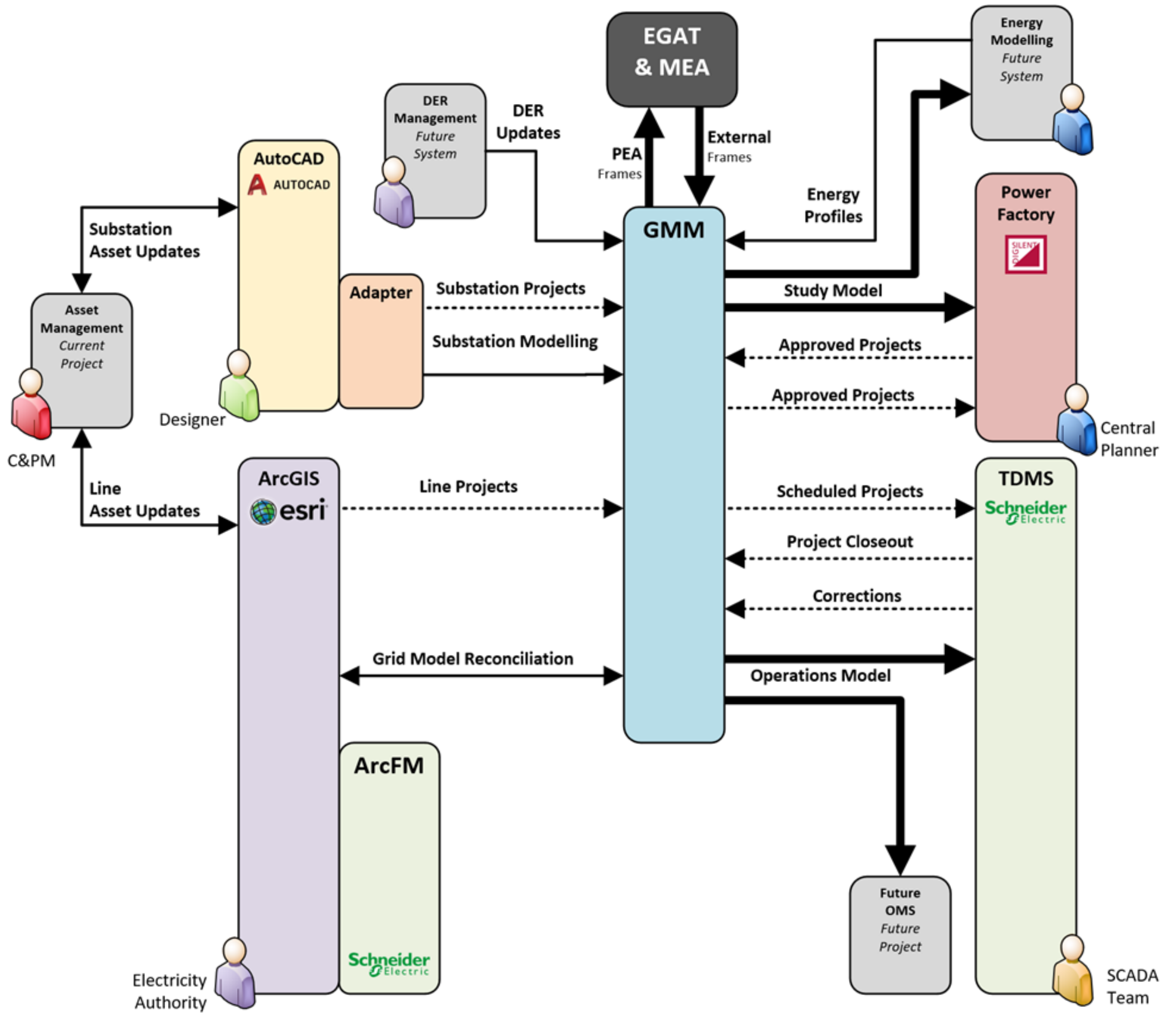


Figure 54. Phase 3 Projects and Future Modelling

Thus, projects server two functions. First, the Planning function allow for engineers to study different options under different scenarios to help evaluate the merits of the options, and the implications of other grid changes under those different scenarios. Second, projects can be used to simplify the energization process. When switching order are developed to energize new or changed grid circuits, the Projects can be shared among different users and systems until the complex set of steps is performed to move that Projects into the As-Built model.

3a: Project Submission

Substations Projects and Line Projects will be generated, as they are today, in AutoCAD and in ArcGIS as currently performed. A new interface, like the model building interfaces but for changes rather than complete models, will be introduced in this phase. The GMM will need the capability of storing a library of these Projects that users may request to be added to their models on publications. Looking even farther into the future, a subset of projects from the Planning Department which make some sort of minimum threshold for publication to the PEA enterprise should be imported from PowerFactory into the GMM. Once the design versions are created, these less detailed planning versions will be deprecated in the GMM.

3b: Project Publication

Projects can be "applied" to models which effectively move the As-Built Model into a future state. Projects can also be "passed" with models, for example passed to Operations' TDMS platform for short-term energization/switching planning. In the former case, there will need to be a new GMM service to allow for the publication of Projects. In the latter, a feature in the GMM will need to be enabled to allow Projects to be applied by users when models need to be built to support future modelling scenarios, and the existing Grid Model publication interfaces will be utilized without major change.

3c: Equipment State Updates

With the implementation of Project energization processing in the TDMS, notifications to the GMM will need to be relayed back to the GMM so that other consumers, and indeed the TDMS upon its next model build, get the appropriate Projects applied to the As-Built Model. Functionally, this GMM feature looks not different from the process of applying any change to the As-Built Model. Operationally, it should be a new interface that automates the process based on steps performed by Operations staff in the TDMS.

Will beneficially for energizing new circuits, the interface to change equipment states in the GMM have many other uses. Any non-temporary chance can be published back to the GMM to make the model more reflective of current state. For example, if there are seasons substation configurations, relevant steps in the switching orders can updates the GMM so that the As-Built model truly reflects the proper "normal" state of equipment.

3d: Model Reconciliation

Finally, it is important to note that by the end of Phase 3 of the GMM project, the GMM is essentially at its design target based on the GMM Architecture EPRI is proposing today. That means that the GMM is the single source of truth for equipment and connectivity and more and more curation of the model will happen I the GMM.

The side-effect is that fewer activities will be performed in the GIS and as this is PEA's system-of-record for line modelling today, it is possible for the GIS model to lag the GMM model. Therefore, a reconciliation process should be established with the GIS (and perhaps with other systems like AutoCAD and Asset Management as well) to ensure synchronicity among models.

There is a “tipping point” in the GMM requirements when Operations beings to leverage Powerflow solutions in real-time. Likely not a matter of if this will happen, but rather when this will happen. Once the transition occurs, Operations (and specifically the Schneider TDMS) will have the most current model of the grid. In turn, this means that Operations must publish those updates back to GMM in a timely and accurate way, so that other systems, perhaps even the GIS, can subscribe to those updates through the GMM. With a complex system of systems all capable of collecting grid changes, the reconciliation and eventual data difference resolution process should not be ignored.

Other Considerations

Staffing

Once the GMM project is completed, there will be an entirely new set of processes and systems to manage grid data. This infrastructure will require a dedicated team not only to manage the information technology, but also the more subtle issues around approving data coming into the GMM from source systems plus changes and Projects and reconciling different contributes from different departments at PEA.

New skills will need to be brought into PEA. Clearly, staff training on the GMM tool itself will be required. There will also be a need to be more PEA staff who are educated and experienced in the CIM. This sort of training can happen well in advance of the project, both formally with other projects leverage the CIM (such as the SCADA Phase 3 project) and informally as staff are encouraged to read about the CIM, explore modelling tools and existing standards, and attend training and user conferences.

When GMM Phase 1 is initiated, it is recommended to assign some staff to the project who will most likely form the nucleus of the GMM support team. Some staff may come from the enterprise architecture and/or IT side of PEA. Others should come from the business side, specifically several staff who understand grid modelling, including how equipment and connectivity are modelling in the CIM. Additional skills in the supporting modelling tools (ArcGIS, AutoCAD, PowerFactory, etc.) will be beneficial.

CHAPTER 6 ECONOMIC ANALYSIS

Summary

Task 6 is an economic analysis continuation which compares the existing process and systems documented earlier in the project versus projected costs and benefits of implementing the proposed GMM vision based on the Task 5 “Conceptual Sequencing of System Design & Implementation” report.

The outcomes of the task are:

- Categorize as-is and future state costs and benefits
- Quantification of costs and benefits
- Cost and benefit calculations based on comprehensive spreadsheet calculations

These results will be utilized by PEA in designing future implementation planning to achieve the CIM-based GMM vision.

Introduction

From an economic analysis perspective, projects such as the GMM vision are challenging to evaluate because some of the benefits are episodic and difficult to forecast or quantify. Also, the GMM vision creates a system with characteristics of a platform, which suggests the possibility of uses and benefits beyond those currently envisioned. That is, platforms may have strategic value that cannot be described or quantified until the new functions appear and mature in the future. A strategic decision adopts a vision of a future state that is not fully formed in the present, and may not appear to completely cover its costs in the present. Nevertheless, it is important to examine the foreseeable costs and the benefits to bridge that strategic leap to the future state.

The GMM Vision: A Strategic Choice

The GMM vision describes a single-source-of-truth model-data management system that fundamentally changes a host of business processes within PEA dealing with how planning and operations system models are established and maintained. The major benefit areas have been described in prior reports as follows:

- Reduce labor, as duplicate modeling is eliminated, as work steps are automated, and as time spent synchronizing, validating and correcting data is minimized
- Improve the accuracy of study results and reduce the likelihood of significant errors
- Increase the ability to perform sufficient and sufficiently timely studies
- Improve the ability to compare study inputs and results across tools
- Enable more efficient and effective sharing of modeling with external entities

- Create an environment in which future study applications can be quickly and easily deployed

From an economic analysis perspective, projects such as the GMM vision are challenging to evaluate because some of the benefits are episodic and difficult to forecast or quantify. Also, as suggested by the final bullet above, the GMM vision creates a system with characteristics of a platform, which suggests the possibility of uses and benefits beyond those currently envisioned.[3] That is, platforms may have strategic value that cannot be described or quantified until the new functions appear and mature. A strategic decision adopts a vision of a future state that is not fully formed and may not appear to completely cover its costs in the present. Nevertheless, it is important to examine the foreseeable costs and the benefits to bridge that strategic leap to the future state.

First, we will examine conventional cost-benefit analysis as it occurs in the utility planning context as it deals with discretionary and non-discretionary projects. Then we will categorize the cost structure of utilities to pinpoint where costs (and cost reductions) occur, along with the customer and societal perspectives that complete an economic evaluation of utility decisions. Finally, we will place costs and benefits within the framework, and provide some brief economic calculations with estimated costs and benefits.

Conventional Cost-Benefit Analysis

Most utility economic analysis in the planning and operations areas deals with problems the utility is obligated to solve. The obligations were established long ago, and their economic value is no longer questioned; we don't have to estimate the value of electric service. Solving these problems is non-discretionary. When utilities encounter problems they must solve, they are expected to solve them at least-cost to customers, but they don't have to justify why they need to solve the problem. However, many projects a utility might see as beneficial are either not yet proven or not really necessary under the current view of its obligations. For these discretionary projects, the utility needs to justify them by showing that their benefits outweigh their costs, all from the perspective of customers and/or society at large. Implementing the GMM Vision is one such discretionary project. If it is not clear that the utility must do it, then the utility should satisfy itself and its stakeholders that the benefits are sufficient to justify the cost. This requires a full two-sided cost-benefit analysis.

Cost-benefit analysis of a project compares its costs with its benefits to determine whether the benefits outweigh the costs. Costs include the cost of implementing the project plus costs of operating and maintaining the asset or service for a period of time. Costs can be offset by monetary savings, or savings can be included as benefits (pointing to a problem with the benefit/cost-ratio metric). Benefits can include many direct or indirect changes brought about by the project. However, it is important to note that the savings are changes relative to an alternative state. The analyst needs to understand not only the costs of

[3] Smart phones are an example of a platform where new uses emerged after the platform became ubiquitous. For example, when it became common for people on the street to be carrying communicating computers with GPS and graphics capabilities, ride-share services emerged to operate through the platform. Smart phones were not created to enable ride-share; ride-share came into being after being made possible by the platform.

establishing and operating with the project, but also the costs and operating of the alternative. Consequently, it is important to understand and describe the alternative.

The alternative to the GMM vision is assumed to be continuing as usual, so the costs and characteristics of this approach must be examined and forecasted into the future. If problems with business as usual are accumulating with time, perhaps because of greater volume of work or added functions related to DERs, for example, then the costs of growing current practices must be estimated along with its increasing difficulties. The cost of labor will likely increase, and the amount of labor required for all the various data-handling activities may increase as well, compounding the business-as-usual costs.

Categorizing Costs and Benefits

Organizing our approach to estimating costs and benefits, it is useful to categorize them in a utility concept beyond just fixed and variable cost. First consider to whom the costs or benefits accrue, whether within the utility, among its customers, and/or to society at large. These categories are nested, in that customers are part of society and customers generally are responsible for utility costs.

Referring to Figure 55, within a utility we identify three domains of costs and benefits:

1. a **utility operations** domain that includes the utility's employees and how they do their jobs, the tools and non-production assets they use,
2. a **system operations** domain that includes the operating costs the physical utility system (most of which will be described within the GMM) and their costs, and
3. the utility's **production assets** that compose the physical system, here referring to cost of the assets and the accounting rules that result in revenue required to recover investments and meet financial constraints.

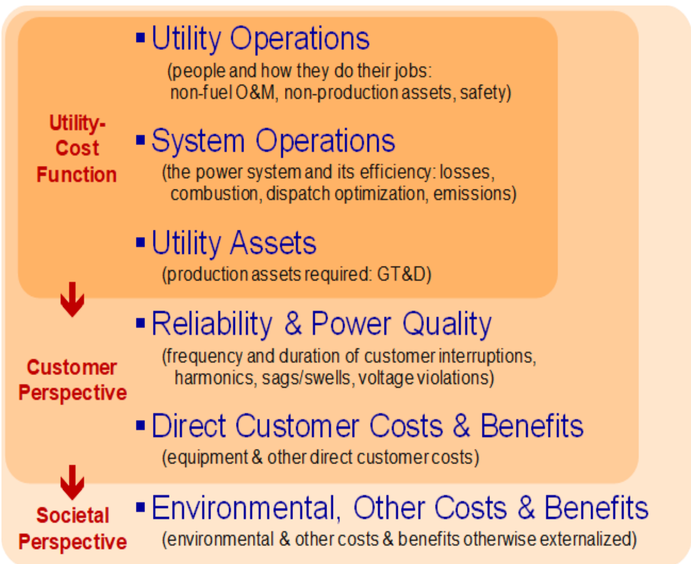


Figure 55. Categorization of Utility Costs and Benefits

For an example, consider a typical substation. Its utility assets include the wires, transformers, breakers, switches, supports, computers, and communication equipment inside and including the fence and the land it occupies. All the production assets are represented in the utility's financial accounts. The system operating costs of a substation are not a large component, consisting of only the losses in the conducting assets including parasitic loads like cooling fans. The utility operating costs of the substation include the labor, materials, reagents, coolants, and non-production assets to service and maintain the assets, i.e., the operations and maintenance (O&M) costs for the substation. Stated differently, the substation has conducting components involved in system operation, it requires utility operation labor and materials, and the substation assets reside on the utility's financial books where their original costs are recovered through the rate-making process. Coincidentally, the physical assets will be fully described within the GMM for use in various planning models and systems, and could include important accounting data as well. The question for the cost-benefit analysis is where and how the GMM vision will impact these various costs within the utility-cost function, and whether there are any impacts falling within the remaining domains.

In a conventional utility planning framework, all utility costs and benefits are passed to the utility customers. But customers have their own costs associated with electric service, and these costs can be included in cost-benefit analysis if they can be quantified and monetized. When customers experience reliability issues, they bear the costs associated with interruptions. Similarly, customers experience the effects of power quality degradation, so a complete perspective of utility decisions in the customers' interest includes not just utility cost, but also these customer costs associated with service quality. In the U.S., customer interruption costs have been used to justify utility investments in distribution automation, justified because these improvements can easily demonstrate improved reliability.

Conventional Economic Planning Methodology
Planning analysis deals with the future, and its analysis framework usually envisions an idealized simpler version of what might happen in reality. Planning analysis assumes, for instance, that under all planning alternatives, the utility recovers its full cost, but only its cost, and that customers pay the utility's full cost through the rate structure. The rate structure itself is not usually a concern in analysis of planning alternatives. Any cost savings are assumed to reduce costs borne by customers, and the utility selects projects among alternative investment paths by choosing the path that produces the least net cost for customers. Utility concerns such as timing of rate relief or current financial conditions are important matters of financial planning, but not usually within the scope of utility system planning analysis.

Finally, there is a societal perspective that includes impacts occurring outside the customer group. For utilities that burn fossil fuels, this might include the cost of emissions of various types, including CO_2 emissions that have implications more global than local. In some jurisdictions, regulators require their utilities to include societal costs in their planning decisions even though the costs are not part of the utility's cost structure. But by planning to minimize customer and societal cost, the utility's decisions are shifted in a way that reduces their societal costs.

Cost and Benefit Categories				Δ Present Worth	Year 1 Δ	Year 2 Δ	...	Year n Δ
Economic Costs and Benefits	System Operations		Fuel					
			Purchased Power					
			Ancillary Services					
			Emissions - SO_2, NOx, CO_2					
			Operator Costs					
			Revenue on Enabled Sales					
	Utility Operations	Non-Fuel O&M (Operating and Maintenance)	Generation					
			Transmission					
			Distribution					
			Customer					
			Admin & General					
		Non-Prod Assets	Trucks, A&G, Tools					
	Utility Assets	Capital Deferral/ Advancement	Generation					
			Transmission					
			Distribution					
	Customer Reliability		Interruption Costs, Sustained					
			Interruption Costs, Momentary					
			Interruption Costs Major Event					
			Interruption Costs, Other					
	Customer Direct		Value of Service (Comfort, Light, etc)					
			Cost of equipment (Devices)					
	Other		Savings from Theft Reduction					
	Power Quality Impacts		Change in Momentary Outages					
			Change in Sags, Swells, Voltage violations					
	Societal Costs/Benefits		Social Cost of Emissions					
			Other					
Qualitative, Informative, or Already Included	Environment		ΔTons SO_2					
			ΔTons NOx					
			ΔTons CO_2					
			ΔPounds Hg					
			ΔParticulates					
	Security Impacts		Oil Saved					
			Major Blackouts Avoided					
	Efficiency Impacts		ΔkWh System Losses					
			ΔkW System Losses					
			ΔkWh Consumed					
			ΔkW Consumed					
	Metering Impact		Metering Accuracy					
	Safety Impact		Public Safety					
			Employee Safety					

Figure 56. Table showing additional details in the cost-benefit domains, complete for a vertically integrated utility

The cost and benefit categories can be divided into more detailed sub-categories that begin to bridge the gap between the conceptual domains and the internal utility accounting. The table in Figure 56 was developed from EPRI's Smart-Grid Demonstration Initiative a decade ago and shows some of these details, as well as a section of indicators or metrics that some analysts or jurisdictions may find desirable. No section is exhaustive, and it is possible that many of these sub-categories may not apply to PEA. Metrics in the lower section are important but difficult to quantify, and thus may be included qualitatively in scoring various alternatives.

