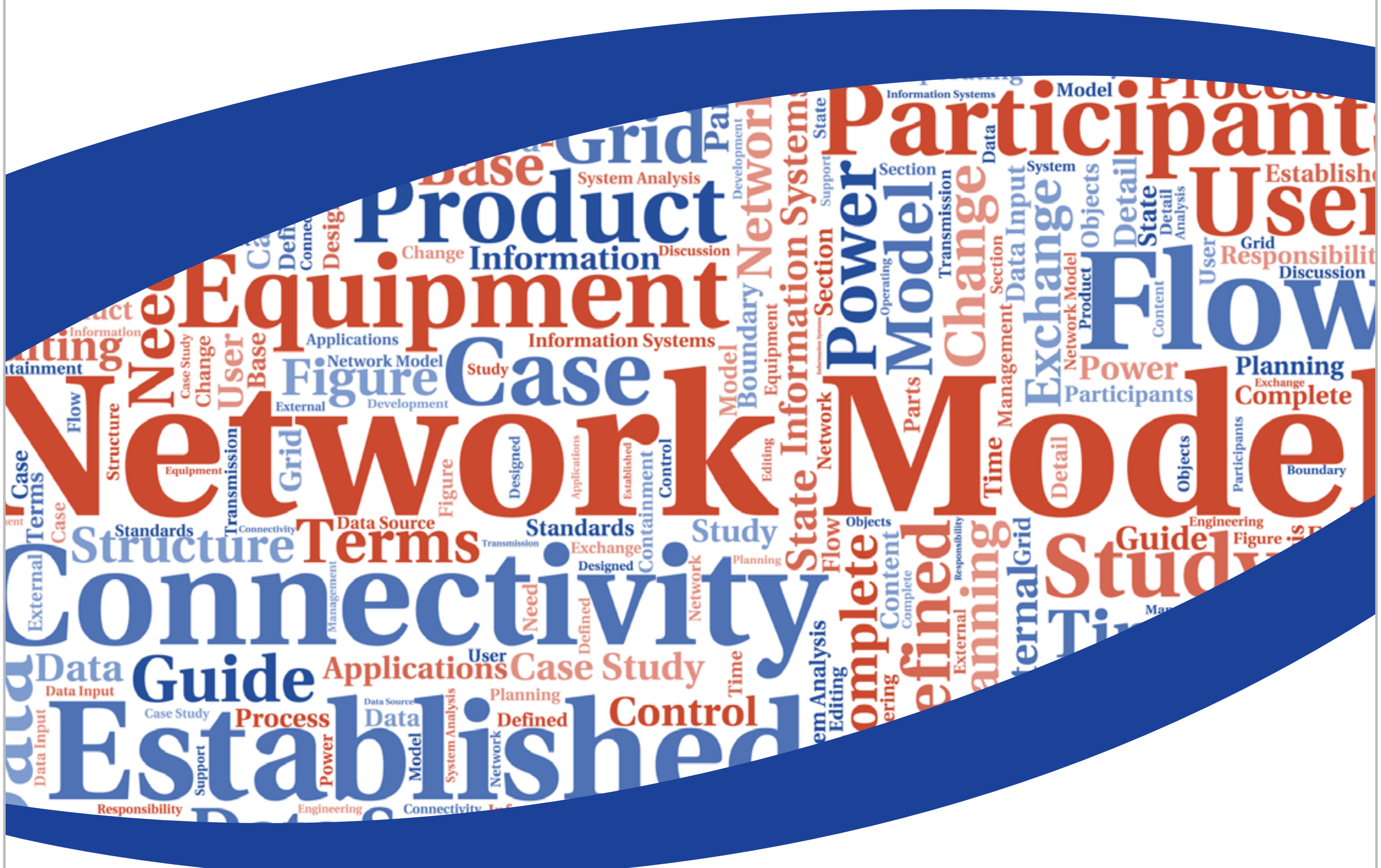
ELECTRIC POWER RESEARCH INSTITUTE

2014 TECHNICAL REPORT

Using the Common Information Model for Network Analysis Data Management

A CIM Primer Series Guide



Using the Common Information Model for Network Analysis Data Management

A CIM Primer Series Guide

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3002002587
Final Report, November 2014

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THE ELECTRIC POWER RESEARCH INSTITUTE (EPRI) AND THE FOLLOWING ORGANIZATION, UNDER CONTRACT TO EPRI, PREPARED THIS REPORT:

Britton Consulting, LLC

NOTE

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This report describes research sponsored by EPRI.

This publication is a corporate document that should be cited in the literature in the following manner:

Using the Common Information Model for Network Analysis Data Management: A CIM Primer Series Guide.
EPRI, Palo Alto, CA: 2014.
3002002587.

Abstract

Today, smarter operation of the power grid means greater dependence on network analysis at the bulk power level for planning, reliable operation, and energy markets and at the distribution level for engineering and distribution operations. The number of network analysis cases being run is skyrocketing, and the challenge of supplying accurate models on a timely basis is daunting.

This guide provides a comprehensive introduction to the revolutionary Common Information Model (CIM) approach to managing high-quality network analysis models. The guide explains how the International Electrotechnical Commission (IEC) 61970 CIM standard builds a solid and flexible foundation for the effective creation, maintenance, and exchange of network model information to support the needs of network analysis applications.

The guide explores the characteristics of network model information and discusses a reference architecture for model management. The use of CIM classes, attributes, and relationships for the creation, maintenance, and sharing of model parts is also reviewed in detail, illustrated by Unified Modeling Language (UML) model diagrams. Finally, the guide describes the design of CIM-based frameworks to aid in the assembly of model parts into cases tailored for specific study needs and examines a typical grid framework.

Written primarily for power system engineers who maintain network models or use network analysis, the guide is intended to provide utilities with a sense of what CIM technology can accomplish to improve network analysis. The guide—another in EPRI's *CIM Primer Series*—complements the *IntelliGrid Common Information Model Primer* (EPRI report 3002001040, published October 2013).

Keywords
Common Information Model (CIM)
International Electrotechnical Commission (IEC)
IEC 61970 standard
International standards
Semantic model
Network analysis
Network models
Data management
Unified Modeling Language (UML)

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Section 1: Intended Audience

Network analysis is on the increase in terms of numbers of studies and in terms of importance to the successful planning and operation of the grid. This Guide, which addresses the urgent issue of network model information sharing within and between electric utility entities, is written for power system engineering professionals who use or support or manage any form of power system network analysis or are otherwise interested in or concerned about organizing the information flow involved in network analysis business processes.

This Guide does not attempt to describe network analysis applications. It assumes that the reader has a good working knowledge of power systems and network analysis applications and understands why network analysis is important. The focus here is how to manage information so that network analysis processes can be carried out accurately and efficiently. 'Garbage in, garbage out' is a principle that holds for network analysis, as it does for most other applications. Assembling quality models for network analysis is particularly challenging. Finding ways to improve network data management has been a major focus of the International Electrotechnical Commission (IEC) Common Information Model (CIM) standards work for some time.

The emphasis here is on the overall process of network modeling, rather than the details (like, for example, explaining the exact meaning of each property of each class within the CIM model, or how to use CIM editing tools). Look here for context, organization, purpose; and elsewhere (such as IEC standards or vendor specifications) for specifics.

No prior experience with CIM is necessary for reading this Guide. The content is focused on how an end user accomplishes network analysis tasks in the CIM world, rather than on how the software works or the CIM methodology for implementation. Some CIM terms are used, but they are defined and there is a Glossary that should provide adequate background for the purposes of this Guide.

For readers whose ultimate purpose is to engage in implementation of CIM-based systems for network analysis, this Guide should be read in addition to other more implementation-oriented documents. A good starting point would be EPRI's *Intelligrid Common Information Model Primer* [1], followed by the selected reading of the 61970 series of IEC documents [2, 3, 4, 5, 6].

This Guide describes the CIM solution developed by IEC Technical Committee 57 (TC57) Working Group 13 (WG13) for organizing network analysis data. Direct references to details of the CIM standards are provided in the text where appropriate and are augmented by information in the Glossary that links the concepts of this Guide to their realization in CIM standards.

Section 2: Introduction

Why Is Network Analysis Important?

A power grid is an enormous, complex, interconnected machine which society depends on to deliver reliable low cost power and which has significant negative impacts on society when it fails.

Reliable operation of the grid is difficult to assure and efficient markets for electricity are difficult to design. The industry direction is to create more sophisticated strategies for planning and operating the grid that depend heavily on computer-based automation. 'Smart grid' is current as a term, but computer (i.e. smart) applications to improve power delivery is a trend that dates back to the 1960s.

It is not the purpose here to analyze the nature of smarter strategies, however, which is a very big subject. The interest here is in one simple fact: virtually all of the smart strategies in use today depend, in one way or another, on computer-based analysis of the power grid, and a large percentage of these involve in some way analysis of the grid as a whole, as opposed to the state of individual components. In short, grid reliability depends on power system network analysis. This is true because a power grid is made up of millions of parts that are bound together in instantaneous interdependence by the physics of electricity, and no decision can be taken about one part without some impact on the rest. Very simply, this means that engineers must carefully study how the whole grid will behave when they consider a modification to any part of it.

This dependence on network analysis has grown, decade by decade, and it shows no sign as yet of levelling off. The core analytic is power flow – which solves for the voltages and flows across the grid under hypothesized steady-state load and generation patterns. But from the power flow base, analysis builds into fault analysis, dynamic and transient analysis, as well as probabilistic and operations research optimization formulations of various kinds. All these analyses are interrelated. All are conducted at very large scales and, in operational situations, under challenging time constraints.

Why the Emphasis on Data Management?

The business processes that carry out network analysis are very complex. The complexity starts with the need to model grid physics but is also related to the size, diversity and distributed nature of the grid. The eastern interconnection in North America, for example, stretches from the Atlantic coast to the Rocky Mountains and is made up of grid parts owned by hundreds of different utilities, plus participating generators and consumers of many types. It is divided into a hierarchical arrangement of planning and operating authorities with a variety of different responsibilities. These grid entities have greater or lesser roles in different analytical processes, but they all play a part, and most of the critical business processes (from the grid analysis perspective) involve multiple participants acting in cooperation.

Analytical systems are expensive to develop and maintain. It is easier (though not easy) for one entity to automate and optimize its internal systems and processes. It is more difficult to automate and optimize exchange of information where other parties are involved. Across the spectrum of current activity, while there is an impressive array of automation and advanced analytical techniques, the processes are far from completely automated. Many important information management steps are still carried out manually; many others are automated but in ways that require too much manual support. In all, too many scarce and valuable engineering hours are required in order to assure proper functioning of processes, when those hours really should be free to review results and make decisions.

Network analysis as a whole is a fundamentally challenging data management problem. Large amounts of complex data must originate from many different sources and flow to many different analytical actors where it must get assembled and work properly in a variety of different tools from different vendors in predictable time frames.

Within IEC TC57, the WG13 focus has been to create interoperability specifications that will optimize current data management and also pave the way for even 'smarter' grid operation in the future.

What Kind of Solution Are We Looking For?

Many interoperability specifications are designed using a fairly simple methodology which boils down to: a) document the business processes to identify required points of interoperability; b) design each identified interoperation individually.

Network analysis business processes in different grids have similar objectives, but the processes are not the same. There is currently no agency that could develop and impose standard business processes globally. Many important 'processes' are not even precisely definable, in that they deal with supporting an engineer's need to explore problems and develop solutions. Practitioners need to be able to take advantage of data and results generated in other analytical contexts, but they may not know where they are headed in the next step until they get the current step done.

The good news, though, is that power systems themselves are very similar. They are made up of the same kinds of components and they use the same network analysis applications. What practitioners need most is a versatile set of building blocks for creating analytical cases, and they need to be able to exchange these building blocks. A good set of building blocks will not come about by designing one procedure at a time, however – a good set of building blocks requires looking at the overall problem to see how it naturally composes / decomposes.

So while the steps of documenting nominal business processes and identifying important interoperability points remain important, they are not the key to problem. A good strategy needs a deeper look at the nature of the network analysis problem.

What is the Scope of the CIM Network Model Management Solution?

It is important to recognize that the focus of IEC is standards for interoperability among different utility organizations and/or different vendor products. Neither IEC nor its CIM Working Groups design or build applications, and the internals of applications are deliberately left open to competition and are not part of the IEC scope for standardization. CIM policy is to maximize opportunities for creativity by restricting standardization to points where exchange of information is required.

So what does this policy mean in terms of the scope of CIM specifications for network analysis? Roughly, this can be summarized as follows:

- Network analysis requires modeling of the power grid expressed in large amounts of structured data. This data must be exchanged between utilities and between vendor products and it is the primary focus of the CIM solution.
- Data management for network analysis requires that different organizational entities cooperate in complex business processes to create and validate necessary network data. These processes are the core 'use cases' which drive the CIM standards, and the end goal of the CIM solution is to enable the network analysis actors to create effective process agreements. At the same time, as discussed in the previous section, there is variability in these processes which is impractical to standardize. CIM standards therefore generally do not completely standardize business processes. Instead, they standardize a flexible set of components that can be used as the basis of different business process designs, whether the purpose of such a business process is to define a local utility usage, or to document an industry best practice, or to establish a formal multilateral agreement among grid participants.
- CIM scope does not include algorithms for network analysis, except in the sense that CIM must satisfy the algorithm's need for data. Algorithms generally are internal to vendor products and their design is left to vendor competition. (Thus this Guide does not include any information about the nature of algorithms for network analysis.)

About Operations versus Planning

Broadly speaking, the term 'operations' describes the minute-by-minute management of the grid as it delivers power to consumers. 'Planning' refers to engineering activity that puts in place the necessary grid components that enable operations to meet demand. In utility organizations these two domains are usually separate, but network analysis is used intensively in both. It is commonplace currently that engineers in these two domains use separate analytical tools and carry out analysis based on separate, independently maintained models.

The CIM goal is to enable more efficient processes, and one of the main potential improvements in efficiency is to eliminate multiple modeling efforts. Hence CIM standards for network model data are designed to meet the needs of both planning and operations. This may require some adjustment on the part of the reader, especially if the reader's background is primarily planning, because the data structures typically used in planning (often referred to as 'bus-branch' modeling) are somewhat simpler than those for operations (often referred to as 'node-breaker' modeling). The difference is driven primarily by two kinds of requirements that have always been basic to operations:

- Operations network models need precise positioning of measurements within the model, so that status and analog measurements from field sources can be used as input to network analysis cases.
- Set up of operations cases must be able to be completely automatic for any time of day. Thus there must be data that describes how to translate a time of day or load level into individual load, generation, device status, target voltages, etc.

An assumption of the CIM effort is that, in the long run, as operations and planning grow closer together and 'operational planning' studies become more and more important, these features will become useful to planners as well and the view of requirements will eventually merge. This is not, however, an argument that operations models are right and planning models are wrong. Rather, the argument is that all studies would be better off based on current as-built system modeling that has been fine-tuned by operations (and verified by field measurements), even if future plans and possibilities are only available at a bus-branch level of detail.

About Transmission versus Distribution

An even higher wall has typically divided transmission engineering from distribution engineering. While transmission engineering uses network analysis intensively in both planning and operations, distribution planning usually relies less heavily on network analysis and distribution operations may not use any.

Times are changing, though. Connectivity analysis to assess customer outages in distribution operations is fairly common. Volt-VAr optimization and other algorithms are on the rise. Distributed energy resources and price responsive demand change the nature of distribution systems and challenge the old assumptions that distribution is just a fixed demand on transmission and transmission is just a fixed source for distribution.

CIM work has taken the following view:

- CIM standards need to cover both transmission and distribution network analysis.
- Transmission and distribution components (overhead lines, cables, switches, transformers, etc.) are mostly the same, and it would not make sense to have different models for the same things.
- There will be an increasing need, driven by smart grid advances, for continuous 'T to D' modeling, in which the hard line between transmission and distribution is erased. Instead, there is just a choice about how much of the grid is represented in a particular analysis.

While some aspects of CIM may obviously be tilted toward satisfying traditional requirements of transmission or distribution situations, the reader should assume, unless explicitly stated otherwise, that all capabilities described in this Guide may be applied to either transmission or distribution network analysis.

Section 3: Main Themes in Managing Network Analysis Data

Network model data management processes are complex, but analysis reveals some primary themes that are very instructive in designing an approach that is significantly better than current practice.

The reason that significant improvement is available seems to be that CIM has allowed itself the luxury of taking a step back and looking at the entire problem, whereas most practicing engineers who have attempted improvements have only been able to engage in changing limited aspects of the problem. Indeed, when analyses of existing practices at utilities have been done, they reveal no shortage of creative patches aimed at improvement, but they dramatically lack a central information architecture for network analysis.

This section outlines the main CIM themes, and the reader is encouraged to think about whether these themes align with their own experience. In any case, though, these are the main drivers behind the CIM architecture for network model management.

Manage the Physical Network Model Separately from Other Data

The term 'physical network model', as it will be used here, refers to the properties and capabilities of the network that are inherent in its construction and cannot be changed except by further construction activity. It can be thought of in two basic parts:

- A set of physical components and their properties.
- The electrical connectivity of the components. I.e. How are they wired together into a network?

For example:

- The fact that there is a breaker that can open or close is part of the physical network model; whether the breaker is open or closed is an operating choice and not part of the physical model.
- The fact that a transformer has a tap-changer with a certain range of settings is part of the physical network model; the way that it is operated – whether it is off control at a specific tap or on control with a regulated voltage – is an operating choice and not part of the physical model.

The first, and most significant, theme on which CIM is based is that the physical network model data should be managed separately from the other data that is input to network analysis studies.

Establish Responsibility for Physical Network Model Data

Why would different studies want to use different physical modeling of a given component? This happens commonly in today's network analysis, in which there are multiple independently created models of the same territory in use for different analytical activities. While there are sometimes justifications for different modeling (such as a need for simplified representations), very often different models simply result from different judgments made by different modeling engineers. These differences make quality difficult to assess, and they make results difficult to compare from one study to the next.

The CIM objectives for the physical network model are:

- Every item of physical network data has a single source and a responsible model authority.
- The authoritative source model satisfies the union of study requirements. I.e. It has all the detail required for any of its users.
- As study models are assembled, each component's representation is traceable to its source, either because it is copied directly or because it is simplified from the source by a defined procedure.

The physical network model constitutes the majority of data feeding each study, and crucially, it creates all of the key 'identified objects' that will be found in analytical studies. When all of the physical network model objects are traceable to a source of record, it becomes straightforward to compare results generated anywhere. This CIM objective therefore enables a degree of confidence in quality and consistency of results that without CIM can only be approximated by very expensive validation and cross-checking processes.

Distributed Sources of Physical Network Model Data

Each item of data in the physical network model should have a single source, but not all data comes from the same sources. Therefore, the architecture must support parts of the model supplied from different sources.

A consequence of this decision is that a method for establishing clear boundaries of responsibility is necessary. The following list identifies some of the kinds of separate sources that may need to be managed:

- Across an interconnection, each TSO is the source for modeling the transmission grid for its territory.
- Distribution organizations may need to supply models that connect with those of transmission organizations.

- Models of 61850 installations may be imported from 61850 source data. (IEC 61850 [7] is a substation automation standard whose usage is increasing.)
- Responsibility for modeling of various types of information sourced from inside a utility (e.g. relay information, equipment ratings or generator dynamic models) may be allocated to different departments from those responsible for the static network configuration.

Electrical Roles versus Assets

It is important to clarify that although physical network model components like transformers, switches and lines sound like things that one could walk up to and touch, the real meaning of 'switch' in the physical network model is that there is an electrical role in the network where a switch is to exist, rather than the actual switch asset that occupies the role.

Why make a distinction between assets and roles? Roles in the network are planned before the assets are known. Sometimes assets are in inventory or in maintenance and not filling any role. An asset can be installed in one role, later taken away for maintenance, and returned to a different network role. History is of interest per asset, but also per role in the network. Separating assets from roles helps manage these scenarios.

The As-Built Physical Network Model

Network analysis takes place in many time contexts, but the overwhelming majority of data describes the power grid as it is currently built, and the 'as-built' physical network model is the foundation around which solid information management practices generally can be based. There are several reasons behind this foundation role:

- Organizationally, engineering and design units are responsible for construction and are the source of the as-built physical network model data, whereas other operational state data and future plans come from other sources.
- Most study models use the as-built model as their modeling core and then build on it if the study is representing a future time frame where new construction is also introduced.
- Accuracy of the as-built model can be quantitatively assessed by the state estimation algorithms that are more and more commonplace in control centers. Quality assurance therefore attaches to the as-built model in a way that does not exist for other data.

The as-built model represents the present grid. It must evolve as new construction completes in the network. This creates a series of versions of as-built, each associated with a moment in time, with the latest version representing the present. Most studies use the present version as a starting point, but past versions are occasionally useful as well.

The Future Physical Network Model

Modeling the physical network model forward in time is different from managing the past. The past is just an evolution of network model states. The future is a collection of individual proposals and plans and what-ifs that, because they are inherently speculative, form a huge collection of possible branching patterns for the evolution of the grid. In fact, the possible future states are impractical to enumerate or manage as separate stand-alone states.

The practical way to manage the future is as a collection of change descriptions. Let's call a proposed change description a 'project'. Think of a project as an envelope. On the outside are characteristics of the whole envelope (who, what, why, when, etc.), and on the inside are a collection of changes to the physical network model which the project would accomplish. The hypothetical situation for a future study can be established by selecting the set of projects that are to be in view for that study.

The current list of projects represents the current view of the physical network model future. Studies are built by starting from the as-built network state and selecting the changes that apply (which is a function of what situation the study is about). If plans change, which they frequently do, the projects list is updated and studies can be rebuilt as long as we know the procedure by which they were constructed.

Operating Hypotheses

There are two basic components of input to any study. The first is the physical network model described in the previous section, which accounts for the majority of the data. The second is an operating hypothesis for the study – in other words, the answer to the question, 'what operating condition is to be studied?'

Algorithms differ to some extent in terms of exactly what they can accept as part of their operating hypotheses. (E.g. A state estimator can take in a flow measurement, but a power flow cannot.) Studies also vary in terms of the way that an operating hypothesis is formed. (An operations study could model a tap setting as it is in the field, but a planning study might want to pretend the tap was variable in order to find out where it should be set in order to maintain a reasonable voltage.) In sum, though, there is much more overlap than there is difference, and it is practical to define one way to describe a 'steady-state hypothesis' that will be useful for all types of network analysis. This description is roughly equivalent to the information that needs to be added to a physical model to create a complete set of input for a power flow.

Complete operating hypotheses are not shared or managed in the same way as the physical network model, however. Instead, there tends to be a collection of different procedures for developing different parts of the operating hypothesis in different analytical situations. While the physical network model should be derived from shared master source material, an operating hypothesis will align with the particular kind of study being run.

To illustrate, consider the question of how a given study would initialize the state of switches and circuit breakers and taps within its steady-state hypothesis. Depending on the kind of study, any of the following actions might be appropriate:

- Initialize from current conditions.
- Initialize from the defined 'normal' state that is part of the physical model.
- Initialize from another power flow case that has been saved.
- Override by adding one or more outages.
- Override by adding a pre-stored contingency.
- Override with any manual selections.

Inconsistent Naming Conventions

Finally, a thorn in the side of network modelers since the earliest days of network analysis has been the lack of consistent practices for identifying power grid components:

- Independent application 'silos' had independently designed identification structures.
- Different utilities (and sometimes even different departments) use different names for the same components.
- Different vendor product designs restrict identities in ways that force different names.
- Naming can be deeply rooted in local operating practice and a universal naming agreement is extremely unlikely.

The most obvious approach to this is to adopt standard naming conventions, but implementing a universal agreement is difficult, if not impossible, to achieve. The pragmatic answer is an approach that will allow multiple names, wherever they exist, to be managed so that as a model is supplied to a particular local application environment, local names can be automatically supplied for that environment.

Section 4: CIM Network Model Management Reference Architecture

This section presents a reference architecture for the CIM solution for network model management. This is essential context for understanding the purpose of the more specific topics in subsequent sections. It explains how CIM architects organized the network model management problem. Specific CIM standards, as detailed later, fit within this organizing structure, but one cannot fully understand the standards without understanding the way the solution as a whole was conceived. Both the reference architecture and this Guide go beyond the standards themselves and portray the complete vision that will ultimately be delivered by a combination of standards, vendor products and utility business process implementation.

Introduction - What is the Purpose of a Reference Architecture?

Network model management is an activity which necessarily involves many independently engineered software systems working together. A reference architecture provides the high level assumptions about how these software systems should interoperate.

To be a bit more specific, the main purposes of the reference architecture are:

- To guide designers of standards for data exchange, by clarifying the purpose of data exchanges between applications.
- To guide application designers by clarifying what the overall vision expects from their systems.
- To guide utilities in establishing an implementation architecture that will accomplish their network analysis tasks effectively.

The reference architecture describes both things that are standardized and things that are not standardized, in order to convey a sense of how the whole structure works to solve the whole problem. The reference architecture is deliberately high-level. Its purpose is limited to communicating roles and responsibilities within an overall problem-solving framework. It says, for example, 'there will be a well-defined boundary with this purpose', but it does not provide the detailed definition of the boundary. Detail is left to more specific engineering tasks.

