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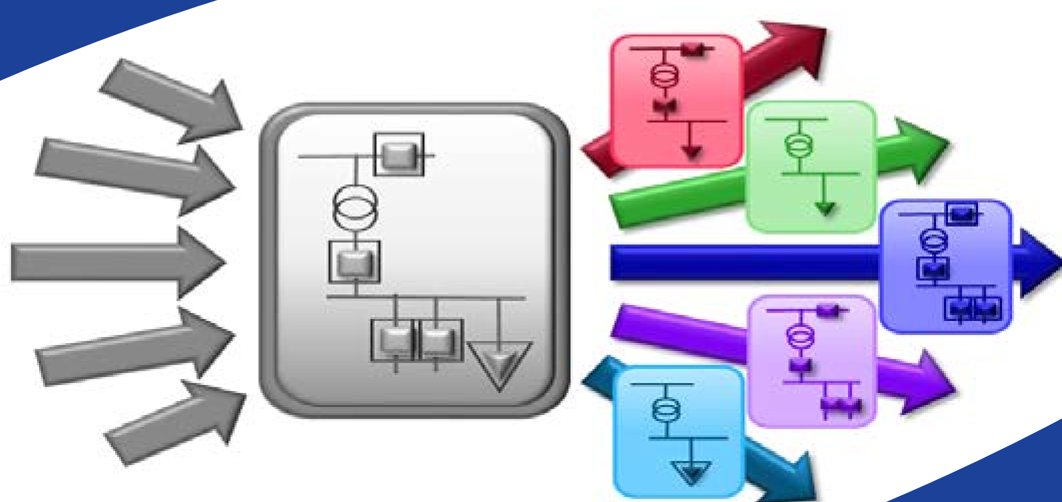
2014 TECHNICAL REPORT

Network Model Manager Technical Market Requirements

The Transmission Perspective



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EPRI Project Manager
P. Brown

ELECTRIC POWER RESEARCH INSTITUTE

3420 Hillview Avenue
Palo Alto, CA 94304-1338
USA

PO Box 10412
Palo Alto, CA 94303-0813
USA

800.313.3774
650.855.2121

askepri@epri.com

www.epri.com

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THE FOLLOWING ORGANIZATIONS PREPARED THIS REPORT:

Electric Power Research Institute (EPRI)

SISCO

NOTE

For further information about EPRI, call the EPRI Customer Assistance Center at 800.313.3774 or
e-mail askepri@epri.com.

Acknowledgments

The following organizations prepared this report:

SISCO
6605 19 ½ Mile Road
Sterling Heights, MI 48314-1408

Principal Investigators
J. Britton
M. Goodrich

Electric Power Research Institute (EPRI)

Principal Investigators
P. Brown
A. Wigington

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Abstract

At a typical utility, a significant and growing number of applications rely on accurate electrical system network models. Model data are generally maintained independently for each application, with variations of the same data manually entered into each application's database. This situation leads to inefficiencies and data inconsistencies that can result in incorrect decisions and adverse impacts on grid operation.

This report defines high-level requirements for a Network Model Manager (NMM) tool—the primary enabler of a Common Information Model (CIM)-based, consolidated approach to transmission network model management. It is intended to help utilities understand and internally promote standards-based, consolidated network model and case management. It is also intended to help vendors gain an enterprise-wide view of required NMM functionality and to help them understand the universality and potential demand for NMM tools.

The CIM provides a basis upon which a coordinated network model maintenance strategy can be built. The CIM is mature and field-tested in the areas of network equipment, connectivity, topology, and power flow solution exchange. However, it has not been widely used in the improvement of model management practices inside the utility.

In this report, an NMM-based solution architecture is proposed for use within the utility, where an NMM tool facilitates the organization and management of network model information from multiple sources and its provision to multiple consuming applications, both inside and outside the utility. NMM tool requirements are identified, including functionality related to physical network model management, object registry, model and case assembly, user workspaces and interfaces, model validation, and CIM-based interface support.