Some regulators may be interested in efficiency improvements, for example, but the monetary impact of such improvements is embedded in fuel or purchased-power costs and would need to be backed out of those categories to avoid double-counting. Of particular interest to the GMM Vision is perhaps the last two categories of public and employee safety. While it is possible to connect improved system information in the field to increases in safety, it is difficult to quantify this connection except anecdotally. Nevertheless, the table has been used in some analyses to illustrate where in the utility's cost structure a project has impacts, whether higher or lower costs, especially in situations where the benefits are difficult to quantify.

Analysis of the GMM Vision in Terms of the Categorized Costs and Benefits

Implementing the GMM vision will affect all three utility domains: system operations, utility operations and production assets. These may have some impact in the other domains in addition to utility-cost changes.

- Most of the cost impacts will be in the utility operations domain. It will require some investments in IT hardware and software. It will also require the attention and labor of utility employees to implement GMM, create the various required interfaces, and adjust procedures to it. As the organization reaches its steady future state of the GMM vision, its labor and practices should cost less and produce superior results compared with the present state. Ultimately, it should improve decisions and timeliness in planning and central operation. It will improve the utility's ability to plan and incorporate newly built assets.
- Outside the utility's offices, the information available to employees in the field will improve their performance, improving reliability and response time.
- Its impacts on system operations are less direct, but a GMM implementation could lead to design improvements and subsequent improved system reliability and efficiency. Subsequently, improved reliability and reduced response and recovery times will affect the customers' cost domain, especially for commercial and industrial customers whose value of continuous service is high.
- Improved information in operations and in the field could reduce the risk of errors or conditions that would compromise public and employee safety by reducing the need for PEA field staff to physically drive to locations in order verify as-built field installations.
- Finally, the platform nature of GMM creates an environment in which future study applications can be quickly and easily deployed.

Cost and Benefit Categories (Distributor Utility)				Impacts
Economic Costs and Benefits	System Operations		Purchased Power	
			Operator Costs	↓
	Utility Operations	Non-Fuel O&M (Operating and Maintenance)	Transmission	↓
			Distribution	↓
			Customer	
			Admin & General	↑
		Non-Prod Assets	Trucks, A&G, Tools	↑
	Utility Assets	Capital Deferral/ Advancement	Transmission	
			Distribution	
	Customer Reliability		Interruption Costs, Sustained	↓
			Interruption Costs, Momentary	
			Interruption Costs Major Event	↓
			Interruption Costs, Other	
	Customer Direct		Value of Service (Comfort, Light, etc)	
			Cost of equipment (Devices)	
	Other		Savings from Theft Reduction	
	Power Quality Impacts		Change in Momentary Outages	
			Change in Sags, Swells, Voltage Violations	
	Societal Costs/Benefits		Social Cost of Emissions	
			Other	
Qualitative, Informative,	Safety Impact		Public Safety	↑
			Employee Safety	↑

↓ Favorable Reduction ↓ Unfavorable Reduction
↑ Favorable Increase ↑ Unfavorable Increase

Figure 57. Summary with cost/benefit areas indicated for GMM implementation. Table is collapsed for a distribution utility with load-serving responsibility.

In Figure 57, impact areas are indicated on a reduced version of the costs and benefits table, which has been collapsed to the rows that might be relevant for a electricity distribution company with load-serving responsibilities. Impacts are shown as increases or decreases in the rows shown, with red indicating impacts that tend to increase cost and green indicating impacts that tend to reduce cost or produce favorable outcomes.

We show some O&M costs in the Administrative and General (A&G) area (IT expenses, especially initially), and in non-production assets (computer systems, office space). Operator costs could decline slightly by virtue of operators having better timely information, but it seems more likely that outcomes of operator decisions and actions will be more favorable. Transmission and distribution O&M cost (in-office planning labor) would likely decline as data-handling tasks are either eliminated or transferred to the IT group handling the GMM. Shown directionally in the figure, these impacts may take place gradually as GMM matures.

The number of workers in the field may not change much as a result of GMM implementation, but their time problem-solving in the field could be improved by earlier possession of accurate information about the system where they are working. This would suggest better outcomes of field work, which would show up as a reduction in customer interruption costs, noting that these costs occur outside of the utility, but they are benefits in the utility economic methodology.

As noted in the introduction, final bullet above references the platform nature of GMM that creates an environment in which future study applications can be quickly and easily deployed. This means that some benefits may someday be realized that are currently beyond reach, either because their applications have not yet been developed or they are out of reach given the limitations of the current environment. Some of these benefits may arise from employees who see creative opportunities made possible after GMM is implemented. So while GMM will have some routine benefits that can be currently envisioned and even quantified, there are potential benefits waiting beyond view that afford this project with its strategic nature, a decision to opt for a future state with flexibility to adapt and create new benefits.

Quantification of Costs and Benefits

While benefits from GMM implementation are easy to describe, the task of quantifying them in a convincing way is challenging; quantifications are approximations at best, reflecting the uncertainty in future performance. Costs may not be known with precision, but costs are a fact of implementation. Benefits depend on future developments and may take time to accumulate as the GMM implementation becomes internalized and routine. Some benefits will be changes in routine procedures that will simply reduce the cost of data handling relative to the current state. However, some of the benefits of GMM implementation will be episodic or event-related, contingent on how events unfold. These benefits may occur within the planning areas, or even in the field, where crews depend on quality information to arrive in the right location with the right equipment, and to know what facilities they are going to work on.

The most straightforward items to quantify are labor and investment numbers, even though a great amount of uncertainty may remain in the estimates used. The key for analysis of this type, especially one with strategic aspects, is being reasonable if accuracy is not possible. The analysis will complete a version of the table below in Figure 58. The completed table will combine judgment of those who know the utility best with judgment of those who know the GMM technology best.

The exact years are not specified; they are numbered from 0 to ten. Year 0 should be thought of as the implementation year, when equipment and software is installed and much of the initial local customized software work is being done with in PEA's offices. Year 0 is also the present-worth reference year; all future cash flows will be present-worthed to year 0, indicated as PW_0.

				BHT										
Change in Labor Hours	Change in Labor by Department	Dept	Δ FTEs	PW_0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
	Total Labor Change				**0.00 M**	**0.00 M**	**0.00 M**	**0.00 M**	**0.00 M**	**0.00 M**	**0.00 M**	**0.00 M**	**0.00 M**	**0.00 M**
GMM Deployment and Operations				PW_0	Revenue Requirements (BHT)									
	GMM costs (capitalized)													
	Equipment													
	Software													
	Project Team													
	GMM Operations (expense)				Expenses (BHT)									
	License Fees													
	Total GMM Cost													
Potential Savings				PW_0	Value of Avoided Time Wasted (BHT)									
	Planning Savings													
	Operations Staff Savings													
	Field Savings													
	Total Potential Savings													
Project Cost-Benefit Summary				PW_0	Net Cost (Benefit) (BHT)									
	Labor Cost													
	Total GMM Cost													
	Savings													
	Grand Total													

PW_0 = Present Worth in Year 0

Figure 58. Format for Quantified Economic Analysis of GMM Implementation and Operation

The table in Figure 58 corresponds loosely with Figure 57, where costs or benefits were identified to occur, and expands the areas into further detailed components. Some of the items may have little or no activity or change associated with them, but they may be useful to indicate that they have been considered and deemed negligible.

The table in Figure 57 includes some items that occur within the customers' domain, such as changes in customer cost of service interruptions. It seems likely that reliability measures will be improved by reducing the reaction/repair time when interruptions occur from weather damage or other causes, but this effect is not quantified in this analysis. Reliability impacts are of the episodic type that are challenging to quantify in more than a general or highly approximate way.

Finally, some capitalized labor and equipment costs represented in the table. The capitalized costs will be converted to annual revenue requirements based on PEA's cost of capital and tax structure. Revenue requirements represent the costs of the capitalized items as they are viewed by customers, preserving the customer-oriented nature of the cost-benefit analysis, consistent with the perspectives shown in Figure 55. Revenue requirements fully meet the utility's financial goals with respect to the project; the goals are built into the revenue requirement calculation.

The final section of the table in Figure 58 brings together all the costs and all benefits, included monetized savings in time wasted in activities the GMM will streamline and eliminate.

Data and Assumptions for the Economic Analysis

Table 1. Parameters required for calculations in worksheet 1

Financial and Economic Parameters	
Capital structure (Debt/Equity)	**75.00%**
Interest rate	**3.10%**
Return on Equity	**6.17%**
Composite Income Tax rate	**50.00%**
Wgtd Avg Capital Recovery Rate	**5.41%**
Discount Rate %	**10.00%**
Equipment Depreciation Lifetime	**10**
Labor-cost escalation rate %	**3.00%**
Licence Fee Escalation/year	**3.00%**

Revenue requirements will be estimated for the 10-year length of study, with the present worth reflecting full recovery of the capitalized cost and taxes. The revenue requirement calculations will reflect the parameters in Table 1, which should be set to accomplish PEA's financial goals with respect to the project. In this way, the perspectives of both PEA and its customers will be respected in the cost-benefit analysis results. For capitalized items, the annual charge rates are shown in Table 2 below. These rates apply to each of ten years of amortization of the capitalized costs, reflecting the capital costs and tax rate shown in Table 1 above.

Table 2. Annual Capital Recovery Rates

Annual Capital Recovery Rates for Capitalized Items (interest, taxes, equity return, and depreciation) (Lifetime = 10, RevReq Rate = 5.41%										
Year	1	2	3	4	5	6	7	8	9	10
ARR	15.14%	14.60%	14.06%	13.52%	12.98%	12.43%	11.89%	11.35%	10.81%	10.27%

The direct costs of the project are shown in Table 3. In addition to direct software and hardware costs, there are substantial development costs during the project's first six years to establish the interfaces between GMM and all of the user applications. These costs, hardware, software, and interface development should be capitalized, as they create a platform of lasting value. In addition to these capitalized costs, there are annual software license fees that will be expensed in each year.

Table 3. Capitalized Project Costs

Capitalized Costs (BHT)						
	System		Capitalized Labor			
Year	GMM Software	Hardware	Data Preparation	Interface Development	Testing & Training	Total Capitalized Labor
0	17.50 M	3.50 M	12.50 M	6.25 M	12.50 M	31.25 M
1			3.13 M	1.56 M	3.13 M	7.81 M
2			3.13 M	1.56 M	3.13 M	7.81 M
3			1.56 M	0.78 M	1.56 M	3.91 M
4			1.56 M	0.78 M	1.56 M	3.91 M
5			1.56 M	0.78 M	1.56 M	3.91 M
6						
7						
8						
9						
10						
Total			23.4 M	11.7 M	23.4 M	

Inputs to Table 3:

- GMM Software @ 17.5 M฿ (based on costs of typical systems).
- Hardware @ 3.5 M฿ (based on costs of typical hardware to support a GMM).
- Data Preparation @ 12.5 M฿ during the project.
- Interface Development @ 6.25 M฿ during the project.
- Testing & Training @ 12.5 M฿ during the project.
- After the initial project, additional capitalized labor will be required, and all are assumed to drop to 25% and then 12½% in years 3-6.

Cost-Benefit Analysis Calculations, Commentary, and Summary

Calculations are provided for the worksheet (Table 4) and the cost-benefit analysis summary table.

Inputs to Table 4:

- The new GMM Team to be formed should not be associated with a specific division, for example SPD or POD, but rather should be under and Enterprise-level group, for example DDD.
- The GMM Team should initially consist of part-time resources from various groups, who will migrate to the new department shortly before or shortly after production go-live (hence not overall change to staffing for the core team).
- +1 FTE Staff added to the GMM Team (assumed DDD).
- + ½ FTE staff added to IT to support the GMM application.
- Average PEA salary including complimentary benefits set to 760,000 ฿/year[4]

In terms of potential savings, we focus on recovered time for staff who either perform a task based on misinformation and the task (in part or in whole) needs to be repeated. This time recovery looks different based on department. In Planning, this recovery comes in the form of fast preparation of periodic study cases, utilizing more accurate data with the need to search for inputs from multiple sources. In Operations, the effects are more subtle. More accurate grid models supporting the tools in operations, such as SCADA, DMS, and OMS, means actions taken are more likely to be correct. Today, when discrepancies are found it takes time to determine the correct information and, as above, tasks may need to be repeated with the correct information. The final areas where savings could be seen is in the field. While more likely a much rarer issue, the fact that there are thousands of PEA field crews means that a small improvement in productivity in this domain means a sizeable net benefit.

Table 4. Worksheet for Additional Labor Cost

				Hours										
Change in Labor Hours	Change in Labor by Department		Δ FTEs	Year-0 BHT/hour	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
	Digital Strategy & Enterprise Data Mgt	DDD	+1	380	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000
	IT	ITD	+ ½	380	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
	Total Labor Hours Change			Hours	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000
Change in Labor Cost				BHT										
	Cost of Added Labor by Dept	Dept	Δ FTEs	$\sum PW_0$	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
	Digital Strategy & Enterprise Data Mgt	DDD	+1	5.4 M	783 k	806 k	830 k	855 k	881 k	907 k	935 k	963 k	992 k	1,021 k
	IT	ITD	+ ½	2.7 M	391 k	403 k	415 k	428 k	441 k	454 k	467 k	481 k	496 k	511 k
	Total Labor Cost Change			8.08 M	1.17 M	1.21 M	1.25 M	1.28 M	1.32 M	1.36 M	1.40 M	1.44 M	1.49 M	1.53 M

[4] Salary information based on 2022 data

Table 5. Potential Benefit Calculations for GMM

		PW_0	Value of Avoided Time Wasted (BHT)									
Potential Savings	Planning Savings	4.1 M	0	0.2 M	0.5 M	0.5 M	0.6 M	1.1 M	1.2 M	1.2 M	1.2 M	1.3 M
	Operations Staff Savings	13.1 M	0	0.6 M	1.7 M	1.7 M	1.8 M	3.6 M	3.7 M	3.9 M	4.0 M	4.1 M
	Field Savings	147.0 M	0	7.3 M	18.7 M	19.2 M	19.8 M	40.8 M	42.1 M	43.3 M	44.6 M	46.0 M
	Total Potential Savings	**164.1 M**	**0**	**8.1 M**	**20.9 M**	**21.5 M**	**22.1 M**	**45.6 M**	**47.0 M**	**48.4 M**	**49.8 M**	**51.3 M**

Inputs to Table 5:

- Wasted time in Planning related to missing or incorrect data: 25% for 10 staff
- Wasted time in Operations related to missing or incorrect data: 5% for 96 staff
- Wasted time in Operations related to missing or incorrect data: ½% for 18,000 staff
- Improvement appears in Year 1 @ 10% of the time recovered, in Year 2 @ 25%, and in Year 5 at 50%.

Quantitative Analysis

There are several ways the CBA quantitative results can be summarized. A customer-oriented revenue requirement analysis, shown in Table 6, shows a Net Present Value to customers and IRR from the customer perspective. Revenue requirements reflect how customers are charged over time to cover capitalized costs. Revenue requirements were estimated for the 10-year length of study, each reflecting full recovery of capitalized cost and taxes. The revenue requirement calculations reflect the parameters in Table 1, which were set to accomplish PEA's financial goals with respect to the project. For items capitalized in each year, the annual charge rates from Table 2 are applied for that year and 9 years forward. The charge rates cover ten years of amortization of the capitalized costs, reflecting PEA's capital cost rates and tax rate. The analysis in Table 6 depicts customers being charged over time to cover the GMM capital costs (which are shown in Table 7). The cost column includes these capital-ownership costs as well as the license fees and additional labor costs.[5] The benefits occur through cost savings, under the planning methodology assumption that customers cover all utility costs and benefit from cost reductions. This analysis is consistent with the economic planning methodology as described in the introductory portion of this report. It is common in the U.S. and elsewhere, reflecting the task of regulated utilities to select among planning alternatives so as to provide service at least cost to customers.

[5] The revenue requirement calculation details are included in the accompanying spreadsheet on the "Benefits Estimation" tab, in the tables labeled "Revenue Requirements for GMM Costs" and "Staff Increase Costs." Savings calculations are shown on this tab in three tables: "Planning Potential Savings," "Operations Staff Potential Savings," and "Field Crew Potential Savings."

Table 6. Revenue Requirement Summary

Year	Cost	Saving	Net Savings	Running Total
0				
1	12.2 M		12.2 M	12.2 M
2	13.4 M	(8.1 M)	5.3 M	17.5 M
3	14.6 M	(20.9 M)	(6.3 M)	11.2 M
4	15.1 M	(21.5 M)	(6.4 M)	4.8 M
5	15.7 M	(22.1 M)	(6.5 M)	(1.6 M)
6	16.2 M	(45.6 M)	(29.4 M)	(31.1 M)
7	16.1 M	(47.0 M)	(30.9 M)	(61.9 M)
8	16.0 M	(48.4 M)	(32.3 M)	(94.3 M)
9	15.9 M	(49.8 M)	(33.9 M)	(128.1 M)
10	15.8 M	(51.3 M)	(35.5 M)	(163.6 M)
$\sum PW_0$	90.9 M	(164.1 M)	(73.2 M)	(73.2 M)
		NPV to Customers		73.2 M
		IRR to Customers		45%

A slightly different presentation of costs and benefits is shown in Table 7, which shows returns to the investment and a cash-flow style NPV and IRR.

Table 7. Returns to Invested Capital

Year	Capital	Expenses	Savings	Net
0	(52.3 M)			(52.3 M)
1	(7.8 M)	(4.3 M)		(12.1 M)
2	(7.8 M)	(4.5 M)	8.1 M	(4.2 M)
3	(3.9 M)	(4.6 M)	20.9 M	12.4 M
4	(3.9 M)	(4.7 M)	21.5 M	12.9 M
5	(3.9 M)	(4.9 M)	22.1 M	13.4 M
6		(5.0 M)	45.6 M	40.6 M
7		(5.2 M)	47.0 M	41.8 M
8		(5.3 M)	48.4 M	43.1 M
9		(5.5 M)	49.8 M	44.4 M
10		(5.6 M)	51.3 M	45.7 M
			NPV	60.5 M
			IRR	21%

Because costs and benefits are uncertain, a sensitivity to changes in costs and benefits is provided in Table 8 below, with heat-map formatting to emphasize changes in NPV.

