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Lessons and Experiences in the Implementation of a Consolidated Transmission Modeling Data System at ERCOT

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ABSTRACT On 1 September 2009, as part of a new node-based market implementation, the Electric Reliability Council of Texas transitioned from its then-prevalent data modeling processes to a new network model management system (NMMS) for model data management. This change represented the culmination of nearly four and a half years of planning and development. The NMMS provided several improvements over the then-current data maintenance processes. This paper describes some of the existing issues facing the power industry in the area of power system model data management and explains how solutions to these issues were addressed conceptually in the development of and incorporated into the final design of the NMMS. Further, this paper explains how these concepts of design and usability are now gaining wider recognition and acceptance from the industry.

INDEX TERMS Common information model (CIM), Electric Reliability Council of Texas (ERCOT), power system modeling.

I. INTRODUCTION

THE rollout of the Network Model Management System (NMMS) represented the solution and/or mitigation to a number of problems that were facing the Electric Reliability Council of Texas (ERCOT) as it confronted migration from a zone-based to a node-based bulk electricity market. Many of the issues with model data management had existed for a number of years; some were due, in part, to ERCOTs function as the independent system operator (ISO) for 85% of the state of Texas or to its performance of financial settlement for the competitive wholesale bulk-power market, and others were systemic problems in the industry. These problems included the following.

1) An ISO does not own transmission equipment used in the data models that simulate the electric grid; consequently, all model data must be submitted to the ISO by the model data owners.
2) While data accuracy was an issue in the zonal model data, the new 500+ nodal point prices potentially created larger margins of error than the four load zone-based prices.
3) ERCOT did not have a consolidated auditing process of model data changes.
4) Generating accurate models representing times in the future was a problematic process due to the existing model maintenance process build around ERCOTs energy management system (EMS) and the EMS system's inability to represent multiple points in time.
5) The processes involving data submission did not have the transparency desired by market participants.
6) The model data submission was bifurcated into two internal organizational structures: a transmission planning department (looking at 1–5 year time lines), and an operation department concerned with the real-time and near-real-time horizons. In processes shared across these structures, such as forward looking transmission congestion hedging, the errors in the individual isolated data models were compounded by the migration of

results calculated using one data set to the other data set for use in grid operations.

7) Since the ERCOT model data for real-time operations were maintained in the EMS, using the vendor's proprietary data formats, sharing of data with the submitter for the purposes of validation was a problematic task.
8) Coordination of data updates was intermittent, with little feedback given to the submitter due to the inability for detailed tracking of model changes.

In addition to the issues listed above, a number of additional items were identified as future concerns. With the unwinding of the vertically integrated transmission service model (in which a single entity owned the generation, transmission, and load service area) and the move toward a more segmented business model, the concepts of data transparency and market power became prominent concerns. ERCOT, as an ISO, was required to coordinate activities between market players [i.e., between the transmission service providers, the resource entities (REs), and the load serving entities (LSEs)] that in the vertically integrated utility model were being handled in-house. In addition, market pressures were driving for the incorporation of new data intensive smart-grid related technologies. There was a realization that these new technologies (solar generation, distributed energy resources, phase-measurement units, etc.) would need to be factored into grid control. The scope of the integration of these technologies would need to include both their modeling and use in the EMS and the market management system (MMS), and additionally, would need to fold data collection and validation into the ERCOT business processes to review, maintain, and update data related to the devices. In this environment, with system decentralization and emerging technologies, ERCOT needed a more accurate model to utilize more of the capacity of the electric grid, taking it closer to its physical limits than it had done so in the past. In addition, the nodal market required more frequent updating of data in the various grid applications, going from a biweekly model load process to a weekly model load process.

A. HISTORICAL PROSPECTIVE

Problems occurring with data management for power systems evolved over several decades. Control systems trace their impetus to pilot-wire controls used in switching of transmission equipment. Over time, these implementations evolved through simple control systems, to provide analog telemetry (first on scan, and then continuously), and then into supervisory control and data acquisition (SCADA) controlled systems interfacing with remote terminal units connected to substation equipment.