Network Analysis Applications are Stateless

Business applications are generally designed to be able to solve a particular problem of interest based on data which describes the problem and thereby 'configures' what the application does.

There are two fundamental configuration patterns:

- Stateless: user session begins by loading a set of data that completely re-initializes the application to the user's subject (e.g. word processors).
- Stateful: application maintains its own state (often in a database); users provide incremental changes (e.g. customer accounts in a Customer Information System).

Virtually all major systems are stateful at some level. If an application part is stateless, then there is usually some external stateful part that manages the data that will configure the stateless part. In the word processor example, this is typically just a file system where work is saved and retrieved.

Network analysis applications use the stateless paradigm for any user session. Older transmission planning applications depended, for configuration management, purely on files that could be saved and retrieved, in much the same way as with word processors. EMS designs, however, introduced a specialized model management function dedicated to building configuration data for the EMS suite of applications. Newer planning suites also have explicit configuration data management functionality. A recent EPRI report entitled *Network Model Manager Technical Market Requirements: The Transmission Perspective* [8] suggests that all network analysis should be able to share a common 'network model management' service for creating the configuration data required by the network analysis applications. This approach is feasible in part because all network analysis applications are designed to be configured externally.

The CIM reference architecture is predicated on the assumption that it must enable a network model management environment separated from network analysis engineering applications. This does not mean that all network analysis must use this service; it means that the reference architecture is designed with this in mind and is suggesting that this is a good idea to consider.

Reference Architecture - Base Case Development

In the CIM reference architecture for network analysis, a 'base case' is the output of network model management processes which configure stateless network analysis applications such that they can cooperate in the conduct of network analysis business processes. Let's call these subsequent processes 'studies'. It is difficult to assemble accurate initial cases for studies, and all the subsequent study activity is invalidated if the starting case is wrong, so it is very important to get the base case right and then proceed.

The process involves the following steps:

1. A physical network model is assembled with the necessary extent for the purpose of the study and representing the time frame of the study including whatever element (like a new transmission line) is the focus of the study.
2. Next a base operating hypothesis is set up and the model is adjusted as necessary to assure that a power flow will solve.
3. The solved power flow is then reviewed carefully to assure that it reflects the right starting assumptions for the study.
4. Finally, the base case is approved as the basis for other engineers running a variety of what-if analyses using a variety of tools.
5. The base case is then distributed as necessary to study environments, where derivative study cases will be created which will form the subject of many subsequent network analysis runs.

This Guide uses the term 'base case' for the result of step 4 above, and it uses the term 'study case' for each analysis that occurs in step 5.

> Note. Operations environments like EMS use somewhat different terminology, but they have the same pattern. The on-line EMS is updated and tested from time to time to reflect new construction – this is the equivalent of base case preparation. Then many real-time state estimator and contingency analyses are run from that base case – these are the equivalent of study cases.

Our first focus in the reference architecture is on the process of base case model development. This is depicted in Figure 4-1.

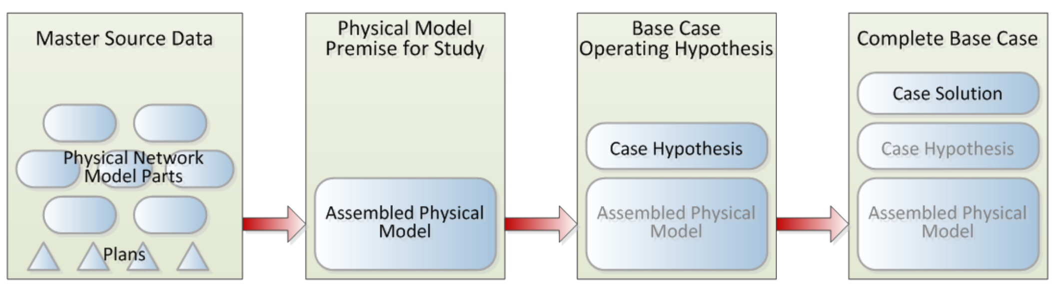

Figure 4-1
Reference architecture for base case development stages

The next few subsections discuss these development stages in more depth.

Master Source Data

The reference architecture presumes that base case development starts from master source data. The master data is maintained in non-overlapping modules, each with a clearly defined source who has maintenance responsibility (but recognizing that different parts may come from different sources and may originate in different places). These non-overlapping modules are labeled Physical Network Model Parts in Figure 4-1.

The Physical Network Model Parts represent the 'as-built' state of the network. As such, they must be updated from time to time by their sources to reflect changes in the network. Most base cases begin from the latest as-built model parts.

The other critical aspect of the master source data is that the modeling must include a representation of how the Model Parts are expected to evolve over time. These are labeled as Plans in Figure 4-1.

The critical design goal at this stage is coordinating the exact coverage of each module of data such that the parts can be combined in a straightforward and reliable manner.

Physical Model Premise for the Study

The first stage in assembly of a base case is to take the appropriate master source parts and assemble a physical network model with the right extent, the right time frame and the right attributes for the purpose of the study.

- Extent means that the right territory and voltage levels are included such that the study results will be accurate.
- Time frame means that the physical network model has been projected to the time frame that is being studied.
- Attributes means that in addition to the basic equipment that must be represented, any necessary supplemental data for the study is present, such as diagram layouts or dynamic models.

Base Case Operating Hypothesis

The second stage in assembly of a base case is to specify the operating hypothesis that will be used for testing. For example:

- In planning, this usually involves setting up a specific condition in terms of energy injection and consumption, device status, regulation settings and the like.
- In operations settings, this often involves populating configuration information from which multiple operating hypotheses may be derived automatically.

Complete Base Case

The third stage in assembly of a base case results is a complete base case that can be distributed to any target analytical environment that will use the case as the starting point for network analysis study. It adds solution information and it commonly also amends the previously established operating hypothesis data as necessary to get the desired study starting point.

It can sometimes be difficult to get base cases to the point where they can be solved. This happens commonly with cases far in the future, or where there are substantial amounts of new data that has not previously been part of a successful base case. This means that the complete base case stage sometimes involves amending the earlier stages repeatedly in a trial and error process.

Achieving a base case solution requires a power flow, at a minimum, and it may involve other analytical applications as well, depending on the nature of the study.

Reference Architecture - Study Cases Derived from a Base Case

By definition, a study is the set of study cases that is developed from a given complete base case. While base case development might reasonably be characterized as the primary focus of the network analysis reference architecture, there are also, in existing model management practice today, important use cases that involve exchange of study cases. In study cases the emphasis is often on expressing the differences of one case from another. Because of that, the following exploration of study cases is provided.

Study cases can be pictured as in Figure 4-2.

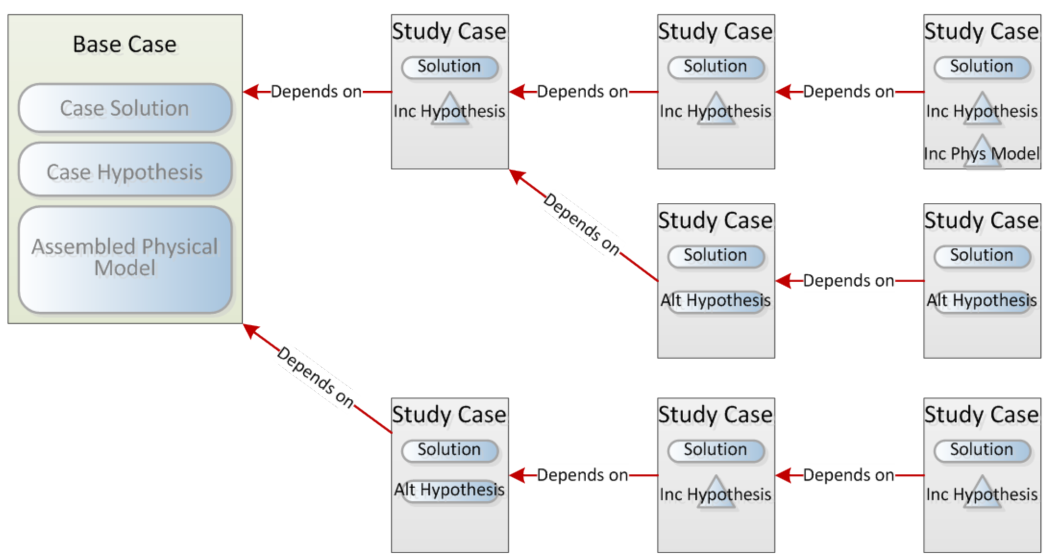

Figure 4-2
Reference architecture for study cases developed from a base case

While the creation of one study case from another study case is a long-standing industry practice (and has led many utilities to implement "case management" strategies), the CIM enables viewing the derivation of one case from another in a concise way. Here are the key points illustrated in this diagram:

- All study cases trace their origin back to one base case presented in three parts.
  - Physical network model
  - Case operating hypothesis
  - Case solution
- Each study case references the case it was derived from, as depicted by the 'depends on' arrows.
- Each study case could be expressed as a complete new set of data, but expressing study cases as changes from the preceding case is encouraged for two reasons:
  - It avoids repeating large amounts of physical network model data that is the same throughout all study cases.
  - It helps inform users about what is different about a particular study case.
- Study cases can branch out in any pattern.
  - Sequences, like state estimator runs where there is a time progression, would tend to generate long linear patterns of cases.
  - Sets of individual trial cases would tend to have many short branches off the base case.
- Each study case contains:
  - The reference to its preceding case.
  - A new solution expressed in complete form.
  - A new case operating hypothesis. Expressed as a complete alternate hypothesis or as an incremental change to the preceding hypothesis. (In the diagram, the delta shape indicates incremental.)
  - Usually, no new physical network model data is included, although one exception to this is depicted in the upper right study case, where both an operating hypothesis change and a physical network model incremental change are shown. This is to indicate that this can happen and is supported, even though it is not the norm.

Reference Architecture - Internal to an Engineering Entity

First let's introduce the term, 'engineering entity'. This term is used here to denote an environment within which objectives are shared and communication is open, and to distinguish this from communication between environments that may have different or even competing purposes. Nominally, each utility, DSO, TSO or ISO/RTO would be one engineering entity.

CIM assumes that master source data is maintained as a re-usable resource for multiple network consumers. Figure 4-3 shows what this looks like within a particular engineering entity. At the left is network model management functionality which maintains the master source data. A base case assembly functionality supports the development of base cases from this source material, as outlined in the earlier Section 4 subsection: Reference Architecture - Base Case Development. These base cases are then consumed by as many different target systems (network model consumers on the right) as need a particular base case.

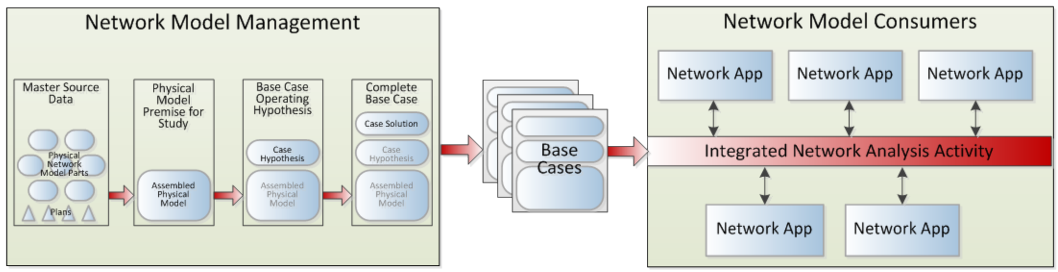

Figure 4-3
Network model management within an engineering entity

The information flow is predominantly left to right in the picture, and shows base cases as the product of network model management functionality. It is important to recognize that analytical functions, like running power flow, take place both on the left, to develop base cases, and on the right, to develop study cases.

This diagram is functional! Be careful not to interpret this as a physical diagram of implemented systems. This diagram does not prescribe how functions must be hosted. The following statements apply:

- A network analysis product may host an engineering entity's network model management functions, so long as it supports all the required services and standards. In theory, the entire picture above could even be hosted in a single system.
- Equally, network model management and various network analyses could all be hosted in independent systems.
- Furthermore, model part maintenance and base case assembly functions could be supported by multiple facilities. There is no reason why a network model management system and one or more network analytical systems could not all host base case assembly capability (perhaps with different optional features).

An important goal of this architecture is to enable a utility to support all network applications from shared master resources. Aside from potential reduction in model maintenance labor, this generates a huge bonus in consistency that enables the network applications to exchange data and compare results straightforwardly.

Reference Architecture - Cooperation among Independent Engineering Entities

Another main requirement of network model management is cooperation among multiple independent engineering entities. Network model management occurs within different entities which must cooperate, and engineering studies must be shared among different entities. Figure 4-4 expands the previous figure to show the rest of the picture, where multiple CIM model management environments cooperate to support multiple network analysis activities. Two kinds of exchange are required:

- Network model management environments must be able to exchange model parts.
- Network analysis environments must be able to exchange base and study cases.

The first of these is especially key because it is this inter-entity cooperation that really clarifies the requirement to exchange the source material in the form of model parts, and not just exchange complete cases.

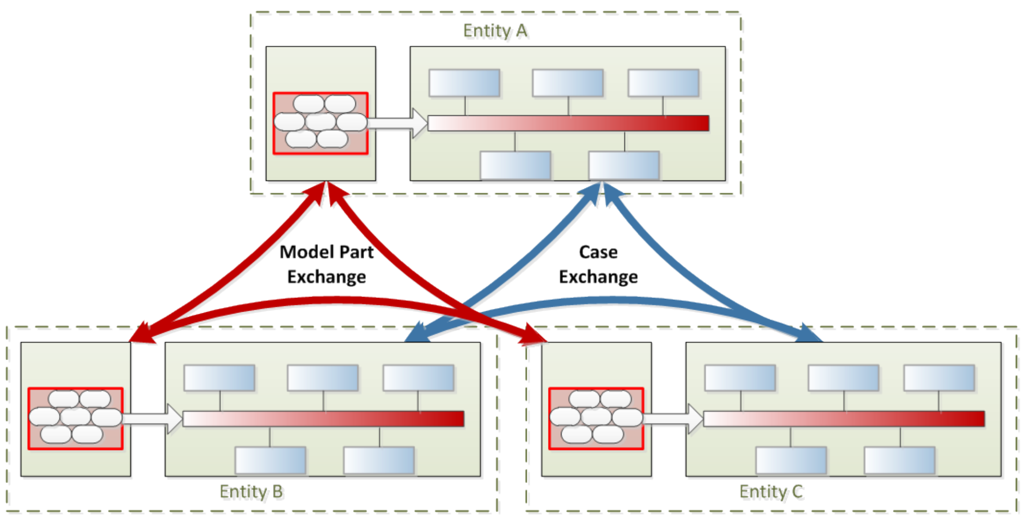

Figure 4-4
Cooperating network model management environments at different entities

Reference Architecture - Critical Points of Standardization

In order to make the previously expressed reference architecture concepts work when application systems are designed and implemented and operated independently, certain points of standardization are required. This is the focus of the WG13 and the resulting standards are documented in the 61970 series of IEC specifications [2, 3, 4, 5, 6].

CIM Model Part Exchange

A standard is required for exchange of individual model parts. The primary focus here is on physical network model parts, but it is also desirable that standards enable stand-alone exchange of operating hypothesis and solution parts. Certain characteristics of model parts (e.g., the territory or extent of the power grid covered, the type of information conveyed, and the modeling authority) need to be able to be identified as part of the exchange as well.

In addition to complete model parts, a standard is also required for exchange of changes to model parts in incremental form.

CIM Case Exchange

A standard is required for exchanging base or study cases, where the component model parts are included either in the payload or by reference.

Section 5: CIM Model Parts – Building Blocks for Network Model Management

This section describes the concept of CIM Model Parts, which are at the core of the CIM approach to network model management. It starts by discussing the reasons behind Model Parts and then proceeds to give a more precise definition of a Model Part.

For the most part, this section sets the stage for more specific discussion of network analysis data management in subsequent sections. Later sections explain 'micro-modeling' as the process of defining the content of each kind of network Model Part, and 'macro-modeling' as the process of combining Model Parts to form network analysis base cases.

Why Do We Talk About Model Parts Rather Than Models?

As introduced in Section 3: Main Themes in Managing Network Analysis Data, one way to divide network analysis application configuration is by type of data:

- Physical network model representing the capability of the power grid.
- Operating hypothesis representing the particular condition under which the grid is hypothesized to be operating.

Another way to divide or segment network model information is based on the following important facts illustrated in Figure 5-1:

- There are different natural sources for the modeling of different grid territory and/or voltage levels. (Shown as different TSOs at the left.)
- Different studies require models covering different grid territory and voltage levels. (Shown as different study types at the right.)
- The entire grid is connected, however, so there is no doubt that there could be a unified grid model (as depicted in the middle).

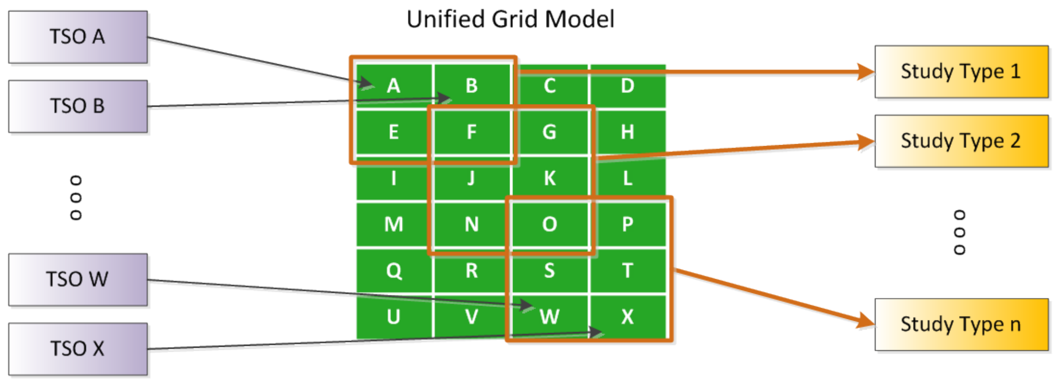

Figure 5-1
Many different base cases assembled from shared model parts

The CIM supports both kinds of segmentation - 1) the territory, or extent that is covered, and 2) the type or kind of data that is contained – via the notion of Model Parts.

The CIM's approach to Model Parts is based around three principles:

- Model Parts can be designed to fit together in a virtual unified grid model. ('Virtual' because, while any combination of Model Parts can be combined to build a case, the entire grid never has to be assembled as a whole in one place.)
- Model Parts should be created and maintained by their natural model authority for general use in network analysis.
- Model Parts should be able to be selectively assembled into appropriate complete base case models for each study purpose.

Partitioning into Model Parts by Extent

In many existing network modeling applications, the only kind of models are complete cases corresponding to the scope of a study. Different studies may have coverage of different parts of the grid, but there would be a case corresponding to each study. These cases would necessarily have overlapping content, because studies overlap in terms of what parts of the grid are represented. If a modeler wanted to take part of a representation from one case to use in another, he or she would typically have to develop customized 'extract and merge' procedures. The lack of a systematic approach to such operations has been problematic and led CIM to develop the idea of Model Parts that are designed to assemble into cases, rather than cases that are torn apart to contribute to other cases.

Partitioning into Model Parts by Kind of Data

CIM aims to develop modeling support that covers all kinds of network analysis, while simultaneously enabling the principle of a single source for each datum. For example, CIM supports both steady-state and dynamic analysis. Dynamic analysis of a power grid requires data that represents the dynamic behavior of network components in addition to needing all of the data that is required to support a power flow of the same network area. But dynamic analysis is performed much less frequently than steady-state, and dynamic parameter data is often maintained by specialists in that kind of analysis. These factors led CIM to define dynamic data as a separate kind of Model Part that can plug into steady-state Model Parts, when needed for dynamic studies.

Introduction to Model Parts

CIM encourages partitioning of overall data into non-overlapping Model Parts to facilitate the goal of single source model management. Sometimes the same kind of data is divided into territorial parts; sometimes the data is divided by kind of data. The section introduces the 'plug-together' architecture of models assembled from Model Parts. This will be covered in more depth in Section 8: MACRO-Modeling I - EQ Model Parts, the Core Building Blocks, but before we start into the details of micro and macro modeling, it is useful to have a quick picture of this approach.

Model Parts

In CIM network analysis, Model Parts are the basic model building blocks. A Model Part has two distinct sets of data associated with it: a content part and also general information of the sort that would appear in a directory that listed Model Parts. This is analogous to computer files stored in a file management system. In this Guide, the two sets will be referred to as the Model Part 'content' and the Model Part 'description'.

Let's explore how this applies to the physical network model portion of network analysis information. Consider the following image. Think of a Model Part as a bag containing lots of little objects, each representing a grid component. Collectively, the objects in the bag are a set of CIM data which is the physical network modeling content of the Model Part. The information model for this set of data describes how equipment is connected electrically, and the objects in the bag are thus tied together to reflect the wiring of the grid. The bag has a label on the outside that describes the contents of the bag. For example, it says 'France Transmission Territory – Equipment and Connectivity data', and has other information like a date and 'produced by the French TSO'. In other words, the content of the bag is not some random collection, it is specifically those objects that make up, in sum, modeling that represents the part of the grid that is the responsibility of the French TSO. The label on the bag is the Model Part description.

Now picture similar bags for Belgium, Netherlands, Germany and all of the rest of the European TSOs. Some of the objects in each bag have dangling ties, because they represent components adjacent to tie points with neighbors. When base cases are assembled, the content of bags are dumped out onto a workspace and the loose ties are connected to make a complete network model.

To make sure this is not misleading, it is important to state here that these loose ties come with a little tag on them listing the identity of the object in some other bag that they will connect to. When a bag is (metaphorically) dumped out onto a workspace, the workspace has the magical property of automatically looking at these tags and tying them to their counterparts. In other words, this is not like a jigsaw puzzle where the user has to spend hours and hours searching for the right connections, rather the identity of the connection is already known.

The labels on the bags (the description data) have nothing directly to do with this process of composing bag content. The workspace magic does not need any information from the bag labels in order to join the contents, and consumers like a power flow algorithm only need the joined content, not the labels. However, the labels on the bags are still of interest because they inform the user about how the case was constructed – for example, they could be independently combined to create an audit trail documenting a base case.

This image highlights the distinction between the content and the description portions of Model Parts. Both content and description have information models, but they are used separately and in different ways, and their information models are similarly separate. The situation overall is very similar to file systems, where file content is defined and used separately from labels that appear in directories.

Now let's go a bit further. So far, the Model Part bags in the example have covered different territory, but the contents of the bags have all been of the same type. That is, they all describe the equipment that makes up a TSO's territory. This means that the same information model is governing the content of all the bags.

Now imagine that there is another kind of information that is needed by a few applications, but not by all. For example, at the French TSO, suppose there is a wallboard diagram of the French transmission territory driven by an independent software application. In addition to physical network model information, the wallboard application needs data objects of a different kind. These are graphic diagram objects explaining how and where to present data on the wallboard about an equipment object. The 'about' in the preceding sentence means that there will be associations from the diagram objects to equipment objects. So, this is a new bag of objects. The label on this bag says 'France Transmission Territory -- Wallboard Diagram Layout' and 'produced by the France TSO', among other things.

If the objective for our workspace was to produce a model for the French control center wallboard application, this bag would be added to the workspace; otherwise it would not. The bag content would have many unterminated ties, but these would resolve as they are added to the workspace, connecting graphic objects to the network model objects from the French equipment bag.

So there are two ways that overall modeling data can be divided into Model Parts. The first separates information of like kind by some criteria like territory or ownership, and the second separates by kind of data. In either case, it is external or 'dangling' references in the content objects that define how one bag content fits together with another.

The micro-modeling sections of this Guide, Sections 6 and 7, explain how to create the contents of the different kinds of CIM Model Parts. The macro-modeling sections of this Guide, Sections 8 and 9, explain how CIM Model Parts are assembled – this latter is primarily where Model Part description data become important.

Incremental Model Parts

Continuing the metaphor of the previous section, consider the fact that base cases must be constructed for many different time frames in the future of the French grid. The French TSO could keep a bag of objects for each time frame – after all, these are computer objects and bytes are cheap. But consider what would be required if a future plan changed. Engineers would have to find each bag where that plan had been represented and make the same modification to each. It is much more efficient if there is one big bag that represents the present or 'as-built' grid, plus a little change bag that represents the effect of each forward plan. This way each datum has one 'bag of origin' and engineers have one place to go to revise a plan.

Okay, that's a great way to avoid duplication of data, but doesn't it complicate the assembly process? Perhaps a bit, but it also clarifies the content of the resulting model. For any forward study, one first goes into the storeroom to get the as-built bags and then goes over to the place where the change bags are kept and grabs all of the bags that are relevant for the particular study. The as-built bags are dumped out first, and then the change bags are added, one by one. There are more steps than if there were a single bag for the desired point in time, but the compensating virtues are simpler maintenance of the source bags and the very valuable information (from change bag labels) that could allow an audit trail to be created documenting exactly what has been assembled.