Table 8. Sensitivity on NPV of Return to Invested Capital

Net Present Value Sensitivity								
		Cost Variation						
		-20%	-10%	-5%	0	5%	10%	20%
Benefits Variation	-20%	48.4 M	38.1 M	32.9 M	27.7 M	22.5 M	17.3 M	7.0 M
	-10%	64.8 M	54.5 M	49.3 M	44.1 M	38.9 M	33.8 M	23.4 M
	-5%	73.0 M	62.7 M	57.5 M	52.3 M	47.1 M	42.0 M	31.6 M
	0	81.2 M	70.9 M	65.7 M	**60.5 M**	55.3 M	50.2 M	39.8 M
	5%	89.5 M	79.1 M	73.9 M	68.7 M	63.6 M	58.4 M	48.0 M
	10%	97.7 M	87.3 M	82.1 M	76.9 M	71.8 M	66.6 M	56.2 M
	20%	114.1 M	103.7 M	98.5 M	93.4 M	88.2 M	83.0 M	72.6 M

Implementation of GMM incurs substantive costs, as summarized in Table 9. Eventually these costs may be reduced by labor savings, but these benefits are difficult to forecast, and they are likely to change over time. As described in this report, there are other benefits more difficult to quantify and monetize. Some benefits may be episodic, arising from improved performance in events, or become built into a system with more accurate design. These subtle benefits will accumulate over time, as PEA streamlines its procedures around a twenty-first century system.

Table 9. Cost-Benefit Summary

Estimated Costs (PW_0)	Potential Benefits (PW_0)
• Capital Ownership* ~ 72 M฿ • Operating Expense ~ 22 M฿ • Increased Labor ~ 8 M฿ **Total ~ 94.1 M฿** * *on Capital Investment of 55* M฿	• Planning ~ 4 M฿ • Operations ~ 13 M฿ • Operations ~ 147 M฿ **Total ~ 164 M฿**

Qualitative Analysis

Reduced labor costs, or the ability to shift labor to more important work is important. However, in the long term, it may be the enablement of new processes to proves to be the most valuable contribution of a GMM architecture at PEA.

New Study/Analysis Types

As distribution utilities see more local resources providing energy and grid services, otherwise known as Distributed Energy Resources, the processes within such a utility will shift to look more like the processes within a transmission utility. Some of the types of analysis that PEA may need to perform include:

- Steady State Thermal Analysis
- Contingency Analysis
- Steady State Voltage Analysis
- Transient Stability Analysis
- Voltage Stability Analysis
- Short-Circuit Analysis
- Power Quality Analysis
- Harmonics Analysis
- Training (System) Simulator
- Flicker Analysis
- Arc-Flash Hazard Analysis
- State Estimation
- Tracing
- Location Price Calculation

Of course, some of these processes are performed today, but the new ones may require a more accurate model inputs. And even the existing ones will benefit for the GMM providing more accurate inputs.

Interconnections

Another major impact to the proliferation of DERs in the need to assess each interconnection request and provide, when necessary, updates to the grid to support those DERs. DERs may be parasitic, for example a large number of change-only electric vehicles on a feeder, or the DERs may be supportive, for example a battery installed to provide local backup but also capable of dispatchable charging by the utility to increased hosting capacity for solar resources on the same feeder.

The interconnection process will become a challenge for several reasons:

1. There will simply be many DERs wanting to interconnect, and the queue will be long.
2. Because of coincident applications on the same feeder, analyses may be comingled.
3. DERs may introduce new issues, especially around protection design, which may require new study types to be introduced into the process, some of which are listed above.

Having accurate and timely modelling to support the DER interconnection process will not resolve these issues, but it should make the interconnection study process smoother and less time-consuming. These actions will (1) keep the queue as short as possible, (2) with a shorter queue, require fewer coincident studies, and (3) facilitate the ability to perform new or more complex study types.

Second-Order Effects

The ability to perform more accurate and more frequent studies, including new study types and the ability to get controllable DERs onto the grid faster have additional benefits:

- Lower interconnection processing costs
- Ability to deploy renewable technologies (by quickly and accurately approving controllable DERs to increase headroom)
- Controllable DERs should also improve system reliability, with more fine control over feeder stability – be that active, reactive, or voltage support.
- In total, both reliability and customer satisfaction should increase.

CHAPTER 7 IMPLEMENTATION PLAN

Summary

Task 7 develops Phase 1 of an implementation plan and is based on the Task 5 "Conceptual Sequencing of System Design & Implementation" report and spans a proposed timeline of one and one-half years. This phase consists of eight (8) different workstreams.

1. Organizational/Technical Coordination and Detailed Solution Design
2. GMM Procurement
3. GMM Install and Configuration
4. TDMS-to-GMM Enhance GMM Substation Data Interface
5. GIS-to-GMM Line Data Interface
6. Consumer Models
7. Baseline Model Creation and Testing
8. After GMM is Operational

Introduction

GMM Phase 1 is designed to deliver several important capabilities to PEA in its journey implementing a state-of-the-art Grid Model Management architecture. In specific, GMM Phase 1 establishes three major capabilities in the GMM Architecture:

1. **Master Grid Modelling.** Establish a GMM solution as the source of master grid modelling at PEA
2. **Master Grid Model Maintenance.** Seed that GMM with an initial "as-built" grid model and implement processes and procedures for updating the model as the grid evolves over time
3. **Consumer Model Building.** Demonstrate the advantages of the GMM architecture replacing manual and uncoordinated processes for building operational models in Schneider TDMS and planning models in DIgSILENT PowerFactory.

GMM Phase 1 also includes several steps to promote CIM understanding and the GMM architecture around PEA:

1. **Organization Design.** Assemble a GMM team structure initially for the implementation project which then transitions into production.
2. **Education.** Document necessary skills and knowledge building activities to educate PEA staff on both CIM concepts and GMM architectural concepts.

Project Management & Development Methodology

The GMM plan is segmented into phases, with each phase delivering specific capabilities. The details in Phase 1 are documented using a "waterfall" methodology where tasks are assumed to begin when all prerequisites are complete. This plan will need to be reviewed for completeness and compliance with internal processes at PEA, as well as for changes based on architectural decisions made before the project begins. Finally, the plan is not resource and hence some leveling will be needed at a minimum. If PEA does uses another methodology, e.g. Agile or Lean, then new plans will need to be formulated.

Risk Management

The largest risk in the GMM program is the potentially that GMM tools will not advance quickly enough to support functional requirements of the user base. To mitigate this risk, Phase 1 has limited features. It focuses on as-build models, and avoids the complexities of future models. A model management tool that can support frameworks and accept model changes is needed, and within the timeframe for GMM phase 1, this should be achievable. As will be discussed later in this chapter, finding the "best" vendor who not only has functions to support Phase 1, but is deemed reliable to be able to delivery the functions for later GMM phases is extremely important.

Other risks revolved around infrastructures that may be lacking or insufficient at PEA, such as identity management and data governance policies. These architectural areas are discussed in detail in Appendix C so that appropriate mitigations can be established if there are gaps.

GMM Design

Data Requirements

The following conditions are assumed to be true for this implementation plan:

- ESRI ArcGIS is a reliable source of modelling for
  - HV circuits
  - MV feeders
  - LV secondaries (optional)
- Schneider TDMS is in production in all divisions and is a reliable source of modelling for
  - Substations internals
  - HV circuits
  - MV feeders
- Furthermore, there are no other sources for modelling information in operations applications, for example OMS, other than either the GIS and/or the TDMS
- The PEA-developed ESRI-TDMS CIMXML interface is functioning properly

- TDMS is upgraded to the most recent version that Schneider supports
- TDMS can import and export substation and line models via CIM XML

Workstream 1: Organizational & Technical Coordination

Organizational Change Management Strategies

The GMM program is a long-term, multi-phase effort. Success depends on developing necessary skillsets and maintaining continuity of staff across many years of activity. We recommend that PEA establish an organization with overall responsibility for the GMM program, including this initial Phase 1 as well as subsequent phases.

Staff skill development and continuity of staff are critical to success. Some degree of project-related staffing is acceptable for specific tasks, but a core of dedicated staff will help to maintain overall quality and integrity.

We recommend the following guidelines when building the GMM team at PEA:

- Acquire as much CIM and GMM expertise in-house as possible
- Supplement with experienced industry experts
- Establish project plans that accommodate staff schedules, rather than a traditional plan that forces staff to meet a determined set of milestone dates.

PEA's core team should take responsibility for the areas described in the other sections of the Phase 1 plan.

The core team should update and add detail to the information architecture work delivered as details become better known. As part of this activity, the current effort to connect GIS to TDMS with a CIM interface should be reviewed. Suggestions for this review are provided in "Appendix A: Review of GIS-to-TDMS CIM Export".

As mentioned in the Task 5 report, once the GMM project is completed, there will be an entirely new set of processes and systems to manage grid data. This infrastructure will require a dedicated team not only to manage the information technology, but also the more subtle issues around approving data coming into the GMM from source systems plus changes and Projects and reconciling different contributes from different departments at PEA.

New skills will need to be brought into PEA. Clearly, staff training on the GMM tool itself will be required. There will also be a need to be more PEA staff who are educated and experienced in the CIM. This sort of training can happen well in advance of the project, both formally with other projects leverage the CIM (such as the SCADA Phase 3 project) and informally as staff are encouraged to read about the CIM, explore modelling tools and existing standards, and attend training and user conferences.

When GMM Phase 1 is initiated, it is recommended to assign some staff to the project who will most likely form the nucleus of the GMM support team. Some staff may come from the enterprise architecture and/or IT side of PEA. Others should come from the business side, specifically several staff who understand grid modelling, including how equipment and connectivity are modelling in the CIM. Additional skills in the supporting modelling tools (ArcGIS, AutoCAD, PowerFactory, etc.) will be beneficial

Data Governance

The CIM-based GMM solution eliminates many instances of different PEA groups entering similar data in different systems by identifying the existing systems which are the "system of record" for specific data. A system of record is where the data is initially populated and once the GMM is implemented it becomes important that a data governance strategy has been defined and implemented.

Data governance is a collection of processes, policies, standards, roles and metrics that ensures efficient use of information. In regard to the PEA GMM project, the data governance strategy will require the agreement of senior leadership as to the importance of the GMM to the overall PEA organization and specific data responsibilities of the different business groups that create data which is used by the GMM.

Once a Data Governance strategy is agreed upon, data stewards can be identified and trained. Data stewards are individuals or groups having primary responsibility for the accuracy and completeness of data used by the GMM which originates in systems which they use, such as AutoCad or ArcGIS. These data stewards should have a basic understanding of the GMM vision and how the systems and tools that they utilize are critical to the GMM and understand their roles and responsibilities for data that they produce.

Workstream 1: Detailed Solution Design

CIM Data Model and Profile Development

Canonical Data Model

The GMM program is based around CIM, which provides a core canonical data model expressed in UML, exchange standards derived from that UML, and a methodology for managing data over time. The CIM UML is continually being improved and expanded, and new versions are released periodically. The CIM is designed so that users who need to extend the CIM UML can do so, and extensions are expected in efforts such as PEA's GMM program that integrate multiple large application. Thus, the PEA canonical CIM will be an extension of some existent version of the CIM and the core team should maintain the PEA canonical data model that defines the official way to express grid information that is exchanged among PEA systems.

Prior to configuring and initializing the GMM, the core team should initialize the PEA canonical model and add any known extensions. It is important to review carefully:

- Which CIM versions are supported out-of-the-box?
- What limitations exist for extending the schema with PEA additions?

- Is the internal schema a CIM version or is CIM only supported on import/export?
- What is required to upgrade to a new extended CIM version? Does it require vendor involvement?
- How are extensions managed when upgrading to new CIM versions?

Ideally, the GMM becomes the vehicle for managing the PEA canonical model but do not assume that products have reached this degree of sophistication. A common shortcoming of CIM-based integration efforts occurs when a utility picks a CIM version but does not consider the need to upgrade periodically. This immediately leads to implementations that are difficult and expensive to upgrade as the data model is considered a static rather than dynamic set of definitions.

Framework Specification

The core team has responsibility for defining the frameworks to be managed by the GMM. Frameworks modularize the GMM master data by the part of the grid they cover. The general idea is that exchanges are composed of well-defined modules, rather than extractions customized to each exchange. More information about designing frameworks is provided in “Appendix B: Developing PEA’s GMM Framework.”

An initial framework concept should be developed to help evaluate GMM products, which may vary somewhat in their support for frameworks. Final frameworks will need to wait until the GMM vendor is selected and capabilities of the GMM are known.

Grid Data Interface Architecture

Before any detailed design is initiated for grid data exchanges, a grid interface architecture should be established. The architecture work can be started in parallel with developing the GMM requirements but can only be finalized as the GMM tool is selected and its specific features become known. It is strongly recommended to follow CIM standards evolution so that the latest CIM developments are incorporated. Interfaces affect both the GMM and other systems, so coordinating with the parties responsible for non-GMM systems is also important.

Interface architecture includes strategies for:

- Adaptor Design
- Canonical Data Exchange Profiles
- Identity Management
- Exchange Payload Structure
- Exchange Mechanism
- CIM Version Upgrade

More details are provided on these concepts in “Appendix C: Infrastructure Considerations.”

GMM Requirements

The core team should assemble a list of GMM requirements and desirable features for the GMM selection. Sources include documents from this project supported by official EPRI publications, including:

- 3002025384 Introduction to Grid Model Data Management: A Best Practice Approach to Managing Distribution Grid Model Data
- 3002025387 Applying the Grid Model Data Management Information Architecture at the Distribution Utility
- 3002025386 Common Information Model Support for Distribution Grid Model Data Management
- 3002025388 Distribution Grid Model Manager Functional Requirements

Additional sources include:

- Information gathered during demonstrations by GMM vendors
- Ongoing CIM-based publications and presentations
- Architecture work by the PEA core team
- Suggestions from industry experts
- And importantly, PEA's own knowledge of the company's needs

Business Process Definition & Coordination

In planning and operating the grid, there are complex activities that are regularly repeated, some with demanding time and quality constraints. The core team should have responsibility for coordinating all business processes that involve multiple systems. Such processes involve two kinds of activity:

- Actions required within a system
- Exchange of information among systems

The core team should define the main steps, define the degree of automation required for the overall process, and define required interface development (such as those outlined in later workstreams). The core team should focus on that part of the overall design that is necessary to establish consistency and coordinate exchange implementation and system participation.

When a business process requires an exchange of information, it is usually necessary to convey metadata that links grid datasets to the business process context. Metadata can describe the contents of a model (for example which regions or voltages), processing which has been performed (for example equivalencing low-voltage circuits), valid timeframes, or future projects which have been applied. The core team should have the responsibility for managing business process metadata requirements as part of its general goal of establishing a common practice for defining and implementing business processes.

GMM plays a central role in most grid data business processes. GMM products will vary in the amount of support they supply out-of-the-box, so an important part of the GMM selection will be answering questions like:

- What capabilities exist to host PEA procedures to carry out actions within the GMM?
- Does the GMM support metadata, both in the CIM and added by PEA?
- How are import and export profiles created for GMM data?
- What support does the GMM have for building adaptors?

Workstream 2: GMM Procurement

Selecting the solution provider which will supply PEA with a GMM is more about finding a trusted partner than a solution that meets the most requirements. To be clear, there are no vendors that support all of EPRI's GMM functional requirements. Vendors who implement some of the requirements currently will, with the correct incentives, expand the capabilities and invent features that our team has not envisioned.

As described in Task 5, the GMM roadmap for PEA is long, with multiple phases occurring over multiple years. The first phase of the project will only require a subset of the GMM requirements. Thus, it will be important to select a solution provider who can both achieve the short-term goals of the scope of GMM Phase 1 while providing sufficient assurance that the software will be advanced so that future phases can also be delivered.

It is common when purchasing a major system for utilities to focus on a selection process which requires writing a technical specification of requirements, requires each vendor to formally respond to the specification, and then scores those responses. Even with common published requirements, as in the case with the EPRI requirements for GMM solutions, this process is arduous and does not always lead to the "best" decision. It is rooted in selecting software solutions which are relatively fungible and tends to break down the more unique the industry, the smaller the pool of potential solution purchasers, and the more visionary the anticipated requirements. In short, the process undervalues the life-cycle value of the ongoing relationship between vendor and the utility.

The first question to ask is: what are the most important outcomes? And after that: how can we best achieve those outcomes?

For a GMM, the life-cycle value is more important than the initial cost of the delivered system. PEA will, in reality or in effect, be entering into a long-term partnership with the vendor. The capabilities of the initial delivered system are of course important, but GMM products are in the early stages of their lifetimes and the PEA should select a vendor who will continue to invest and support their GMM product. PEA needs quality training and implementation advice as its GMM becomes central to the PEA data management goals. Our recommendations here cover several phases of PEA development with acquisition of a GMM at the beginning. The specifics of those recommendations will need to be adjusted as business needs and technologies evolve.

A preferred procurement method for GMM is outlined in the following sections for PEA's consideration. The key element in this method is its emphasis on hands-on testing rather than dependence only on demonstrations, written technical requirements, and written responses.

Documenting Requirements and Screening Vendors

PEA should develop an understanding of what a GMM product should be able to perform. This requires simultaneously looking at what PEA needs to achieve and discovering what is available. Interviewing prospective vendors and other outside sources as internal requirements are being considered helps keep the requirements reasonable and typically introduces new and interesting ideas.

Documentation of requirements is essential, but writing requirements is much simpler if the primary objective has clarity within the PEA's team. Keep in mind that PEA should strive to find a vendor product that will be supported and evolved over time. It should avoid a customized software delivery that may not be supported or that will require PEA to pay for expensive vendor services for each needed upgrade. PEA should consider expressing requirements in terms of <u>what</u> is necessary to accomplish rather than <u>how</u> it is accomplished, so that PEA is open to reviewing how each vendor has approached each requirement.

Based on initial conversations with vendors, PEA should develop a list of qualified vendors that will receive invitations to participate in bidding on providing a GMM and supporting services to PEA. Qualified vendors should be evaluated based on a period of ***hands-on*** testing.

Rather than spending time turning PEA requirements into exacting specification language, PEA might rather focus on defining a series of hands-on experiments with the vendor's products designed to expose how the product may be used to satisfy requirements. Tests should stay at the level of business needs, again here avoiding <u>how</u> the need should be accomplished. This allows the vendor to show off their product's features applied to <u>what</u> PEA wants to achieve. For example, a GMM test might be 'define and save a description of a proposed project to add a new substation' but the test would not state details about how such editing would occur or even if it was graphically based (even though it may be obvious that only a graphic-based editing is acceptable).