Keywords
Network Model Manager (NMM)
Common Information Model (CIM)
Consolidated network model management

Executive Summary

Purpose

A Network Model Manager (NMM) is the key component in an integrated and unified approach to managing network model data for transmission system utilities, transmission system operators (TSOs), and independent system operators (ISOs). This document outlines a set of high-level requirements for an NMM function.

This work is the product of a collaborative effort between eight utilities (American Electric Power, Bonneville Power Administration, Électricité de France, ISO New England, Midcontinent Independent System Operator (MISO), National Grid UK, Oncor, and PJM Interconnection), two vendors (Alstom Grid and Siemens/Siemens PTI), and EPRI. The collaborative work expanded and refined a set of initial requirements derived from the in-depth analysis of current practice at two utilities, FirstEnergy and American Electric Power, which are believed to be typical examples of the state of the art. That work, in turn, built on previous efforts of the International Electrotechnical Commission (IEC) and EPRI, which explored various approaches to coordinated model management using the Common Information Model (CIM).

The need for and value of articulating high-level NMM requirements became apparent as potential network model management improvement strategies were explored at FirstEnergy and American Electric Power. That work underscored the universality of transmission network model management challenges and the widespread applicability of a consolidated network model management solution approach. The work also clarified the central role that an NMM product should play in such solutions and revealed the limitations of the current NMM product market. This document is intended to help encourage maturation of the NMM market in two ways:

- By providing guidance to utilities in understanding and internally promoting standards-based, consolidated network model and case management
- By helping vendors gain an enterprise-wide view of required NMM functionality and an understanding of the universality and potential of demand for NMM tools

Scope

The term network model management, as used herein, refers to all data management activities for all types of analysis that require network models (including power flow, state estimator, contingency analysis, short circuit, dynamics, and transients) and all situations that require network analysis (operations, operations planning, and long-term planning). While the main emphasis of this document is on an NMM used for network model management in the transmission domain, many of the solution strategies, potential benefits, and requirements are also valid for the distribution domain.

Report Structure

A significant portion of this document focuses on establishing the basis for a consolidated model management approach from which NMM requirements can be developed. This includes providing an overview of current industry model management practices, describing a vision for improvement based on the NMM architecture, exploring NMM functionality via use cases, and identifying expected benefits. The document enumerates fundamental high-level requirements for an NMM tool and provides guidance on how an NMM-based model management improvement project might be implemented. These topics are examined in the following paragraphs.

Existing Network Model Management

Existing network model data management practice has primarily evolved ad hoc, as individual engineering groups within an enterprise developed specialized processes to accomplish specific engineering tasks. When actual practice is reviewed, the single observation that stands out is that existing data management practices generally lack any sort of unifying architecture. Network model information flows originate from a number of sources in a variety of forms, flow to multiple target systems, and are inconsistently triggered by many different events. When requirements are analyzed, it becomes clear that the same power system components are represented in case after case, and therefore most of the data in most of the cases should be the same. This is a natural quality around which an information design could be based. Instead, however, engineers generally create new cases by copying or borrowing from old ones, using procedures that have developed incrementally. The knowledge required to create accurate models is not built into data management design. Rather, success primarily relies on the experience, thoroughness, and energy of modeling engineers.

Scope of Vision for Improvement

In developing a vision for improved network model management, all processes were considered as part of one problem in order to recognize the big picture potential for the elimination of redundant effort and to identify opportunities where more effective data management tools would be beneficial. The technical vision for improved model management is based around the architectural concept illustrated in Figure ES-1. On the left side are original enterprise data sources in the typical utility (station engineering, for example) from which network model data are drawn. On the right side are consumers of network models, such as an Energy Management System (EMS) or a suite of planning applications. Between these two, an NMM function is introduced. The role of the NMM is to maintain a master repository of network model data that is shared by different network model consumers.