These change bags are called Incremental Model Parts. As with Model Parts, they have both content and descriptions. The content contains the modifications to the content of their corresponding Model Part and the description describes the plan (name, source, effective date, status, etc.).

Exchanging Model Parts

A fundamental requirement of network analysis is that grid entities must cooperate by sharing network model data. Thus the processes described in the previous sections are occurring concurrently and independently in many different organizations with interrelated responsibilities for the overall effectiveness of the grid.

Again using the bag metaphor, this means that France needs a bag representing Netherlands and Netherlands needs a bag representing France. While each could guess about the other and maintain their own bags representing the other, a more sensible arrangement might be for France to use a Netherlands bag produced by the Netherlands TSO and vice versa. A good way to facilitate this is for the interconnection to create a bag sharing repository:

- Each TSO agrees to maintain, for the benefit of the interconnection, models of its territory appropriate for interconnection use, in the form of an up-to-date as-built bag and change bags for each approved plan.
- Each TSO has access to the bags created by their neighbors.

Of course, the need to copy bags has now been introduced, but fortunately in computers, this is easy. It is just necessary to assure that bag labeling carefully identifies exactly what version of bag content is inside.

Model Part Content

This section introduces Model Part content generically. Sections 6 and 7 will describe the content of specific kinds of network Model Parts.

Model Parts are made up of individual items of data. In order for any of this data to make sense, it is necessary that both human users and software systems can recognize what each datum represents. Loosely speaking, the information that allows us to identify the datum is called ‘metadata’, or ‘data about the data’.

People distinguish one item of data from another by a variety of means:

- The kind of data is one indication -- .e.g. a resistance
- The item is associated to some object – e.g. a line
- The object has a name – e.g. line 11307
- The object has context – e.g. it connects to stations X and Y, and it has geography defined in a series of points.
- The object appears on a diagram in a recognizable position.

Of these, the object name is perhaps the most basic, but humans use the entire set of information to recognize the object, which is why the term metadata is necessarily somewhat loose, as all aspects of the whole are in some sense ‘about the whole’.

Computer systems, however, are not intuitive in the way humans are and in CIM they depend on two explicit mechanisms to identify a datum.

- Information models describe the structure of information – As an example, an information model might say that objects of a class called ACLineSegment have an attribute called reactance expressed as floating point data type with a unit of ohms.
- Unique object identifiers distinguish individual instances of structured objects of a given class.

CIM is based on consistent approaches to this metadata, which are presented in the next subsections. These principles are fundamental to understanding the design of any Model Part.

CIM Datasets and Information Models

The term CIM Dataset will be used occasionally in this Guide. In most cases, the reader can simply read this as meaning 'a set of data with some unifying purpose and a CIM-based structure' and not worry about the finer points, but a brief explanation is offered here for completeness.

CIM interoperability standards define exchanges of information. A data exchange will be made up of one or more CIM Datasets and/or CIM Incremental Datasets.

The structure of these standard Datasets can be defined by UML models for the Datasets. These information models contain the structural metadata that all software uses to understand how to process CIM information exchanges. At the heart of any CIM specification for a data exchange, there is a specification of the governing CIM Dataset information model, often expressed in UML.

> Note. The Dataset information model is sometimes referred to as a 'profile', but that term is used sparingly in this Guide because it is not very well defined and tends to have different meanings assigned to it by different parties. This Guide uses the phrase CIM Dataset Type to describe the identity of the information model which governs the content of a CIM Dataset.

Here is a quick summary of basic concepts:

CIM Data Object (or Data Object). A CIM Data Object consists of an object identity plus a set of data about the object. This is the fundamental unit of data in a CIM Dataset.

CIM Dataset (or Dataset). A collection of CIM Data Objects <u>with a common purpose</u>. Important things to know about a CIM Dataset are:

- CIM Datasets are often referenced, managed or exchanged as a whole.
- There are different 'types' of CIM Datasets for different purposes.
- The CIM Dataset Type is defined by an information model, often expressed in UML.
- The structure of the CIM Data Objects in a CIM Dataset is governed by its type.

CIM Dataset Type (or Dataset Type). An information model, expressed in UML and derived from the overarching CIM canonical UML, which defines the structure of a kind of CIM Dataset or CIM Incremental Dataset.

CIM Incremental Dataset (or Incremental Dataset). A collection of ADD, MODIFY, DELETE changes to CIM Data Objects of a specific CIM Dataset Type. This is used to express a logical change to a CIM Dataset.

So, the key distinguishing feature of a CIM Dataset is that all its contents obey an information model (called a Dataset Type in this Guide). In network analysis, Dataset Types are all derived as subsets of the CIM canonical UML under a principle of 'composability'. Composability means that a simple union of the instances obeys a simple union of the UML metadata for the datasets. (No 'fiddling' with the data is required to get the combined data to make sense.) The effect of composability is to simplify design of applications that receive multiple kinds of CIM Datasets, which for network analysis means that different kinds of Model Part Datasets will plug together to make larger CIM-based models without any additional fiddling with the data.

CIM Object Master Resource Identifiers (MRIDs)

Objects in CIM network Model Parts often correspond with real components of the power grid. As cases are constructed and analyzed in various systems, the same real component may be mentioned in thousands of base and study cases spread across many computing systems managed by many different grid entities. In past practice, a component might acquire several names by which it is known in different environments, and sometimes the same name might appear attached to different real components. This practice made it impossible to determine programmatically whether a component of one case was the same as a component in another, unless additional identity-mapping information was supplied.

CIM early on made some basic decisions about object identity:

- Interoperability standards should rely on a unique Master Resource Identifier (MRID) assigned to any real world thing or concept about which information would need to be exchanged.
- Names (for human consumption) are considered attributes that can change.
- MRIDs should be globally unique.
- MRIDs should not have interior structure that could change. For example, it should not contain an owner's name, because the owner could change.

Use of Universal Unique Identifiers (UUIDs) [9] is a currently accepted practice for MRID structure, although most CIM standards will work with any kind of MRID that is globally unique and stable, as long as the participants in the exchange have mutually agreed on the form.

A narrow reading of an individual standard may give the impression that the main purpose of an MRID is to uniquely identify elements within a given exchanged CIM Dataset. This is true, but the more important aspect of an MRID is that the same MRID shall always be used for a given CIM Data Object in all exchanges where it appears. In other words, MRIDs are like VIN numbers for vehicles, or social security numbers for people. They allow different instances of data to be correlated as referring to the same thing.

Because of this, and because of the fact that network model management is always distributed among a number of actors, it is quite important to full realization of the CIM vision that a registration business process is clear. All parties must have a clear understanding as to who assigns MRIDs to what things. Otherwise, things that should have one MRID may wind up with zero, or two, or whatever. The term 'Model Authority' will be used in this Guide as referring to the party responsible for a given datum, but the Model Authority for the MRID is especially significant.

Model Part Connections – Dangling References

CIM Datasets that are Model Part content normally contain 'dangling references'. That is, objects within the Dataset content of one Model Part will reference objects that are in the Dataset content of a different Model Part. These can be thought of as the 'connectors' that plug building blocks together. There are two types of dangling references:

- An object of one class may reference an object of another class, as allowed by associations defined in the CIM UML.
- Sometimes one Model Part will have the purpose of declaring the existence of an object, and another Model Part will supply additional information about the object. In this case, the same object appears in both parts, but the type of the Model Part (which reflects the Dataset Type of its content) indicates whether objects of each class are roots or add-ons.

In both cases, these dangling references are directional and they create a dependency (for completeness) of the referencing Model Part on a referenced Model Part. In other words, the referenced Model Part may be useful without the presence of the referencing Model Part, but not the other way around.

Section 6: MICRO-Modeling I – Equipment (EQ) Model Parts

A good way to think about CIM network modeling overall is to divide it into two kinds of activity:

- Micro-modeling to manage the content of re-usable Model Parts.
- Macro-modeling to assemble Model Parts into base cases for analysis.

This section launches the reader into CIM micro-modeling with a discussion of EQ Model Parts, which define the equipment components and their connectivity, which is the core description of the electrical grid and the foundation on which all CIM network modeling rests. (Here, 'EQ' modifying the Model Part indicates that the content of the Model Part conforms to the Equipment (EQ) information model which defines equipment components and their connectivity.)

> Note. This Guide provides a comprehensive discussion of micro-modeling, but it is nevertheless still an overview. For network modeling detail and instructions for hands-on model builders, the reader should consult IEC specifications (such as IEC 61970-301[2] and the IEC 61970-45x series [3, 4 ,5]), the EPRI *Intelligrid Common Information Model Primer* [1] and/or detailed User's Guides to software products designed for CIM modeling. Anyone interested in exploring the CIM UML is similarly encouraged to get a copy of Enterprise Architect and join the CIM User Group (www.cimug.org) in order to get access to the actual CIM UML .eap files – this Guide only gives selective educational simplifications of CIM UML. These other documents are the place to go for step-by-step, class-by-class, property-by-property explanation of CIM network modeling.

Most of this initial micro-modeling section is devoted to describing how to create an EQ Model Part that represents one state of the network. There is quite a bit to this, as a power grid is a fairly complex assembly of components.

In CIM network modeling, an EQ Model Part instance always represents just one state of the network, while the evolution of the network through time is captured as EQ Incremental Model Parts whose content describes changes. The content in an EQ Incremental Model Part is governed by the same information model (Dataset Type) as is the content of an EQ Model Part it modifies, though the content of the EQ Incremental Model Part is augmented by descriptions of changes. Incremental Model Parts are covered in detail in a later Section 6 subsection: EQ Projects – EQ Model Parts through Time.

Assumptions about Modeling Tools

Normally, an axiom of CIM for integration is that it sets standards for exchange of data and makes no statement about how the internals of any application should be designed. At the same time, though, the requirement that any network analysis application must speak CIM when it exchanges data is likely to be a huge influence on its design, so for any new application, one would expect that its internal data architecture would at least be strongly influenced by CIM.

In the specific area of network model management, CIM influence should be particularly strong and, as a consequence, this Guide simply presents network modeling as if it is being carried out by a heavily CIM-inspired network model management application.

This is a fine line to walk. Strictly speaking, the only requirement is that CIM models are produced with the requisite characteristics, but in this Guide the reader would not get the full sense of what CIM envisions for modeling if the text did not include at least a generic discussion of the functional operations that would go on inside a modeling tool.

So, the reader of this section should bear in mind that this Guide is not just a description of CIM. It is a description of what CIM plus generic CIM-inspired tooling will enable.

The EQ Model Part Description versus Content

As was introduced earlier in the Section 5 subsection: Introduction to Model Parts, there are two distinct aspects of a Model Part: its description and its content.

The description provides information about the Model Part as a whole. It contains labeling that says who is responsible for the Model Part, why it exists, when it was created and any other information relevant to business processes in which the Model Part plays a role. EQ network descriptions are very often partitioned into multiple EQ Model Parts by territory and/or voltage levels, which of course become a very important part of the overall characterization of the Model Part.

The Model Part content provides the actual network model or case information itself. In this micro-modeling section, the focus is on the content of an EQ Model Part, whose content is the description of power grid components and their connectivity.

Defining Connectivity and Equipment

The core of network modeling – and arguably the core of power grid modeling as a whole – is describing the set of components (conducting equipment) that make up the network, along with the specification of what is connected to what electrically. In CIM, this wiring is collectively called the 'connectivity' of the network and the components are loosely referred to as the ‘equipment’, although in terms of the actual UML specification, the equipment is defined by an inheritance hierarchy of classes with more specific names.

Note. In UML, inheritance is a modeling concept where a class is described as being a sub-class (or child) of another class. As a sub-class, it can have attributes and relationships of its own, but it also inherits all the properties (attributes and relationships) of its parent class. More detailed information on UML modeling concepts can be found in the EPRI *Intelligrid Common Information Model Primer* [1].

Equipment and connectivity are the core of the physical network model, and in terms of micro-modeling processes, this is where everything begins. The first step in actual Model Part creation is to define the master EQ Model Parts that describe equipment and connectivity.

Note. The adjective ‘master’ here indicates EQ Model Parts whose content defines the existence of equipment and connectivity objects, and thus the modeling activity here includes the responsibility to generate MRIDs, not just supply data.

Equipment Containment

Whether we are talking about physical network data or the input/output of any analytical solution, the data involved is voluminous and challenging to organize and understand. CIM has three organizational concepts that help humans to navigate and understand this data:

- An equipment containment hierarchy supports user navigation within Model Parts or assemblies of Model Parts down to individual equipment details.
- Model Parts are organized into frameworks according to what makes the best macro-modeling assembly process.
- Customized geographic and schematic diagrams may be created which facilitate visualization and human understanding.

Here in Micro-Modeling I, the focus is on the first organizational strategy: the equipment containment hierarchy, which is the most basic organization and the only one of these three that is required by the CIM. For this discussion, the reader should picture the modeling task as if the entire grid being modeled is in a single Model Part.

The Containment Hierarchy Classes

The present containment hierarchy was developed based on the traditional organization concepts of transmission grids, meaning that it is not necessarily effective in accommodating distribution modeling, but at the present time, it is what it is. Figure 6-1 is a slightly simplified view of the basic CIM UML containment classes used in EQ Model Parts, but it shows the major concepts that a CIM network model user needs to deal with.

> Note. The existing containment has been criticized for being biased toward transmission modeling and too rigid. Both of these criticisms are valid, and it is very likely that this structure will be reviewed (and revised or extended) in the near future.

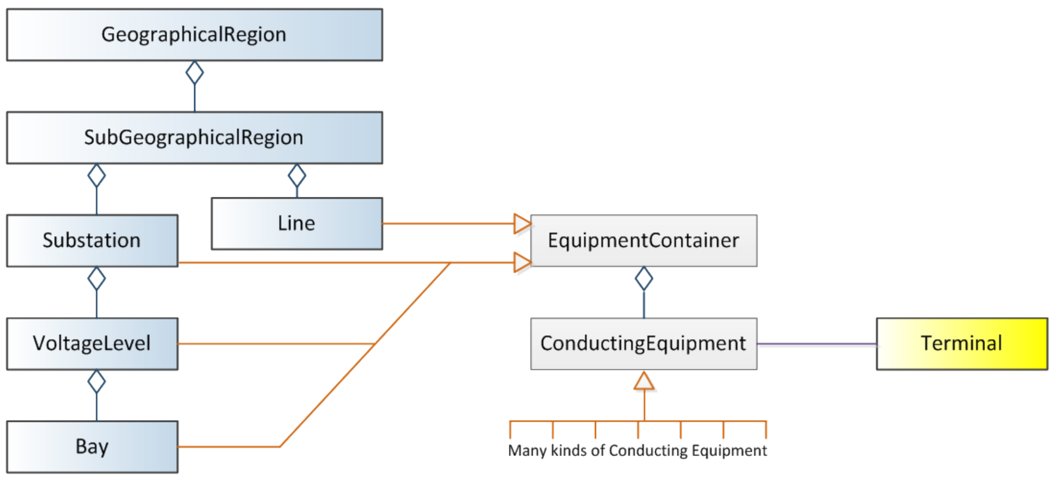

Figure 6-1
Simplified view of the CIM equipment containment hierarchy for network modeling

The equipment containment hierarchy consists of the blue class boxes at the left in the figure. The diamond shape at the end of the lines connecting these boxes indicates a 'containment' relationship between classes, so Bays are contained in VoltageLevels, which are contained in Substations, which are contained in SubGeographicalRegions, which are contained in GeographicalRegions. Bays are optional in this structure, but the other containers are all required in EQ Model Parts.

Okay, so what is contained by this structure? The simple answer is 'equipment'.

- In the CIM information model the containment classes all 'inherit' from the EquipmentContainer class. (Inheritance is represented in Figure 6-1 by a line with a triangular head on the parent end of the relationship.) So a container like Substation 'inherits from' EquipmentContainer, which is an 'abstract' class.
- Then the EquipmentContainer class has a 'containment' relationship with the ConductingEquipment class. (Containment is represented by a line with a diamond on the container end.)
- And equipment-specific classes representing many kinds of conducting equipment 'inherit' from the ConductingEquipment class.

This is the UML way of saying that the container classes all share the fact that they may contain a variety of types of equipment.

Finally, the association between the ConductingEquipment class and the Terminal class is important – not to containment, but to electrical connectivity - since Terminal is the key class that allows connectivity to be defined. Details on the various equipment-specific classes and on the use of the Terminal class in support of connectivity are explored in a Section 6 subsection: The CIM Approach to Conducting Equipment later in the Guide.

Don't be too concerned if the UML notation is a bit difficult to take in. In an editing environment, the user really just deals with the concrete elements of the specific containers, like Substation and Line, and the specific kinds of equipment, like Switch and ACLineSegment, that are contained within them. (The abstract classes do not appear.)

How to Plan a Containment Hierarchy

Before a user begins to populate a Model Part in detail, it is a good idea to plan a containment hierarchy. This is much like organizing directory structures for storing files; its purpose is to allow a user to navigate quickly and efficiently to any aspect of the data.

Transmission Containment Hierarchy

At the transmission level of the power grid, the existing CIM hierarchy usually works reasonably well. Transmission grids are organized around transmission substations. In an EQ_Model Part for transmission, the modeler should define a Substation container for each actual substation. These will also be the primary means of navigation through the Model Part.

Inside a CIM Substation, CIM provides VoltageLevel and Bay containers to further organize the substation model, and editing products may add other useful tricks. For example, an editing tool may allow the user to create templates for common substation patterns, like breaker-and-a-half schemes.

The other major structure for transmission Model Parts is the Line. A CIM Line is designed to mimic the normal operational concept of a line, which is 'everything that is isolated in a line fault'. This means that in addition to line segments, a Line can contain switches, tap points, customer transformers and basically any kind of equipment, the same as Substation. This view of a Line also aligns well with the way that many utilities organize the detailed design data that leads to computation of impedance and rating data for circuits.

> Note. Currently in the IEC 61970-452 profile, Line containers are restricted to contain only ACLineSegments and SeriesCompensator objects. This restriction is a compromise that allows products which don't support the full CIM Line definition to be conformant to 452. For a utility embarking on complete adoption of CIM network model management, Line should be used in its unrestricted form and transformed to the narrower definition if necessary for more limited products.

CIM allows Substations and Lines to be contained within GeographicalRegions and SubGeographicalRegions, but makes no particular statement about how these should be used. One common approach is to model the territory of a TSO as a GeographicalRegion object and any territorial subdivisions of TSOs as SubGeographicalRegion objects. This is probably as good a strategy as any. These containers have no required effect other than as an organizing tool, but an individual editing product could offer other features based on these containers.

Distribution Containment Hierarchy

> Note. At present, distribution Model Parts are forced to use the same containment classes as transmission. This can be done, but it is not very satisfying, and distribution is a major force driving an expansion in the containment mechanism. Hopefully, the next edition of this Guide will be able to present an appropriate CIM approach for distribution containment.

How to Create a Containment Hierarchy

A good Model Part editing tool will provide a number of different views of Model Parts. Not surprisingly, the view that would commonly be used to define a containment hierarchy is a hierarchical view much like a directory structure. This view would normally allow the user to create new objects within the hierarchy structure.

Another way that a containment hierarchy often becomes established is by transforming an existing network model into a CIM structure. Here, the designer of the transformation logic must make a decision about how to take information in the source model and convert it to CIM containers. Often the source material is less rich in detail than what is possible in CIM, and the initial imported structure might need to be edited manually before it will form a good containment organization.

The CIM Approach to Conducting Equipment

This section describes how equipment and connectivity are defined in a CIM Model Part.

Conducting Equipment and Terminals

There are many different kinds of conducting equipment supported in CIM. As a general rule, CIM tries to follow the basic modeling principle of 'staying true to the real world', and in that spirit, it provides explicit classes for each kind of equipment. Underneath the hood, the CIM UML uses inheritance to relate similar kinds of equipment together, but the user of a CIM network modeling tool will not necessarily be aware of that.

The common element that, quite literally, binds conducting equipment together is that fact that all kinds of conducting equipment have Terminals. A Terminal is a CIM object that is associated to conducting equipment. Conducting equipment objects are wired together by associating their Terminal objects to ConnectivityNode objects, as will be explained a bit later.

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. 3-winding transformers are the most common device that has more than two terminals.

AC Conducting Equipment Types

Figure 6-2 shows the types of AC conducting equipment currently defined in CIM.

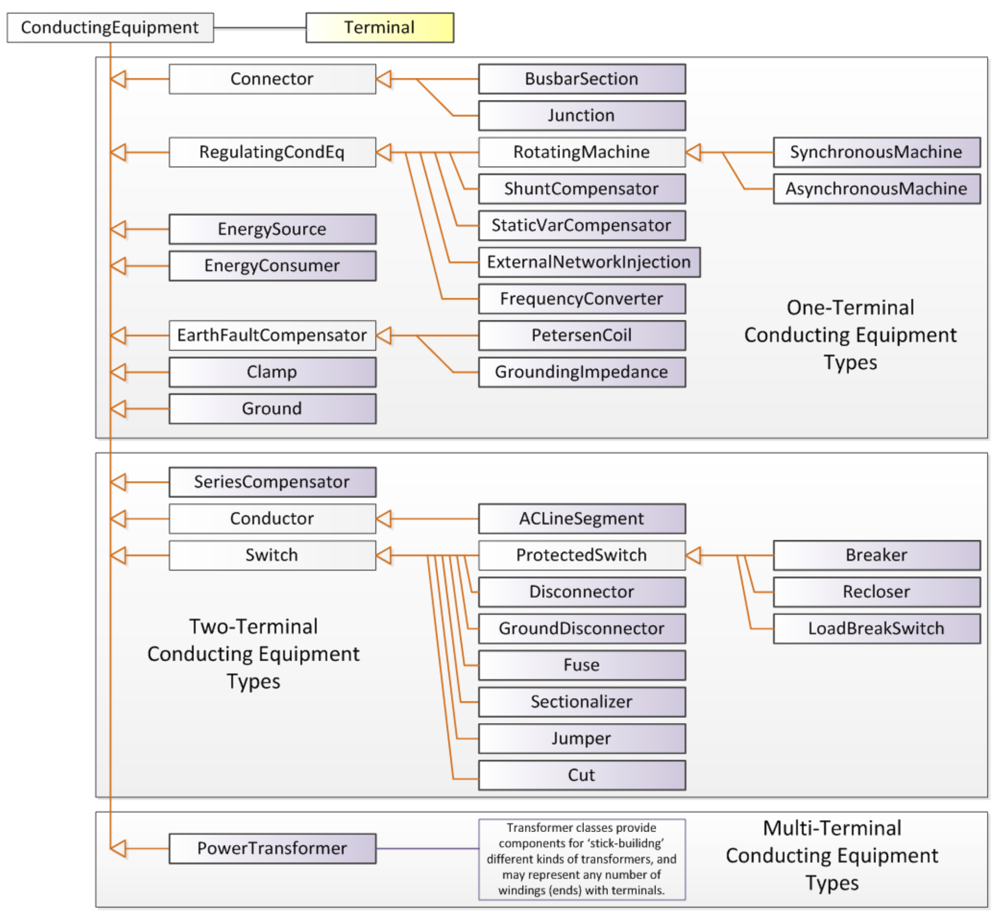

Figure 6-2
Types of AC conducting equipment in CIM

A hands-on modeler, of course, will need to know the detailed purposes and properties of all these classes. The reader is referred to IEC 61970-301[2] and 61970-452 [3] and/or modeling product guides for this detail. Here, our purpose is to provide a good overview.

The first thing to notice is that there are a lot of equipment types – certainly more than the typical planning power flow needs. The rationale behind this is 1) staying close to physical reality, and 2) the desire to enable one source model to support all forms of analysis. Nothing forces use of this detail, though. Simple single-purpose models can be built using just a few of the basic classes.

Users may find that when CIM network models that have a lot of detail are imported into a network analysis tool, some CIM classes will have been combined and simplified into the nearest equivalent that the tool needs and supports. This is fine. CIM does not intend to dictate the level of detail inside any particular tool.

Figure 6-2 illustrates equipment types arranged in an inheritance hierarchy, as CIM does it. So, for example, an abstract class such as Switch is broken down into many different specific types. This inheritance may or may not be apparent to the user of a network modeling editing tool. In the end, the user only needs to see a way to add objects of different kinds. The reason for showing this diagram here is just to give a sense of the kinds of equipment that can make up an EQ Model Part.

Transformers

Transformers do not quite follow the same pattern as other conducting equipment. Whereas the same set of ACLineSegment attributes is sufficient to describe all sorts of different line segments, 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 a basic classes for components of transformers that will allow users to assemble representations of the kinds of transformers that exist in their territory.

It would be inefficient, though, if a user had to hand-build commonly used transformer arrangements over and over again. It is anticipated that modeling products would provide some out-of-the-box transformer templates, as well as the capability for users to 'stick-build' their own templates. These transformer templates would then be treated like any other standard kind of conducting equipment as far as existence definition and network model connection.

The reader is referred to IEC 61970-301 [2] and IEC 61970-452 [3], the EPRI *Intelligrid Common Information Model Primer* [1] and/or modeling product guides for detail, but the summary statement is that a diligent effort has been made by CIM modelers to cover all known types of transformers, including both voltage and phase transformation, regular and irregular tap steps, balanced and unbalanced representation, and so on.