During this evolution of technology, new methods of grid control were being introduced. Once analog telemetry was available on area tie lines on a continuous basis, automatic generation control (AGC) became a possibility. By adding telemetry to tie lines for a control area, area interchange line flows could be monitored. Signals could be sent to generators that could raise or lower their power output to reduce area interchange to zero. As AGC evolved, frequency correction was also incorporated, and area control error became the standard system operation. As more telemetry became available, other functions, such as load forecasting and economic forecasting, were developed. As these systems became more advanced and computer computational ability increased, EMS began running load flow and contingency analysis calculations to verify the system was secure in real time. From there, other applications and functionality developed, either as integrated portions of the EMS system, or as standalone systems with their own support structure. MMS developed as the economic transactions within the power industry became more complex and nonvertically integrated systems became the norm.

In this same timeframe in which control system command and control were evolving, the data requirements to operate the power transmission system also evolved. Simple one-line drawings and maps were adequate when grid control was performed using pilot wires for breakers; relatively few items were required in the simplified mathematical models used in early AGC calculations. However, as the EMS and MMS applications evolved, and ideas like state-estimation and locational marginal pricing took hold in the industry, the data requirements grew.

B. COMMON ISSUES WITH DATA COLLECTION

Prior to the development of the NMMS, ERCOT faced a number of issues related to the management of individual data models used in its operations of the grid management systems. When beginning the NMMS system requirements gathering in the beginning of 2006, ERCOT performed an informal survey of several ISOs and RTOs, including California ISO (CAISO), midcontinent ISO (formally midwest ISO), and PJM. The survey concluded that the process of transmission data gathering was largely confined to e-mail-based submission of supporting documents, and that, while ERCOTs processes were somewhat inadequate for the amount and scope of data being gathered, its processes were in line with industrial norms.

While at a certain level, all applications require some amount of model data, to help constrain the topic to more substantive discussions, this paper will focus only on the model data need of the EMS, MMS, the congestion revenue rights (CRRs) system, the outage scheduler (OS), and in long-term system planning. Focus will be directed at common data-related issues faced in the operation of these systems holistically, and how these issues are corrected using a singular modeling system. In addition to explaining the aspects of the NMMS design, the focus will also be directed to secondary business processes enhanced (or made possible) by the NMMS system. This includes items, such as one-line maintenance and contingency definition review.

II. ASPECTS OF NMMS DESIGN

Prior to the nodal market, having recognized many of the deficiencies with the current model data collecting process, ERCOT had internally set about developing criteria for a new approach. The NMMS was initially envisioned as an internal data repository integrated with the EMS and addressing deficiencies with the EMS model data management application. When the nodal market redesign was enacted, the scope of the NMMS project was expanded and additional requirements were added. In designing the NMMS system, ERCOT leveraged a number of observations and lessons learned to aim for key aspects in the system design.

A. DATA EXCHANGE USING INDUSTRIAL STANDARDS

One of the ongoing issues during the operations of the zonal market was the opacity and inaccessibility of model data residing in the ERCOT EMS. When operational or application issues occurred due to suspected data inaccuracies, the process for data correction was convoluted. In general, the process involved two parties [the ISO and the transmission operator (TO)] who each housed their transmission network model in a propriety vendor-provided database. The standards for data format and storage varied widely with the individual vendors (MVA base, per unit versus SI, etc.) making confirmation of data accuracy problematic. From this experience, ERCOT decided that all model data should be exchanged in a common format that could be easily communicated and verified by all interested parties. However, system planning groups for many years had used a defacto industrial standard for bus-branch model exchange, commonly referred to as RAWD format. While the RAWD format was not granular enough to support the kind of data exchange envisioned by ERCOT, due to historical precedent it was recognized that downstream support of this format would be required as well. After a review of the standards available, and in consultation with external data providing parties, the common information model (CIM) standards [1]–[3] developed by EPRI were deemed ideal for data communications.