Testing is best conducted on-site by PEA personnel, but with a vendor-supplied coach who can explain the product's approach to addressing each need and make sure that PEA personnel are using the product as it is intended to be used. Hands-on experience is critical so that they better understand each the product fully – especially the effectiveness of its user interfaces, which is very important and very difficult to describe in testable requirements language.

The number of tests and the length of testing will depend on the overall complexity of the requirements but should be aimed at the goal of eliminating clearly deficient candidates rather than defining a fully comprehensive testing. For example, limit testing to one week per vendor and reserving more time for a full evaluation only for the one or possibly two finalists.

Candidate vendors must be prepared to:

- Provide and install their product on PEA's hardware for the duration of the selection process.
- Provide a knowledgeable coach on-site to guide PEA's personnel through testing.

Vendors often have new features in development and may want to bring a development or even demo version rather than released product. This may be allowed provided that the vendor signs a binding statement that every feature used in the testing will be in the product delivered to PEA prior to some date. The invitations to participate describe the selection process and ask each vendor to provide:

- Initial license pricing
- Pricing of ongoing maintenance and support
- Pricing and availability of custom engineering support
- Training course descriptions
- Policy for issuing upgrades and rights to upgrades
- Commitments (if any) to important future features
- Annual projected investment by vendor in the product
- Customer references
- An installation of the produce with full documentation

Vendors would also be given the opportunity to state whether they would require any remuneration for participating in stages of the evaluation process, as many vendors may expect to participate in the first phase without any remuneration but may wish to set limits on later stages if there is no payment for a potentially extended evaluation period.

Testing of the Product

The objective of this stage is to carry out the first round of testing to eliminate vendors and reduce to a manageable number of finalists. Experience with first round testing will give the PEA team a better idea about final testing, so while some final testing may have been defined it is best to wait to complete the final testing regimen until the first pass is complete.

Tests in this stage will be complex and should address difficult issues like how to build procedures for assembling the models to be exported to potential consumers. Tests should cover all major areas of requirements but as before, expressed in terms of the functional objective rather than the method.

Testing at this stage should be extensive enough to prevent major questions surfacing after vendor selection. It is very likely that testing will reveal some deficiencies that the vendor says it will address in upcoming product releases. PEA should ask whether the vendor is able to make a binding commitment to such promises. Testing may also reveal areas where adaptation of the vendor product to PEA's needs will require some development that the vendor wants PEA to pay for. PEA should then ascertain whether the vendor is willing to make a binding commitment to support the addition as part of future product releases. In short, testing in this stage is partially testing and partially preparing for contract negotiation.

In addition to the planned testing, PEA should also be evaluating how easy it is to work with the vendor and whether they are getting access to the engineers behind the product (as opposed to sales). An important intangible in the evaluation is gauging whether the product will remain best of breed in the future.

Testing should allow for unplanned test excursions. It will be common that the sorts of tests that are planned for this stage will raise other questions that want other testing. This should be allowed. Testing in this stage should proceed until a conclusion is clear about the winning vendor, not just whether all the tests in the list have been completed.

Workstream 3: GMM Install & Configuration

GMM products should be highly configurable. Configurability means that features of the product are model-driven, allowing a standard product to be adapted to the needs of a user without customizing the software. Configuration of a product entails creating the driving models – the sets of data that are installed in the product prior to being put into active service and which are not changed during regular usage.

GMM products will differ in configurability. The next subsections describe some important areas of configurability but the features of the selected GMM product will determine the actual areas of configurability. During GMM product evaluation, we recommend that PEA focus on hands-on configuration exercises.

Configure Grid Data Models

GMM products will typically have an internal grid data model defined in some sort of schema, subsets of which can be imported or exported using CIM profiling. Configurability of these data models is expected but products will vary in their data configurability by users. Internal data models should be extensible but will restrict changes to additions so that features dependent on certain data will persist past the update. Some products may also support configurable import/export profiles.

Most GMM products will support one or more versions of CIM out-of-the-box and will support user extensions. Ideally, the PEA canonical model (See Workstream 1) will be the same as that which configures the GMM.

Configure Frameworks

PEA must supply a framework configuration. CIM is currently developing standards for grid metadata that should include UML for frameworks. Some of the interface implementations and business process implementations will depend on some aspects of frameworks.

Configure Business Metadata

The CIM community is currently working on a specification for business metadata, expected to take the form of UML for metadata that will allow PEA to define the metadata that it requires for its business processes. Each kind of grid data set stored in GMM and each kind of exchange will have an accompanying set of metadata. Some metadata will be required by CIM standards, and some will be defined by the needs of PEA.

Design/Implement Support Operations

The GMM product should come equipped with a variety of useful data operations, such as those required to combine models in an assembly or add change models to a model. The GMM should also support user-supplied operations that would be developed by PEA. Examples include the calculation of impedance matrices from line geography and geometry and the calculation of circuit ratings by evaluating the most limiting series element.

Design/Implement Master Model Update Procedures

The GMM should come equipped with support for updating master models but specific update procedures for PEA should be considered and implemented. In phase 1, substation models are expected to be maintained in GMM and line models are expected to be imported by frame from GIS (but these types of source models must be verified as complete before implementation).

The recommended procedure for updating models is a two-step process. The first step is to prepare each change, expressing each as a change model. These may be examined and tested as necessary prior to committing the changes to a new master model version. The second step is the update commit which may include multiple change models at once. This procedure should be followed for substations. If line models are complete as imported, a direct replacement of models may be performed. If not, it is probably best to convert an import to a change model by a difference operation against the previous GIS export, and then proceed with the change model procedure.

PEA should consider what metadata is desired for documenting master model updates.

Design/Implement Import/Export Procedures

Each of the interfaces described in the subsequent workstreams requires some action in the GMM either to build datasets for export or to process datasets that are imported. GMM products will vary somewhat in the way they support this requirement, but PEA should assume that each kind of import or export will require PEA to write procedures that the

GMM will host. These procedures are part of configuring the GMM to perform the actions that PEA needs. They are not expected to be difficult in most cases – a good GMM should anticipate this kind of activity and have well thought out approaches.

Workstream 4: TDMS-to-GMM Substation Data Interface

The objective of this interface is to populate GMM with substation models from TDMS, assuming TDMS is the best source for substation modeling. The expected GMM source for lines is a direct transfer from GIS to GMM, but an optional path is to populate initially from TDMS, if the TDMS turns out to be a more complete source for GMM requirements. This decision should be made before initiating the interface design. Exchanges utilizing this interface are manually initiated with its purpose limited to initial GMM model population.

The TDMS Import Profiles

The import profiles determine the GMM information that is received from TDMS for substations and lines. It should match the information content in the TDMS imports and exports.

Framework Considerations

Schneider does not currently support CIM frameworks. Schneider TDMS line models indicate substation connection terminuses by "stitching nodes". These stitching nodes, in turn, match the line terminuses.

Exported substations and lines (from either TDMS or GIS) include the stitching nodes. Stitching nodes are therefore duplicated whereas CIM models in GMM should not overlap. Interface design will be simpler if the lowest level framework in GMM has one frame per substation and one frame per line. In that case, stitching nodes simply become nodes in boundary models. If a different framework is chosen, more complex logic will be needed to insert a substation or line model into a larger frame model in GMM.

Identifier Considerations

Schneider has implemented CIM support that includes a mapping between CIM MRIDs and local Schneider identifiers. It is desirable to use the Schneider-assigned MRIDs in GMM because these MRIDs should also appear in GIS-to-CIM mappings. However, it is not known for sure whether the TDMS export identifies all required CIM objects. For example, does it assign consistent MRID to Connectivity Nodes?

A related design question is whether TDMS names for equipment will be the same as GMM names. It is often the case that naming conventions in different systems differ because of local traditions or requirements or because of limitations on names imposed by software products. GMM names should be chosen for general usability and clarity. CIM does have the ability to support concurrent naming schemes using the concept of Name Authorities which allows different names from different sources or systems.

If there are any identification or naming variations between TDMS and GMM, the interface will need to include mappings. Mappings should be generated according to the identity management policy in the data exchange architecture.

The GMM Data Population Business Process

Since initializing GMM is a one-time activity, no formal business process definition is required, and procedures are manually orchestrated. However, this does not mean that the procedures are only executed once. Typically, population is attempted multiple times before it is deemed correct. And in this case, population can occur by frames and the best design is one in which frames can be individually resent in any order as needed

The population business process consists of:

1. Activity in TDMS to build/select a set of data for export
2. Transfer via the TDMS-to-GMM interface
3. Activity in GMM to incorporate the data into an internal configuration

Step #1 should be supported by native features in the TDMS. Step #2 can be a implemented may ways, including asynchronous and file-based.

A procedure installed on the GMM side will define how to process and store received models in step #3. Each model corresponds to a substation or line frame merged with its boundaries. The merged information must be separated into frame and boundary models in the GMM:

- Each substation contains a connectivity node at each line terminus, marked as a Schneider stitching node
- Each substation model can be stored as a new substation frame model after removing its stitching nodes
- Stitching nodes (and potentially open disconnects) must be checked against existing boundary models to detect changes. If changes are found, they need to be separated out for further analysis.
- After all imports are processed, compatibility of boundaries must be checked, and users notified of any problems.
- In the case of open disconnects, if they change, both lines must have been updated because equipment will “move” between the lines.

Workstream 5: GIS-to-GMM Line Data Interface

The objective of this interface is to populate GMM with line models from ESRI GIS, assuming GIS is the best source for line modeling. This section assumes that HV and MV circuits will be transferred; with LV secondaries added during GMM Phase 2. As discussed previously, the GMM should be selected and the key GMM Architecture principles should be established before proceeding with interface design.

Unlike the TDMS-to-GMM Substation Data Interface which is used to populate the grid models in GMM only during the project, the GIS-to-GMM Line Data Interface may be used:

a. In manual mode, to populate the initial model in the GMM during the project, and
b. In automated mode, to populate updates into the GMM as field changes take place during production operations

The Existing GIS to TDMS Implementation

PEA has implemented a GIS-to-TDMS interface that exports CIM in a form that Schneider TDMS can import. Substation data is entered in TDMS. Each substation model in TDMS will have "stitching nodes" created to match the line terminuses of lines imported from GIS. GMM substation models will be populated initially from the TDMS substation modeling. If each substation and each feeder is assigned to a frame in GMM, then the stitching nodes in GMM will be mapped to boundary models. This means that when GIS export of lines is switched to GMM line terminuses of existing lines will align with GMM substation boundaries.

As part of the GIS to TDMS interface, the existing GIS adaptor end will have been constructed to perform a number of translations, including:

- Extraction of lines with terminuses at substation exit points and at open switches connecting to other lines. Open switches are handled similarly to stitching nodes in TDMS and are included in both lines.
- Translation of data into the TDMS CIM-compatible format
- Creation of a **persistent data structure** that maps GIS objects to CIM objects. This mapping will assure that CIM objects representing the same grid element will have the same CIM MRID each time the element is exported.

When imports are received in TDMS, the imports will contain transformed GIS representations of recently completed field work which the TDMS will already **also** have modeled as temporary additions. When an update is put on-line, PEA personnel must remove any temporary modeling that is replaced by the formal GMM update, requiring careful attention by operators to avoid errors.

Strategy for GIS to GMM

The basic strategy for implementing GIS-to-GMM is to preserve the GIS adaptor from the GIS-to-TDMS implementation and create a new adaptor to connect to GMM. The GMM adaptor will be very similar to the adaptor used for TDMS-to-GMM and should be able to use much of the same code.

Exported line models from GIS include terminuses. In GMM, assuming that there is a frame for each line, the line model must be split into a line frame model and one or more boundary models. If the boundary models match existing boundary models, they can be discarded. If they disagree, then either software or users may have to determine which is correct. If boundaries between lines change both feeders must be included in the export to ensure proper modelling in the GMM because equipment will have moved from one feeder to another.

CIM Profile Considerations

In an ideal CIM implementation, data is transferred among systems in its canonical form, meaning that the data structures conform to a profile derived from the PEA CIM version that is configured in the GMM. There will likely be small differences between Schneider CIM and GMM CIM. If so a transformation layer in the GMM adaptor will be needed.

Identity Management Considerations

The GIS adaptor mapping will assign CIM MRIDs. These should be acceptable as GMM MRIDs but this needs review. It is an open question as to whether the names given to exported CIM elements are in a desirable canonical form, but this should be deferred to the GMM adaptor. Formally, the GMM should be the true source of truth for grid modeling and therefore the GMM is responsible for canonical names.

Framework Considerations

The narrative here assumes that the GMM will have lowest level frameworks that define a frame for each line and substation. If these do not exist, the adaptor will require special logic to insert line modeling into larger frame models based on CIM extensions that annotate stitching nodes and open switches between lines.

Comment on Later Phase Development

Later phases of the CIM grid data management program may revise the GIS-to-GMM interface toward assuring consistency with GIS, rather than supply from GIS. This will happen if the primary flow of information is ultimately from TDMS to GMM. The primary reason that information may flow from TDMS to GMM is that information in the TDMS may be more promptly entered into that system. Another is that information entered in the system may be more reliable, as it will be utilized by the operations staff at the time of insertion. However, this is not a certainty. Data may also be entered into the GIS promptly and more field-enablement devices are implemented. Thus, the end state of the GMM architecture is less of a one-way information flow from GIS to operations, but rather GMM comparing various data sources to identify the best source of truth. Thus, a consistency check will have many similarities to the GIS to GMM export in that it will ultimately depend on maintaining a mapping between GIS objects and GMM objects. Importantly, as more components of the GMM architecture are realized, the GIS is freed from maintaining objects essential to that GMM but tangential to the core purpose of the GIS: documenting facility design and facility reality.

Workstream 6: Consumer Models

In phase one:

- GMM will supply TDMS with as-built modeling of both substations and lines, as changes occur.
- GMM will supply Power Factory and possibly other applications with as-built master models.

GMM to TDMS Model Update

Once the GMM has been fully populated, GMM will supply TDMS with the substation and line modeling it requires and the responsibility for maintenance of those models will be with GMM. Prior to activating GMM supply to TDMS, testing shall have verified that GMM modeling matches the needs of TDMS.

The TDMS Update Business Process

The TDMS update business process may be initiated as changes occur, or on a periodic bases, or on demand. Each update consists of a set of individual substation or line models.

The TDMS update business process consists of:

- Activity in GMM to build a set of models for export.
- Transfer of the export via the GMM to TDMS interface.
- Activity in TDMS to incorporate the export into an internal configuration to be put on-line.

The GMM activity collects a set of models for export to TDMS. Each model corresponds to a substation or line frame.

The foregoing assumes that each substation and line in GMM has a corresponding frame. If this is not the case, then more logic is required to determine the scope of lines and substations.

Interface Design Considerations

The TDMS adaptor may need to include:

- Profile transformation if there are differences between Schneider CIM and GMM CIM.
- Name mapping if GMM names are not satisfactory for TDMS.

Workstream 7: Baseline Model Creation & Testing

The GMM must be populated with a complete baseline set of modeling before it can go live and begin supporting consumers. However, modeling data in GMM is also required in order to test any of the interfaces described in the foregoing workstreams. This means that population is intertwined with testing of the integrated GMM. This workstream discusses the process of end-to-end testing leading ultimately to a fully populated GMM and the ability for the GMM to go support consumers.

Test Substation Import and Export

Test the substation import from TDMS. If this looks correct in GMM, then test exporting the substation to TDMS to verify that TDMS can consume the models.

After a round-trip appears to work, compare the Schneider CIM models of the export with the original imports. They should contain exactly the same information. That is, each should contain the same set of objects, as identified by their MRIDs, and for each pair of objects sent and returned, the properties should be identical. This is a CIM difference operation, which is a very useful general tool. These tests will reveal information lost in the circuit. This may result from software bugs but may also reveal the need to extend the PEA CIM in GMM.

Test Line Import and Export

If line data is to be populated from TDMS, the circuit of line data from TDMS to GMM and back to TDMS should be tested in the same manner as with substations. If the GIS is supplying all data that is in the TDMS export, testing can be proceed by exporting the line to TDMS and comparing that TDMS import to what TDMS would export. Since GIS populated TDMS, these two CIM models should contain the same information.

If there is information that must be added in GMM to complete line modeling, this step needs to be added to the test. The subsequent import to TDMS can still be compared to what TDMS would export but the resulting differences must be examined to see if they correspond to the data that was added in GMM.

If there is added line information, it must be preserved when updated line models are imported, so that must also be tested.

Test Power Factory Export

Also verify whether power flow results in PowerFactory match power flow results in TDMS. These may not be perfect matches because two power flow algorithms may not always get the same result from the same input, but they should both recognize the solved state as a solution – in other words, as a result that matches all of the problem constraints.

Populate GMM and Go Live

When interface testing is complete, a complete population of GMM can take place. Update of TDMS should be suspended while this takes place. After population is complete, update of GMM from GIS can be enabled, followed by update of TDMS from GMM.

Workstream 8: After GMM is Operational

Design the AutoCAD to GMM Interface

The initial model population for substations will come from the TDMS. The baseline assumption for Phase 1 is that substation modeling thereafter will be carried out in the GMM. The long-term solution, subject to review of its feasibility, is to import new substation modeling from AutoCAD substation facility designs. Assuming that such an import is deemed feasible and desirable, it may be implemented and put into service at any time after GMM goes into production. When implemented, however, an AutoCAD import is not likely to completely replace the need for GMM substation modeling, because 1) not all substations may be modeled by AutoCAD and 2) AutoCAD imports may not cover all required information.

Extracting all electrical aspects of a substation design from AutoCAD and transforming the result into complete, CIM-based grid modeling is expected to be a challenging task. An idealistic view of this effort is that it will implement an interface that supplies GMM with a complete substation model without adding to the cost of producing and maintaining AutoCAD substation designs. The realistic view is that these kinds of interfaces often impose additional constraints on the source and generate incomplete results at the destination.

The realistic goal, therefore, is to accomplish accurate and complete substation modeling in GMM at minimum overall cost, where cost includes:

- One-time cost of developing the automated import
- Ongoing cost of maintain the automated import over time
- Ongoing cost of any data editing labor on either the AutoCAD side or the GMM side to achieve complete and accurate modeling

Several versions of AutoCAD import are suggested for review.

1. Import equipment and equipment properties only, completing connectivity and developing single-line diagrams in GMM.
2. Import equipment and connectivity but leaving diagrams to GMM.
3. Import equipment and connectivity and derive single-line diagrams from AutoCAD diagrams.

The cost/benefit of these approaches depends greatly on the AutoCAD data structures and whether they can be easily and accurately converted to GMM modeling.