DC Conducting Equipment Types

Note. DC modeling is on the increase in importance. This work is under construction and will be described in the next release of this Guide. For now, the reader can assume that it will follow closely the patterns that have been established for AC modeling.

Connectivity

Regardless of the kind of conducting equipment, the definition of how components are connected together works the same way. The relevant CIM classes are shown in Figure 6-3.

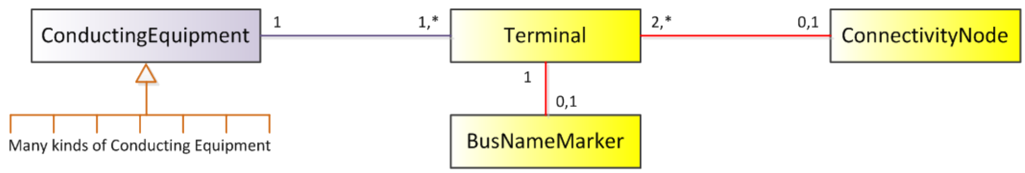

Figure 6-3
How terminals are connected in CIM

Connectivity in network models is defined as follows:

- Each kind of conducting equipment has a defined number of terminals. When an instance of equipment is created, the appropriate number of terminals is created with it. This mimics physical reality. The actual equipment has terminals, regardless of whether 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 only has meaning if it connects at least 2 Terminal objects, and it can connect any number of Terminal objects together (cardinality of 2,*). (Note, though, that ConnectivityNodes in individual Model Parts can stand by themselves, so one could also claim that an 'in process' cardinality of 0, * is also valid.)
- In addition to a connection to a ConnectivityNode object, a Terminal object may have an associated BusNameMarker object. This is an instruction that says, 'If this terminal is ultimately part of a power flow bus, here is a name to use for that bus.' A priority is also assigned, so that if more than one BusNameMarker object is part of a bus, the software can know which name to pick. The purpose is to allow network analysis output, which is normally expressed in terms of buses, to have consistent names and identifiers – something that is very important to network modelers when they have to compare results of many different studies.

The reader may wonder why BusNameMarker is associated to Terminal rather than ConnectivityNode. The reason is that CIM has tried to keep ConnectivityNode limited to one purpose, electrical junctions, so that wiring exercises can easily break and remake junctions without breaking other data specifications. Normal practice is expected to be that the places in the network that need BusNameMarker objects also are real bus sections which would logically have BusbarSection objects, which have an association with a Terminal object, which is the logical place to associate the BusNameMarker object.

Bus-Branch (Planning) Modeling

A quick word is appropriate here about 'bus-branch' network modeling, which is shorthand for models that planners have typically used which do not show details of switching. Operations models (in control centers) have always modeled any devices that are telemetered via Supervisory Control And Data Acquisition (SCADA), which includes most circuit breakers. CIM network modeling originally began as a means of allowing control centers to exchange models, so it has always allowed this so-called 'node-breaker' kind of modeling. When CIM is proposed as a universal network model, planners are often concerned about how that will affect the way they work.

The answer is actually fairly simple, but it has to be broken down into a few sub-concerns.

> Question. Can a planner use CIM, but continue to maintain a separate simpler bus-branch model?
>
> Answer. Yes. CIM does not require a single source model, nor does it require use of switches or any other particular device in a model. Nothing prevents connecting, for example, ACLineSegment objects and PowerTransformerEnd objects directly to ConnectivityNode objects that have BusbarSection objects attached. This is not necessarily what a true CIM believer would recommend, because the holy grail is to eliminate duplicate modeling, but even a true believer would support this kind of approach as a step toward phasing in the vision.
>
> Question. If my utility moves to a consolidated CIM network model, how can I produce planning base cases that have the familiar bus identifiers that are required when we do interconnection studies?
>
> Answer. CIM allows BusNameMarker objects to be added, as described earlier. Topology processing functions take node-breaker detail and convert it to bus-branch in every network analysis study, whether it is operations or planning. BusNameMarker objects can be created and placed so that when the network is in any state that could be modeled by traditional bus-branch modeling, the bus names in network analysis result will be the same.
>
> Question. Can a consolidated CIM network model mix areas of node-breaker detail with areas of bus-branch detail?

Answer. Yes, because nothing in CIM enforces the use of Switch objects. Moreover, there are circumstances where mixing in bus-branch level of detail is appropriate: 1) for long-range plans, where detail is not yet available, and 2) for circumstances where the best available source for modeling a particular part of the network is a bus-branch model.

Unbalanced Models

Most transmission studies are conducted on the assumption that phases are balanced. For many key parts of the grid, only balanced representations are required, but there are situations, most commonly in distribution, where unbalanced models are necessary. CIM supports the modeling of phase detail, though it certainly does not require it. A number of features of the CIM which support individual phase modeling (phase wire, cuts/clamps/jumpers, transformer tanks, etc.) are described in IEC 61970-301 [2].

> Note. There have been a limited number real-world situations where CIM unbalanced modeling has been implemented and fewer yet with mixed balanced and unbalanced modeling. As more field implementation experience is gained, the topic will be covered in more detail in future releases of the Guide.

Creating Equipment Objects Graphically

The preceding sections described features of the CIM that support detailed physical network model definitions. The purpose of this section is to give the reader a feeling of how a CIM-inspired model management tool might support model creation. It assumes that equipment containment has been worked out and the containment objects exist, and focuses on the process by which a user would populate a model with power system components.

In the past, network model editing tools have been primarily tabular. They required a user, for example, to define a node (or bus), type in its name, and then define a line and type in the name of the two buses on each end to define its connectivity. This was okay for bus-branch models, but was a major source of errors for more detailed operations models that needed to include switching detail.

The best way to define equipment and connectivity is graphically. The procedure for the user would be something like this:

1. The user asks the editing tool to show the modeling schematic for the line or station container where the new equipment is to go.
2. The editing tool responds with the schematic view:
    a. It initializes a blank diagram if this is a new container.
    b. If a model has been imported but there is no current diagram, an algorithm is invoked to automatically generate a diagram of the container contents.

c. If the container has been previously edited graphically, the diagram that resulted from the last graphic edit session for that container is presented.

3. A tray of icons is also presented, showing the different kinds of components that can be added. (A really good editing tool would let users make up common patterns of equipment for quick addition and would show them in the icon tray also.)
4. To add a piece of equipment, the user drags an icon from the tray and drops it into the diagram.
5. Each equipment icon has sensitized terminals. The user can grab a terminal and drag it to terminals of other equipment to make a junction.
6. The editing tool keeps track of the junctions. (These are the ConnectivityNode objects in CIM.) The user no longer needs to name them unless he or she wants to.
7. The user may access property sheets to add any properties that the user wants to add while looking at the schematic.
8. The user may add, remove or modify other components, to make up one complete logical modeling 'project' (a related set of changes).
9. The user may name the project and add other attributes of the project as a whole. (Projects are an extremely important part of the CIM modeling and will be discussed in more depth later.)
10. When the user is satisfied with the project, the user saves the project. At the point of the save operation, the new objects are 'real', in the sense that they have been assigned MRIDs and perhaps registered in an object registry.

> Note. The graphic editing described above is strictly an internal feature of the network model editing tool, and as such, is not required by CIM. However, CIM data structures consciously enable and encourage this sort of design. It also makes great sense for the editing tool to simultaneously support user entry of geographic locations and definition of schematics of various kinds (often used in network analysis settings like control centers) along with editing of the network model itself. In CIM, geographic location and schematic diagram layouts are exchanged in separate Model Parts. The reality of a good editing environment, however, would be that the user could move easily back and forth between different renditions of diagrams to define the EQ Model Part contributions and their geography as well as the diagrams themselves.

Editing Object Properties

In addition to the graphic editing capability described above, a good editing tool should provide the user two ways to review and edit the details of objects:

- Property Sheet
- Tables by Component Class

Property Sheets

Property sheets are presentations that show all detail about an individual object and allow the values to be edited. This is a familiar part of many user interfaces and a model editing tool is not different except perhaps in the ways that users can navigate from other views back and forth to the property sheets.

Tabular Presentations

In a tabular presentation, a table of like data is presented with columns representing properties and rows representing objects of the type being presented. This kind of presentation is quite important for good Model Part editing and perhaps not as commonplace in everyday user interface designs (although it shares a lot of characteristics with typical spreadsheets).

The key aspects of user functionality that tabular presentations uniquely deliver are:

- The user can see detail of like items together in a way that makes unusual data entries stand out, which is helpful in debugging.
- The tabular presentation allows editing by column. e.g. 'Change all entries in this column to TRUE.'
- Tabular presentations can support fairly powerful visual versions of SELECT functionality by defining filter conditions on columns. e.g. 'Show only those Breakers where the normal position is OPEN.' Combining this feature with the column edit is very useful.

Physical Network Modeling versus Physical Asset Modeling

There is a subtle but important difference in CIM between the position in the network that is to be occupied by a transformer and the specific transformer asset occupying that position at a certain point in time.

- When a network addition is planned, the transformer role is established, but it is not known which transformer asset will be installed or what its exact electrical properties will be.
- When a transformer asset is purchased and tested, its exact electrical properties are known, but it may not be known where it will be used in the grid.
- When a transformer asset is installed in a specific role, then of course, the properties of the asset become the properties of the transformer role.
- From time to time, a transformer asset may be removed from one position, taken to the shop for maintenance, and re-installed in another position.

Equipment classes in the CIM define roles in the network and are not concerned with asset in the role, except to the extent that the asset is the source of the electrical properties (and perhaps asset condition or risk-of-failure information) needed by network analysis functions.

There are other very important analyses that study assets – for example, studies of the operating history of an asset and its relationship to failure rates, analytics that help determine maintenance scheduling or replacement prioritizing, etc. Typically, asset-related functions, which may group assets by class or model or manufacturer, do not have the need for the complete picture of how grid components function together that network analysis functions do.

> Note. Obviously, there is a relationship between the physical qualities of an asset and the properties of equipment in a physical network role and CIM supports this relationship. The mechanisms and processes for defining this relationship are currently under discussion in CIM Working Groups. WG13 has responsibility for network analysis while WG14 has responsibility for asset management.

About Load

In CIM, the concept of load in a network model is represented by a specialization of the EnergyConsumer class. However, unlike other conducting equipment, load in a network model is not a model of some real equipment item – it is always a simplified representation of parts of the electrical system that are not modeled explicitly.

> Note. To most people, the term 'load' connotes energy flowing out of the grid, but the distinction that really matters is not the sign; it is whether a given CIM object represents an explicit item of equipment or is approximating the net effect of an un-modeled part of the grid. The clear trend, especially in distribution models, is toward more explicit modeling of equipment, and CIM will be providing classes that represent the necessary kinds of load, generation and storage equipment. These classes will probably be distinct from EnergyConsumer, which is designed as an equivalent for un-modeled parts of the grid. The next edition of this Guide can be expected to expand coverage of this topic and its impact on transmission and distribution modeling.

In this section, it is assumed that the scope of a Model Part is known, so a decision has already been made about where to cut the detailed representation off and substitute a load. (Later in this Guide, the macro-modeling discussion will cover how this decision is made.)

EnergyConsumer equivalents have two main aspects:

- An electrical response characteristic may be defined to model how the load will vary with voltage and frequency.
- An energy allocation strategy for the load must be defined so that energy forecasts can be distributed to individual EnergyConsumers. This is discussed further in a Section 7 subsection: Default Energy Forecast Allocations.

Defining Steady-State Controls

Power systems employ many control schemes to keep the grid operating within desired ranges. Power flow algorithms, the most common and basic form of network analysis, typically are steady-state, but not single state, in that they will try to find a state in which controls have finished acting and the grid is within its desired ranges. This is a very important aspect of network analysis, and it means that the physical network model must include a representation of controls, such as:

- Voltage control by generation
- Voltage control by LTC
- Voltage control by switched capacitor banks
- Interchange control – roughly this approximates Automatic Generation Control (AGC)
- Line flow control by phase-shifters
- Line flow control by DC lines
- SIPS

The modeling for all of these controls is similar in that it breaks down into three parts:

- The control – that is, the aspect of the equipment that is controllable.
- The conditions that will trigger a control action.
- The control action that is triggered.

Real Controls versus Hypothetical

As a general rule, CIM network modeling focuses on modeling real implementations of controls. It therefore describes specific measurements, linked to specific controls, under specific models for control actions. The assumption is that when an engineer is studying far in the future (where control coverage and settings would not be well known) or where engineers are studying how to best set controls, these activities take place within analytical environments. Only the conclusions of these activities are fed back into master network model sources and shared with other analysis applications.

So, for example, engineers planning long term capacity may need to allocate speculative reactive controls in order to get studies to converge. This experimenting would not take place within a CIM network model management context, but, once a reasonable pattern of such reactive controls was determined, that pattern would be incorporated into the future physical network model in order that other studies could benefit from a stable network model.

Basic Controls

Voltage control is the most basic need in a power grid. It is accomplished through a combination of reactive sources and transformer taps. Flow control, though, is also important. The CIM modeling for these basic controls follows the structure shown in Figure 6-4.

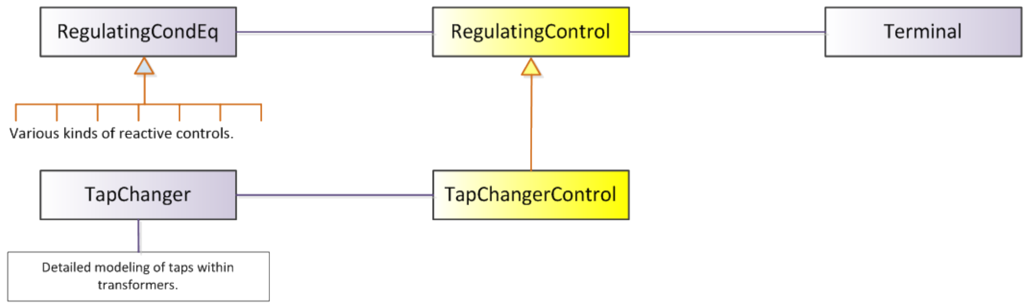

Figure 6-4
Basic regulating controls as modeled by CIM

In the above diagram the purple class rectangles at the left of the diagram represent control capability that is established as part of the equipment modeling discussed in the previous Section 6 subsection: Conducting Equipment and Terminals. The actual control relationship is established by the yellow class rectangles in the center.

Control by reactive sources (synchronous machines, static VAr compensators, and the like) is established by a RegulatingControl instance (object) that relates a control source to a Terminal object. The Terminal object would have been defined as part of some conducting equipment. In the case of voltage regulation, this is the terminal at which the voltage is monitored. In the case of flow regulation, this is the terminal through which flow is monitored. The kind of regulation is determined as an attribute of RegulatingControl.

Control by a tap-changer requires the more specialized TapChangerControl object, which contains a relationship through a TapChanger object into the detailed transformer modeling.

SIPS – System Integrity Protection Schemes

SIPS schemes are fast becoming an extremely important aspect of network modeling for reliability studies. They are characterized by more complex triggering logic and more complex control actions (or sequences of actions).

> Note. SIPS modeling in CIM is under construction and will be covered in the next edition of this Guide.

AGC Controls

CIM currently provides a way to describe AGC control in a network. This consists of:

- The list of generation sources that can be on control for an AGC area.
- The list of tie locations that are summed to determine the net interchange for an AGC area.

While the main driver for this part of the CIM is support for EMS AGC functions, area interchange control information can be used, if needed, by network analysis as well.

Defining Measurements

The measurements that exist on the power system are critical to all real-time network analysis and to any study network analysis performed for other time frames where the desire is to use recorded measurements as part of the setup of the case. As a consequence, CIM considers the description of where measurements are placed in the network to be part of the physical network model.

CIM scope goes beyond the requirements of network analysis. The whole measurement model within CIM is designed to support SCADA in operations centers, in addition to network analysis, so network analysis only uses a part of the measurement modeling. A summary of this is shown in Figure 6-5.

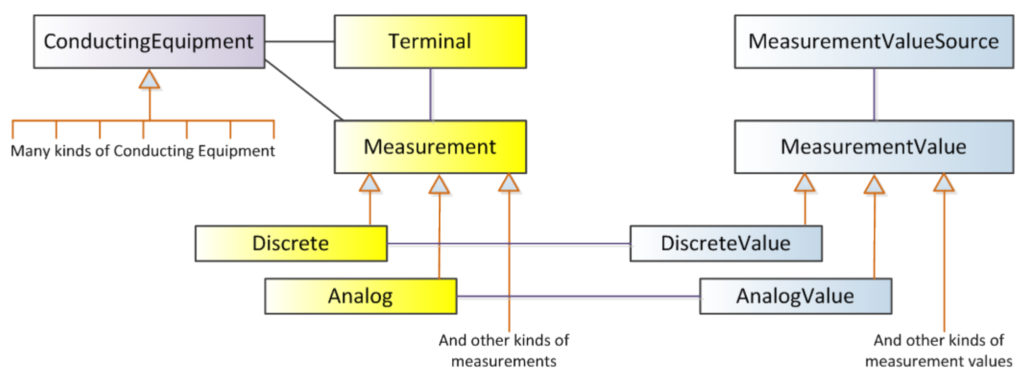

Figure 6-5
Measurements located in the network model in CIM

In this drawing, objects of the ConductingEquipment and Terminal classes (shown at the upper left) would be created, as described in the earlier Section 6 subsection: Conducting Equipment and Terminals, prior to the specification of measurement locations.

Measurement objects describe a particular measured thing. MeasurementValue objects distinguish different measurements of the same thing, so in general, there is a 1:n relationship between any particular Measurement object and its

MeasurementValue objects, even though it is most common to have a 1:1 cardinality. There are many different kinds of Measurements supported in CIM, but for network analysis the primary interest is in Discrete objects, representing measurement of the status of switches, and in Analog objects, representing either flow through a terminal or voltage at a terminal.

Once again, Terminal is used here rather than ConnectivityNode in order to keep ConnectivityNode as lightweight as possible.

The Role of As-Built EQ Model Parts

EQ Model Parts are the core building blocks for network analysis models. The suggested (and assumed) practice is that utilities will maintain EQ Model Parts, and a given Model Part will be distinguished mainly by the territory it covers and the voltage levels it covers.

A given instance of a Model Part represents one state of the physical network. They can represent any state, but in best practice, master EQ Model Parts (the ones that are core building blocks) are designed to represent the 'as-built' network – in other words, the state of network as it is currently constructed. There are two key reasons for this:

- The as-built is a logical starting point for the vast majority of case building procedures.
- The accuracy of as-built modeling for network analysis can be quantitatively assessed by state estimation.

The real physical network does not change very rapidly (at least compared to other information needed for cases). An as-built model can change for two reasons:

- Field work (new construction, storm restoration) completes.
- Corrections are needed to existing modeling.

As new construction completes in the network, new versions of EQ Model Parts must be created to keep pace, and it is natural to keep older versions of the as-built as a historical record and for support of cases that examine historical events.

Many if not most studies are run at future times and CIM assumes that these studies will be supported by starting with the as-built EQ Model Parts and projecting them into the future using projects (Incremental Model Parts), as described in an upcoming Section 6 subsection: EQ Projects – EQ Model Parts through Time.

In this edition of the Guide, the assumption is that as-built EQ Model Parts are created by editing operations based on information produced by the engineering and construction departments. In other words, an engineer is looking at the drawings and documents from the engineering and construction process, extracting the content that is needed for network analysis, and then manually editing the EQ Model Part.

> Note. It is conceivable that information from engineering and construction could be derived and imported automatically. A realistic example of this would be extracting an EQ Model Part from a 61850 automated substation design source file, which is something that is actively under discussion by a joint CIM-61850 task force. However, for now, this is beyond the scope of this Guide.

Derived or Simplified EQ Model Parts

Not all EQ Model Parts are as-built master Model Parts. Sometimes network analysts want to create simplified representations of parts of the network. These could be alternative models generated manually, but preferably, they would be EQ Model Parts that are derived from source EQ Model Parts by automated procedures. Additional consideration is given to this topic in a Section 8 subsection: Mesh Equivalent EQ Model Parts and in a Section 9 subsection: North Study – Equivalents?.

EQ Projects – EQ Model Parts through Time

Network analysis requires the ability to configure cases for future and for hypothetical situations, which means that EQ Model Parts representing future or hypothetical situations are required. Given that the main source material is in the form of 'as-built' EQ Model Parts, how is this achieved?

In CIM, the prospective evolution of the network is expected to be managed as a collection of independent Incremental Model Parts called Projects that can be added to an as-built Model Part. Each Project has a schedule and a status. The status indicates what stage of the planning process the Project has reached. (Most Projects would go through many stages, beginning with someone's idea and ranging through various stages of analysis and approval by multiple authorities.)

Whenever any forward base case is being created, the engineer in charge needs to select the Projects that are to be added to the as-built in order to create a Model Part representing the intended physical network model state. Selection of Projects would be based, as a minimum, on the estimated timing and status.

Plans change on a regular basis. Their content changes. Their dates change. Their statuses change. A base case created from one view of plans can be invalidated when plans change. A CIM goal is to know which plan selection criteria was used in a base case, and which plans were selected for the case, so that a user can tell whether the base case needs to be regenerated.

EQ Incremental Model Part Content

An Incremental Dataset always aligns with the same information model as the Dataset it is designed to modify, so EQ Project content is defined in the same way as the EQ Model Part content that has been discussed in the preceding sections. The only difference is that EQ Projects have content (ADD, MODIFY and DELETE instructions) which describe how to change a full EQ Model Part.

> Note. Current CIM standards support several approaches to forming actual data exchanges (see the *Intelligrid Common Information Model Primer* [1] sections on CIM RDF XML and CIM XSD Messages) and the strategy for handling ADD, MODIFY and DELETE instructions varies from one data exchange approach to another. Discussions are currently underway to unify the handling of change instructions and the outcome of those discussions will be reflected in the next version of the Guide.

Exchange of Projects Independent of Model Parts

Projects need to be exchanged among transmission grid participants for the same reason that Model Parts need to be exchanged. If an engineer needs to set up a study which must include representation of territory for which some other party is the Model Authority, and the study focus is a future time, then that engineer will need to know both the as-built and the planned changes. Access to planned changes can be supported either as direct exchanges among peers or via a service that would maintain the latest view of plans approved by some grid-wide planning authority.

Section 7: MICRO-Modeling II – Other Network Model Part Types

The aim of CIM network modeling overall is to be able to produce all of the kinds of 'base cases' that are required by utility engineers. In general, what distinguishes a base case from any other analytical case is simply that a base case is what the network model management environment prepares and sends to a target analytical environment as the basis for a series of related analyses. Examples:

- The modeling environment creates a Summer Peak base case for a particular year and sends it to a target suite of planning tools where it is studied in various ways.
- The modeling environment creates an 'immediate future' base case which will be installed in an EMS or DMS and then used for state estimation and contingency analyses.

A simple (and largely correct) way to think of the content of a base case is as equivalent to a power flow case, but this varies somewhat with the target environment. There are a number of Model Part types which add onto the EQ Model Parts to produce complete base case content. The two main categories of additional Model Part types are:

- Physical Network Model Part types that add information to EQ Model Parts.
- Steady-State Hypothesis Model Part types that specify the operating assumptions for the base case.

All of these additional Model Part types are dependent on EQ Model Parts, meaning that they have objects in their content which have dangling references that point to objects in the content of EQ Model Parts. In this section, each of the additional Model Parts types are explained, along with their relation to the EQ Model Part type that was covered in the previous micro-modeling section.

> Note. The content described in this section primarily comes from IEC 61970 specifications [2, 3, 4, 5, 6] that were created with transmission network analysis as the primary focus. At present, there is a separate specification, IEC 61968-13 [10], which deals with distribution network analysis based on the same CIM UML. The intent of WG13 is to remove all distinctions so that network analysis specifications are the same for transmission or distribution. The next edition of this Guide will report on this in greater depth.

Reference Model for Case Model Parts

The diagram in Figure 7-1 describes a nominal information flow for setting up a network analysis base case. It is used in WG13 as a reference model for creating the detailed specifications of Model Part types, and it helps to explain the way that overall case content is modularized according to which kinds of information come from what processes and sources.