B. CHANGE MANAGEMENT

It was clear that this paper and email-based submission processes utilized by ERCOT during the zonal market were archaic and error prone. TOs and REs were attempting communication with multiple groups within ERCOT, and each of those groups was also manually maintaining independent data sources (Fig. 1).

Besides the multiple points in the process where error could be introduced, an additional issue was the inability to tie submitted data changes to the model data in the EMS application. Since the data change involved a manual key entry into an EMS model dataset based on an interpretation of a paper document, there was very little possibility of being able to track data changes in the EMS back to their source documents. An operator might notice a change in the EMS one-line of a substation, but finding out who made the change, why it was made, or when it occurred was a difficult task highly dependent on tribal knowledge within the organization.

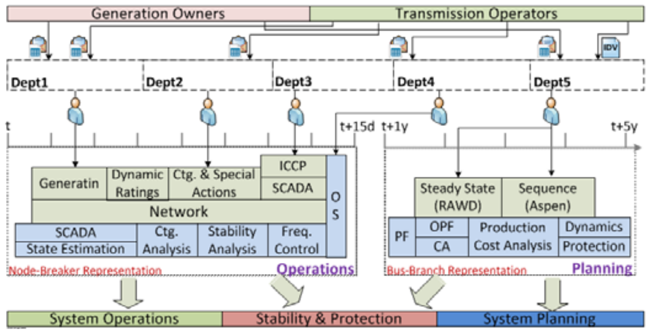

FIGURE 1. Data submission and processing in the zonal market.

From these lessons, ERCOT decided to develop a project tracking and coordination process that would unify all changes in the model back to the data submission source; in short, to build the new system in such a way that every model data change would have supporting information of the who, what, when, where, and why to answer any audit questions concerning data submission. ERCOT designed its change management solution around two interrelated data packages: one was a CIM-based incremental file, and the other was a metadata package associated with the CIM file. While the CIM file contained an incremental XML-formatted data package that described an alteration to the transmission network model, the metadata package contained all of the information that supported the change (i.e., submitting party, time that the change should be implemented (energization date), supporting instructions explaining the modeling or operational capability of any new equipment, etc.). These two data packets were referred to together as a Network Operations Model Change Request (NOMCR).

ERCOT designed a change management process around an application it called the project tracker and coordinator (PTC). The purpose of the PTC was to facilitate the submission of NOMCRs directly from the outside sources removing the intermediate level of data transcription from submitted documents to model dataset previously performed by ERCOT staff (Fig. 2), and allow for the NOMCRs review and testing.

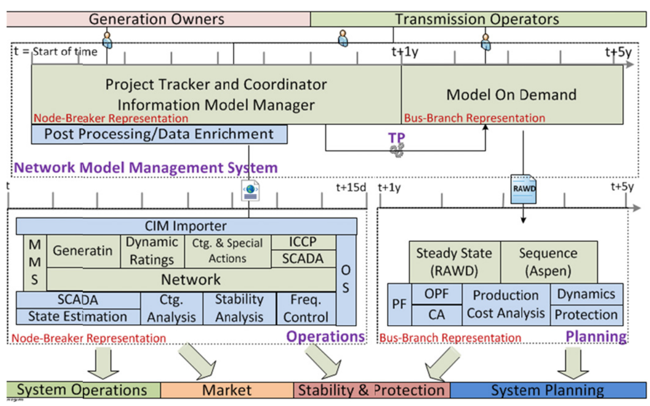

FIGURE 2. Data submission and processing in the nodal market.

This would eventually provide an audit trail from the submission of a model data change to its implementation in the real-time network model being used to run the EMS and other grid control applications.

Prior to inclusion in the operational network model, every NOMCR is required to undergo five levels of validation, which are logged and tracked using the PTC.

Level 1 is a primitive data check of the incremental file in the NOMCR. This level verifies that changes to equipment parameters fall within certain tolerances, and that associated data are present to support the change (e.g., whether the resistance for a transmission line falls within a realistic bandwidth, and whether a generator is associated with a substation that is physically located nearby).