Future Incremental Project-Based Update of TDMS

The future of the ADMS industry is focused on the use of analytical tools, which will require more accurate grid modeling. The implication of this trend is that the real-time modeling of the grid must be designed to stay in sync with field work. An advanced ADMS will enhance the traditional switching order so that each work step is modeled, and the impact of steps can be analyzed with load flow and other tools and the model of each work step is ready to be put on-line as soon as the field crews have executed the step.

Utilities today largely regard GIS as the source of truth for grid modeling and like to think of information flowing from GIS to consumers like ADMS. The trend toward real-time distribution analysis, however, will challenge this thinking because the GIS is not a real-time system and the ADMS is going to be the first place where grid modeling is created and demonstrated to work with advanced applications.

For PEA, as real-time grid modeling in the TDMS increases, incremental project exchange will be bi-directionally valuable. TDMS can send final as-built project models to GMM and when GMM produces new updates for TDMS, it can do so by project so that TDMS can identify which temporary project models are being replaced.

While these functions are not currently contemplated in the present view of phase 1, it may become possible to do more in phase 1 depending on the capabilities of the Schneider and GMM products. At the very least, design of phase 1 should be aware of the future steps

Business Case

Financial Analysis

The GMM project financial costs and savings over a 10-year period are detailed in the Task 6 – “Economic Analysis” report.

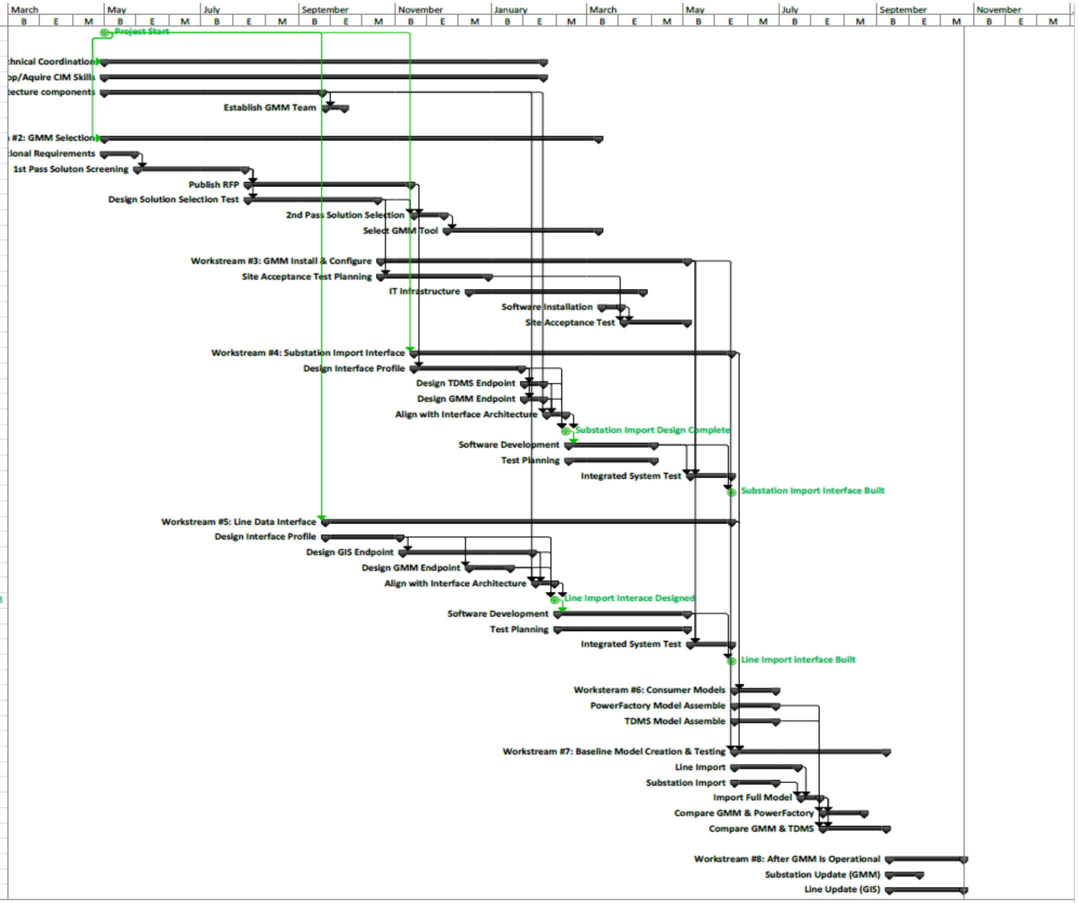
Benefits Analysis

The GMM project benefits will be detailed in the Task 9 “Developmental Impact Assessment.”

Schedule

Schedule Summary

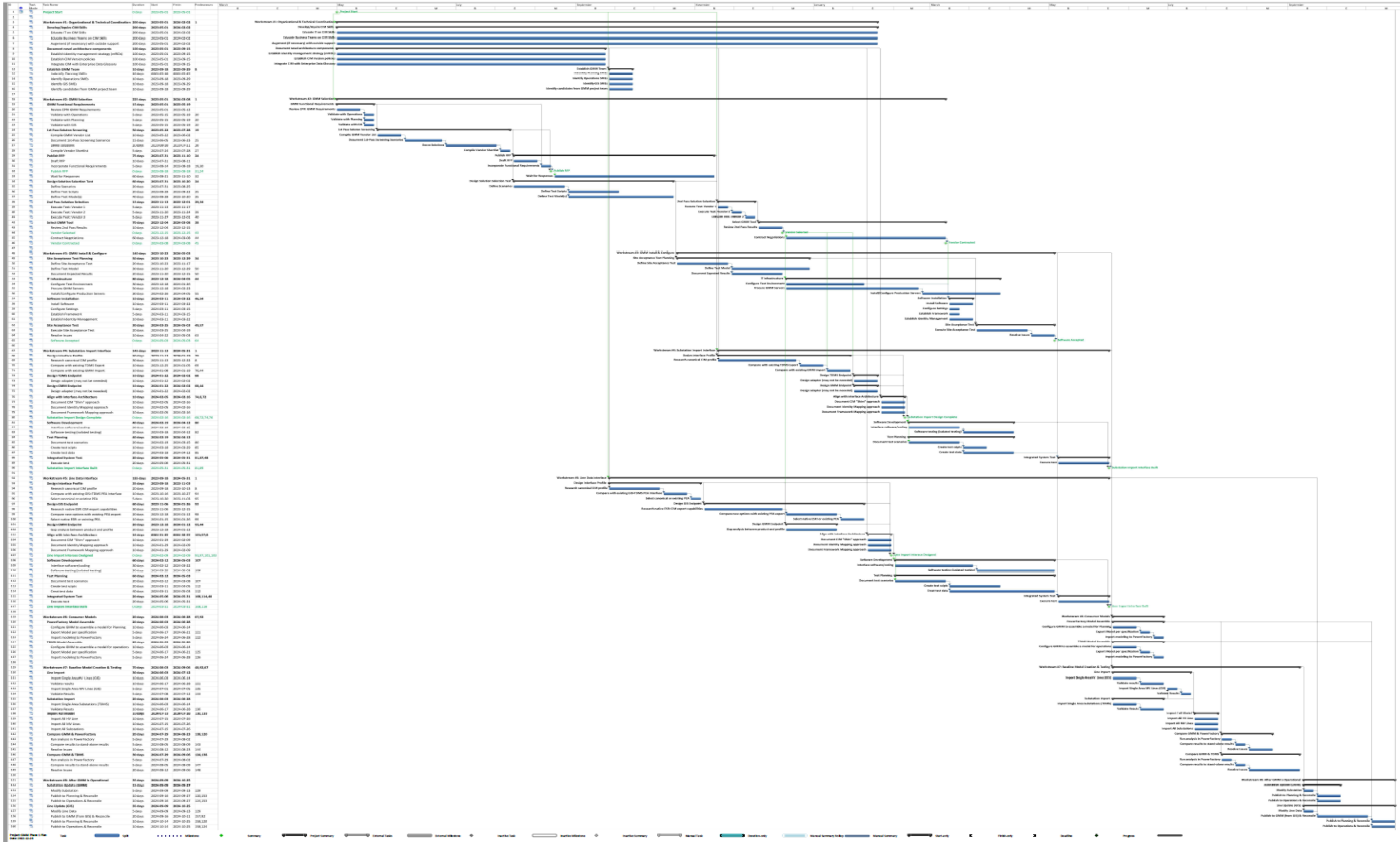
ID	Task Mode	Task Name	Duration	Start	Finish	Predecessors
1		Project Start	0 days	2023-05-01	2023-05-01	
2						
3		Workstream #1: Organizational & Technical Coordination	200 days	2023-05-01	2024-02-02	1
4		Develop/Aquire CIM Skills	200 days	2023-05-01	2024-02-02	
8		Document novel architecture components	100 days	2023-05-01	2023-09-15	
12		Establish GMM Team	10 days	2023-09-18	2023-09-29	8
17						
18		Workstream #2: GMM Selection	225 days	2023-05-01	2024-03-08	1
19		GMM Functional Requirements	15 days	2023-05-01	2023-05-19	
24		1st Pass Soluton Screening	50 days	2023-05-22	2023-07-28	19
29		Publish RFP	75 days	2023-07-31	2023-11-10	24
34		Design Solution Selection Test	60 days	2023-07-31	2023-10-20	24
38		2nd Pass Solution Selection	15 days	2023-11-13	2023-12-01	29,34
42		Select GMM Tool	70 days	2023-12-04	2024-03-08	38
47						
48		Workstream #3: GMM Install & Configure	140 days	2023-10-23	2024-05-03	
49		Site Acceptance Test Planning	50 days	2023-10-23	2023-12-29	34
53		IT Infrastructure	80 days	2023-12-18	2024-04-05	44
57		Software Installation	10 days	2024-03-11	2024-03-22	46,54
62		Site Acceptance Test	30 days	2024-03-25	2024-05-03	49,57
66						
67		Workstream #4: Substation Import Interface	145 days	2023-11-13	2024-05-31	1
68		Design Interface Profile	50 days	2023-11-13	2024-01-19	29
72		Design TDMS Endpoint	10 days	2024-01-22	2024-02-02	68
74		Design GMM Endpoint	10 days	2024-01-22	2024-02-02	68,44
76		Align with Interface Architecture	10 days	2024-02-05	2024-02-16	74,8,72
80		Substation Import Design Complete	0 days	2024-02-16	2024-02-16	68,72,74,76
81		Software Development	40 days	2024-02-19	2024-04-12	80
84		Test Planning	40 days	2024-02-19	2024-04-12	
88		Integrated System Test	20 days	2024-05-06	2024-05-31	81,87,48
90		Substation Import Interface Built	0 days	2024-05-31	2024-05-31	81,89
91						
92		Workstream #5: Line Data Interface	185 days	2023-09-18	2024-05-31	1
93		Design Interface Profile	35 days	2023-09-18	2023-11-03	
97		Design GIS Endpoint	60 days	2023-11-06	2024-01-26	93
101		Design GMM Endpoint	20 days	2023-12-18	2024-01-12	93,44
103		Align with Interface Architecture	10 days	2024-01-29	2024-02-09	101,97,8
107		Line Import Interace Designed	0 days	2024-02-09	2024-02-09	93,97,101,103
108		Software Development	60 days	2024-02-12	2024-05-03	107
111		Test Planning	60 days	2024-02-12	2024-05-03	
115		Integrated System Test	20 days	2024-05-06	2024-05-31	108,114,48
117		Line Import interface Built	0 days	2024-05-31	2024-05-31	108,116
118						
119		Worksteram #6: Consumer Models	20 days	2024-06-03	2024-06-28	67,92
120		PowerFactory Model Assemble	20 days	2024-06-03	2024-06-28	
124		TDMS Model Assemble	20 days	2024-06-03	2024-06-28	
128						
129		Workstream #7: Baseline Model Creation & Testing	70 days	2024-06-03	2024-09-06	48,92,67
130		Line Import	30 days	2024-06-03	2024-07-12	
135		Substation Import	20 days	2024-06-03	2024-06-28	
138		Import Full Model	10 days	2024-07-15	2024-07-26	130,135
142		Compare GMM & PowerFactory	20 days	2024-07-29	2024-08-23	138,120
146		Compare GMM & TDMS	30 days	2024-07-29	2024-09-06	124,138
150						
151		Workstream #8: After GMM Is Operational	35 days	2024-09-09	2024-10-25	
152		Substation Update (GMM)	15 days	2024-09-09	2024-09-27	
156		Line Update (GIS)	35 days	2024-09-09	2024-10-25	



Project: GMM Phase 1 Plan
Date: 2022-12-26

Task | Split | Milestone | Summary | Project Summary | External Tasks | External Milestone | Inactive Task | Inactive Milestone | Inactive Summary | Manual Task | Duration-only | Manual Summary Rollup | Manual Summary | Start-only | Finish-only | Deadline | Progress

Schedule Detail



Chapter 7 Appendix A: Review of GIS-to-TDMS CIM Export

Review 1: Populating GMM in Phase 1

The current assumption for Phase 1 is that the GIS to TDMS export will be redirected to GMM to supply GMM HV circuit and MV feeder modeling -- and will also be expanded to populate LV secondary. Before proceeding with phase 1, the success of the GIS to TDMS export should be reviewed.

Many utilities have implemented GIS to ADMS interfaces. Every ADMS requires feeder modeling and GIS is always the best source for initial population and usually is also set up as the supplier of ongoing updates as construction projects complete. Success in fully populating and updating ADMS varies, however. Variable factors include the data content and structure of the GIS, the modeling policies chosen by the utility for maintaining the GIS data, and the sophistication of ADMS applications and their requirements for data. An ADMS that supports connectivity tracing, switching orders and SCADA, for example, is less demanding of modeling than an ADMS that expects run power flow, state estimation, and volt-var optimization, for example.

When the information available from a GIS is not sufficient, there are two choices:

- Add the necessary information to the GIS.
- Add the necessary information in the ADMS as supplement to the GIS import.

Typical implementations evaluate each kind of information to determine the best option so the answer in most cases is that both options are used. In the end, this usually means that there is some grid modeling in an ADMS that is not in the GIS.

The question for PEA to examine in phase 1 is what data is added in the TDMS that is also needed in the GMM. If there has been a significant investment in such data, then it may be that the better choice is to populate GMM from TDMS – always provided, of course, that there is no important data content lost in going through the TDMS. The alternative for populating GMM is:

- Populate HV circuits and MV feeders in GMM from the TDMS (in addition to the export of substations from TDMS).
- LV may be populated in GMM either by adapting the existing GIS to TDMS export to select LV modules or by adding CIM transformation to the existing Open DSS export.

This decision only impacts initial population. For ongoing update, any missing information from GIS can be completed in the GMM and passed to the TDMS.

The review of GIS to TDMS should proceed as follows.

1. Itemize all grid modeling activities that take place in the TDMS. Possibilities include such items as:
   - SCADA configuration
   - Substation grid modeling
   - Mapping SCADA to substation equipment
   - Substation diagram layouts
   - Substation control schemes
   - Line / feeder / circuit diagram presentation adjustments to pure geography
   - Completing connectivity modeling if there are some gaps in the GIS export
   - Adding line impedance modeling
   - Adding circuit ratings
   - Mapping SCADA to line equipment
   - Other measurement sources
   - Line control schemes, such as cap banks and DER
   - Etc.
2. Determine which of the above categories of data should remain local to TDMS and which should be managed in GMM. This will depend on whether the data has potential value to applications other than TDMS.
3. If there is significant data that has been added to TDMS and should be in GMM, evaluate the tradeoff between populating from TDMS or populating by hand in GMM.

Review 2: Maintaining TDMS from GIS

An ADMS maintains a representation of the real-time state of the grid. This is central to its successful operation. Construction activity is ongoing and results in additions, removals, and reconnections of equipment. Some ADMS choose to wait for an update from GIS, so that all changes are pushed from the GIS to the ADMS. This creates a major challenge in moving data fast enough around the loop from the field through the GIS back to the ADMS to keep ADMS applications running as they should.

The alternative, which we believe will dominate as ADMS become more sophisticated, is that the ADMS operators enter 'temporary' modeling as changes happen. The ADMS real-time grid model then consists of a base configuration with temporary additions. Temporary additions are most likely grouped according to the work projects that the ADMS is tracking in the field. This scheme maintains real-time fidelity in the ADMS but presents a challenge in coordinating with backend sources like GIS and GMM. Eventually, as work completes, a permanent and official version of the completed work is updated in the backend and pushed forward to ADMS as a new base configuration. When that happens, the temporary modeling that is replaced must be recognized and removed. Ideally, the same project indicator that ADMS uses to group temporary changes is also used in the backend update cycle and when a new configuration is pushed forward it contains a list of the projects that have been incorporated into the new configuration. In this scheme, TDMS may also supply backend processing with its temporary modeling, as a proposal for the grid modeling of the closed work.

In PEA phase 1, the expectation is that TDMS will continue to be updated as before, except that the new line models it receives are coming via GMM. The questions for review are:

- How are TDMS temporary models maintained and organized?
- How do TDMS personnel recognize what has changed in each line model update that is received?
- How do TDMS personnel match an update with temporary modeling that needs to be removed?
- Does this update process present possibilities for data errors or require significant engineering time to avoid errors?
- Are there mechanisms built into the TDMS update or TDMS itself that aid in this process?

While it is not expected that this review will reveal changes in the planning for phase 1, it should contribute to planning the overall flow of information for future phases.

Chapter 7 Appendix B: Developing PEA's GMM Framework

PEA Frameworks

Frameworks are a CIM convention that defines how grid modeling may be formally subdivided into non-overlapping Models. Models that fit into 'frames' in a framework are managed by one (and optimally only one) producing party or system. Models that fit into 'boundaries' in a framework define a set of objects that separate two frames and define how the adjacent frame Models fit together. Frameworks allow Models to be combined to meet the needs of different study scopes by a simple union of Model objects.

Frameworks are central to organizing both the collection of data and the assembly of consumer modeling in GMM. Configuring GMM frameworks is an essential first step in the implementation of phase 1. Good framework choices will make everything else easier to implement because it is much easier to say 'combine model A with model B' or 'import model B into frame X' than it is to deal with individual objects within models that should be included or excluded.

Multiple interrelated framework agreements are typically necessary interconnected grids. They allow nesting of lower-level regional frameworks to be defined within higher-level frameworks.

GMM products may approach this requirement differently but support for framework hierarchies is essential.

This note illustrates framework possibilities for PEA. The master modeling division frameworks have the primary purpose of facilitating interfaces for supply of modeling to GMM. (Sections of this plan dealing with import interfaces to GMM assume their existence.) Other frameworks are presented illustrate support for the construction of analytical models. In general, though, the final set of framework configuration used in GMM should be determined as part of the PEA interface architecture, considering:

- PEA interface requirements for importing data to GMM.
- PEA assembly requirements for producing exports from GMM.
- Capabilities of the selected GMM for framework configuration and usage.