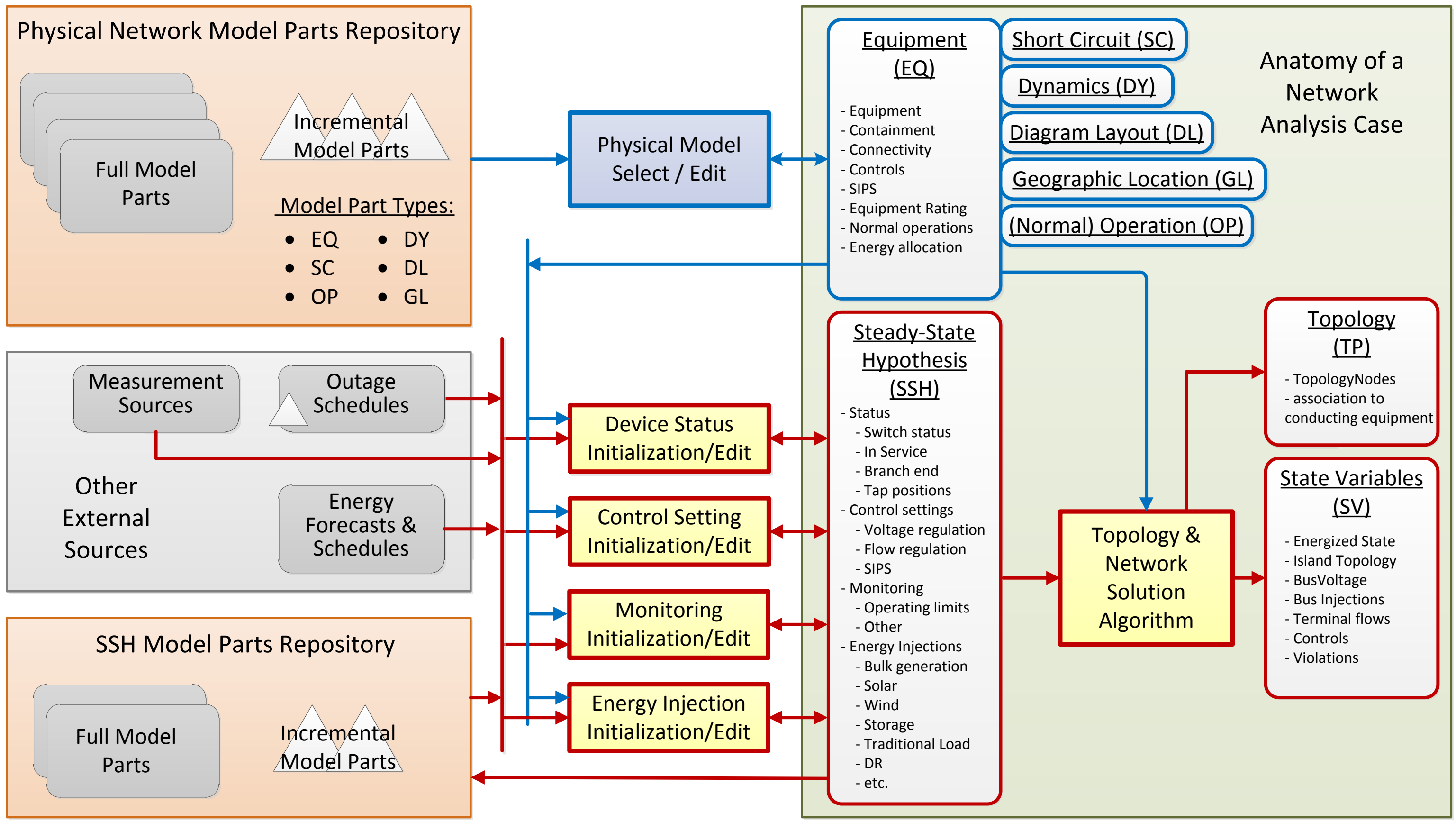

Figure 7-1
Anatomy of a network analysis case

The left side of this diagram shows sources for data needed in network analysis. The right side shows the Model Part types that make up a case. In between are a set of nominal processes, represented as square-cornered rectangles.

The main elements of this diagram are as follows:

- The top-center blue process box is Physical Model Select / Edit. This develops the state of the physical network model that will be used in the base case.
  - The assumption is that there is some sort of repository (shown at the upper left) which maintains as-built master EQ Model Parts (as described in Section 6: MICRO-Modeling I – Equipment (EQ) Model Parts) plus other additional physical Model Parts that will be described later in this section. It also maintains a view of the future as Incremental Model Parts.
  - The initialization process begins by selecting the EQ Model Parts that determine the extent of the power system which the base case will cover.
  - After the extent is determined, the state of the selected EQ Model Parts is set by adding selected Incremental Model Parts.
  - Finally, depending on the nature of the case, other Physical Network Model Part types are added corresponding to the EQ Model Parts.
- When the physical network part of the base case is populated, all the equipment objects in the case are populated, with their names, physical properties and schematics. The rest of the base case set up processing only adds information about the particular state of the equipment that is relevant for this study. Hence on the diagram, the blue arrow from the assembled EQ Model Part rounded-corner box feeds the other process boxes.
- Setting up the operating hypothesis for the base case creates a Steady-State Hypothesis (SSH) Model Part on the right, but this action breaks down into a series of different steps.
  - There are two main sources of information that feed the creation of an SSH Model Part in the base case:
    - Some information comes from external sources (which is another way of saying 'sources outside the coverage of the CIM network analysis standards'). These include systems like load forecasting, market outcomes, outage scheduling and the like.
    - Other information comes from some sort of repository (shown at the lower left) of saved previous SSH Model Parts, because it is quite common that some or all of the assumptions made in one case are relevant to the new base case.

- Unlike the physical network model initialization, the processes that set up an SSH Model Part tend to be different for different kinds of base cases. Thus, to take one simple example, for some base cases it would be logical to initialize switch status from a real-time SCADA source, but other base cases should have switch state be initialized to normal status.

- Finally, a Network Solution Algorithm uses the input to generate a calculated network state result as Topology (TP) and State Variable (SV) Model Parts.

Model Part Types versus CIM Profiles

The observant reader may notice that the Model Part types discussed in this Guide do not correspond exactly 1:1 with IEC 61970-45x specifications [3, 4, 5] or with the profiles defined within the specifications. Instead, in some instances several Model Part types share the same IEC standard pedigree. This is structurally legal because Model Parts do not need to be complete – only assembled models need to be complete. In other words, it is fair game to subdivide the standard UML if it serves a purpose.

For reference, the IEC profiles and their source specifications are shown in Figure 7-2 below.

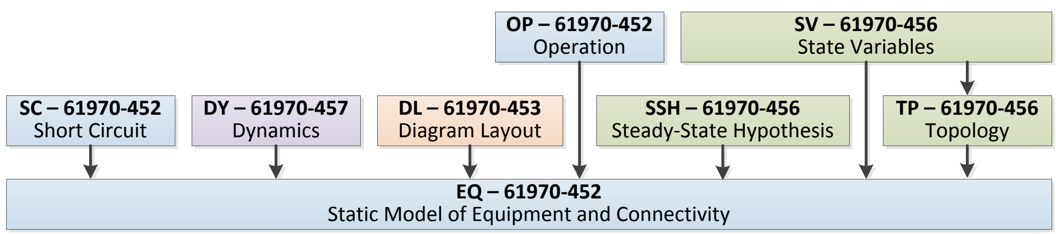

Figure 7-2
IEC network analysis UML profiles and their source documents

More Physical Network Model Part Types

Section 6: MICRO-Modeling I – Equipment (EQ) Model Parts discussed the EQ Model Part, which is the core of the physical network modeling in CIM. However, there are a number of other important Physical Network Model Part types that contribute to a complete physical network modeling. This section discusses these additional types, which are shown pictorially in Figure 7-3.

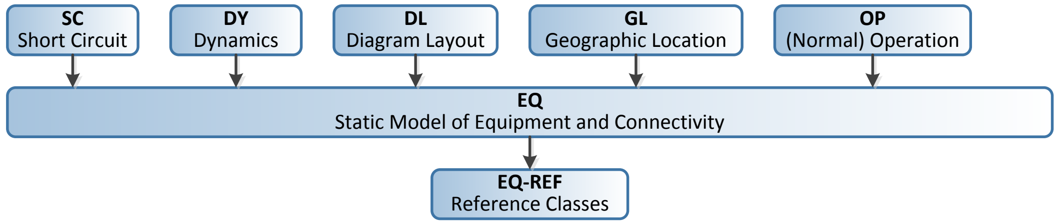

Figure 7-3
Physical Network Model Part types and interdependency

The EQ-REF Physical Network Model Part Type

When large interconnected power grids are divided territorially so that, for example, each TSO is responsible for an EQ Model Part, there are a few modeling choices that should be made consistently in all TSO Model Parts. The easiest way to assure this is to put the objects that define these choices in a separate common EQ Reference (EQ-REF) Model Part. (An alternative, which also works, is to repeat the information in each TSO Model Part.)

An EQ-REF Model Part may be exchanged using any software that can exchange an EQ Model Part, but there will be an agreement among the grid participants about what it contains. Such an agreement could be formalized as a local standard if participants choose to do so. It requires no modification of CIM.

Objects contained in EQ-REF content have no dangling references. All associations are from objects in the content of other EQ Model Parts to objects in the content of EQ-REF. These associations make the other EQ Model Parts dependent on the EQ-REF Model Part, if it is used.

Suggested contents for EQ-REF include:

- **BaseVoltage.** BaseVoltage objects define the nominal operating voltages for the grid. Putting these in a common Model Part assures that parties will use the same set of nominal voltages.

The SC Physical Network Model Part Type

Short circuit analysis requires the basic information supplied by EQ Model Parts plus additional construction detail necessary for accurately computing fault currents of various types. SC is considered a separate Physical Network Model Part in CIM, defined as one of several profiles in the IEC 61970-452 specification [3].

Note. The next edition of this Guide will provide a more complete description of the short circuit Model Part.

The DY Physical Network Model Part Type

Some analytical processes study the reaction of the power system to change, especially to sudden change due to events like loss of lines or loss of generators. These analyses usually are distinguished by the time frames being studied. Transient analysis operates in the sub-second range, while other studies simulate longer-term dynamic system behavior.

Dynamic studies require all steady-state properties, because they always use a steady-state as a starting condition, and then they need a large set of additional physical network properties. They do not introduce any new kinds of physical objects. Dynamic data is supplied as a separate kind of Model Part, called Dynamics (DY). Objects in the content of DY Model Parts reference corresponding objects in the content of EQ Model Parts.

Both synchronous and asynchronous machines are modeled, with several hundred standard models covering turbine governors, turbine load controllers, excitation systems, over/under excitation limiters, power system stabilizers, PF/VAr controllers, voltage adjusters and voltage compensators. In addition, CIM supports wind models based on the draft IEC 61400-27-1 Ed.1: Wind turbines - Part 27-1: Electrical simulation models standard. Dynamics load modeling in CIM supports combinations of aggregate static and motor loads, as well as composite loads and generic loads.

Since the use of dynamics models in cases is very specialized, dynamics models are considered separate Physical Network Model Parts in CIM, defined by the IEC 61970-457 specification (which is currently in draft form).

The DL Physical Network Model Part Type

Most network models and network analysis data is difficult to interpret without schematic and/or geographic diagrams. There are many kinds of diagrams. A partial list includes:

- Station schematic one-lines for SCADA operation. (Correspond to CIM Substation container.)
- Circuit schematic diagrams. (Correspond to CIM Line container.)
- Control room wallboard schematics.
- Area bus-branch schematics – show network analysis overviews (Reflects typical planning view).
- Geographic or pseudo-geographic distribution operations diagrams.

CIM is designed on the premise that production and maintenance of these diagrams should be integrated with the production and maintenance of the EQ Model Parts that define the equipment shown on the diagrams. This has two beneficial effects:

- Integrated editing makes it much less likely that a display field on a diagram will be linked to data associated with the wrong equipment – a mistake that is very easy to make in many systems and often very hard to find and correct.
- Editing graphically reduces both labor and the likelihood of errors in the EQ Model Parts.

Since diagrams are not used in all cases, they are considered separate Physical Network Model Parts in CIM, defined by the IEC 61970-453 specification [4].

Both the IEC 61970-453 standard [4] and the EPRI *Intelligrid Common Information Model Primer* [1] provide additional detailed information about diagram layout.

The GL Physical Network Model Part Type

The geographical location or geographical footprint of equipment is modeled in the CIM UML and is an important set of information for presentation of network analysis results. It is shown in Figure 7-3 as a distinct Model Part type.

> Note. There is an ongoing discussion as to how to best meet the need for geographic location Model Part information in both transmission and distribution network analysis. Detail is deferred to the next edition of this Guide.

The OP Physical Network Model Part Type - Defining Normal and/or Expected Operating Conditions

This section discusses an important aspect of the physical network model that perhaps is on the borderline of what should be considered as part of the physical network model. The easiest way to explain this is to talk about the use case that drives it. In traditional planning power flow case setup, only limited numbers of situations are modeled, and the operating hypotheses are typically copied from another case and then hand-modified as necessary. When network analysis was moved into the control center, however, it was necessary to be able to set up study cases automatically for any given point in time.

Some of data required for doing this is obtainable from sources outside network analysis:

- Load forecasts (usually by AGC area) are available.
- Generation forecasts (at least some of it in some form) may be available from market outcomes.
- Interchange may be available from interchange schedules.
- Outages may be available from outage schedules.

But this is not sufficient to allow complete automation – data related to states of switches, positions of taps, specific load injections, specific generator levels and specific controls is also necessary. The requirement is that there needs to be information that allows complete initialization given only a time, plus a load forecast for each forecasted set of energy and a net interchange for each control area.

To satisfy this requirement, EMS control center products have added to the physical network model a set of default operating practice assumptions that are sufficient to allow automated setup to compute values for operating hypotheses from time and forecasted energy totals. This section explores that set of information which is considered a separate Physical Network Model Part in CIM, defined as one of several profiles in the IEC 61970-452 [3] specification.

Normal Status

The most straightforward part of this data is the normal state associated with switches and taps. It really is true that the system designers, when they decided on switches, had in mind a normal state (usually closed, but not always). It is less true for transformer tap positions, but it is still reasonable to think in terms of a normal tap, especially with fixed taps.

In terms of how this information is conveyed in CIM network models, normal status is simply another attribute of equipment, enterable on equipment property sheets or on tabular lists.

Default Energy Forecast Allocations

Energy forecasts typically only provide totals for energy. They do not allocate that energy to individual components. CIM currently provides a set of load allocation classes that are summarized in Figure 7-4.

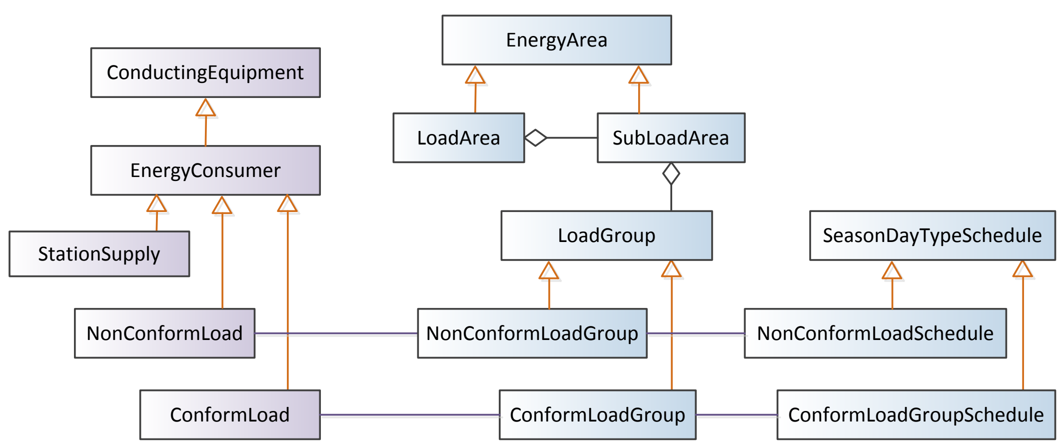

Figure 7-4
Energy forecast allocation to energy consumers in CIM

In CIM, a point of consumption is called an EnergyConsumer. As mentioned in the Section 6 subsection: About Load, points of consumption in network analysis are always equivalents for detail that is not worth modeling explicitly. Instead, an EnergyConsumer approximation is used. The part of that approximation that is of concern here is setting the level of consumption from an energy forecast, represented by the EnergyArea class.

The energy allocation structure would be much simpler if every EnergyConsumer always took the same percentage of the EnergyArea forecast in which it participates, but real power systems don't usually follow such regular patterns during the weekly load cycles. Usually, industrial versus commercial versus residential load follow different weekly patterns and sometimes certain important loads don't relate very well to anything else. In order to allow energy forecasts to be distributed well for any time of the week, CIM modeling allows EnergyConsumers to be specialized as StationSupply, ConformLoad or NonConformLoad. The latter two are assigned to LoadGroups, which can have different weekly schedules of allocation factors. EnergyArea forecasts are distributed to LoadGroups via LoadAreas and SubLoadAreas, which usually are geographically oriented.

> Note. Making these allocation models work well is a bit of an art and beyond the scope of this Guide. Usually, first cuts at CIM (or EMS) models don't even try – they just create a simple proportionate allocation of forecasts to ConformLoads. Then additional sophistication is added as the need becomes apparent.

Default Energy Scheduling Input

The other part of automated setup of energy is to determine how schedulable resources will meet the net forecasted energy demand. Usually, this involves scheduling generators. It can take two basic paths. Either scheduling is based on the properties associated with the generator equipment, such as capability and economic characteristics, or it can be derived from external guidance that is not part of the CIM network model, such as market outcomes or typical block loading patterns.

Default Control Target Schedules

Regulating controls, as discussed in the Section 6 subsection: Basic Controls, define relationships between physical control capability and specific controlled locations in the network. A network analysis function like a power flow also needs to know a specific target value to sustain. For example, if a generator is regulating voltage, the location where voltage is measured will be identified by a relation to a terminal, but the power flow will also need to know what the target voltage is, and target voltages may vary based on time. In order to allow automated setup of power flow for any time, a RegulationSchedule may be defined for any RegulatingControl object.

EQ-REF, SC, DY, DL, GL, OP Projects

All of the Physical Network Model Part types can and should be modeled through time using Projects, in the same way that has been described for EQ Model Parts in the Section 6 subsection: EQ Projects – EQ Model Parts through Time. As a general rule, whenever an EQ Project is created defining a prospective evolutionary change of the physical network, it is appropriate (either at the same time or when needed) to produce amendments to short circuit, dynamics, diagram layouts, geography and so on.

Case Model Part Types

This section discusses the Model Part types pictured in Figure 7-5, which describe the operating hypothesis for a base case:

- Input Model Part Types
  - SSH-ST Status Model Part Type
  - SSH-EG Energy Model Part Type
  - SSH-LIM Limits and Constraints Model Part Type
  - SSH-CTRL Control Settings Model Part Type
- Output Model Part Types
  - TP – Topology Model Part Type
  - SV – State Variables Model Part Type

The input Model Parts describe the starting conditions that the engineer setting up the base case specified. The input Model Parts all conform to the SSH IEC profile, but here the SSH is further sub-divided into Model Parts because the content of these different kinds of SSH Model Parts provide greater flexibility in assembling base cases if managed independently. The SSH sub-types described here can still be exchanged using the SSH specification – the only caution that users need to recognize is that the sub-type parts must be combined before they will validate as a complete SSH. (The SSH profile is defined in detail in IEC 61970-456 [5], but the IEC specification does not sub-divide SSH, as is done here.)

The output Model Parts describe the solution that the network algorithm generated. The reason these are different is that most algorithms, to one degree or another, are feasibility searches where the algorithm will attempt to find to steady-state condition that most closely matches the input conditions, but where the degree of match will vary, which means that the output result does not necessarily match the input condition.

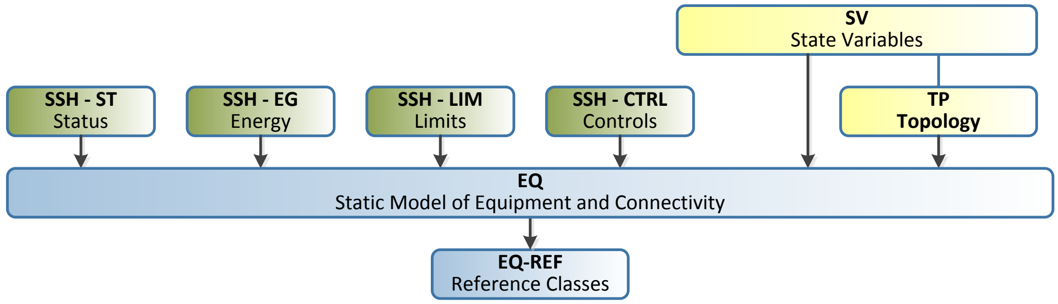

Figure 7-5
Case Model Part types and their interdependency

Note. The next edition of this Guide will provide more detailed description of these Model Part Types.

Section 8: MACRO-Modeling I – EQ Model Parts, the Core Building Blocks

Section 5: CIM Model Parts – Building Blocks for Network Model Management introduced the fundamental notion of a Model Part and the idea that Model Parts fit together to build analytical base cases. Section 6: MICRO-Modeling I – Equipment (EQ) Model Parts and Section 7: MICRO-Modeling II – Other Network Model Part Types discussed micro-modeling functionality, which deals with how to create and manage individual Model Parts of various kinds. This section introduces CIM macro-modeling, which has two main themes:

- How should modeling be organized into Model Parts to best meet the full range of network analysis requirements?
- How are Model Parts assembled to produce the complete 'base cases' for each analytical purpose?

This first macro-modeling section presents a functionally-oriented description of Model Frameworks, primarily from the point of view of the power system engineer. Model Frameworks define a decomposition of the overall scope of the power grid into parts. It focuses almost entirely on the macro-view of EQ Model Parts, which were discussed at length in Section 6: MICRO-Modeling I – Equipment (EQ) Model Parts.

Model Framework and the Unified Grid Model Objective

The idea of a virtual unified grid model was introduced in the Section 5 subsection: Why Do We Talk About Model Parts Rather Than Models? The illustration used there is repeated in Figure 8-1 below.

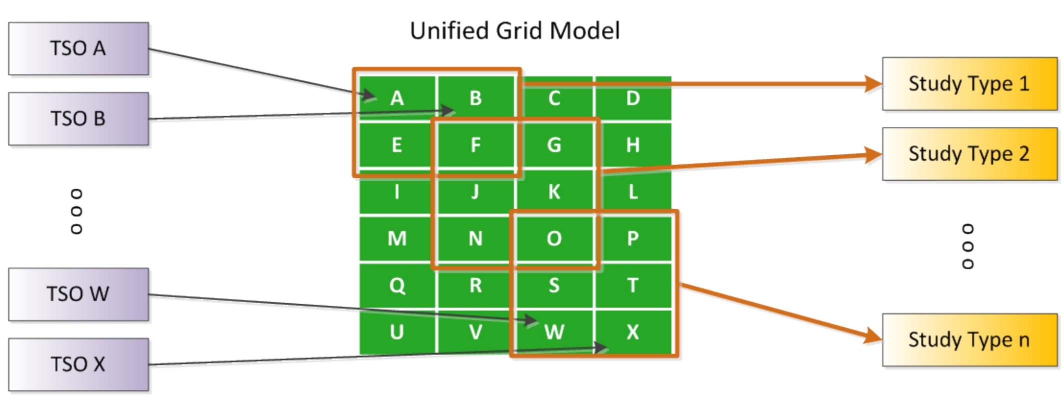

Figure 8-1
Many different kinds of studies configured from shared Model Parts

In CIM, the closer a set of CIM users get to the objective of a unified grid model, and the more comprehensive the framework is that defines it, the more the users will realize the full potential value of CIM standards. Any formal method of documenting an agreement on a unified grid model structure is referred to in this Guide as a 'Model Framework'. IEC WG13 is currently developing a standard method of specifying a Model Framework, but the reader may assume that all of the functionality described in this section may be achieved without this standardization, unless explicitly stated otherwise.

The added value of a standard specification for a Model Framework is expected to be that a single master definition may be exchanged and used by participants to assure that their testing regimens and other business processes are in agreement with the Model Framework. Without a standard specification, such assurance will rely more on manual verification.

In the end, any Model Framework is primarily a method of achieving agreement about how Model Parts should align so that they can be combined without additional processing. The greater the number of parties there are to the overall network model management process, the greater the value in formally establishing a Model Framework. Model Parts can be exchanged and combined as pictured in Figure 8-1 with any method of specifying a framework – standardization of the framework specification is a plus but is not required.

And one final point is extremely important. Achieving a comprehensive Model Framework is normally a multi-year process that necessarily will begin from whatever modeling processes currently exist and will include a number of intermediate stages before any complete vision is reached. As a consequence, CIM is designed so that it does not in any way require that a Model Framework be in place, or inhibit intermediate levels where partial agreements may be active.

The Entry Position - Working Without a Model Framework

While most of this macro-modeling discussion is predicated on a Model Framework specification shared by a group of cooperating modeling entities, the right starting point is to set some context about how Model Parts can be used in the absence of a framework or where frameworks exist only unilaterally.

Network Model Management without any Kind of Framework

As was said earlier, a Model Framework is not necessary in order to assemble a base case from Model Parts.

If a TSO is just beginning to experiment with CIM, a first activity might be to take existing cases, in other formats, and convert them to CIM. Each would produce a set of Model Parts (one EQ, one SSH, one TP, one SV), representing whatever whole territory was covered by the case. If all the TSO wanted to do was to carry on with their current modeling practices, except using CIM formats and CIM tools, they would now be all set to do that. There is nothing illegal about having one EQ Model Part describe all the equipment and connectivity in a case or one SSH describe all the operating hypothesis in a case. There is also nothing illegal about continuing the duplication of modeling effort that existed in the TSO's procedures. In fact, CIM would yield some significant benefits even at this basic level, such as better flexibility in moving information between tools of different vendors and better ability to choose the slickest tools for each chore. This is an important statement, because this is probably the first stage of CIM adoption and a utility might spend some time at this stage, getting acclimated to CIM.