Level 2 is a manual check that verifies that the NOMCR metadata are consistent with its CIM-related data change. The reviewer will also verify that the user data submission is complete, and that the accompanying documentation is sufficient to support the testing process.

Level 3 is a screening study performed by an ERCOT engineer looking primarily at the viability of using the NOMCR in an EMS testing platform. The testing consists of analyzing the model changes in the NOMCR with respect to their impact on the EMS base model power flow solution. The results of this analysis, while not definitive, are a good screening of data to determine its correctness. Level 3 is the last testing of the NOMCR as an individual change package.

Level 4 testing is integrated testing for a batch of NOMCRs with energization dates corresponding to a date range using the EMS test system, in which the base model data are expected to be active in the network applications with the model data from the NOMCRs applied. While the Level 3 testing screens for effects of individual NOMCRs on the base model data, the Level 4 testing process screens for data clashes within the NOMCRs themselves and for cumulative effects of model changes on the base model data.

Level 5 testing is full-model testing of all NOMCR changes for a given timeframe incorporated into the base model data across all applications. This is also referred to as integrated testing. This testing verifies that all of the model changes not only function in the EMS, so that all of the additional applications using the data are able to load the new model, and that none of the model data changes have affected the secondary data exchanges that take place between the applications (EMS, MMS, OS, etc.) when used in a real-time live system environment.

While this testing may appear time-consuming to the casual reader, it is important to note that the testing is structured for two goals. The first is provide faster initial review for NOMCRs, screening for common mistakes and allowing for prompt correction so as to not slow the updating process. The other goal is to structure the time-intensive testing toward the end of the process. Since integrated testing involves loading all of the applications in a test environment, and time constraints become more pressing later in the process as the model data load approaches, it's important to minimize the chances of failure that late in the process.

C. TEMPORAL CAPABILITY

One of the many drawbacks with maintaining the data model using the EMS application was that the EMS system represented only a single point in time. This limitation meant that data changes could not be modeled or tested until a narrow window approached before the next model load date, when all of the staged changes could be quickly keyed into the application and tested. This limitation meant that changes could have been submitted to ERCOT weeks or months prior to the model load date, but screening and testing had to be delayed until the testing window. In addition, the process did not allow time for data correction during testing but still prior to a model load date. This lack of system capability was also evident in the OS. Since the OS is an application integrated with the core EMS system and shares the same model, the ability of the ISO to study the effects of equipment outage, and grant the necessary permissions to the TOs to remove equipment from service for maintenance or system upgrades was greatly impacted. For these reasons, the NMMS system design needed to be temporal in nature, in that rather than containing a single view of the power system data model, it needed to contain an accurate view of the power system across all points in time. This meant that data submissions would be housed in the dataset in such a way as to allow their inclusion or exclusion based on date parameters provided to the NMMS for the requested model build. CIM was useful for dealing with this issue, since the CIM standard already supported the concept of incremental model changes. This was coupled with the data tracking and testing functionality of the PTC to create a temporally based modeling system.

D. COMMON SCHEMA

A problem that many ISOs face is that their data collection processes tend to be focused on individual applications. This means that ISOs tend to have the same departments that maintain the individual applications also create and manage data collection for the application as well. This method tends to cause two primary issues: one being data divergence, and the other allowing defects in the application logic to be masked by the manipulation of the data. Market participants placed a high value on data consistency across all the applications in the ERCOT ISO, and this concern helped drive consistency requirements for the model data that lead to the solution of using a single dataset for all of the applications that utilized the data. It was also realized that since CIM was being used for communications and data exchange, it could also serve as the model schema for the database. The CIM standard, while ostensibly a data exchange standard, serves as the core schema for the design for the ERCOT data model schema. This was seen as a good choice for several reasons. First, the CIM is a well-documented standard and is focused on the modeling of the power transmission system. Also, while using the CIM standard for data storage, the number of times that the data-model format is required to change when transferring from one system to another is reduced. Finally, the end resulting schema was less work to maintain, and if the NMMS had a different internal schema (other than CIM), any schema modifications (new device attributes, equipment classes, etc.) would require changes to not only the internal schema, but to a NMMS-CIM data adapter, while housing the data in a CIM schema removed this requirement.