Existing HV Practices (without frameworks)

EGAT represents PEA as loads at its substations. This makes EGAT blind to impacts on PEA. It also means that flow through the PEA HV is ignored, and it is assumed that contingencies in the PEA system will not affect the EGAT grid. In the future, EGAT should have the ability to represent PEA HV in better detail by importing modeling of relevant HV from PEA divisions.

PEA represents EGAT as infinite sources, but since PEA connects at multiple points a PEA HV study needs to know the relative voltage and angle at each EGAT connection, which must come from EGAT studies. In this mode, PEA cannot study the effect on the PEA HV of contingencies in the EGAT system and when studying contingencies in the PEA HV, flow through the EGAT system will not be represented accurately. In the future, PEA would benefit from being able to import EGAT models and use them in HV studies.

PEA division studies sometimes need to represent adjacent divisions to some extent. Divisions have access to adjacent division modeling but a more systematic support for importing and using HV models of adjacent divisions would facilitate such studies.

A Thailand Bulk Power Framework

A top-level framework is recommended that covers Thailand HV and EGAT. Its purpose is to aid in assembling HV studies.

The framework proposed for Thailand in Figure 59 would facilitate data exchange with EGAT as well as exchange of HV models among PEA divisions and with MEA. While PEA cannot compel EGAT or MEA to participate, their eventual participation makes sense and would be mutually beneficial. And in the interim, PEA can act as a proxy modeler for non-participating entities to whatever extent is needed.

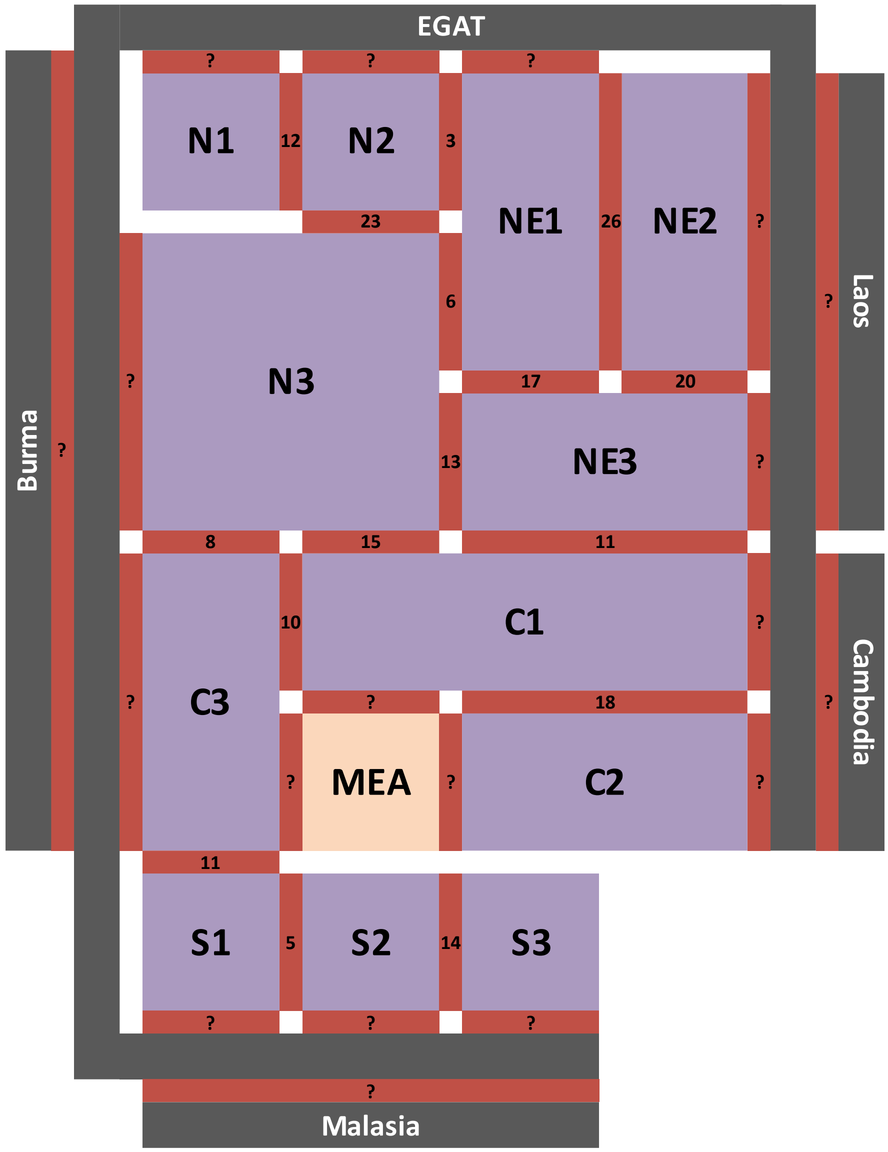


Figure 59. Proposed Thailand Framework

More importantly for our current purposes, this framework is useful as a top-level framework for PEA.

- Note that while there is a frame for EGAT, nothing says how detailed the models are that populate that frame, so to match the current practice, PEA divisions can (as they do now) simply make EGAT models consisting of infinite sources at PEA substations and the farther out Laos and Malaysia models can be empty.
- The framework defines how neighboring division HV models fit together, which will facilitate studies that need to represent more than one division.

- In future, PEA is likely to want more detail from the EGAT studies and a Thailand-wide agreement on model exchange will make sense for all parties. The proposed framework would, for example, allow PEA to import a complete study result for the Thailand framework from EGAT and then substitute any detailed PEA division HV model to carry out more local studies. (This kind of exchange is common practice in North American and European grids.)

Using this framework, GMM will be able to:

- Import individual EGAT models (if EGAT participates).
- Import EGAT studies and use parts (if EGAT participates).
- Import MEA HV models (if MEA participates).
- Build and export models of PEA divisions.
- Built complete HV study assemblies for export.

Master Modeling Division Frameworks

The representation of PEA divisions in the preceding section typically would only include HV lines and substations with MV represented as load. Analysis of MV and LV within a division, however, requires MV and LV detail. A primary objective of GMM is to serve all analytical needs from a single source of truth that doesn't duplicate master modeling.

The bedrock of GMM modeling is a set of frames that fit together to form a continuous detailed master representation of PEA divisions through all voltage levels, as depicted in Figure 60. The Figure 59 models of divisions and all other kinds of analytical modeling that PEA requires will be derived from the master modeling base.

Note: Other sections of this plan assume that the GMM is configured with master base frameworks as shown in Figure 60. This does not mean that frameworks must be defined as in Figure 60. It means that if PEA decides on frameworks that differ from Figure 60, PEA may also need to amend comments in the parts of this plan that assume Figure 60.

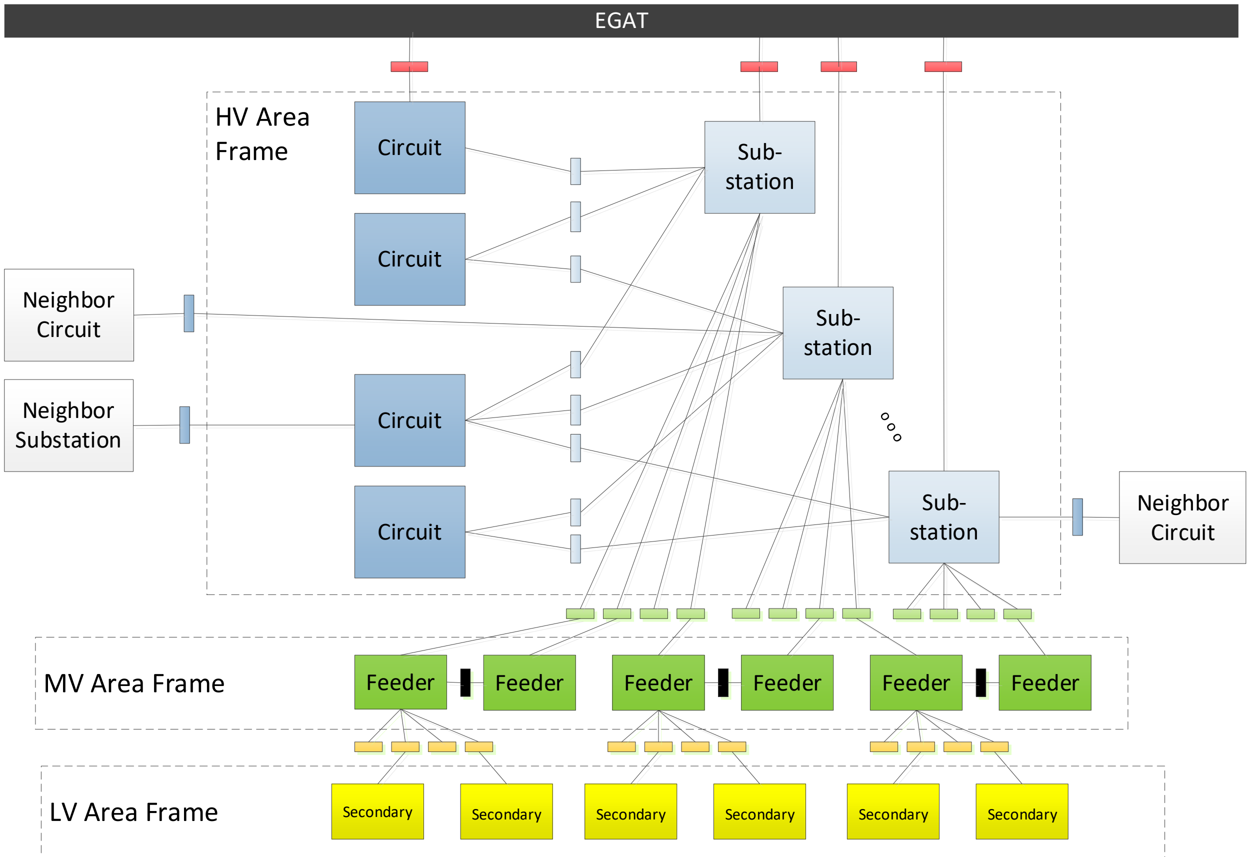


Figure 60. Lower-level import frameworks for HV, MV, LV.

By design, these lower-level frameworks contain frames that correspond to the modules of data that sources like GIS and AutoCAD are designed to export. The following frames are expected:

- HV substations
- HV circuits
- MV feeders
- LV secondaries

Boundaries are defined as follows:

- A substation – EGAT boundary at each connection to EGAT.
- A substation – circuit or substation – feeder boundary at each substation exit point.
- A feeder – feeder boundary at each open switch between feeders.
- A feeder – secondary boundary at each secondary transformer.

Most boundaries are quite fixed over time but boundaries between feeders at normally open points can change. When such changes occur, objects move from one feeder to another, and this requires simultaneous processing of both affected feeders. This is usually not a major problem if the feeder models are produced by the same source (such as GIS) because then that source can re-issue both models. It can, however, become a more significant problem if any systems depend on equipment membership in feeders being stable.

The Figure 60 modeling also supports analytical models for secondary since each secondary frame is typically studied on its own.

PEA HV – MV Division Analysis Frameworks

Representation of divisions for various analytical purposes my always be developed directly from the Figure 60 master components. However, PEA may find it helpful to provide an intermediate framework, such as that pictured in Figure 61. Such a framework normally implies that when changes are made in master models, new derived Figure 60 Models will be produced from the Figure 61 frame Models, which then form a simpler basis for building what studies need.

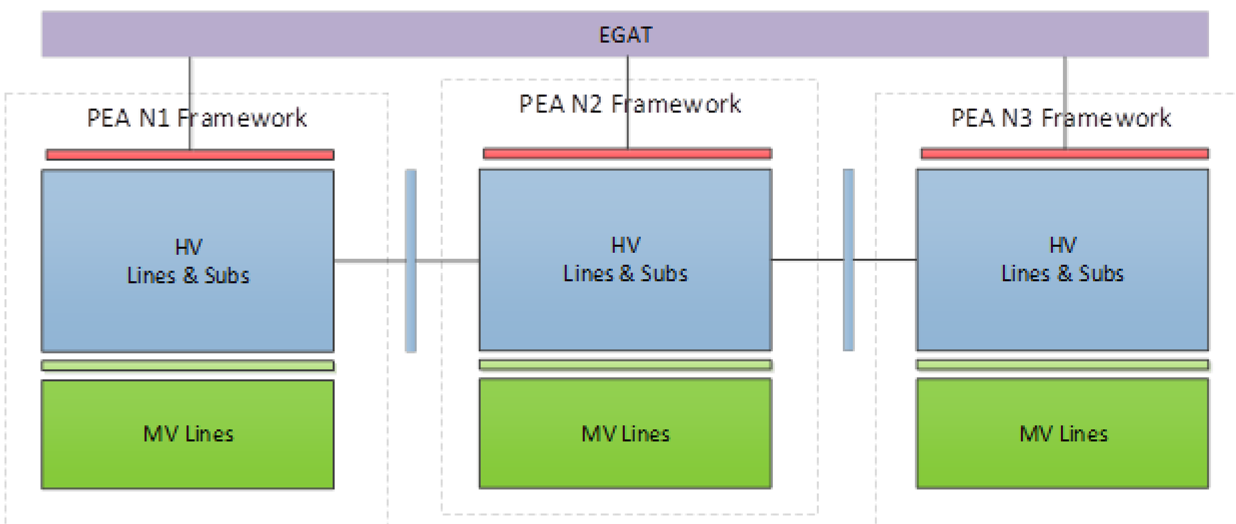


Figure 61. Division level frameworks for analysis.

Figure 61 HV frames Models are unions of Figure 60 HV frames. Figure 61 MV frame Models are unions of Figure 60 MV frames merged with edge load Models of LV.

From a Figure 61 framework,

- HV models for the Thailand framework may be produced by merging an HV Model with an edge load model of the MV.

- Local HV studies may also use edge load model of MV but use a Thailand study to compute edges for neighbor divisions and EGAT sources. MV edges may be computed in several ways:
  - By forecasted load.
  - By forecasted total load distributed according to rollup of MV feeder content.
  - By rollup of individual forecast of LV loads in MV feeders.
  - By dynamic equivalents computed in real-time from MV state estimation.
- Complete MV representations may roll up load edges from LV and either use HV studies to compute source edges for MV or just establish infinite source edges.

MV Individual Feeder Analysis

MV feeder analysis is normally conducted only on connected parts of the MV grid but here actual connectivity must be considered, rather than the export modularity.

This usually means that to prepare an MV study, a trace is required from the designated substation source / head-end of feeder through the network until the trace finds either open switches or another substation source. The subject of the analysis will be the entire traced part of the grid.

Carrying out the trace requires a full division MV model, as in Figure 61, but once the trace is complete, the construction of the area to be studied can consist of those frames in the Figure 60 frameworks that were touched by the trace if a limited export is desired.

Chapter 7 Appendix C: Infrastructure Considerations

Hardware, Software and Cyber Security Infrastructure

This section is focused on some of the common features to consider while implementing the GMM that can affect decisions in the future, as well as topics to consider when embedding the GMM into the PEA secure computer network. There are a number of features that will affect software decisions: identity management, exchange formats and payloads, and system interface designs. These can affect the software systems, and potentially drive new support systems like enhancements to exchange service bus (ESB) solutions. Software solutions, in turn, may require hardware updates and/or expansions to support new requirements. All of these issues should be explored in the initial phases of the project.

In North America, any utility system which exchanges data across the control room systems interface boundary is subject to enhanced security protocols, called Critical Infrastructure Protection (CIP). Similar policies may be in place in Thailand and will be examined in more detail in later phases. At this stage, it is important to note that cyber security should also be assessed at this point, as data will be exchanges with operational systems in the GMM implementation.

Finally, the interface architecture is of note as the GMM is a highly coupled system, meaning it has interfaces with many systems in many different departments. Therefore, it is important to confirm a reliable and extensible interface architecture is in place. In not already sufficient, staff should develop an approach to building interfaces between systems that can provide consistency across all such implementations. This will improve quality of implementation and foster establishment of a group with integration skills. It will avoid the orphaning of knowledge that occurs when one person or project decides how to implement each interface and after completion, they are unavailable to carry out upgrades or improvements. Over time, interface implementation and especially maintenance will turn out to be a surprisingly large effort. Well-engineered interfaces have much lower life-cycle cost than ad hoc interfaces and they also facilitate more rapid deployment of new business functions.

Canonical Plus Architecture

A common failure in integrating systems is that each interface is considered a project of its own and the implementers look for the quickest easiest way to implement the currently required transfer without regard for required ongoing labor to maintain mapping tables or the difficulty of upgrading to support either new requirements or product upgrades of interface participants.

PEA should adopt a canonical plus architecture:

- A canonical architecture for integration is one in which each kind of exchange takes place in a 'canonical form'. All parties to each type of exchange are required to convert to canonical form (if they are senders) or from canonical form (if they are receivers).
- A canonical plus architecture is one in which the canonical forms of business data in exchanges are derived from a common information model that serves as a sort of super-dictionary, defining not only common terminology but also common information structure. CIM UML is the super-dictionary for grid planning and operations.

CIM requires a well-engineered interface architecture to reach its full potential. It is impossible to establish a perfect information model that will support all needs over time. Provision should be made from the start for periodic upgrades of the canonical modeling. Products also are continually improved, and it is necessary to periodically upgrade to latest versions. These events as well as changing business requirements necessitate regular update of the interface implementations. Designing interface implementations for change is the key to minimizing long-term integration cost.

All of this comes down to two important aspects of interface engineering:

1. The management of the canonical model and its derivative profiles over time to achieve business objectives, minimizing lifetime costs and maximizing ability to respond to new requirements.
2. The design of adaptor software to minimize the cost impact of change. (Adaptors are the shock absorbers in the architecture.)

Regarding #1, experience with databases shows that most schema are logical when they are initially conceived but as time goes by, changes are patched in that de-normalize the structure and erode the descriptive power of the information design. For a canonical architecture, however, descriptive quality and good modeling principles must be maintained over time. This is a challenge because patches are often a cheaper and easier way to resolve an immediate requirement. The CIM working group provides one aspect of the solution. It strives to maintain a core information model in good order that addresses the common requirements of grid planning and operations. PEA, however, must plan for periodic uptake of new CIM work as well as for sensible management of PEA extensions.

Regarding #2, adaptor software should be carefully layered so that dealing with different sorts of changes usually comes down to updating a layer rather than replacing everything. It is expected that products in the grid planning and operations space today have CIM support that supplies part of what is required to create CIM-based interfaces, but PEA will have the ultimate responsibility for completing each interface design, either by developing software or by contracting with vendors for additional support.

The next sections elaborate areas of particular engineering concern, without discussing implementation or technology specifics, which will evolve.