A utility could also take some further steps without formally creating a Model Framework. Suppose the TSO was a member of an ISO/RTO organization that was a good source of external modeling. It could take its best base case for its internal footprint and, using CIM modeling tools, cut away all of the external modeling, and then save the result as a Model Part 'My TSO' representing just its internal. Then the TSO could use the same process with an ISO/RTO import, except this time cutting away the model of the TSO's internal territory and saving the result as Model Part 'My External'. An engineer doing this process would have an implicit idea about how these two parts were going to mate. CIM tools would allow the engineer to attempt to compose a case from My TSO + My External. Errors would show up as unresolved dangling references between the two Model Parts. With a bit more work, the engineer would be able to get the Model Parts to mesh and, depending on how slick the editing tools were, there might even be some pretty good help remembering the steps that were necessary to import and cut down the external model, so that the process would go faster in the future. Now, the TSO only has to maintain the Model Part covering its internal territory and can import an up-to-date external by a reasonable procedure – a significant improvement is achieved and this is done without a formal Model Framework (although there was an implicit model framework in the engineer's head).

In general, anyone at any time may create a Model Part with any content, and may take that Model Part and try to combine it with other Model Parts to make analytical cases. When Model Parts are combined without the guidance of a Model Framework, it just means that the Model Parts may generate errors when combined and adjustments will be necessary.

Such implicit frameworks will work okay with relatively simple schemes involving a small group of engineers, but the more parties and kinds of cases are involved, the more everyone will benefit from a formal Model Framework agreement that can validate contributions to the overall modeling effort.

Unilateral or Transition Frameworks

For a TSO, there are usually different levels on which Model Frameworks may operate:

- Up – coordinating a TSO with its ISO/RTO.
- Peer – coordinating a TSO with its neighboring peer entities.

- Internal – coordinating TSO departments with each other (as in operations and planning, for example).
- Down – coordinating with TSO participants, like customers or distribution entities.

A TSO may not control all these levels but it surely controls some of these levels, so is it possible to create useful Model Frameworks when there is only partial participation? A closely related question is: if there is a Model Framework in which some Model Parts represent territory of non-participating entities, how does this work?

The short answer is that Model Frameworks tend to deliver additional value roughly in proportion to the degree of participation in the agreement by the natural sources of data. It is eminently practical to launch a framework part by part, achieving more value with each additional participant. The consequence of having a non-participating part of a Model Framework is simply that the TSO will have to continue whatever it was doing to get coverage of that particular bit of modeling. This might range from hand-modeling the other entity to developing extract and merge procedures from accessible cases.

Note that while step by step expansion of participation may be forced because parties are not willing to participate, it is equally true that step by step expansion is sometimes the best choice because it eases the constraints on planning and organizing a transition to a CIM Model Framework.

All these same comments will hold for entities other than TSOs, but with a slightly different list of potential coordinating entities.

Principles for Defining Model Frameworks

The following subsections introduce the principles for partitioning the overall grid into Model Parts.

Principle: Single Source of Each Part

When all of the data in a given part is the responsibility of one party and comes from the one source which is the most natural authority for the data, then the development of business processes for information flow can deal in complete parts, and will be more straightforward. This is the most basic principle of partitioning data.

This does not mean that all aspects of the process that developed the data are in one place. The data could have a long and complex pedigree. It just means that whatever goes before has arrived at a result for which the source takes responsibility.

Principle: Non-Overlapping Parts

Any collection of parts that will be combined to form a model should be non-overlapping.

Let's reason backward. If two Model Parts contain values for the same information, then there will need to be some processing which will have to decide which one to pick. Thus there is at least some other intermediate set of data which is the outcome of this decision and is the responsibility of the party making the decision. The best way parts can be combined unambiguously is by a simple union of 'disjoint sets' – i.e. sets with no common properties.

There are places in the network analysis processes where data processing will necessarily occur – for example, in the development of equivalents or simplified representations, so the point here is not to say that all parts have to be exactly perfect and no intermediate processing may occur. Two objectives can be stated, however:

- In the end, assembly of a base case should be by a simple union, even if some intermediate part needs to be generated.
- In the beginning of a procedure, source parts that are non-overlapping are desirable because they eliminate processing to choose among alternatives.

Principle: Clear Boundary Agreements

When there are multiple sources of modeling information, in order to achieve non-overlapping parts, we need to know unambiguously who is responsible for each model data object. There are two kinds of agreements:

- Implicit agreements are defined by the CIM standards that differentiate kinds of Model Parts with dependencies between kinds. Tooling usually enforces these boundaries and users are not involved.
- Explicit agreements are defined by modeling users to partition data of the same kinds into distinct Model Parts – usually to establish some form of territorial or organizational division of responsibility. This kind of boundary must be established by user agreements.

Setting Scope and Assigning Responsibility for Model Parts

A Model Framework is an agreement among a set of parties to cooperate in network modeling. The Model Framework assigns roles and responsibilities within this cooperation, which then dictate how various responsible parties must create their Model Parts. The desired end result is that each item of physical model data has a single well-defined responsible party and that any base cases that are created can formally trace their content back to its responsible parties.

In theory, any interconnected grid could be covered by one all-inclusive Model Framework, stretching from customer premises through the high voltage grid and all points in between. In the longer run, this is probably also a good goal, because of the increased impact of distribution conditions on the high voltage grid that are the result of smart grid initiatives. In most real situations, however, CIM Model Frameworks will usually start with a narrower, more prioritized view and then grow from that base as a value proposition becomes clear. The most likely starting point for a CIM Model Framework is managing transmission network models, and that is the assumption in this section.

The first step in setting up any Model Framework is to determine the participants and the scope, which are set by:

- What sources are going to participate and supply data?
- What are the anticipated kinds of studies that are going to be supported? (In this latter category, the biggest determinant is likely to be whether the Model Framework is to support both operations and planning, or is limited to one or the other.)

The CIM vision is to enable both operations and planning from the same Model Framework, so that will be the default assumption in this Guide, but it is nevertheless important to recognize that CIM does not force this choice.

Most large grids have multiple entities that participate in the planning and operation of the grid. Not all grids are organized the same, but roughly speaking, we can talk about the following:

- Regional or grid-wide entities (RTOs/ISOs) that have responsibility for operational reliability, energy markets and long-term capacity planning.
- Transmission System Operators (TSOs) who operate parts of the high voltage bulk power grid, and who have detailed planning and reliability responsibility within their grid.
- Distribution System Operators (DSOs) who plan and operate low voltage distribution to customers.
- Active energy participants, which are load and generation connections that are individually registered as participants, which usually also means they have some responsibility to supply modeling data.
- Passive energy participants (load and generation that is not individually registered) that are collectively represented by some other modeling authority.

Ownership of grid components that require modeling is distributed among these entities. Usually, the owner of a component will be the model authority for the physical model of the component (except in the case of passive energy participants). A fairly common exception to this rule, however, occurs where a participating entity is small and has limited engineering resources, and a different entity agrees to act as a proxy authority.

The EQ Model Part type discussed at length in Section 6: MICRO-Modeling I – Equipment (EQ) Model Parts is the Model Part that establishes the existence of basic objects in the network model. This gives it a special status as the Model

Part type that determines the scope of the Model Framework and any base case derived from it. As a practical matter, this means that Model Frameworks are driven by how the EQ layer of modeling is to be divided among responsible Model Authorities. Usually, additional Model Part types in the physical network model have the same division of scope as the EQ Model Parts (for example, one DY Model Part for each EQ Model Part).

Normally, an initial framework agreement would take place in written document form, and probably forms the basis of contractual agreements. It would list the participants and define, in words and/or maps, the territorial and voltage level responsibility for modeling. It might also go on to define how the framework might be extended to include other parties, if its original form was limited.

Exploring Model Frameworks from the TSO Perspective

A TSO sits in the middle of a fairly complex and demanding set of modeling requirements, and a good way to explore Model Frameworks is to begin by looking at the world from the TSO perspective.

A Basic Model Framework Example

Let's start out with the example shown in Figure 8-2. It shows a Model Framework for a grid divided into nine territories with clever names like Central, East, North, etc. Let's assume that these territories correspond with the territories of nine TSOs that make up the transmission part of the grid, and let's further assume for the moment that we are only interested in creating a system for supporting studies of the transmission part of the grid.

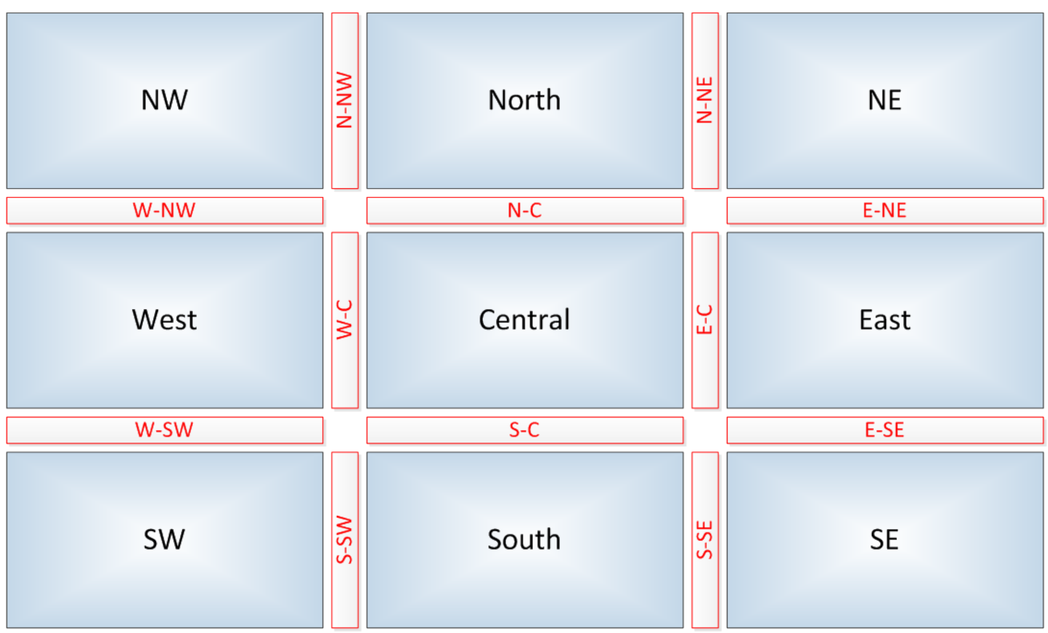

Figure 8-2
A transmission grid divided among nine TSOs

This Model Framework actually consists of 21 total parts. There are 9 'Frame' parts corresponding to the TSOs and 12 'Boundary' parts (in red). Each Boundary separates exactly two of the TSO regions. In other words, a Boundary is a bilateral agreement between two TSOs as to how their two parts will fit together.

As has been explained earlier, Model Frameworks explain how EQ Model Parts fit together. The reason for this is simply that EQ Model Part scope drives everything else. Other kinds of Model Parts plug into EQ Model Parts.

Now comes a slightly tricky part. 'Central' in the Model Framework is not an EQ Model Part – it is a Model Framework part of type Frame. It specifies a position in the framework into which an EQ Model Part for the Central territory will fit. It is therefore intimately related to Model Parts representing the Central TSO, but multiple Model Parts are allowed to be defined for the same Frame. For example, Central might have one Model Part with full as-built detail and another Model Part in which the sub-transmission has been simplified away, but both Model Parts can be used within this same framework definition because they have both been created to match the Boundaries of the Central Frame. (More will be said about how to take advantage of this feature later on.)

The same relationship holds for Boundaries – EQ Model Parts fill Boundary roles. This is discussed in greater detail in a following Section 8 subsection: The Framework Agreement, but for now, think about the following statements:

- Boundary EQ Model Parts contain the minimal set of objects that must be mutually agreed between adjacent Frames, such that their Model Parts will fit together.
- Frame EQ Model Parts can be created and validated independent of other Frame EQ Model Parts (because they only have external references to EQ Model Parts that fill the Frame's Boundaries).

Looking Inside a TSO Frame

The previous section introduced a simple framework which would allow a group of TSOs to coordinate their modeling efforts. This is quite a valuable contribution as is, but if that is as far as the framework goes, then some work remains for each TSO to prepare the views of its own territory that are necessary to support all types of study requirements. To explore some additional valuable options requires looking inside the TSO.

Let's first assume that a Frame like the Central Frame is filled by a single monolithic TSO Model Part. Such a Model Part would nevertheless have different aspects, as depicted in Figure 8-3.

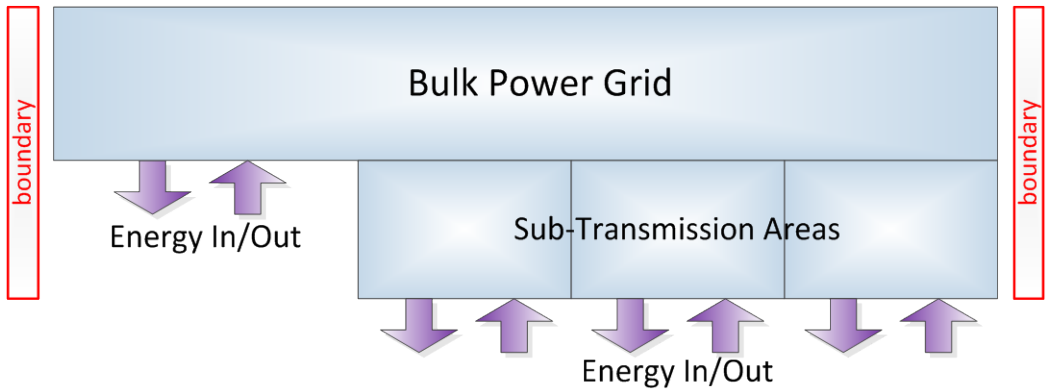

Figure 8-3
Aspects of a monolithic TSO Model Part

Complete TSO modeling will include:

- Explicit representation of the lines, transformers, breakers, large generators and other equipment that are important to any network studies.
- Explicit representation of lines, transformers, breakers, generators and other equipment that make up parts of the power grid that are only of local concern in studies – called Sub-Transmission Areas in the figure. This is modeling that is needed when focusing on the TSO internal state, but is not needed from the perspective of a study by a neighbor of its internals, or a study by the interconnection of the bulk power grid overall.
- Points at which energy is injected or consumed are represented such that energy assumptions may be computed from forecasts and schedules. This consists of a number of components and is becoming increasingly a more complex part of network modeling:
  - Larger generators and especially those that are important to grid dynamic behavior are represented explicitly.
  - Other points of energy in or out of the modeled grid represent parts of the real grid that are not significant in transmission studies and are simplified to a load or to an equivalent generator.

Modelers in a TSO may choose to independently hand-build each kind of Model Part that is needed within their Frame by different studies. This commonly happens now. It is not unusual for a TSO, for example, to prepare an internal model with the necessary detail (as described above) for its own internal studies, and then maintain a different simplified model for use in grid reliability studies at ISO/RTO entities. Of course, a CIM goal is to eliminate such duplication of modeling effort. The next section suggests how this may be done.

Decomposing a TSO Frame with a Sub-Framework

Model Frameworks in CIM are made up of two kinds of parts, Frames and Boundaries. Frames and Boundaries, however, can also be made up of Frames and Boundaries. This 'recursive' relationship that may be employed as deeply as is useful in any particular situation. Moreover, a Model Framework may be initialized with a simple structure such as was depicted in Figure 8-3, and then later expanded with sub-frameworks as various participants find it useful.

This section describes a first step in this process. It starts with the picture of a TSO presented in the preceding section and shows how to formally decompose it into parts that will allow the TSO modelers to avoid multiple models of the same things.

Let's talk about the objective first. We assume here that the TSO has two basic requirements that will be addressed. The first is to be able to build base cases that represent both the bulk power and the sub-transmission, together with at least a first tier of neighboring TSOs, for internal studies. The second is to be able to supply models of the TSO bulk power only for use by its regional reliability authority in conducting studies of the grid as a whole. The objective is to be able to do this without having to build and maintain two complete models, so basically, the idea is to share the bulk power representation. This means that we need to decompose the TSO so that there is a distinct bulk power part. Figure 8-4 shows an example of this kind of approach.

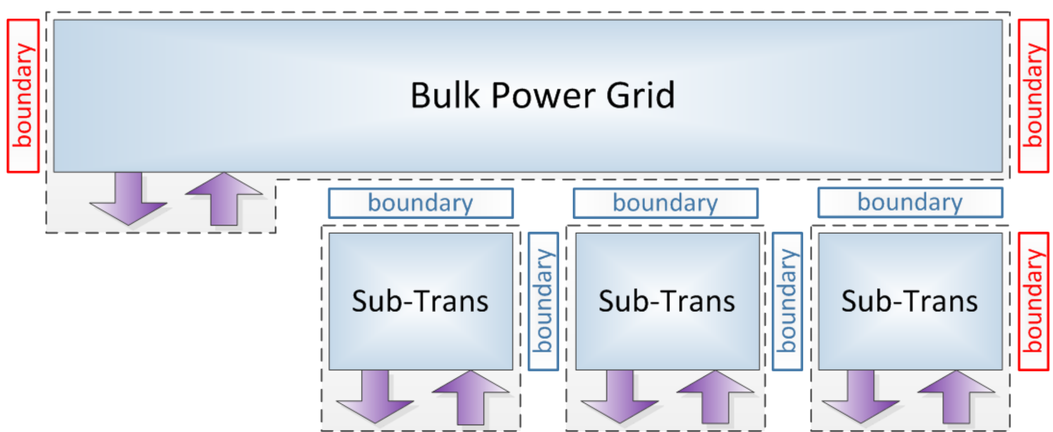

Figure 8-4
TSO Frame decomposed into sub-framework.

In the figure, the dashed boundary lines show the extent of each Frame within the TSO. Note that each Frame is expected to be filled by an EQ Model Part that includes both the explicit grid components and attached energy in/out modeling. A single bulk power Frame with three sub-transmission Frames is depicted, but the numbers of each could be whatever is natural for that TSO. Between each new internal Frame a new Boundary is defined. (Five new Boundary parts are shown in blue.)

Notice also, though, that if the sub-transmission had any external ties, the previous Boundary of the whole TSO may also need to be sub-divided into Boundaries for the bulk power and boundaries for the sub-transmission.

The theory here is that if the TSO maintains one EQ Model Part version for each of these sub-Frames, then both of the kinds of base cases that are needed can be constructed without duplicating any modeling. The answer is that this is almost true. The modeling shown in Figure 8-4 is exactly what is required to represent the TSO for internal studies, but when the sub-transmission modeling is eliminated for a bulk-power only representation, something must be done to move the energy in/out that was part of the sub-transmission Model Part up to some equivalent energy in/out at the bulk power level.

One way to do this is to run base case power flow on the detailed model, which will produce solved flows at each tie point between the bulk power and sub-transmission. These flows can then be converted to equivalent energy in/out at the boundary between bulk and sub-transmission. The new energy in/out forms a new EQ Model Part. This kind of equivalent EQ Model Part will be used frequently in creating base cases, and it is called an 'Edge' Model Part. An Edge Model Part is a Model Part that properly terminates (in the modeling sense of cutting off parts of models) one side of a single bilateral Boundary.

The end result is an Edge Model Part that is an alternative to the sub-transmission Frame consisting only of energy in/out, as shown in Figure 8-5. (Note here the assumption is that both the TSO and its neighbor are eliminating their sub-transmission for this model, so the external sub-transmission boundary is not needed.)

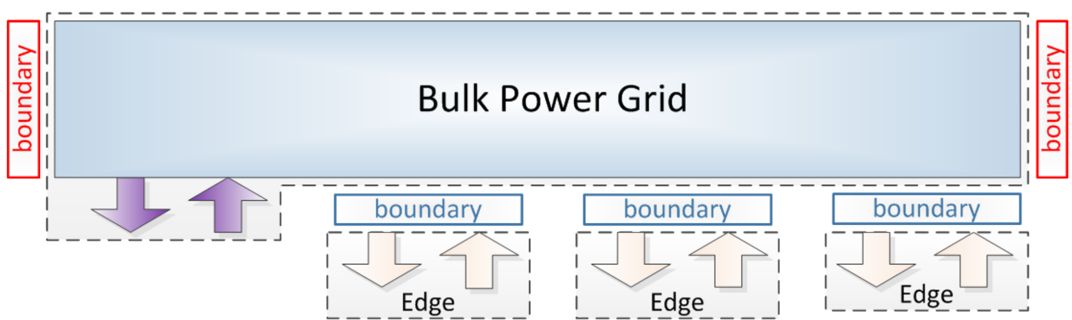

Figure 8-5
TSO simplified to bulk power only

What has been achieved by this? For starters, the duplicate modeling of the bulk power grid has been eliminated. The calculation of edge loads remains, but this is not new work – something similar must have been done when two models were being maintained. The calculation is probably a bit simpler now, though, because the power flow result of the detailed model is guaranteed to mesh with the boundary points of the bulk power only model. In fact, it would be straightforward to write automated routines for calculating the Edge Model Parts from the solved detailed Model Parts.

Using Recursion to Include DSO Models within TSO Models

Model Frameworks may be defined recursively. This means that any Frame created by the kind of decomposition explained in the preceding section can itself be further decomposed. One way that this feature might be used is depicted in Figure 8-6, where some decomposed parts of a TSO may represent a DSO, which itself is decomposed into parts.

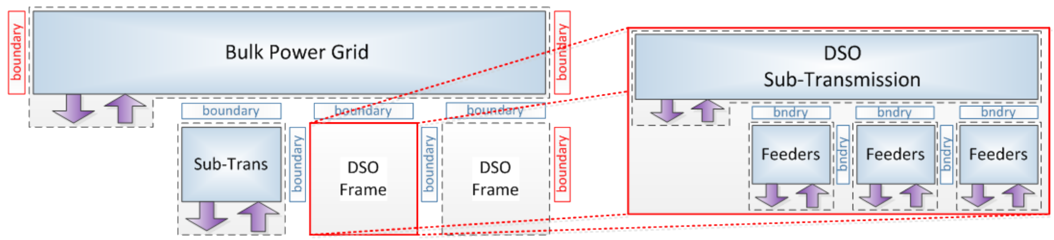

Figure 8-6
Embedding DSO Frames within TSO Frames

Constructing the Model Framework in this way would allow the TSO to import DSO modeling from the DSO. In a TSO study, the DSO may be represented in detail or simplified according to the same sorts of procedures that were outlined in the preceding section.

If this sort of recursive modeling is carried out such that all distributed energy resources, customer participants, renewable energy sources and the like can be captured in some level of the modeling, then when higher level studies of the grid are run, load in those studies may be aggregated from the detail and can add an important level of accuracy to grid reliability studies.

Meshing Transmission Models with Distribution Models

Distribution entities are beginning to invest more heavily in network analysis for system operations. Usually, the 'head end' of the distribution system is a substation which is modeled in distribution analysis and is also a normal part of transmission studies. Sharing of substation models between transmission and distribution has major benefits, especially in operations contexts where the substation models are complex. These benefits include:

- The substation models are only created and maintained once.
- Conditions computed from transmission studies may be used to set head end conditions in distribution studies.
- Energy in/out on the distribution studies may be more accurately translated to load at the substation which would be of benefit to transmission studies.

Figure 8-7 illustrates a Model Framework that would facilitate sharing of substation modeling between transmission and distribution.

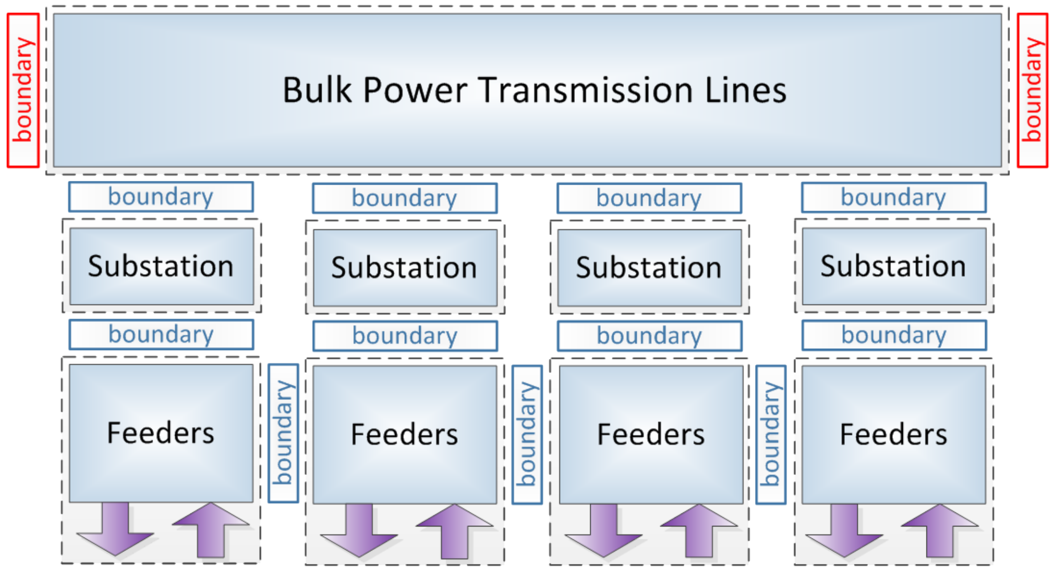

Figure 8-7
Model Framework designed for sharing substation models between transmission and distribution

With the above kind of model, distribution studies can use Edge Model Parts to reflect transmission and transmission studies can use Edge Model Parts to reflect distribution.