E. EXTENDIBILITY

One of the lessons learned with the zonal experience was that system extendibility and flexibility were key components to the success of the organization. In ERCOT, during zonal operations, systems required enhancement as conditions in the field dictated. For example, as dc ties became prevalent, it was necessary to somehow simulate their effects on the grid as part of the power flow solution calculated by the EMS. A dc tie was a component not directly supported by the ERCOT EMS system model and due to implementation limitations, along with costs that would be associated with EMS enhancements to directly support the modeling of dc ties, it was considered necessary to instead model the dc tie as a generator and load on a common bus (all model components supported by the EMS). However, it was soon apparent that this solution is not ideal in that it in turn leads to other issues: i.e., when attempting to use combinations of standard model devices to build a customized representation of another model device, other unforeseen issues arise. For example, if the dc tie is partially modeled as a synchronous machine, what is the reactive curve for a dc tie? Does it apply? Will not having the curve modeled cause the EMS to fail? In this respect, using CIM in the implementation of the base schema provided a readily expendable platform, with methods of extending and adapting the available schema as necessary to support an implementation tailored to a user's needs. This allowed for the base CIM schema to be extended in areas to collect data that were specific to the ERCOT ISO's nodal market operations. For example, the CIM 10 standard provided no support for the modeling of combined cycle plant transition states, which was necessary for the ERCOT MMS in determining which combined-cycle power plant configuration was most desirable for grid operations [4].

F. TOPOLOGY PROCESSING

Within the power industry, there are two primary varieties of models:

1) *Bus-Branch Models:* A traditional model for power-flow calculations, consisting of generation buses, load buses, and a swing bus. Breakers and switches are collapsed into the bus, and only the transmission lines and transformers form the branches. This type of model tends to aggregate all devices with zero impedance to the Bus that represents them, and is typically used in long-term planning studies.
2) *Breaker-Node Models:* These models attempt to represent the reality of the actual power system, and consist of modeling with as much fidelity as its holding application will support. Breaker-node models are mapped into ad hoc bus-branch models based on switch and breaker positions telemetry at run time for the power flow calculation. After the solution to the power flow calculation is obtained, the results are mapped back into the breaker-node model for display purposes. This type of model typically is used to support real-time operations using an EMS.

Since the NMMS was designed as a single consolidated modeling environment, it was necessary that the system be able to produce both formats. The CIM model that the NMMS created was already a breaker-node model (since NMMS was the single source, effort was made to make the model schema as granular as possible). This left development of a topology processor module to take the CIM model produced by the NMMS and create a bus-branch representation for transmission planning purposes [5].

G. ABILITY FOR DATA ADAPTATION

Given the past difficulties with application to application data migration, there was a strong drive by the NMMS designers to develop any new infrastructure on widely accepted industrial standards, and build flexibility into both the NMMS system and the corresponding business processes. Utilizing existing industrial standards (at least in theory) will reduce integration costs by allowing vendors to develop applications that integrate to the standard rather than integrating to yet another application. Having an open source standard and using flat file format for data migration (as opposed to a message bus) allowed for the capability of ERCOT personnel to write internal applications that can manipulate the CIM/XML model data file, allowing for data changes to the model to support individual grid applications without impacting other downstream systems.

III. SUPPORTING COMPONENTS

In addition to the direct CIM data import components needed for the NMMS to provide data to the downstream systems, a number of additional supporting components were also identified. These components primarily took the shape of secondary applications that mined the information in the NMMS CIM model and through the use of application logic produced a model data-related product necessary for one or more of the applications. Examples of these products from these secondary applications include: graphical one-line displays of various areas of the electrical grid (primarily substation layouts); data deliveries to the OS providing temporal information of new or deleted equipment (helping to control outage information submission); contingency definition generation that is used to autodefine contingency scenarios based on the latest topological information; and so on.