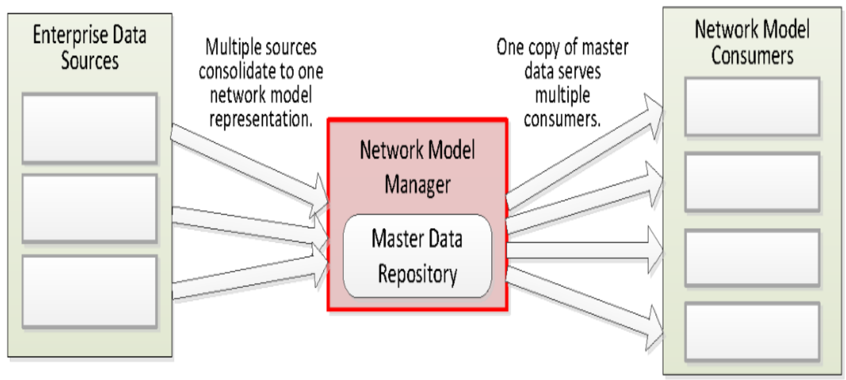

Figure ES-1
Network Model Manager Vision

The NMM provides an environment for maintaining master source information in a form that enables efficient maintenance, sound quality control procedures, and construction of the network base cases needed by the various analytical processes. Master data elements are created once, but used many times.

Additionally, the NMM is designed as a vehicle for integrating systems, taking advantage of the IEC CIM interoperability standards.

Use Cases and Expected Benefit

A number of generic use cases, which sketch typical network modeling processes, have been developed and provide both substance behind the general expectation of benefits as well as insight into NMM requirements. The expected benefits of implementing an NMM-based model management approach, which serve the ultimate utility objective of ensuring reliable and economic operation of the transmission system, are summarized as follows:

1. Labor savings from two sources:
    a. Elimination of duplicate modeling work
    b. Automation of manual processes

2. Better quality control in order to improve the accuracy of both models and results and to reduce the likelihood of significant errors
3. Shortened response time to complete studies
4. Other intangibles such as better documentation of processes and ease of supporting new processes

High-Level NMM Requirements

Based on the use cases, a core set of high-level requirements, which a commercial NMM product would be expected to meet, were outlined. These included the following:

1. Physical Network Model (PNM) Requirements

   The NMM shall provide a PNM that provides a secure, redundant, permanent store for PNM parts.

2. Object Registry Requirements

   The NMM shall support object registry services to manage the names of network modeling canonical objects in different contexts.

3. Workspace Requirements

   The NMM shall support multiple workspaces for carrying out NMM operations in parallel.

4. User Interface Requirements

   The NMM shall provide users with the capability to browse and edit NMM content.

5. Model and Case Assembly Requirements

   The NMM shall support the IEC CIM modular concept for assembling network models and network analysis base cases.

6. Validation Requirements

   The NMM shall support development of a testing and validation regimen.

7. Integration Requirements

   The NMM shall provide CIM-based integration services that will allow the NMM to be integrated with other systems without requiring amendment of the NMM product code.

8. Extensibility Requirements

   Data content of the NMM shall be model driven, definable by an information model, and compatible with the idea that a utility may have a Canonical Data Model from which CIM dataset types may be derived for the NMM.

Implementation Recommendations

The implementation of an NMM-based revision to network model management is best accomplished as two distinct cooperating efforts:

- Acquisition of NMM functionality from a vendor who sees this as a product opportunity that can be delivered to other utilities
- Incremental integration of the NMM with existing utility systems via CIM standards

Conclusion

The NMM architecture, with its integrated and unified approach to network model management, has the potential to reduce engineering labor and increase the accuracy of utility network models. The high-level NMM requirements articulated in this report could help utilities recognize the feasibility and benefit of consolidated model management, assist vendors in enhancing their product offerings, and encourage the industry at large to move toward viewing network model management as an enterprise-, region- and interconnect-wide undertaking that calls for specifically designed model management software.