General Terminology

- A system may participate in multiple interfaces.
- An interface is designed to handle a business process step that requires exchange of information among parties to the process.
- Some interfaces may involve multiple exchanges, such as a query and a response.
- A payload is a package of 1 to n datasets.
- Datasets in exchange payloads are in canonical form, defined by a profile consisting of:
  - A subset of the PEA CIM UML that defines the information content and structure.
  - Additional constraints as necessary.
  - Selection of a serialization method (e.g. -552).

Grid Data Interface Assumptions and Terminology

For grid data interfaces, the concern is exchanges of four types of grid datasets:

- Models. Models are instances of grid data profiles defined by WG13 or extended by PEA, together with metadata describing the purpose of the Model.
- Change Models. Change Models are instances of changes to grid data profiles defined by wg13 or extended by PEA, together with metadata describing the purpose of the Change Model.
- Assemblies. Assemblies are sets of Models that join together to serve some purpose (such as defining a power flow case), together with metadata describing the purpose.
- Change Sequences. Change Sequences are ordered sets of Change Models with a common purpose (such as a switching sequence), together with metadata describing the purpose.

Note that in exchanges, metadata must always accompany grid data to explain to receivers what they are receiving.

The CIM community is currently working on standards for the metadata and for the exchange of these kinds of grid datasets. PEA should follow this work closely and adopt what is available at the time Phase one is being implemented.

Identity Management

If a participant receives grid data, understanding any object in the data requires knowing what kind of object it is, which is given by the UML, and also the MRID of the object, which says what real world grid thing or concept the object represents. Two parties, however, can only make sense of the MRID if they are party to a common method of assigning MRIDs. If A thinks switch X is represented canonically by # and B thinks switch X is represented canonically by %, exchanging a Model between A and B will be pointless.

This problem cuts across all grid interfaces and must be dealt with at a higher level. It is essential that PEA adopt an identity management scheme. Broadly, an identity management scheme has these parts:

- An understanding of which party is the model authority for each thing and assigns the canonical MRIDs.
- An understanding as to how canonical identities are conveyed to all who need to know them.
- A scheme and service for managing mappings between canonical identities and local identifiers or names (when those are different).

There are many variations on this theme that can work. Some are better than others. A recommended scheme is described in [ref]. A GMM product may have built-in identity management capability but PEA should be cautious in that there will likely be exchanges about network model variables that occur directly between non-GMM participants.

The Exchange Payload Structure

A CIM grid modeling payload is a zipped set of files, the content of which conforms to 61970-552. But there are some extremely important additional choices that PEA needs to make at the architectural level.

We assume that the GIS to TDMS export that is currently being developed uses edition 2 of 61970-552. In this version, a model is formatted in CIM xml with a header that identifies the model and provides some additional general description capability. The metadata provided in this header is fixed in format and has proven inadequate in the broader spectrum of CIM applications. A new format is being proposed that is referred to as 'dataset' exchange. Dataset exchange formats grid data in CIM xml in exactly the same way as edition 2 but provides for flexible, user-definable metadata.

In dataset exchange, business metadata is packaged as a metadata dataset rather than a header. The business process designer defines metadata profiles that are serialized in CIM xml just as the grid profiles are serialized in CIM xml. Then metadata datasets are linked to grid datasets by object references from metadata objects to grid datasets. This allows business processes to create exactly the metadata that they require to coordinate parties exchanging data.

The current expectation is that wg13 will publish edition 3 with some needed updates to edition 2 and then publish the dataset exchange specifications as edition 4. This technology should be available for use by PEA in phase 1 and it is strongly recommended that PEA adopt dataset exchanges universally. A standard UML for defining metadata is also in process and should be ready for use in phase 1. Even if dataset standards are not published by phase 1 start, we recommend working with vendors to implement the dataset approach rather than investing in the edition 2 methodology. The compromises that might be made in getting a bit ahead of the final dataset specification are likely to be less serious than the compromises necessary to make the edition 2 header work well.

Payload Transport Mechanisms

PEA needs to decide how to move payloads between exchange participants. In some cases, a simple file-sharing mechanism will suffice, but there are many other possibilities.

- A mechanism must be available to transport large payloads, although not all exchanges will be large.
- A mechanism must be available to transport through security perimeters.
- A mechanism must be available to exchange with entities outside PEA.

- A mechanism must be available to ensure timely delivery.
- A mechanism must be available to ensure verification of receipt.

It may be desirable to use multiple transport systems as PEA develops a more automated and sophisticated integration. For example, it may be practical to mix file sharing for large grid datasets with messaging for business process communication.

Note that Schneider has implemented CIM support that includes a mapping between CIM MRIDs and local Schneider names. This should enable consistency between TDMS and GMM MRIDs. An open question is whether TDMS names for equipment will be the same as GMM names. It is often the case that naming conventions in different systems differ because of local traditions or requirements or because of limitations on names imposed by software products. GMM names should be chosen for general usability and clarity. The identity registry architecture should provide a means of supporting translation between MRIDs and each local set of names and support for this should be built into the interface between GMM and TDMS.

Grid Data Interface Design Requirements

Initiating an Exchange

Initiation of an exchange between systems may take place in several ways:

- By a higher-level business process orchestration communication with a sender.
- By a sender pushing information to a receiver.
- By a sender providing information 'to whom it may concern'.
- By a sender asking for information from another party.
- By receipt of an exchange prompting action by the sender.

At the Sending System

The sending system interface consists of a vendor product with certain export capability and any additional adaptor functionality added as PEA layers:

1. The sending product produces export datasets in some CIM form.
2. If the profile exported does not align with PEA canonical profile, a transformation layers such as the following may be required:
    a. Between different standard CIM profile versions.
    b. Between extended CIM profile versions.
    c. Between serialization versions.

Stacking different layers of transformation can improve flexibility.

1. If the sending system does not use the canonical identity and naming, a further transformation must map from sender's identities to canonical identities using PEA's chosen identity management approach.
2. The sending side packages all datasets required for the type of exchange according to the rules for the payload.
3. The sending system finally initiates transfer by the chosen transport mechanism.

At the Receiving System

1. The payload side of a receiving adaptor stores the payload datasets and determines the purpose of the payload (which determines what subsequent business processing should be initiated).
2. If the PEA canonical profile does not align with CIM profile import capability, transformation layers may be required:
    d. Between different standard CIM profile versions.
    e. Between extended CIM profile versions.
    f. Between serialization versions.
3. If the receiving system does not use the canonical identity and naming, a further transformation must map from canonical identities to receiver's identities using PEA's chosen identity management approach.
4. The vendor is expected to support some version of CIM import and transform to local data structures.

CHAPTER 8 REGULATORY ANALYSIS

Summary

This task is focused on the identification of relevant regulations that may impact project viability or prognosis to proceed. Examples of such regulations and/or compliance issues to be investigated may include but are not limited to: cybersecurity/network security requirements, compliance, with ICT infrastructure requirements, rate and/or operating restrictions. etc. It also includes a regulatory impact assessment of pertinent internal, national, regional and international regulations and policies and assesses three areas for regulatory barriers.

- Cybersecurity / Network Security
- Information & Communication Technology Requirements
- Jurisdictional/Operational Requirements

Cybersecurity/Network Security

Cybersecurity is a critical component of operating any grid today. The power system is one of the more important, if not the most important, set of any country's critical infrastructure. And unlike other systems like water and telecommunications, it is inherently unstable, requiring constant controls and monitoring to keep the system balanced and stable.

In previous chapters, this report has made the case that improved grid model management techniques will improve reliability, by providing more accurate and more timely information to the people support the operation of the grid. In this section, we will discuss the potential that the GMM architecture could introduce new risks which could be exploited.

First, we examine the information itself. Does have a grid model which is centrally managed introduce any new risk? Given that grid models are already stored in several systems, adding a new system, albeit with a more accurate model, does not change that fact that PEA models its own grid. Furthermore, there is a general trend towards making this information more readily available outside the utility. More information sharing is occurring between operators, for example with the CGMES process in Europe, and between local utilities and entities with bulk-power balancing responsibilities.

With the influx of distributed generation, many utilities are providing a subset of their grid models to the public as a method of publishing hosting capacity. For example, National Grid provides this service to customers in Boston, as illustrated by the example screen capture shown on the right.

Second, it is important to consider the risk of introducing a new system with potential security vulnerabilities. Our team has reviewed PEA Policy 2566, and we did not find anything which leads us to believe that a GMM would present a substantial risk. However, it is important that the GMM is vetted with the same security procedures as would any critical system deployed at PEA, going deeper than our team's cursory investigation.

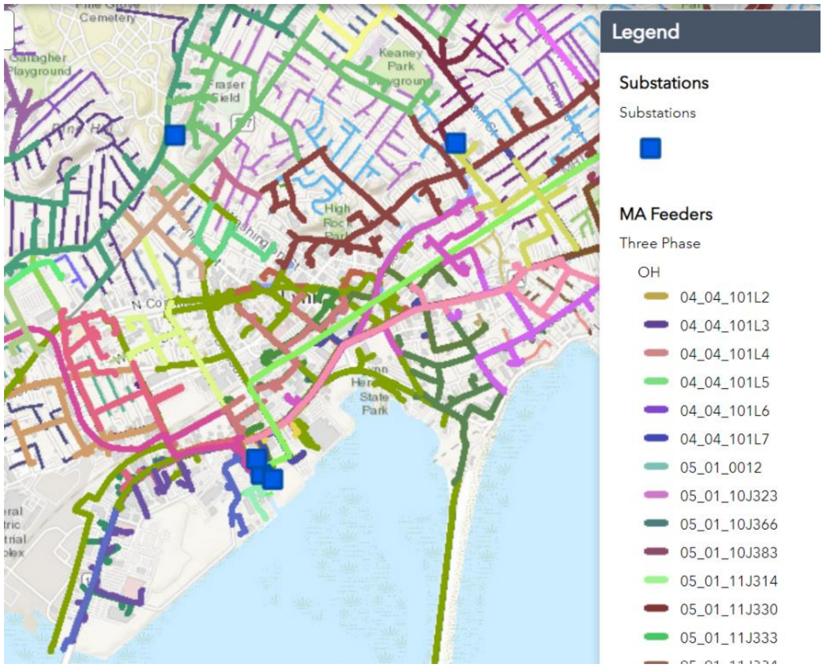


Figure 62. Example of public-facing grid model data from National Grid in the United States

Information & Communication Technology Requirements

From an information architecture perspective, a GMM is most effective when the IEC Common Information Model is used as the foundational model for interfaces. The underlying CIM information models (classes, attributes, and associations) can be used as an input not only to the GMM and communicating applications, but also to the evolving data governance process at PEA which should be enterprise wide. Adopting CIM as the foundation for the data dictionary (or at least some of the data dictionary), will help group who leverage GMM data but are not central to its management more easily understand and utilize the data which becomes available with an open GMM platform. PEA has already embraced the CIM and therefore implications of a GMM utilizing CIM as well should be viewed as a reinforcement of this decisions and would not represent a departure from PEA's architectural guidelines.

Beyond interface model requirements, there are no specific application architecture requirements from GMM. Whatever preferences exist at PEA and how those preferences are used to evaluate and ultimately select technology solutions should be applied to the GMM selection just as any other project would utilize them.

Jurisdictional/Operational Requirements

PEA was established by royal edict in 1960, and its role further clarified in the Energy Industry Act of 2007. Based on these documents, PEA has wide latitude to procure systems to meet its objectives, and no obvious impediments are apparent in our assessment of these Acts. The pertinent regulations identified, and impact assessments are noted below.

Additionally, the GMM has several potential benefits (see Task 6) which should help to deliver on Energy Regulatory Commission (ERC) goals. The following mandates are documented in Section 11 of the Energy Industry Act of 2007 should be strengthened with the implementation of the GMM architecture:

(3) impose measures to ensure security and reliability of electricity system

The GMM should improve electricity system reliability both in the planning and operational domains with a more accurate and reliability grid representation.

(13) promote and support study and research on energy industry operation

Having a single grid representation inside PEA, should make it easier to supply grid models (or portions of grid models) to research institutes in an equitable fashion.

(16) promote economical and efficient use of energy, renewable energy and energy that has minimal impact on environment, with due consideration of efficiency of electricity industry operation and balance of natural resources

A better grid model will help facilitate the interconnection of Distributed Energy Resources which themselves may be suppliers of renewable energy. Other DERs, notably storage, will be able to increase headroom on the distribution system and allow for more local, renewable energy to be installed without major feeder updates.

(17) coordinate with other agencies in relation to the execution of the duties stipulated in this Act

If also adopted by EGAT and/or MEA, information sharing with these peer agencies will be improved.

Grid Model Data Exchanges In Practice

One of the benefits of adopting CIM in a region where other utilities have done the same is the ability to exchange grid models. Exchanges can be performed for multiple purposes, the two most common being (1) to build regional models to more efficiently coordinate long-term term grid reinforcements plans and (2) closer to real-time to coordinate operations among control centers.

The IEC 61970-600 series supports the Common Grid Model Exchange Standard (CGMES) in Europe. Quoting from the ENTSO-E website:

The CGMES was developed to facilitate the exchange of operational and grid planning data among transmission system operators. The CGMES is required to implement a series of network codes including the one on capacity calculation and congestion management and the one on system operation.

The Common Grid Model Exchange Specification (CGMES) Part 1[6] describes the process:

The purpose of model exchanges is not only to exchange the data from one authority to another but also to satisfy the ultimate goal, namely to perform common studies using shared data. All parties involved in the process should be able to perform the same types of studies and be able to share project tasks between different parties which are using different power system analysis applications. Indeed, the interoperability between different applications used in the exchange process is therefore crucial in both reaching seamless data exchange and obtaining comparable study results when using this data.

Coreso, one of the reliability coordinators in Europe, explains the processes in more detail[7]:

To allow operational coordination and to ensure security of supply on a European level, TSOs share information with RCCs. Each TSO publishes its Individual Grid Model (IGM) which represents the best detailed forecast of its electricity grid. Afterwards, RCCs merge about 40 TSO IGMs to create a pan-European Common Grid Model (CGM) representing the European electricity network.
The CGM service consists in different tasks performed by RCCs: (1) Checking quality and plausibility of IGMs provided by TSOs and facilitating their improvement to meet the criteria of quality and plausibility; (2) Merging of IGMs into CGM; and (3) CGM model improvement.
The CGM service also includes the use of a harmonised data format (CGMES) allowing precise description of the network. The exchange of files is supported by the Operational Planning Data Environment (OPDE) which is a platform to exchange data and which contains central business applications to support RCC services.

The CGM service is being provided in different timeframes. While some of these timeframes are made mandatory by the network codes, others can be defined at a regional level. The supported timeframes are: (1) Year-ahead; (2) Month-ahead; (3) Week-ahead; (3) Two-days-ahead; (4) Day-ahead; and (5) Intraday.

The CGMES process is sophisticated, as illustrated by these timeframes. With dozens of TSO all providing not only their grid representations hourly to the reliability coordinators, these models

[6] Common Grid Model Exchange Specification (CGMES) Part 1

[7] https://www.coreso.eu/services/cgm/

also include information about the unique state of each grid at the time covering temporary conditions like outages.

Thailand could adopt a similar process, examining the entire Thailand grid assembled from EGAT, PEA, and MEA individual grid models. Furthermore, a simplified representation of the Thailand model could be shared with neighboring countries to develop regional planning and operational models. Coordination both among the grid operators within Thailand and among grid operators in the region will become more important as more intermittent renewables resources are deployed and operators are forced to rely more heavily on imports and exports with their neighboring grids.

CHAPTER 9 DEVELOPMENTAL IMPACT ASSESSMENT

Summary

Task 9 is a developmental impact analysis of not only economic benefits to the Provincial Electric Authority of Thailand, but also beneficial impacts on human capacity development, supporting international data management best-practices, physical safety as well as positive social gains.

The outcomes of the task are:

- Categorize and document positive development impacts
- Provide assessment of each benefit either quantitatively or qualitatively

Impact Assessment

From an economic analysis perspective, projects such as the GMM vision are challenging to evaluate because some of the benefits are episodic and difficult to forecast or quantify. Also, the GMM vision creates a system with characteristics of a platform, which suggests the possibility of uses and benefits beyond those currently envisioned.[8] That is, platforms may have strategic value that cannot be described or quantified until the new functions appear and mature. A strategic decision adopts a vision of a future state that is not fully formed and may not appear to completely cover its costs in the present. Nevertheless, it is important to examine the foreseeable costs and the benefits to bridge that strategic leap to the future state.

In Task 6, we examined a conventional cost-benefit analysis as it occurs in the utility planning context as it deals with discretionary and non-discretionary projects. Then we categorized the cost structure of utilities to pinpoint where costs (and cost reductions) occur, along with the customer and societal perspectives that complete an economic evaluation of utility decisions which will be summarized in this report. Finally, we will examine developmental impacts as detailed in the Tor.

A GMM effort is a capital intensive effort which takes several years to see a return on investment. Most quantifiable savings occur due to reduced staff hours currently being spent validating models and investigating data error or discrepancies resulting from current business processes. Many times this involves sending field staff from the area offices to confirm or investigate actual as-built facilities. A potential secondary benefit of reducing these activities will be few PEA vehicles dispatched on these types of activities which not only reduces operating expenses associated with fleet vehicles, but also should improve employee and public

[8] Smart phones are an example of a platform where new uses emerged after the platform became ubiquitous. For example, when it became common for people on the street to be carrying communicating computers with GPS and graphics capabilities, ride-share services emerged to operate through the platform. Smart phones were not created to enable ride-share; ride-share came into being after being made possible by the platform.

safety by reducing PEA vehicle traffic accidents. These benefits could be measured through internal vehicle accident and on-the-job accident reporting metrics.

The remaining developmental impacts are qualitative and difficult to measure until PEA's GMM vision matures and begins to enable secondary technology and societal benefits discussed in the report.

Conventional Cost-Benefit Analysis

The GMM vision describes a single-source-of-truth model-data management system that fundamentally changes a host of business processes within PEA dealing with how planning and operations system models are established and maintained. The major benefit areas have been described in prior reports as follows:

- Reduce labor, as duplicate modeling is eliminated, as work steps are automated, and as time spent synchronizing, validating and correcting data is minimized
- Improve the accuracy of study results and reduce the likelihood of significant errors
- Increase the ability to perform sufficient and timely studies
- Improve the ability to compare study inputs and results across tools
- Enable more efficient and effective sharing of modeling with external entities
- Create an environment in which future study applications can be quickly and easily deployed

Implementation of GMM incurs substantive costs, as summarized below. Eventually these costs may be reduced by labor savings, but these benefits are difficult to forecast, and they are likely to change over time. As described in this report, there are other benefits more difficult to quantify and monetize. Some benefits may be episodic, arising from improved performance in events, or become built into a system with more accurate design. These subtle benefits will accumulate over time, as PEA streamlines its procedures around a twenty-first century system. The potential benefits shown are accrued over a 10-year period and will be measurable through labor savings once the project is completed.