A. TOPOLOGICAL ONE-LINE GENERATION

The ERCOT EMS system has a full set of substation one-line diagrams integrated with the SCADA system and used by the operators in grid control. Prior to NMMS, the processes and applications necessary to maintain the one lines used in EMS were built and retained along with the data model in the EMS domain. With the new NMMS, this business process would be too complicated and time constricting to allow for the model updating schedule envisioned by ERCOT. ERCOT developed a new process built around the NMMS, and developed the capabilities to read a CIM model scheduled for loading in the EMS, compare it with a previously loaded CIM model, identify the differences between the two models, and determine which one-line diagrams required updating based on the model changes. Once these changes are verified, an entirely new set of one-line diagrams is produced for the EMS model load, ensuring that every model has an accurate set of one-line diagrams associated with it. This new process has since been recognized as a far superior process to the one-line diagram process used in the zonal market.

As a part of the old process, in the past, typically the one lines were manually updated as part of the manual data model change process. Paper documents listing the changes in the EMS data model were given to the EMS modeler, who determined which changes required one-line diagram changes; these changes were then manually modeled. This process was prone to error, sometimes missing the necessary one-line diagram changes. The problem was further compounded by the fact that the time at which the one-line diagram errors were most likely to be detected was when they were inspected by the grid operations department either as part of a grid evolution or due to an emergency in the area. For example, if a breaker switching action was being performed, the operator might discover that the one-line diagram was incorrect and that the breaker was incorrectly mapped in the one line if the breaker status indicator of the wrong breaker changed on the one line. By automating the task of telemetry mapping using the base model data in the NMMS, modeling error could be reduced (which is not to say that the submitted data could not be wrong, or that the breaker could not be wired incorrectly in the field, but that at least one source of error introduction was eliminated).

B. OUTAGE SCHEDULING (RELATED EQUIPMENT)

This was perhaps the first case in which ERCOT determined that a simple CIM importer for the data model would be insufficient. In this case, the OS had a business process that needed to be provided with a list for each piece of equipment that can be outaged, that is, a list of all equipment that is electrically connected to that piece of equipment. This list would be used to supplement the OS web-based user interface and to grant the TO using the system access to that information when entering an outage. For example, if the TO selected a transmission link for an outage, the line disconnects would be displayed to the user, to determine if those pieces of equipment should also be added to the outage request. This enhancement is used by the ERCOT ISO as a passive way to gain more accurate outage information from the submitting TO.

C. CONTINGENCY DEFINITION GENERATION

Building on the success of an initial pilot project for the OS related equipment file, it was quickly realized that the same electrical equipment element-tracing algorithm that was utilized by the OS had other applications. In the past, the definitions of contingencies (scenarios modeled in the EMS to simulate the loss of pieces of equipment, to verify that no single loss of any piece of equipment would lead to a condition where any of the remaining pieces of equipment would be overloaded) were hand-modeled. A modeler would review the connectivity of the current breaking devices isolating a transmission line or transformer, and then create the contingency definition by manually entering all of those associated devices and their postcontingency position (i.e., the scenario might call for circuit breakers to be open to show a situation in which a line-to-ground fault might cause the breakers to open on an overcurrent condition). This process was very manual and prone to error. In addition, changes in modeled topology could invalidate any of the contingencies. Using the OS tracer program, and extending the CIM model with a few attributes, ERCOT was able to automate the process of contingency definition production, allowing for the creation of better contingency scenarios and a more complete simulation of all possible contingency scenarios [6].

D. POSTPROCESSOR FORMATTING APPLICATIONS

A number of applications were developed for meeting niche ERCOT business needs. These were primarily applications that read the CIM model file and extracted either human-readable reports for the model (i.e., lists of transmission lines with corresponding MVA ratings) or small data packages for application support (i.e., the settlements and billing department needing an XML-formatted file listing substation to load zone mappings). The open nature of the CIM allowed for these to be written and tested quickly, and therefore allowed quick implementation into the business process. This approach left open a possible phase-out approach for these applications when better functionality was available for integration into the core systems, rendering some of the postprocessing unnecessary.