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Section 1: Introduction and Network Modeling Background

A Quick History of Network Modeling

By the late 1960s, digital computer analysis was already basic to the process of planning an interconnected power network. Power flow applications used card input and paper output, but for limited studies of a generally overbuilt grid, this sufficed – or at least was a significant improvement over analog computers. Even at that time, however, practitioners began to dream of common data formats and common naming conventions that would make constructing models easier.

Beginning in the mid-to-late 70s, data editors and disk-resident data had made it significantly easier to edit data and to store input data. These advances did nothing to alter the form of input (one card deck became one file of card images). They did, however, multiply the number of copies of input data, essentially creating a filing problem and questions like: "Which file has the modeling that is the best starting point for my next study?"

Also in the late 70s, driven by fallout from the 1965 Northeast blackout, utilities began to add network analysis capability to their transmission control centers. Initially, more utilities purchased the capability to do state estimation and contingency analysis than actually got it working. Many were simply not able to allocate the engineering resources necessary to construct the required network models, given that these real-time models were more detailed than planning models and support tools were still primitive. The universal experience of all transmission owners that achieved running state estimators was that their initial models had many errors and it required a lot of work to get the models scrubbed to the point where they would enable a close fit between the state estimate and measurements.

As the industry moved toward the 90s, transmission owners were typically maintaining two complete network models – one for planning and one for operations – and then both of these models tended to have variations. For example, a utility's planning model for internal studies would be different from a planning model for its local pool entity or for interconnection-wide studies. At the same time, the grid was getting a little less overbuilt each year and the importance of network analysis was growing. During this time period, far more attention was paid to improving the analytical functionality of applications than was paid to improving the model data management capability.

Then a tidal wave of change hit the industry. Downsizing tightened resource availability while deregulation and markets forced the grid into a greater variety of operating patterns. Industry dependence on network analysis was greatly expanded. Orders-of-magnitude more studies for both operations and planning were required. Financial results depended on network analysis in ways that had not previously happened. A new set of requirements arose for studying near-future operating conditions based on maintenance requests. It became common in control centers to have staff dedicated to maintaining network models.

The expansion in requirements for numbers and accuracy of studies drove further improvements in the EMS and planning application suites. While those improvements included some improved capability for managing network model data, each tool focused primarily on its own data needs. What was missing was an enterprise-wide view of data management.

Network Modeling at Today's Utilities

The most common situation for transmission utilities currently is that they have many business processes that depend on network analysis and, in each situation, the engineers responsible have evolved their own procedures for constructing network models. These procedures involve acquiring data from both previous studies and other internal or external entities that have important reference data (like station engineering). They also commonly involve both manual steps and individually developed aids like spreadsheets for converting and manipulating data into required forms. Such automation as is achieved tends to be limited to what could be done with the tools available and familiar to the engineer.

Most of the data in most network studies should be the same, because most of the network components are the same in study after study. However a majority of the modeling processes have been developed with a narrow focus limited by available tools and intended to meet very specific goals. When viewed from an enterprise perspective, the same time-consuming operations are often repeated, and there is insufficient cross-checking to assure that studies have consistent representations of the grid or are up-to-date with the latest changes in plans. Often, key knowledgeable senior power system engineers are spending a significant amount of time designing and executing network data management operations, instead of performing engineering and system analysis.

Potential for Improvement

It is not easy to quantify precisely the potential for improvement, but it is clear that significant improvement can be made by unifying the development of network models into one information management problem which has the objective to support all network analysis functions across the enterprise. That is the essence of the approach that underlies the concepts of this report.

Labor savings are the most obvious expected improvement. Significant labor savings can be made by eliminating duplicate modeling processes and by improving the automation of model-building processes.

The next most important outcome is probably increased confidence in the accuracy of models – and hence in the accuracy of analytical results. In particular, the risk of significant errors in studies should be considerably reduced.