Mesh Equivalent EQ Model Parts

There are times when network analysts want to create representations of parts of the grid by procedures which are more sophisticated than just replacement of whole Model Parts with Edge Model Parts.

A CIM Model Framework does not change the process by which such equivalents are calculated, but it reduces the number of situations where these procedures are required and can greatly improve the ability to automate and track what is going on when they are used.

Usually, an equivalent is a simplification derived from a solution of a more detailed model, so it is not normally master source material in the same sense as other Physical Network Model Parts. However, the need for simplified representations is a factor that should influence the design of the Model Frameworks. Good framework design can make equivalent procedures simpler.

The basic rule is that equivalent procedures should produce new Model Parts that still fit into the same overall Model Framework. If we returned to the overall grid-divided-into-TSOs picture of Figure 8-2, for example, suppose the Northeast TSO wants to create an equivalent of the Southwest. The result is simply a new Model Part that fits into the Southwest Frame and may be used in any studies where the simplified variant is appropriate. Or, Northeast could make a combined equivalent of both West and Southwest – this could still be assembled with standard boundaries. A partial outcome that has to be knitted together with an existing Model Part instance should, however, be avoided.

Incorporating Models from External Sources - Generic

One major aspect of Model Framework design deserves a bit more discussion. A primary CIM goal is to allow data to be sourced from the most natural Model Authority such that it can be composed with data from other natural sources to form complete cases. Acquisition from other sources is a bit different from building one's own Model Parts. This section outlines import generically – the next section gives some examples.

The Framework Agreement

A Model Framework defines an agreement among natural sources about exact responsibility for supplying data so that there are no gaps or overlaps in Model Parts from each source. It is not necessary to have a formal agreement. Two engineers could regularly exchange Model Parts informally, and, if they were well enough coordinated, they could use their imported data as described in this section. However, Model Frameworks are recommended, and the more parties are involved, the more important they are.

Framework agreements are captured as bilateral Boundary framework parts within a larger Model Framework. Each individual Boundary part is an agreement between two parties as to how their parts fit together. There are two stages in reaching this agreement:

1. A nominal agreement is reached about the need for, and agreement to participate in, a bilateral Boundary.
2. A specific agreement is reached in which a Boundary Model Part is created against which each party may test their Frame Model Parts for compliance, by checking whether the Model Part dangling references terminate successfully on Boundary Model Part objects.

More detail about how to define Boundaries is discussed in a later Section 8 subsection: Best Practices for Defining Boundaries.

CIM Import Management

While each engineer assembling a base case could be left to go out to each of the sources for the Model Parts that are needed, this would neither be very efficient nor very well controlled from a quality point of view. In general, it is better to separate the Model Part import function from the case building function.

Model Part import is a facility for importing, validating and storing Model Parts needed for assembling the TSO or DSO base cases, which must be acquired from external sources. It would normally be part of a network model management facility, which would also include the ability to edit and manage (and export) Model Parts for which the TSO or DSO was responsible. Usually, the import process will be designed assuming that the source will periodically update the Model Part and that, when this occurs, the TSO or DSO will import and check the new version to assure that it is ready to be used. The process may also be able to notify users of the new version, so that important studies based on that Model Part can be updated.

When an import function is present as part of a network model management facility, engineers who are creating base cases for studies only need to go to this facility to get the latest official (and validated) version from each model source.

Converting from Non-CIM Sources

Sometimes sources of data are not CIM-based systems. Such systems can still function as sources within a CIM Model Framework as long as the source material can be transformed into CIM Model Parts. Such a transformation is simply executed as an initial step prior to the import process described in the previous section.

Note also that similar transformations are sometimes useful to convert CIM Model Parts to other formats.

Incorporating Models from External Sources – Examples

This section presents several specific examples of import from external sources.

CIM Peer Organizations

Conceptually the simplest situation was illustrated in Figure 8-2 which showed a grid divided into 9 TSO peers. The Central TSO, to take one, would build its own model, but needs to acquire the models of each of the other 8 TSOs in order to adequately represent the grid external to itself.

The first step in organizing these imports is to establish a formal Model Framework that defines the set of Boundary parts that each TSO agrees to obey. In Central's case, there are four pertinent agreements, one each with East, North, West and South. To keep this simple, this discussion will be limited to the exchange of one Model Part representing the as-built state of each TSO.

Each party in this arrangement has an obligation to make their as-built Model Part available. In return they can import any of the other Model Parts that they need. While not absolutely necessary, the easiest way to conceive of this is that there is a shared repository somewhere to which each party submits updates of its Model Parts as they are created, and from which each party can acquire the other TSO's Model Parts as they are updated.

Whenever a new Model Part version is imported, it is validated and stored locally, as described in the preceding section.

61850 Substation Models

An increasingly popular development in the power industry is the IEC 61850 standard [7] for substation automation, which is designed to improve the ability to design, build, operate, monitor, and maintain substations. Of interest here is the fact that a 61850 substation design is documented in a language called Substation Configuration Language (SCL) [11], which has most of the information required to represent the substation in CIM physical network models. This means that if a substation is designed using SCL, the master source for substation models can be an SCL file, and the duplicate activity of manually editing a separate network model representation can be avoided by importing the information from the SCL.

Of course, some substations are 61850 and some are not – and each 61850 source is separate from every other 61850 source. Thus an individual decision is required in each instance of a 61850 import. Each such import must fit into its own slot within the overall Model Framework.

The first step for a 61850 substation (or any other 61850 installation) is to create a Frame for the model of that installation within the CIM Model Framework. Figure 8-7, shown previously, illustrated how this can be done for substations. Once the territory that will be imported from each source is defined in this way, it may be imported as an EQ Model Part according to the process outlined in the preceding section.

> Note. Such an import is an example of a situation where the source, IEC 61850 SCL [11], is not semantically consistent with CIM, so a transformation is required to extract the desired material and formulate it in CIM terms. There is currently an IEC task force that is defining how this transformation should be done.

GIS Feeder Models

Especially in distribution analysis, another common external source of network model information is a GIS. Describing distribution feeders well enough to produce accurate network analysis results is an enormous chore, and even when GIS systems only have part of the required data, connecting to the GIS as a source is far preferable to duplicating the work in another data editing environment.

Establishing the Role of GIS

The first problem in automating import from a GIS source is to establish how much information is going to be mastered from the GIS. Unfortunately, utilities vary both in terms of what information is currently managed by the GIS and in terms of their philosophy about how much information should be managed by the GIS.

Let's start with the philosophy. Most often, the original purpose of the GIS was not network analysis. GIS orientation is usually more toward asset management combined with geographical organization and presentation. However, sometimes the role remains at this level and sometimes it morphs into 'the master source for all distribution network information for all purposes'. Occasionally, it acquires a source role for transmission as well as distribution. Unfortunately, these decisions are not very consistent across the industry, nor are they necessarily based on any kind of comprehensive information architecture.

The key factors in making good decisions are the structure of data within the GIS and the purpose of the GIS. Among existing GISs, the majority are based around data structures that are primarily mapping and geography oriented, while a smaller number have electrical connectivity schema that make them more compatible with the needs of network analysis. As an example of the difference between these two approaches, the former would represent a switch as a point to which other drawing objects (like lines) can connect, whereas in an electrical representation, a switch is a branch connecting two points through which power can flow. This may not seem like much, but the consequences in terms of ease of working with network models is very significant. Building a demanding network management facility based on a data structure designed for something else is like building a skyscraper in swampy ground – it costs a lot to make it work.

The underlying GIS tool is basically just a database with a lot of specialized access and user interface features. One can put any schema (including a CIM schema) into a GIS. Thus if one wanted to expand a GIS into a full-fledged do-everything-required-for-network-analysis system, the right way to do it would be to drop a CIM-inspired schema into the GIS that would enable full-featured management and exchange of CIM standard data, and it may well be that some enterprising GIS vendor will do just that. Barring such a development, the best route is to design an appropriate integration with a product-based CIM network model management environment, because a one-off customization of a GIS is probably not a good investment.

The most difficult part about giving general advice about GIS imports is the range of different roles for and designs of GISs in different organizations. The best rule of thumb, though, would be to not try to expand GIS to do things it was not designed to do. It will usually be better to find the most straightforward way available to integrate existing GIS capability with an environment designed for network analysis model management.

Importing from a GIS

For the purposes of this discussion, the assumptions about GIS are as follows:

- The coverage of GIS is limited to feeders. (Other possibilities would include substation models and even transmission.)
- The content only contains part of the information required for complete network models. (For one example, it is common that measurements are not modeled in GIS, but they are needed for operations network models.)

- The structure of the connectivity information is in mapping terms and not electrical connectivity.

Again, the starting point is to design a Model Framework such that exports to the network model management environment are in the form of complete Model Parts. Most likely, the choice as to scope will either be that a feeder is one Frame or that all the Feeders from one substation are one Frame. The latter is what was depicted in Figure 8-7. Boundaries will exist between the feeder Frame(s) and the substation Frame. Bilateral Boundaries may also exist wherever there are field connections between feeders.

Picking the Frame is the easy part. The trickiest decision is how to manage the fact that a GIS will not have complete sets of data. One avenue is to make the GIS complete, which is practical in some cases and not in others, depending on the GIS. The other avenue is to partition EQ_Model Parts into two sub-kinds, one being 'whatever GIS has' and the other being 'whatever GIS does not have'. Then the procedure from the point of view of the network model management side is:

- Import the whatever-GIS-has Model Part via the normal external source import procedures (including a transformation from the native GIS schema to a CIM EQ_Model Part schema, if necessary).
- Build and maintain the whatever-GIS-does-not-have EQ_Model Part in the network model management side. (It will have dangling references to the GIS import, so that the network model management can plug the two parts together to get a whole normal EQ_Model Part.)

A word of caution is appropriate about the transformation that is required to create electrical connectivity models from GIS drawing models. This has been done, and a number of papers have been published documenting the experience. Usually, however, such transformations are based around a set of rules that say 'if you see this kind of drawing configuration, convert it to this kind of electrical connection'. The rules are not usually guaranteed to cover every possible situation, but because power systems and GIS mapping of power systems follow patterns, one can usually find a set of rules that will work for a very high percentage of the data. Then with some slight modifications of the GIS data to avoid un-transformable situations, one can usually raise this to 100%. After the initial development, if GIS modelers understand what patterns will transform and stick to them, then everything should be fine.

Best Practices for Defining Boundaries

Previous sections have talked a lot about Boundaries and what their purpose is, but the reader could reasonably still be puzzled as to exactly how one defines a Boundary. This can be approached either from a power systems point of view or a software design point of view. This section will stay mostly on the power systems side.

Guiding Principles

First, remember that a Boundary is actually just a part of Model Framework that says, 'Hey – a boundary agreement is required here.' The content of the Boundary is an EQ Model Part that fits into that position in the Model Framework. (Yes! Frames and Boundaries are both filled with EQ Model Parts!) A couple other important concepts to keep in mind:

- An EQ Model Part that is designed for a Boundary role can be created by exactly the same editing procedures as are used for an EQ Model Part related to a Frame role. Any kind of object that can go into the content of an EQ Model Part is legal to have in a Boundary.
- Keep in mind that a given equipment component may be represented in one and only one Model Part that will be used in the same base case assembly, which also says that a decision must be made about whether a given object is to be part of an EQ Model Part filling a Boundary or a Frame.

The essential technical differentiation between EQ Model Parts filling Boundaries and those filling Frames occurs only in terms of the external associations that are allowed:

- Objects in an EQ Model Part filling a Frame can have <u>external</u> references only to objects in EQ Model Parts filling Boundaries (or an EQ-REF Model Part, if one exists).
- Objects in an EQ Model Part filling a Boundary can acquire external associations only from objects in EQ Model Parts filling one of the two adjacent Frames during assembly. This establishes the bilateralism.

The final guiding principle is:

- The Boundary contains the set of objects on which two parties must mutually agree in order that their Frame Model Parts will fit together. Therefore, the normal objective is to make the Boundary Model Part as small as possible, in order to minimize the amount of coordination that must occur between the parties.

In practical power engineering terms, the power system is all linked together in EQ Model Parts because the Terminal objects that are part of conducting equipment have associations to ConnectivityNode objects which represent the electrical junctions. In most cases where boundaries need to be established, the best approach is to put ConnectivityNode objects in the EQ Model Parts filling Boundaries, and put the conducting equipment objects and their Terminal objects in the EQ Model Parts of the adjoining Frame. ConnectivityNode objects are very lightweight and will not change often. Most of the data is associated with the equipment. This kind of boundary choice will minimize the likelihood of changes to the EQ Model Parts filling Boundaries.

Process for Defining a Bilateral Boundaries Agreement

Consider the situation in which TSO A owns and models part of the grid and TSO B owns and models another part, and there are tie lines between them. How can it be assured that model parts of the same type supplied by A and B can be developed independently but fit together reliably?

The answer to this question must mimic what is necessary at the business process level. The pre-requisite step is a boundary agreement where the two parties get together and agree on the exact boundary points. CIM's job is to express that agreement such that it can be interpreted in software.

In order for two parties to agree on a modeling boundary, they will each have to agree on at least a minimal common bit of modeling – and they must furthermore agree that neither will change this part of the modeling without consulting with the other. In other words, a subset of modeling is created that is not unilaterally controlled by either authority, but is instead bilaterally controlled. The fundamental observation here is that there will be three subsets needed to support combined TSO A and TSO B modeling, not two.

The CIM solution approach is simply to recognize that an agreement between A and B requires three Model Parts: the part that is A's sole responsibility, the part that is B's sole responsibility, and the joint modeling where there is a bilateral responsibility. (All parts are of the same type (EQ Model Part), which means that the bilateral boundary part can be created with the same tooling as the unilateral parts.)

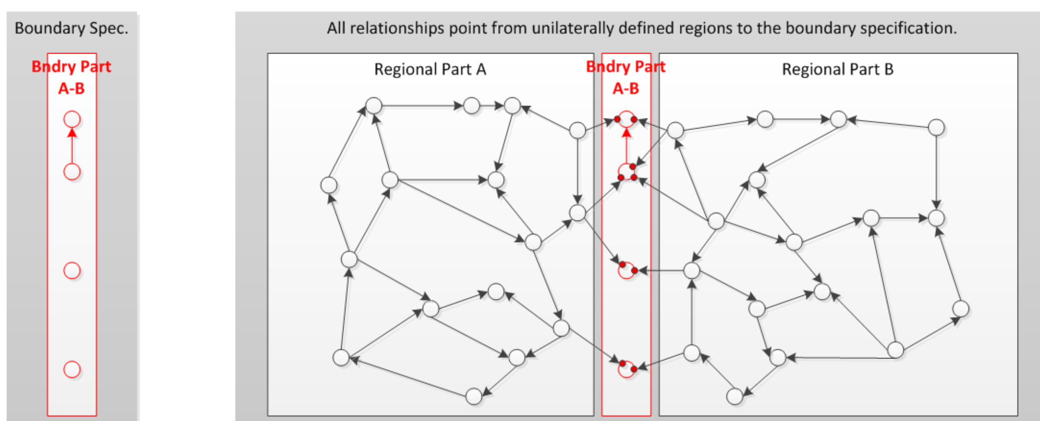

Figure 8-8
Bilateral boundary agreement illustrated as object graph

Figure 8-8 illustrates this approach in object graph form. The small circles (the nodes of the graph) represent EQ data objects and the directed arcs are associations, such as the associations between Terminal objects and ConnectivityNode objects. The arrow on the arc denotes the fact that the association is defined in one object by a reference to another. The defining node 'owns' the relationship and the node that is pointed to, by itself, has no knowledge of the relationship.

The boundary Model Part (at left shown in red) is agreed upon first. It contains boundary objects and any relationships that exist between boundary objects, but it contains no references that define relationships to regional Model Parts for A or B. This establishes a strict dependency of A and B on A-B. (If A-B contained references to A, then there would be an object in A that was special in that it could not be deleted without affecting the boundary.)

> Note. For those familiar with databases and foreign keys, there is an implication here that may seem a bit odd: References here are not limited to pointing from the n side objects to the 1 side object in a 1:n cardinality (as is true with the way that relational databases store foreign keys). Instead, relationships are always defined from objects in the Frame EQ_Model Part to objects in the Boundary EQ_Model Part, even if that means that the reference is a part of the 1 side object.

A and B define their dependency with dangling references which terminate on A-B objects. They are constrained not to contain dangling references to each other, which would bypass and essentially break the boundary agreement. The whole point of this approach is to keep A and B independent of one another, so that each model authority can validate its modeling simply by checking whether the dangling references mate with A-B. A corollary principle is that one would try to keep the A-B set as small as possible, so as to minimize the difficulty in maintaining a boundary agreement.

So, how might this work in practice between A and B?

- A and B decide they will both benefit if they stop manually creating models of each other's territory and instead exchange compatible Model Parts.
- Step one is to define the boundary.
    - A and B get together to discuss the boundary.
    - They will probably each bring drawings of the way they currently model both A and B.
    - Tie by tie, they will compare models and make an agreement about where the boundary should be. These agreements identify specific CIM objects that must be part of the boundary EQ_Model Part.
    - Then one party will take on the task of creating an initial boundary EQ_Model Part that will fill the Boundary.
- Next an initial alignment needs to be accomplished.
    - A and B both begin removing the representation of each other from their existing models, paring back to just their own territory, and making any adjustments to their models to match up with the agreed boundary.
    - They each compose their new EQ_Model Parts with the EQ_Model Part filling the Boundary to validate agreement.

- If they find errors in the EQ Model Part filling the Boundary, they call the other party and negotiate a fix.
- Eventually, they both converge on initial definitions of A, B and A-B that fit together.

▪ Life gets easier after initial agreement is established.
  - The boundary is fixed and both A and B can evolve their models without consulting each other -- unless a change impacts a tie, in which case they are coordinating anyway.

Each time that A or B makes a new version, they would validate their new version to assure it is compatible with the EQ Model Part filling the Boundary and then make the new version available for other parties to use.

Section 9: MACRO-Modeling II – Other Model Parts and Case Assembly

The previous section introduced the idea of Model Frameworks based on EQ_Model Parts that represent the equipment and electrical connectivity of the grid. This section continues the CIM macro-modeling discussion to show how Model Parts and Model Frameworks are used to assemble complete base cases. Assembly begins with selection of the desired EQ_Model Parts and follows with the addition of other kinds of Model Parts, as required by whatever analytical process is being supported.

Introduction to Case Assembly

Let's define 'case' to mean the set of information required to define the input and the output of a power flow – i.e. one steady-state condition. As was described in Section 4: CIM Network Model Management Reference Architecture, it is typical in network analysis business processes that a 'base case' is prepared first and then many variations from that base ('study cases') are then explored.

In this section, the focus is on setting up a base case. The process consists of the following phases of work:

1. Physical model extent
   - The parts of the overall network Model Framework that are required for the base case are determined.
   - The source EQ_Model Parts that will fill in the Assembly Framework for the case are identified.
   - Any hypothetical or future objects are added to their respective EQ_Model Parts.
   - Any simplifications that are required are developed from source EQ_Model Parts.
2. Other physical network model information
   - Add other Physical Network Model Parts defining schematics, dynamic data, etc. as necessary.
3. Operating hypothesis
   - Set up SSH Model Parts to define operating assumptions for the base case.

A critical aspect of this process is that it may take quite a while to complete a valid base case. During that time, a case is in varying partially constructed stages. This is perfectly normal and, because of the collaborative nature of network analysis, works-in-progress often need to be exchanged among engineers using different tools. Thus while the objective is ultimately to get a complete correct base case, the data standards must be able to deal with partial, error-filled work-in-progress.

The next few sections discuss the base case process in more depth.

Physical Model Extent

In large grids, a given network study never represents the entire grid. Instead, the scope of the network is selected to fit the nature of the study:

- A grid-wide capacity planning study might represent all areas, but only include the high voltage bulk power modeling.
- A local TSO reactive planning study would include lower voltage detail, but would only need the immediate neighbor TSOs represented.
- A distribution feeder study includes feeder detail but models the transmission as a voltage source.

The same statement can be made about the coverage of a specific base case in relation to the coverage of the Model Framework from which it is generated. In general, and especially as the Model Framework is expanded toward coverage of the entire grid, a base case for a given study will be a subset of the complete source Model Framework. Let's call this the 'Assembly Framework'.

Defining the Assembly Framework is the first step toward determination of the 'extent' of the base case. The exact specification of extent is complete when the specific Model Parts that will fill the Assembly Framework are known. This involves a number of steps:

- Decide on the Frames that are important to the study.
- Include all Boundaries touching at least one included Frame.
- Determine how the 'edges' will be completed where there is only one included Frame paired with a Boundary.
- Identify the latest as-built source EQ_Model Part for each Frame and Boundary.
- Identify any future changes (EQ_Projects) to included EQ_Model Parts that are appropriate for the base case.
- Determine any simplifications of EQ_Model Parts that are necessary.

The end result of this is that the exact set of equipment and connectivity that will be included in the base case is known. (None of the other kinds of Model Parts that will be used will introduce any additional equipment.)

The next subsections work through a specific example of base case extent development.

North Study – Selecting the Primary Assembly Framework

Referring to the grid framework with nine TSOs portrayed earlier (in Figure 8-2), let's suppose that the North TSO wants to study summer peak load conditions for the next year. Our objective in this exercise is then to create a base case for that study. Such a base case will need a detailed model of North, and it will need a model of the parts of selected neighboring TSOs in order to represent flow through external areas and to represent all components whose outage can potentially impact North. For the purposes of this example, the assumption is that modeling for Northwest, Northeast, West and Central bulk power grids are necessary, as shown in Figure 9-1.

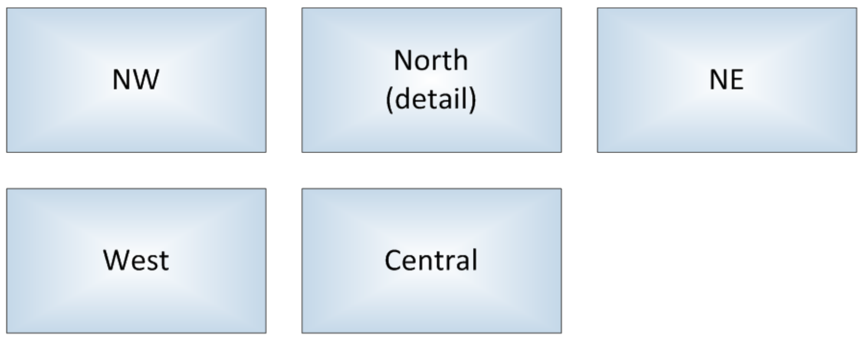

Figure 9-1
Required coverage for a North summer peak study

EQ Model Parts that will fill these five primary Frames will contain dangling references to objects in Boundaries. Theses references must be completed, so Boundaries must be added to the case extent, giving us a first cut assembly pattern as shown in Figure 9-2.

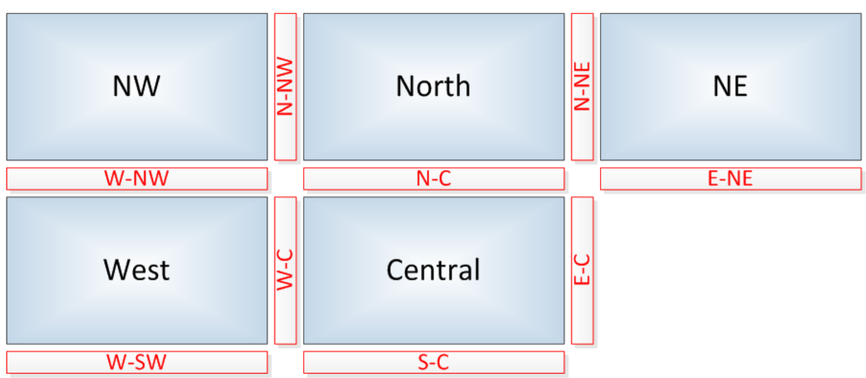

Figure 9-2
First cut assembly pattern for North summer peak study

Notice now that there are four Boundaries which have only one adjoining Frame. Looking ahead to the point in time when EQ Model Parts will be selected to fill all Frames and Boundaries, the following situation emerges: from the point of view of completing dangling references, this first cut of Frame and Boundary selections is fine, but a tie-line segment in a Central EQ Model Part, for example, that connects to a ConnectivityNode object in the E-C Boundary EQ Model Part, would have nothing on the other side of the Boundary. In effect, that line segment would simply be a radial connecting to nothing and could not carry any power. This is obviously not realistic. While it is not desired to represent all of East in the model, something must be there to allow representation of a flow through the tie. A common approach, when the full detail is cut off, is to replace the detail with an equivalent generator at the end of each real tie. These equivalent generators must be part of some EQ Model Part, but they are clearly not part of either the regular Central, E-C or East Model Parts, because the equivalent generators only come into play for particular base cases that cut at the Central-East Boundary.