Table 10 - Cost-Benefit Summary

Estimated Costs (PW_0)	Potential Benefits (PW_0)
• Capital Ownership* ~ 72 M฿ • Operating Expense ~ 22 M฿ • Increased Labor ~ 8 M฿ **Total ~ 94.1 M฿** ** on Capital Investment of 55 M฿*	• Planning ~ 4 M฿ • Operations ~ 13 M฿ • Operations ~ 147 M฿ **Total ~ 164 M฿**

Application Systems Development

Capacity added, security/redundancy gained, or reliability improved through implementation of CIM standard, modernized enterprise architecture, a primary and backup data center, and diverse systems and technologies for network operations (e.g. GIS, SCADA, OMS/LMS, CRM)

Some potential benefits include:

- Better understanding of grid will lead to more optimal use of assets, leading to higher utilization of resources. Depending on the actual increase in asset utilization, this could enable PEA delay distribution system upgrades.
- An enterprise-wide approach to grid modelling should reduce error in the modelling, reducing or eliminated data issues as a root-cause for electricity delivery interruptions.
- A modernized architectural approach which enables interoperability and utilizes standardized approaches to data management and sharing utilizing the CIM, will be foundational for future application systems development. In addition to benefits discussed in the *"Promoting Effective Markets and Governance"* section of this document, an improvement in Customer Relationship Management (CRM) could be expected. Benefits could include the ability for retail and wholesale customers view energy consumption, renewable energy management, receive outage notifications and service status notices, etc leading to greater overall customer satisfaction.

Additionally, there are several types of system studies and analysis which may be needed in the future that an implementation of a GMM at PEA could either enable or aid in supporting the analysis and resolution of undesired system conditions, particularly power quality issues. These types of future studies are:

- Steady State Thermal Analysis
- Contingency Analysis
- Steady State Voltage Analysis
- Transient Stability Analysis
- Voltage Stability Analysis
- Short-Circuit Analysis
- Power Quality Analysis
- Harmonics Analysis
- Training (System) Simulator
- Flicker Analysis
- Arc-Flash Hazard Analysis
- State Estimation

- Tracing
- Location Price Calculation

These studies impact several business domains and functions.

Table 11 - Business Domain/Function

Business Domain	Business Function
Long-Term Planning (>1 Year)	System Expansion / Reliability / Adequacy Planning
	Non-Wires Alternative Evaluation
	Resource Planning
	Hosting Capacity Analysis
	Interconnect Evaluation
	Volt/VAR Strategy Planning
	Relay Coordination / Relay Setting
	Load-Shed Strategy Planning
	Long-Range Load/DER Forecasting
Operations Planning (+1 Day to +1 Year)	Operating Instruction Development
	Short-Term Operating Analysis
	Planned Outage Management
	Feeder Load Balancing
	Short-Term Load/DER Forecasting
	Training Simulator
Operations (Near Real-Time)	Situational Awareness
	Real-Time Contingency Analysis
	Unplanned Outage: Fault Location
	Unplanned Outage: Fault Isolation
	Unplanned Outage: Service Restoration
	Volt/VAR Optimization (Centralized)
	Power Quality Management
	System Reconfiguration
	Grid Optimization
	DER Output Management / Coordination
	Dispatch
	EV Charging Management
	Adaptive Protection
	Automated Islanding / Reconnection
	Emergency Load Shedding
	Real-Time Load/DER Forecasting

Application Interfaces

Efficiency gains and reductions in losses as a result of project implementation, including reduction in time, expense and quality improvements.

There were no reductions in system power losses identified as a direct result of the GMM implementation. As mentioned in the previous section, the GMM project will prove to be an enabling technology that could facilitate more advanced operational technologies shown in Table 2. Some of these technologies such as volt/var optimization would likely result in a reduction of system losses but these longer range impacts are only secondary benefits of a GMM, and are unknown at this time.

All quantifiable efficiency gains related to GMM application interfaces were identified in the Task 6 Economic Analysis report, and summarized in the Conventional Cost-Benefit Analysis section of this document. Qualitative benefits in this category could include.

- Leveraging CIM will allow for new systems and processes to be implemented more quickly with the establishment of a foundation for the PEA enterprise data glossary.
- Establishing some of the architectural principles, some of which are detailed in Task 7 such as Identity Management, can improve integration and security among PEA applications and shorten new interface development times.

Skills Developments

Training and human capacity development delivered to host country stakeholders over the course of a USTDA activity and into the implementation phase of the project. Implementing standard and capacity development are among the primary goals of the project.

During the course of the project, multiple CIM-related training workshops were conducted for approximately 20 PEA staff members. During the GMM implementation, it is anticipated that up to 20 staff members in the IT and Digital Office groups would develop proficiencies as CIM practitioners, and many more staff in the Planning, Operations and Area Offices would experience skills development directly related to the GMM concepts and how their work impacts PEA as a whole.

During the GMM project, a 10-day site visit to Bangkok, Thailand was conducted and during the visit a CIM Study Forum workshop was hosted by Thammasat University. Students from the College of Engineering, as well as representatives from Thailand's Transmission and Generation Operator EGAT, and also the Bangkok metro distribution company MEA. Dr. Choompol Boonmee of DigitalSiam and EPRI staff presented during the workshop. The exposure to CIM and utility data management technologies could generate interest among Thailand's utility operators in these technologies prompting the engagement of utility professions as well and Universities and young engineers.

Some additional skills development potential include:

- Higher understanding across PEA of grid modelling concepts, leading to employees with a deeper understanding of how the grid (and PEA) functions.
- Additional training on CIM as a design philosophy and new tools such as Enterprise Architect can improve staff expertise and morale, especially in the data/information architecture disciplines at PEA

Promoting Effective Markets and Governance

USTDA engagement will lead to the adoption of internationally recognized best practices that support positive environmental or social gains, efficiency, transparency, or competition.

Some Governance and Market benefits could include:

- Implementing the GMM will enable model exchange with MEA and EGAT and promote effective governance both within these entities and also with the Ministry of Interior through increased transparency of system performance and renewable energy penetration.
- Better grid modelling will enable the integration of more renewables and DERs onto the grid, perhaps reducing interconnection study times.
- Provide improved distribution work planning, equipment maintenance cycles, vegetation management and future distribution system expansion.
- Create a more efficient means of justifying tariff cost recovery through potentially better asset management, planning techniques, outage rates and duration.
- GMM and the CIM can provide a data foundation when markets are established for wholesale trading and as customers start to engage with aggregators and alternative suppliers for distribution services. This will also allow Distributed Energy Resources to be aggregated and included in total system generation capacity.
- By providing a clear view into DER and EV penetrations, CIM-enabled data sharing will also promote effective marketing strategies to increase DER and EV penetration in high energy consumption areas such as large urban centers.

CHAPTER 10 U.S. EXPORT POTENTIAL

Summary

Task 10 requires the documentation of potential U.S. sources of equipment and services applicable to the PEA CIM project. The Terms of Reference stipulates that this documentation include.

- Likely U.S. suppliers for equipment and services
- Detailed description if relevant products, solutions and services for the project
- Contact information for the parties responsible for marketing/sales in the Host country including business name, point of contact, address, telephone number and email for each identified party.
- Engage the relevant potential suppliers in a discussion and analyze their interest in supplying equipment or services for the project and document this information.
- Within its nonprofit parameters as an independent and objective scientific research institute
- that does not endorse vendors and subject to applicable competition laws, based on information reasonably available in the marketplace, EPRI is providing information for PEA's assessment
- of potential U.S. vendors to support a future GMDM project. These are supplier based in the United States who have equipment or services, and for each a short description of the relevant offering is providing along with the primary contact. Each has been contacted about the potential opportunity and has expressed interest in being listed in this directory.

Industry Organizations with CIM-related Activities

EPRI

Founded in Palo Alto, Calif., in 1972, EPRI is an independent non-profit energy research, development, and deployment organization, with three specialized labs. EPRI also maintains an employee presence in more than a dozen countries in Europe/Middle East/Africa, as well as Asia, and the Americas through its subsidiary EPRI International Inc. and its Ireland-based research arm, EPRI Europe DAC. Should PEA become an annual funding member of certain research programs and project sets, there are direct benefits.

- Access to research result from the funded areas
- Participation as an Industry Advisor and opportunities to network with other utility professionals.

- Ability to direct a significant portion of membership fees "self-directed funds", as examples:
  - Annual 2-Day Workshop on 161 & 200 results and how to apply the results.
  - Custom supplemental based on a specific research activity

Specific areas of interest to PEA might include:

Program 200: Distribution Operations and Planning

- Project Set A: Tech Transfer and Industry Engagement
  This project set is designed to provide members with high-impact resources that cover topics relevant to distribution operations, planning, and protection to keep members up-to-date on the latest technology advancements and industry issues.
- Project Set E: Analytics for Operations and Planning
  This project set provides engineers with the analytics necessary to modernize how existing assets/data and new resources are modeled/simulated for grid analysis.

Program 161: Information and Communication Technology

- Project Set A: Emerging ICT and Technology Transfer
  This project set tracks and analyzes the rapid advancements in grid modernization technologies and standards to minimize the risk of planning and procuring equipment. Subject matter experts capture and analyze information and provide insightful feedback.
- Project Set E: Enterprise Architecture and Integration
  This project set aims to put the best tools and techniques into the hands of enterprise architecture practitioners and others driving towards the same objectives, with an eye to the unique needs and operating environments of utilities.

Contact:

Paul Pickering | ppickering@epri.com | 1-650-855-2147

3420 Hillview Ave | Palo Alto, CA 94304 | USA

UCA international Users Group

UCA International Users Group is a not-for-profit corporation focused on assisting users and vendors in the deployment of standards for real-time applications for several industries with related requirements. The Users Group does not write standards; however, works closely with those bodies that have primary responsibility for the completion of standards (notably IEC TC 57: Power Systems Management and Associated Information Exchange). The UCAIug as well as its member groups (CIMug, Open Smart Grid, and IEC61850) draws its membership from utility user and supplier companies. The mission of the UCA International Users Group is to enable integration through the deployment of open standards by providing a forum in which the various stakeholders in the energy and utility industry can work cooperatively together as members of a common organization.

Contact:

Scott Coe | Scott.Coe@ucaiug.org | 1-203-047-5269

11 Louis Allan Drive | Danbury, CT 06811 | USA

GMM Solutions

As part of the activities within Task 4, the team created a list of worldwide vendors with products and can supply many of the GMM capabilities required for the implementation steps described in Task 7. Although ESRI is currently utilized by PEA for Engineering Design functions and will play a role in more advanced Engineering Design and GMDM data sharing capabilities, they do not offer a GMM solution and are not included as a potential vendor. Given that the list contains several non-US companies, we can narrow the list of potential software providers of GMM solutions to:

GE Digital, (d/b/a GE Grid Solutions Thailand Limited)

GE Digital, is a software and solution services provider specializing in grid orchestration software to help transmission and distribution energy utilities orchestrate the clean energy grid. GE Digital's GridOS® Orchestration Software, is the first grid software portfolio designed for grid orchestration that brings together energy data, network modeling, and AI-driven analytics across the grid to power a suite of composable applications from GE, utilities, and expert partners that help utilities orchestrate an integrated, flexible and secure clean energy grid.

Contact:

Stephanie Song | Stephanie.Song1@ge.com | +65 86611402

5 Necco Street | Boston, MA 02210 | USA

Open Systems International (OSI), Inc.

CIM Studio – OSI's CIM-native editing tool that provides a set of features based on the EPRI Network Model Manager (NMM) specification: full CIM transmission modeling capabilities, including automatic one-line display generation; simultaneous user projects/jobs working on the same or different model versions, current and future; user-specific workspaces; profile-driven import and export; and conversion to and from native monarch models. In addition to IEC 61970 and related standards, CIM Studio also supports import, viewing, editing and schema-based validation of any CIM model defined using a valid schema. CIM Studio can also handle valid XML input without a schema definition, however with limited model validation. CIM Studio's flexible and extensible internal architecture makes these features possible out of the box, without software modifications or database extensions.

Contact:

Elmes Fang | elmes.fang@aspentech.com

4101 Arrowhead Drive | Medina, MN 55340 | USA

Oracle Corporation

Oracle Utilities Network Management System (NMS) and related solutions monitors and manages every aspect of utility OT systems, from distribution to customer-owned grid edge devices. Partner with Oracle to improve reliability and performance across your territory when it matters most. As part of the EPRI Grid Model Data Management Vendor Forum, Oracle successfully participated in the IEC 61968/70 CIM Interop the EPRI/UCAIug CIM Interoperability Event held in Charlotte, NC on June 14-16, 2022. Oracle brought our NMS data CIM model exchange tools to the table and ten test witnesses, from utilities and integration consulting firms, watched dozens of grid models exchanged in Common Information Model (CIM) form with other vendors.

Contact:

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Vancouver, WA | USA

Enhanced Planning Tools

Within the Planning division, several tools are currently in use for interconnection and grid enhancement planning, namely DIgSILENT's PowerFactory for HV and MV analyses and OPSAonGIS (built on EPRI's OpenDSS) for LV analyses. The GMM Vision enables several things not present today, such as

a. a single source for Planning Grid Models.

b. the ability to look “across” voltages,

c. Grid Models with more detailed substation information,

d. Grid Models with more accurate EGAT and MEA representations, and

e. a common format enabling easier introduction of new tools.

Thus, we encourage PEA to look at more sophisticated solutions in the planning domain as these applications are upgraded. Example of US-based planning solutions include:

Electric Power Research Institute (EPRI)

The EPRI Open Distribution Simulator Software (OpenDSS) was created to determine the value (location and time) of distributed energy resources (DER) for distribution planning. It has become multi-faceted platform and suite of tools that enables distribution engineers and researchers around the globe to tackle a broad range of distribution modeling challenges.

OpenDSS was designed from the beginning with capabilities to capture the time dimension. This initial capability of performing quasi-static time-series2 simulations is one of the key features that set the stage for moving time-based distribution planning tools forward on a large scale. Additional core capabilities consisted of harmonics analysis, fault analysis, machine dynamics, voltage regulator controls, switched capacitor controls, fault elements, load and generator models, and load shapes. Through the course of industry projects additional capabilities were added, including DER models, advanced control systems, high-performance computing (HPC) capabilities.

There are several ways that EPRI could assist PEA in the design and deployment of advanced Distribution planning tools. Specifically, the following EPRI research programs would be beneficial for PEA.

Contact:

Paul Pickering | ppickering@epri.com | 1-650-855-2147

3420 Hillview Ave | Palo Alto, CA 94304 | USA

Enhanced Engineering Design Tools

In the GMM Vision, Engineering Design plays a key role in the production of new Grid Model data. Today, design is performed in AutoCAD and/or using tools leveraging the ArcGIS data platform. In the future, these tools will provide updates to the GMM whenever new elements are designed and when elements change based on construction and maintenance operations. The GMM may have automated links to these tools (and any newly acquired tools in the Engineering Design realm) so that any change to the grid can be captured promptly and accurately.

Depending on the vendor's GMM capabilities, tools may either supply Change Models that are directly useable by the GMM to update Grid Models or tools may supply updated design fragments which the GMM will use to generate its own internal Change Models. The vision does not anticipate a need for Engineering Design tools to consume Grid Models, but the option is always available should the need manifest.

Thus, it is likely that both tool manufacturers will see some potential to sell enhanced services to PEA.

Environmental Systems Research Institute (ESRI)

Esri, the global market leader in GIS software, offers the most powerful mapping and spatial analytics technology available. Since 1969, Esri has helped customers unlock the full potential of data to improve operational and business results. Today, Esri software is deployed in more than 350,000 organizations including the world's largest cities, most national governments, 75 percent of Fortune 500 companies, and more than 7,000 colleges and universities. Esri engineers the most advanced solutions for digital transformation, the Internet of Things (IoT), and location analytics to inform the most authoritative maps in the world.

Contact:

Brett Dixon | bdixon@esri.com | +61 488 550 131

380 New York Street | Redlands, CA 92373 | USA

CIM Consultants/Integrators

Implementing CIM-based systems is a niche-field given the limited number of utilities around the world. That said, the United States has a number of independent consulting firms which have experts in this field have expressed interest in the PEA CIM project:

Britton Consulting

Jay Britton is a Power System Operations consultant specializing in Architectural design and implementation of Network Analysis software. Mr. Britton is an IEEE Fellow, and is active in the IEC standards body CIM working groups and the CIM User Group.

Jay Britton | jpbritton@outlook.com | 1-425-503-0828

603 Windmill Drive | Freeland, WA 98249 | USA

GridOptimize LLC

GridOptimize is a consulting firm specializing in bridging the gap between wholesale markets and distribution resources. Staff have been involved in wholesale market implementations since their inceptions in the 1990s and have played key roles in integrating demand response and more recently DERs into those markets. On the distribution side, GridOptimize focuses on preparing utilities to be able to plan and operate distribution grids with better ties to the wholesale markets above and the DERs embedded into their network.

Scott Coe | Scott.Coe@GridOptimize.com | 1.203.947.5269

11 Louis Allan Drive | Danbury, CT 06811 | USA

PCItek

PCItek is a CIM system integrator and consulting firm which specializes in IT/OT integration services with a focus on standards-based solutions that will enable a high degree of interoperability. The technical staff at PCItek are considered CIM industry experts who have been active in the IEC CIM standards body since the inception of CIM.

Margaret Goodrich | margaret@pcitek.com | 1-903-477-7176
P.O. Box 315 | Schell Knob, MO. 65747 | USA

Spatial Business Systems, Inc.

SBS is a leading provider of intelligent design software to utilities and critical network infrastructure assets. SBS's suite of vertical-focused software solutions automate and streamline engineering & design workflows, integrate spatial and design data and improve design effectiveness. The Company serves a blue-chip customer base including many of the world's leading utility, infrastructure and engineering firms. SBS is headquartered in Denver, Colorado with an office in Melbourne, Australia.

Patrick Reid, COO | pat.reid@spatialbiz.com | 1-303-847-4200

190 W. Littleton Blvd | Littleton, CO 80120 | USA

Strateture Solutions

Jim Horstman is an independent consultant specializing in business, information and system architecture for electric utilities based on a significant number of years experience at a major utility. Mr. Horstman is active in the development of the IEC CIM as a part team lead and the EPRI GMDM project.

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Xtensible Solutions LLC

Xtensible Solutions, LLC is a consulting firm specializing in Strategy & Architecture, Business & Technology, Enterprise Information Management, System Integration, Business Intelligence & Data Analytics and Training. They have specialized experience in the Electric Utility sector including EMS, SCADA, ADMS and ODMS. Xtensible is very active in the CIM standards community and delivers professional and utility-based expertise throughout the life-cycle of implementation and ongoing support.

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