IV. OTHER DEVELOPMENTS IN DATA COLLECTING EFFORTS

The use of CIM in data exchange communications is a relatively new area for the power industry, but one that has been needed for some time. In the past, data exchange has been limited to low-fidelity bus-branch models used by the TO planning departments, and this was considered antiquated for the processes that the constructed models were used for, since it primarily consisted of aspects of long-term transmission planning. However, accurate modeling has taken on additional importance with the decline of vertical integration and the introduction of new market products, and the net effect has been to push the grid closer and closer to its physical limitations. While ERCOT has been at the forefront with its use of CIM, other organizations have also made progress.

A. EUROPEAN NETWORK OF TRANSMISSION SYSTEM OPERATORS FOR ELECTRICITY MIGRATING TO CIM

Earlier this year, the European Network of Transmission System Operators for Electricity (ENTSO-E) announced that it would be using IEC base CIM 16 as its basis for an extended model data exchange standard called the Common Grid Model Exchange Standard (CGMES) as part of its ten-year network development plan (TYNDP) to create pan-European network models. The CGMES is primarily developed to meet necessary requirements for TSO data exchanges in the areas of system planning and system operation (i.e., TYNDP and network codes) and was initially published in December 2013.

This change has been driven by a number of the same factors that drove ERCOTs development of the NMMS [7]. Currently, ENTSO-E is looking to use the CIM format to perform not only data exchange of power system equipment and grid topology but also use the CIM to exchange case information and load-flow study results (this area of CIM is referred to as steady state hypothesis information). Other areas of CIM (one-line diagram layouts and geographic locational information) are currently under draft in the ENTSO-E CGMES [8]. ERCOT CIM usage does not currently support those areas either, but is currently evaluating their usage as well.

B. DETAILED MODEL EXCHANGE IN NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Recently the System Analysis and Modeling Subcommittee presented a set of findings from the Modeling Working Group [9] including the recognition of the following:

1) a growing need for more accurate interconnection power-flow and dynamics cases;
2) issues concerning proprietary models and nonstandard components that are impacting the development of dynamics cases;
3) based on findings from the Southwest outage, that there were discrepancies between the planning models and the real-time models used in the EMS [10];
4) a need to move from bus-branch models to breaker-node models for operational and planning analysis.

And that due to this, there was a need to:

1) create a library of standardized models and model components;
2) develop validation procedures for power-flow cases;
3) migrate from the bus-branch models to breaker-node models;
4) establish a uniform structure for devices and parameters for the exchange of breaker-node data with their use in 2020.

All of these issues were addressed by the initial NMMS design with the exception of the CIM modeling extensions required to support dynamic models (this is scheduled to be implemented in the NMMS by the end of 2014).

C. PJM MODELING PROCESSES

PJM uses a project tracking and change coordination data submission portal that they designed internally for model data submission (new equipment, updates, etc.). PJMs system called eDART contains a network model application that is used to collect data needed to model planned system changes. This data are interpreted and coded to prepare updates and input; in addition, the model changes are forwarded to other PJM groups to incorporate these changes, as appropriate, into models used by day-ahead markets, and so on [11].

The data can be submitted to PJM in several formats, which is then interpreted by internal personnel and modeled into a single staging environment. Once the models are built, they are loaded into offline EMS environments, tested, and promoted to online. Once the EMS model is validated, it is sent to downstream applications as a customized CIM common power system model or other CIM export profiles from the single staging environment. Some downstream systems are updated incrementally from an EMS model difference report. PJM does this model load four times a year, with an additional focus on collecting member projects for the summer and winter seasonal updates for each model. Given the amount of time that the model must remain relevant, PJM uses double modeling and switch configurations to represent changing topology. Currently, PJM has begun using the CIM format internally for model creation and updates, but are not using CIM for data submissions from their members or model exchange to external parties. Data submissions for planning and the planning model building processes are independent tasks from the real-time data submission processes.