The answer is that a special kind of EQ Model Part, an Edge EQ Model Part, is required for each unpaired Boundary, as shown in Figure 9-3.

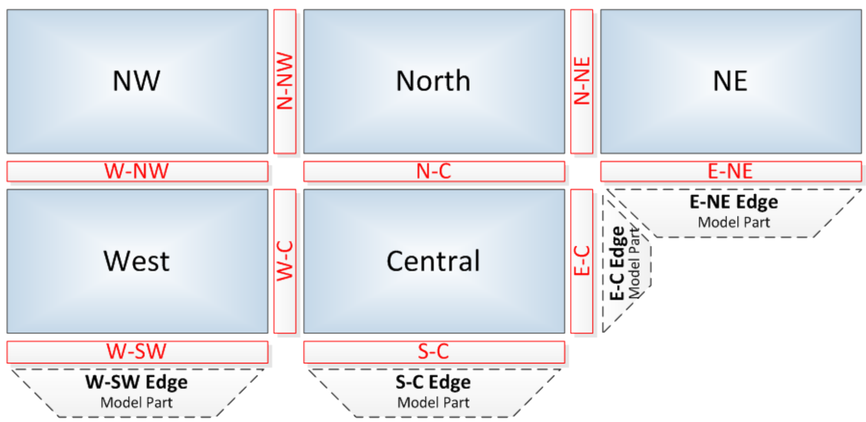

Figure 9-3
Adding Edge Model Parts for a second cut assembly

Each Edge EQ Model Part contains an equivalent generator connecting to each ConnectivityNode object in the Boundary. (The output energy of the generation is not part of the EQ Model Part; it is established later as part of the case operating hypothesis defined by an SSH Model Part). Edge EQ Model Parts of this kind just declare the existence of the equivalent generators and therefore can be automatically created whenever an EQ Model Part filling a Boundary is created, so that they are available for use whenever a base case assembly needs it.

North Study – Sub-Assemblies

The base case is supposed to contain a detailed model of North, but only a bulk power model of the other Frames. In the previous Section 8 subsection: Decomposing a TSO Frame with a Sub-Framework, we saw that it is useful to create the internal view of a TSO in parts, so that different levels of detail may be available.

Figure 9-4 shows this principle applied. The blow-up of North is composed of a bulk grid part with several detailed sub-transmission parts, while West is shown as using only the bulk grid part of a similar sub-framework to remove unwanted detail.

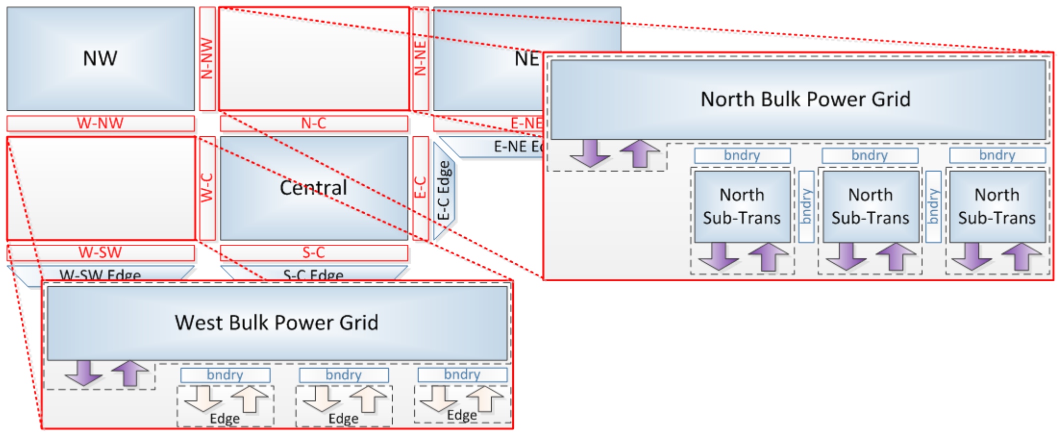

Figure 9-4
Looking inside at how the TSO models are composed

From the Model Framework point of view, there are actually two distinct ways that this sort of flexible sub-assembly can be managed:

- In the first method, there is one high-level Model Framework with just 9 TSO Frames for the whole transmission grid. The TSO Model Parts that will fill those Frames will be generated from 9 completely separate TSO Model Frameworks, one for each territory, the details of which are not visible at this level of assembly. Each TSO Model Part is then the end product of an assembly carried out by the owning TSO.
- In the second method, there is one comprehensive Model Framework that makes all the Frames visible, and base cases like North's are generated directly as one assembly process.

CIM standards support both methods and the end result differs only in that the final base case assembly in the first method only shows a single TSO Model Part, whereas the second method shows all the sub-parts.

North Study – Select Source EQ Model Parts

Two steps are required before a final base case extent is defined: EQ Model Parts need to be specified for each Frame and Boundary, and selected EQ Projects need to be applied to roll the case forward to the appropriate point in time. The master EQ Model Parts selected to fill the Frames and Boundaries in the Assembly Framework for this study are those which represent the power grid as it is currently constructed. The study is supposed to be about next summer's peak condition, and between now and then, additional new construction will take place. This new construction is currently modeled as EQ Projects (EQ

Incremental Model Parts). These incremental additions must be identified and added to their respective as-built EQ Model Parts.

North Study – Equivalents?

The ideal situation is that studies are trimmed to a reasonable size simply by selecting or rejecting entire Frames and then completing with standard Edge EQ Model Parts. In fact, one of the aims of CIM Model Frameworks is to modularize such that more problematic network equivalent strategies are avoidable. However, there may still be situations where network simplifications must be made. There are many ways to do this, ranging from manual cutting to automated mesh equivalent calculations. It is beyond the scope of this Guide to discuss techniques for reduction. What can be said, though, is the following:

- Simplification procedures usually start from detailed EQ Model Parts representing the areas being simplified.
- The procedure may require solved power flow results as input (which means that they may only be accurate for specific case operating assumptions), and will probably generate one or more simplified EQ Model Parts plus other SSH Model Parts that define an operating hypothesis.
- In a CIM Model Assembly, they must generate new EQ Model Parts which fit into existing Boundaries.

The final bullet is the important one for the process currently under discussion. If any simplification is done for this North study, it should be done so that it results in a new version of one or more EQ Model Parts.

North Study – Compose the EQ Model Parts

The entire base case assembly extent is now defined. Because case building is often an iterative process, it is good at this point to capture the case assembly process thus far as an executable procedure. Running the procedure grabs all the previously selected EQ Model Parts and EQ Projects and composes them into a single workspace. This validates that all EQ Model Part dangling references are properly resolved, and other validation may also be run as appropriate to screen for modeling problems.

At this point, North is ready to move on to adding the other Physical Network Model Parts and creating the particular operating hypothesis that will be used for the base case.

Other Physical Network Model Parts

As discussed in the Section 7 subsection: More Physical Network Model Part Types, there are other Physical Network Model Part types which may be important to include in a base case. As a general rule, these Model Parts will align with EQ Model Parts in terms of scope, and the selection of additional Physical Network Model Parts is straightforward, based on:

- The kind of study, which determines which Model Part types are needed. (For example, DY Model Parts are only required if there will be dynamic analysis.)
- The extent of the EQ Model Parts, which determines which instances of a given Model Part type are required.

Operating Hypothesis Assembly

As discussed in the Section 7 subsection: Case Model Part Types, a complete base case must include Model Parts that define the input conditions that the power flow is supposed to resolve, as well as Model Parts that capture the solution which is generated.

Usually, the SSH Model Parts which define base case input will be developed in 1:1 correspondence with the EQ Model Parts for the case. This is common because the procedures and the authorities for operating hypotheses are often different from one Frame to another.

The individual procedures that define SSH Model Parts vary with the kind of study. For example, a European day-ahead operations case would set up its generation and load based on their market outcomes, but such a procedure would not be relevant for most other kinds of studies.

Once the input SSH Model Parts are determined, a power flow is run to generate the topology and steady-state solution Model Parts (TP and SV). Each of these are often generated as a single Model Part covering the entire extent of the base case, but there is no rule requiring this. It is completely up to the designer of a particular network analysis business process as to whether solutions are reported in a single Model Part that covers the full extent of the Model Assembly or in Model Parts that align with the EQ Model Parts or something in between.

Base Case Assembly Documentation

At any point in time, there exist a large number of base cases that could be deemed 'active'. These include all base cases under development plus all previously completed base cases that are still currently relevant. Good documentation is essential to maintaining the usefulness of these base cases. The basic components are:

- General descriptive information (purpose, creation date, etc.)
- The versions of information model used to store the case
- The source that generated the base case
- The network state result (TP and SV Model Part information)
- The operating hypothesis on which the result was based (SSH Model Part information)
- The physical network model on which the result was based (EQ and other Physical Network Model Part information)

Model Part and Project Identity

Even a basic implementation of improved case documentation will require a system for identifying basic components, such as the Model Parts that occupy Frames and Boundaries, the Projects available to be selected, and the components of operating hypothesis.

Manifests and Model Part Audit Trails

A manifest is a description of the payload in an exchange. An audit trail is information about how a case (and its constituent Model Parts) were created. The more information a consumer of a case or a Model Part in an exchange has about the payload of an exchange or the steps involved in its creation, the easier it is for that consumer to assure quality of whatever network analysis operation is being conducted. A manifest should include, at a minimum, references to the Model Parts making up a case (which would be the payload in an exchange). An audit trail should include:

- References to source Model Parts (e.g. the as-built Model Part version).
- Operations performed prior to sending (e.g. added Projects X, Y and Z).

> Note. Discussions related to the modeling of manifests and audit trail standards are currently underway in WG13.

Section 10: Future Edition Topics

This Guide presents a comprehensive review of the CIM solution for network model management. CIM, however, is a living breathing program -- not just a solution. CIM encompasses three major IEC Working Groups who continue to work hard to tackle new problems, and CIM incorporates methodology for solving problems in a way that the results will complement one another. In this document, we try to present what is implementable today, while also giving a sense of the immediate direction of work without getting too speculative.

CIM is a process. To understand the impact of this, look around at other familiar major technologies, for example browsers, phones, operating systems, databases – even your favorite network analysis product. None of these are constant. A user takes the plunge and buys into a given technology when it reaches the point where its value exceeds the cost to apply it. Then the manufacturer releases a new version. Adapting to new releases is not always pleasant but by and large, it is the way that we can both enjoy immediate benefit and move forward without throwing away everything from the previous level. CIM's standards evolve in a similar way. CIM goes through releases. Most of the new aspects of a release preserve existing investment, but sometimes they require adjustments. We can unreservedly endorse the current CIM as ready to be put into practice, but we cannot say that it is complete, or that there will not be costs incurred in moving to subsequent releases. Adopting CIM is also a process.

In general, everything presented in the preceding sections is implementable today, unless accompanied by a specific note to the contrary. However, this does not necessarily mean that the full vision has been achieved, or that everything that users will want is there. In this section, we want to call out a number of particularly important areas that are in active development today.

Current active areas of CIM standards discussion include:

- Incremental Model Parts. A comprehensive discussion of how changes to CIM Datasets are described is currently underway. This includes consideration of Projects (Incremental Physical Network Model Parts) and changes to other types of Model Parts as well as work on a unified model for expressing ADD, MODIFY and DELETE instructions that could be used across different exchange approaches.
- Model Frameworks. The need for standard modeling, perhaps in UML, of the framework that supports independent model part maintenance and facilitates model part assembly is being considered by WG13.
- Audit trails and assembly manifests. Both are seen as valuable features in truly effective network model and case exchange and their modeling has been and will continue to be discussed in WG13.

- DC modeling. The existing CIM UML includes initial HVDC modeling which is expected to be refined and improved in the near future as ENTSO-E data exchange initiatives start being implemented.
- Modeling of distributed energy resources. As new renewable technologies are deployed and as the need for distribution network modeling becomes more widespread, there is growing interest more complex, detailed models of load, generation and storage.
- System Integrity Protection Schemes (SIPS). As these grow in number deployed and complexity, the need for modeling them in the CIM is becoming more apparent.
- Network modeling across transmission and distribution. Information exchange across the transmission/distribution boundary is growing in importance. In addition, revisions to the existing IEC 61968-13 standard [10] (describing the Common Distribution Power System Model) are underway. Both of these factors will contribute to unification of transmission and distribution model approaches and to refinement of the CIM's handling of balanced and unbalanced models.
- Geographic Location. There is an ongoing discussion as to how to best meet the need for geographic location Model Part information in both transmission and distribution network analysis. Geo-location information is recognized by WG13 and WG14 as being crucial physical network model information. It is not, however, currently described as part of the IEC 61970-452 (transmission) exchange standard [3], though it is included in the IEC 61968-13 (distribution) standard [10].
- CIM / 61850 harmonization. Efforts are underway to harmonize the CIM standards [2, 3, 4, 5, 6, 10] and IEC 61850 standards [7] at specific touchpoints. One of the areas of interest centers on the use of IEC 61850 SCL [11] files to provide substation network model information to CIM-based network model management environments.

Future editions of this Guide are planned. They will keep pace with these developments, as well as fill in some of the parts of the preceding sections that were simply deferred due to time and budget limitations on this initial edition.

Several additional topics are under consideration for the next version of the Guide as well. These include:

- Description of the scope of the network analysis domain, including actors, applications and types of studies
- Overview of network model management tools and repositories
- Special topics of interest in network modeling, like object registry functionality, interoperability testing, and security and access control
- More detailed descriptions of some CIM features which were only touched on in this version: short circuit modeling, the topology (TP) Dataset Type and the State Variable (SV) Dataset Type.

Section 11: References

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10. International Electrotechnical Commission, (2008-06). IEC 61968-13 ed1.0 Application Integration at Electric Utilities - System Interfaces for Distribution Management - Part 13: CIM RDF Model Exchange Format For Distribution. Geneva, Switzerland: IEC.
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Appendix A: Glossary

The official CIM standards specifications have evolved over a span of almost 20 years. By and large, the top priority for the standards authors is precision for software implementers, and no comprehensive functional description of the whole network analysis solution has heretofore been produced by the IEC. In writing this Guide, which is primarily aimed at providing a sense of the whole to potential users, the authors have adopted a number of terms that are new in the sense that they are not used, or are minimally used, in current IEC documents. The authors nevertheless believe these terms faithfully convey the central direction and capability of the CIM work, and probably will find their way into the IEC documents as they go through their usual revision cycles. A summary of these terms is provided here.

Assembly Framework. A subset of a complete source Model Framework which defines the extent of a specific case and is used during case assembly.

> Note. Assembly Frameworks are not yet explicitly defined in the CIM UML. However, both Model Frameworks and Assembly Frameworks can be implemented using the existing IEC 61970-452 and 61970-552 CIM standards by organizing exchanged data in an agreed-upon manner. Discussions are currently underway in WG13 to formalize Model and Assembly Framework modeling.

Boundary. The element of a Model Framework which describes a portion of the power grid whose modeling requires agreement between two modeling entities. A typical use of Boundaries is to reflect the change in modeling authority that occurs on tie-lines between companies. A Boundary separates two Frames. As part of the case assembly process a Boundary is filled by a Model Part (typically an EQ Model Part) that has been bi-laterally agreed upon by the two adjoining modeling authorities. The EQ Model Part filling a Boundary has Data Objects pointed to by 'dangling references' in the content of other Model Parts (typically the EQ Model Parts filling the adjoining Frames) which support case assembly.

> Note. Boundaries, as elements of Model Frameworks, are not yet explicitly defined in the CIM UML. However, they can be implemented using the existing 61970-552 CIM standards by organizing exchanged data in an agreed-upon manner. Discussions are currently underway in WG13 to formalize Boundary modeling.

CIM Data Object (or Data Object). A data object (consisting of an object identity plus a set of data about the object) which is an instance of a CIM information model class. It is the fundamental unit of data in a CIM Dataset.

CIM Dataset (or Dataset). A collection of CIM Data Objects which have a common purpose and whose structure is defined by an information model (a CIM Dataset Type or 'profile') which is a subset of the CIM canonical information model. CIM Datasets are often referenced, managed or exchanged as a whole.

> Note. Neither Dataset nor Incremental Dataset are terms currently used in the CIM standards, but the concepts they represent (Datasets being collections of data objects complying to the CIM, Incremental Datasets being sets of changes to those objects) are foundational ideas of the CIM.

CIM Dataset Type (or Dataset Type). An information model derived from the overarching CIM canonical UML, which defines the structure of data allowed in a kind of CIM Dataset or CIM Incremental Dataset. In the CIM standards CIM Dataset Types are referred to as 'profiles', though the word 'profile' has many interpretations in the data integration domain and its use is avoided in this Guide. This Guide identifies the following CIM Dataset Types:

- Equipment (EQ, as well as its subset EQ-REF)
- Short Circuit (SC)
- Dynamics (DY)
- Diagram Layout (DL)
- Geographic Locations (GL)
- Operations (OP)
- Steady-State Hypothesis (SSH and its possible subsets SSH-ST, SSH-EG, SSH-LIM, SSH-CTRL)
- State Variables (SV)
- Topology (TP)

> Note. The information models of CIM 'profiles' are defined in the following IEC 61970-45x standards and described in the following UML packages:
>
> - IEC 61970-452, Edition 2 (Edition 3 in progress)
>   - **Equipment (EQ).** Primarily described in the following UML packages: Model>TC57CIM>IEC61970>Base>Core, OperationalLimits, Wires, DC, LoadModel, Equivalents, ControlArea
>   - **Short Circuit (SC).** Primarily described in the following UML packages: Model>TC57CIM>IEC61970>Base>Core, Wires, Equivalents
>   - **Operation (OP).** Primarily described in the following UML packages: Model>TC57CIM>IEC61970>Base>Core, Wires, LoadModel, Equivalents, Meas, ControlArea
> - IEC 61970-457 (in progress)

- **Dynamics (DY).** Primarily described in the following UML package: Model>TC57CIM>IEC61970>Dynamics

- IEC 61970-453, Edition 2
  - **Diagram Layout (DL).** Primarily described in the following UML package: Model>TC57CIM>IEC61970>Base>DiagramLayout
- IEC 61968-13, Edition 1 (Edition 2 in progress)
  - **Geographic Location (GL).** Primarily described in the following UML package: Model>TC57CIM>IEC61968>Common
- IEC 61970-456, Edition 1 (Edition 2 in progress)
  - **Steady-State Hypothesis (SSH).** Primarily described in the following UML packages: Model>TC57CIM>IEC61970>Base>Core, Wires, Generation, DC, LoadModel, Equivalents, Meas, ControlArea
  - **State Variables (SV).** Primarily described in the following UML package: Model>TC57CIM>IEC61970> Base>StateVariables
  - **Topology (TP).** Primarily described in the following UML package: Model>TC57CIM>IEC61970> Base>Topology

Drafts of IEC CIM standards in progress, as well as the UML of the CIM canonical model are downloadable from www.cimug.org for UCAIug members.

CIM Incremental Dataset (or Incremental Dataset). A collection of ADD, MODIFY, DELETE changes to CIM Data Objects of a specific CIM Dataset Type. An Incremental Dataset is used to express a logical change to a CIM Dataset and are often referenced, managed or exchanged as a whole.

Note. Existing 61970 support for description of model changes is not as complete or generally applicable as what is described by Incremental Dataset, though it is an urgent topic of discussion in WG13. The current support for changes appears as part of the header defined in IEC 61970-552, specifically in the forwardDifferences/reverseDifferences relationships. Modeling work is currently underway in WG13 and a more formal definition of Incremental Dataset will likely be created, perhaps using UML.

CIM Incremental Model Part (or Incremental Model Part). A set of changes to a subset of network analysis case information. A CIM Incremental Model Part reflects the same segmentation philosophies as a CIM Model Part. Incremental Model Parts are composed of two parts: content (a CIM Incremental Dataset which conforms to a CIM Dataset Type) and description (data about the Incremental Model Part, including model authority and purpose/timing of changes among other information).

> Note. The term Incremental Model Part is not currently defined in the CIM. It is, however, a basic concept reflected in the IEC 61970 standards where the various IEC 61970-45x standards and the IEC 61970-552 standard support Model Part definition (see CIM Model Part) and the IEC 61970-552 standard header supports the definition of changes (see CIM Incremental Dataset).

CIM Model Framework (or Model Framework). A formal method of expressing an agreement among a set of parties to cooperate in network modeling that defines a decomposition of the overall scope of the power grid into parts. A Model Framework is composed of Frames (which can be filled by unilaterally maintained Model Parts) and Boundaries (which are filled by bilaterally maintained Model Parts).

> Note. The existing IEC 61970-452 and 69170-552 standards can be used to implement the concept of Model Frameworks by effectively organizing exchanged data into Model Parts in an agreed-upon manner which reflects the existence of Frames and Boundaries. Discussions are currently underway in WG13 to formalize the definition of how Model Parts relate to Model Framework components (Boundaries and Frames) in UML.

CIM Model Part (or Model Part). A subset of network analysis case information reflecting two types of segmentation supported by the CIM:

1. Type of information.
2. Natural source of information or model authority.

Model Parts are composed of two parts: content (a CIM Dataset which conforms to a CIM Dataset Type) and description (data about the Model Part, including model authority among other information).

References to Model Parts are often prefaced with the abbreviation of the CIM Dataset Type governing their content (for example, EQ Model Part) to describe the purpose of the Model Part.

> Note. The term Model Part is not currently defined in the CIM. It is, however, a concept which underlies all of the IEC 61970 standards. Existing CIM support for Model Parts is defined in:
>
> - the various IEC 61970-45x standards, which support segmentation by type of information and describe the information model of Model Part ‘content’
> - the IEC 61970-552 standard, which addresses Model Part ‘description’ in its definition of header which contains:
>   - Model.scenarioTime
>   - Model.description
>   - Model.modelingAuthoritySet
>   - Model.profile

- Model.version

Discussions are underway in WG13 that will likely result in Model Parts being more formally defined, probably in UML.

Distribution System Operator (or DSO). An entity that plans and operates a low voltage portion of the electrical grid that distributes energy to customers.

Edge EQ Model Part. A special kind of EQ Model Part created in conjunction with an EQ Model Part which fills a Boundary. An Edge EQ Model Part contains an equivalent generator connecting to each ConnectivityNode object in its paired Boundary EQ Model Part.

Note. Edge EQ Model Parts are not specifically defined in the CIM at this time. Discussions are underway in WG13 on the topic of model assembly and the need to formally define Edge EQ Model Parts is part of that conversation.

Frame. The element of a Model Framework which describes a portion of the power grid whose modeling can be created by a single modeling entity. The extent of a Frame is defined by the Boundaries which border it. During case assembly, a Frame can be filled by Model Parts (containing content governed by various Dataset Types) created by a modeling authority. (This is not to say, however, that all Model Parts that could potentially fill a Frame will be created by the same modeling authority, rather that each Model Part has only a single model authority). The 'dangling references' from Data Objects in the content of a EQ Model Part filling a Frame can refer only to content of Model Parts filling the Boundaries which adjoin the Frame.

Note. Frames, as elements of Model Frameworks, are not explicitly defined in the CIM. However, they can be implemented using the existing 61970-552 CIM standards by organizing exchanged data in an agreed-upon manner. Discussions are currently underway in WG13 to formalize Frame modeling.

Physical Network Model Part. A Model Part describing part of the physical network model. Specifically the content of a Physical Network Model Part has one of the following CIM Dataset Types: Equipment (EQ), Short circuit (SC), Dynamics (DY), Diagram Layout (DL), Geographic Location (GL) or Operation (OP).

Note. Physical Network Model Part is a term that is not currently found in CIM standards, but it does have a universally understood meaning among WG13 experts, does accurately describe the underlying data organization assumptions on which the IEC 61970-45x standards are based and is supported by way in which IEC 61970-552 is commonly used in practice.

Project (or Incremental Physical Network Model Part). An Incremental Model Part whose content is governed by one of the following CIM Dataset Types: Equipment (EQ), Short circuit (SC), Dynamics (DY), Diagram Layout (DL), Geographic Location (GL) or Operation (OP). Projects are used to describe planned changes to the physical network model.

> Note. The Project functionality discussed in this Guide can be implemented based on current CIM specifications defined in IEC 61970-552, specifically in the forwardDifferences/reverseDifferences relationships. However, Incremental Model Part description data would currently need to be supplied via CIM extensions. There is consensus in WG13 that standard modeling of that information is a very high priority.

Regional Transmission Organization / Independent System Operator (or RTO/ISO). Regional or grid-wide entity that has responsibility for operational reliability, energy markets and long-term capacity planning.

Transmission System Operator (or TSO). An entity that operates a portion of the high voltage bulk power grid and who has detailed planning and reliability responsibility for that portion of the grid.

Program:

IntelliGrid

3002002587

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