A similar quality improvement can be achieved by reducing the time required to generate new study cases, and thereby improving the responsiveness of engineering processes.

Finally, there are important intangibles. Developing an efficient unified overall process will clarify organizational roles and responsibilities and enable more efficient communication. It will make the support of new analytical processes simpler to design and implement. And it will position a utility to take maximum advantage when standardized data exchange becomes more prevalent across the industry.

Current Industry Initiatives

For the past 15 years or so, IEC Technical Committee 57 (TC 57) CIM Working Groups have been developing industry standards for network modeling. This work began with a fairly narrow focus – exchange of network models between control center applications. It has grown in scope and into a methodology based around a Common Information Model (CIM) for power systems. CIM methodology produces interoperability standards, but the methodology and the information model can also be adopted by utilities and applied to local information management problems. This technology, though still evolving, has reached a level where it is successfully being applied.

Electric Reliability Council Of Texas (ERCOT), operator of the Texas interconnection, is a notable case in which CIM has been successfully applied to unifying the development of planning and operations models. Other regional organizations currently using CIM include PJM Interconnection, California ISO (CAISO), and European Network of Transmission System Operators for Electricity (ENTSO-E). Additional information on several of these projects is provided in Appendix B.

The importance of improved modeling and model management has been underscored in documents such as the 2008 report, "Real-Time Tools Survey Analysis and Recommendations", from the NERC Real-Time Tools Best Practices Task Force, and in conferences such as the 2012 NERC-sponsored Network Modeling Workshop.

Section 2: Proposed Solution Overview

Network model management at most utilities currently involves too many manual steps and too many instances where the same information is maintained in multiple places. The premise upon which this report is based is that the best path to improvement is to install a 'Network Model Manager' function to serve as the central vehicle for consolidating model data and automating network model management. For the implementing utility, this will divide the improvement effort into two major parts:

1. Procure, install and initialize an NMM component.
2. Integrate the NMM with other existing systems and applications.

The remainder of the report presents a summary of the approach, including:

- Rationale: why this particular approach?
- A functional overview of the NMM component.
- A functional overview of integration of the NMM with other existing utility systems.
- A set of high-level use cases that illustrate how business processes could execute in an NMM-based environment and show where benefit will accrue.
- A summary of NMM requirements identified to date.
- A discussion of implementation options and considerations.

Rationale

The key technical observations upon which this proposal is based are:

- The typical utility currently performs thousands of network analysis cases to plan and operate its transmission grid. The industry trend is strongly in the direction of requiring more cases and more accurate cases.
- Most of the data in each of these cases are the same, because most of the grid components are the same. Only the specific hypotheses about operating condition or planned evolution typically differ.
- The constant part of the cases is a very large, complex set of data which is difficult to put together and validate as accurate.
- Studies almost always involve more than one utility, and therefore require coordination among multiple sources of information.

- Maintaining models and keeping studies up to date with model changes is a significant cost.
- From an information management point of view, the desirable objective is to assemble one master copy of this information, focus quality control on the master set, and assure that analytical cases all take their data from the master.

These facts stand out from other requirements as the foundational elements around which to design effective information management. The future vision should be built around a consolidated master source for the electrical modeling of the grid components and their connectivity, augmented by a clear and replicable process for assembling cases. The primary mission of an NMM would be to collect, test and validate modeling of the inherent physical qualities and capabilities of the network as it is constructed (or as it is planned to be constructed). The secondary mission of an NMM would be to support the management and selection of sets of assumptions (or hypotheses) used in the creation of cases.

Organizing network model management around an NMM will deliver benefit in a number of ways:

- It will eliminate existing duplicate processes for model management, thereby reducing costs.
- It will better define modeling processes and facilitate automation that will further reduce costs.
- It will improve the overall accuracy of models.
- It will reduce the elapsed time required to perform or update studies.
- It will reduce the likelihood of serious operating or planning errors stemming from bad models.