D. CALIFORNIA ISO

Currently, CAISO have the entities external to the ISO submit their model changes manually to an internal ISO employee who then interacts with their enterprise model management system (EMMS). The information for topological changes from the external entities is submitted in lower fidelity bus-branch format, and then internally augmented with additional support information for operations and market activities. However, based on the 8 September 2011 system disturbance in Arizona, which caused cascading outages impacting five balancing authorities (including CAISO), CAISO intends to enhance its EMMS and fully expand its network model. Part of the functional requirements is for the full model to include the full Western Electricity Coordinating Council region, and expand market model to a full loop model, consistent with EMS model for use in its market application [12]. The reasons cited include the following:

1) to enhance visibility of the network in the market for reliability;
2) alignment of modeled and actual flows by accounting for loop flows in the day-ahead timeframe and by more

accurately modeling the flows resulting from intertie dispatches in the real-time market;
3) alignment of the EMS, market, and CRR network models by maintaining a single network model for all applications.

The requirements for the upgrades include the ability to create and export CIM from their EMMS for use in their market applications. In addition, upgrades to the EMMS functionality and submission process are planned in the near future [13].

V. OBSERVATIONS SINCE IMPLEMENTATION

After the system was exposed to the user community, multiple issues have been identified and corrected. These run the gamut of software/hardware/performance issues with the physical hardware hosting the NMMS, operator/user errors in utilizing the system, and true issues with the NMMS design and implemented processes. These observations will be confined to NMMS design and processes:

1) Integration with CIM turned out to be a much larger project than was originally envisioned. ERCOT required multiple iterations of extending the CIM schema with ERCOT extensions to support the downstream applications.
2) Rules associated with creating the topology processed bus-branch model were more complex than initially thought. The users of the planning model wanted multiple enhancements to allow the continuation of some legacy business processes. These included items such as planning versions of transformer tap changers, differing modeling philosophies (some of the planning groups wanted equipment located in the bus-branch model differently located from the actual physical locations, or wanted equipment modeled based on functionality with the receiving application, such as modeling two parallel lines as a single line because the application could run single-element contingencies automatically).
3) The centralized dataset and ability to extend the model as necessary to support the model management has proven to be an asset in both supporting additional applications and in discovering data-related issues. Essentially, having all of the data to look at in one place sped up the processes for development and troubleshooting, as well as saving on integration costs.
4) Temporal modeling, once established, allows for a number of grid operations and planning support tasks. The ability to produce a model representative of 45 days out and of 90 days out has helped the outage scheduling department evaluate and approve requested transmission outages with much greater certainty than was previously available. Indeed, prior to temporal modeling, outage analysis was done using the same model as was running in real time on the EMS, which meant that outage evaluation for future equipment was not possible. In addition, the availability of information on future energization of equipment has allowed for greater coordination between the ISO and the equipment owner before and during the equipment energization process.
5) Imposing data security and creating a sense of data ownership with the equipment owners have proven useful. In the past, data submission was a less transparent process. Since the equipment owners did not have access to the data in the ERCOT production applications, it was virtually impossible for them to verify data quality and accuracy. By providing a user interface and basic instructions [14], [15] that allows only the data owners to view, modify, and coordinate activities around their equipment, owners are more easily able to identify and correct issues with the associated data.

VI. CONCLUSION

Although the development of the centralized database concept was difficult in the implementation stages, the results have been good. Through the development of the NMMS, ERCOT has created an architecture that is easy to modify at both the data and business process layers, resulting in easier-to-implement solutions and cost savings. The design philosophies considered in the NMMS have gained wide attention, and the design approach has received acceptance in parts of the power industry. Since the implementation of the nodal market, the NMMS has served as the source of record for model data used by ERCOT to operate the applications necessary to secure the electric grid, and has the capability to do so for the foreseeable future.

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