NMM Component Overview

The NMM will play a central role in network model management. Its purpose is to maintain the master data components that should be shared by most analytical processes.

- The term 'network model management' is used here to refer to the entire set of business processes involved in collecting and validating model data, and in assembling the base cases that are required for planning and operating the grid.
- The term 'master' as used here means 'the authoritative source for a given set of information'. It implies that the organization has decided that it is important to maintain one high quality version of this information that multiple users will draw upon.

The master Physical Network Model Parts Repository (PNM) is the part of the NMM that defines the inherent physical qualities and capabilities of the network. Because this information is both slowly changing and critical to all studies, a PNM is a natural focal point for network data management activities.

The Case Model Parts Repository (CM) is the part of the NMM that defines the assumptions, rules and conditions that together allow the assembly of complete 'base cases' that can be supplied to analysis applications.

Note here that three important acronyms have been introduced:

- NMM refers to the software facility for managing all master data components.
- PNM refers to the physical network model part of the master data managed by the NMM.
- CM refers to the case parts managed and used by the NMM in the construction of cases.

Figure 2-1 gives a nominal functional overview of the NMM components, which are described in the following sections. (Note: this drawing is not intended as a design; it is simply a way to illustrate functionality visually.)

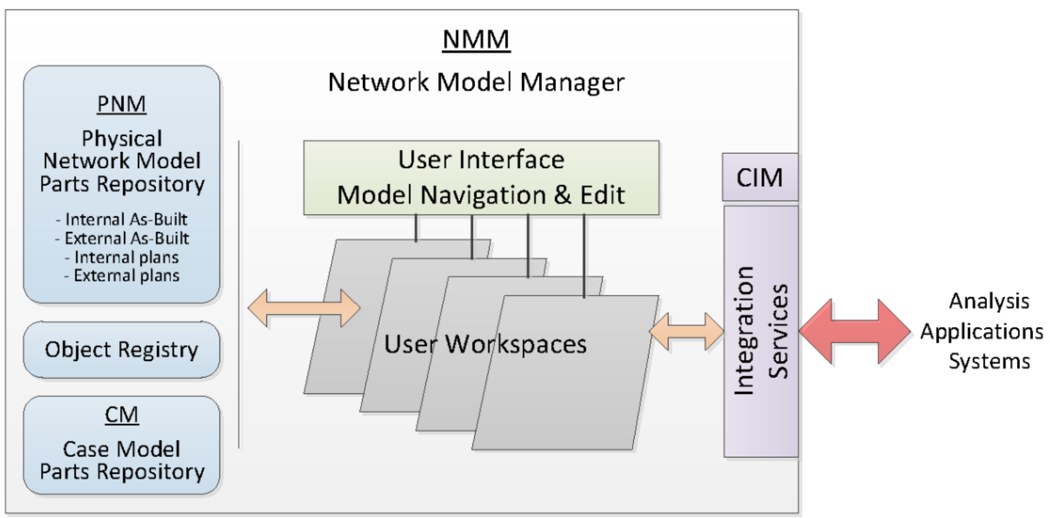

Figure 2-1
Nominal components of an NMM implementation

The Master Physical Network Model

The most important part of the NMM permanent store is the master Physical Network Model Parts Repository. The master PNM scope includes modeling of the analytically significant capabilities of all of the electrical components that make up the transmission grid. To take a simple example, a particular transformer has a model of its electrical behavior that is derived from its detailed configuration and nameplate characteristics. This model should be the same in virtually all network analysis cases. There should be one place, the PNM, where the official modeling for that transformer is maintained and all processes should obtain the data from the PNM. The PNM includes the electrical connectivity and schematic diagrams of connectivity. It is organized expressly for support of functions that analyze the grid as a whole.

From a TSO perspective, there are four main subsets of PNM data:

- A model of the host TSO components and their connectivity, as the system is currently constructed.
- A model of neighboring TSO components and their connectivity, as the system is currently constructed.
- A set of all planned changes to the internal TSO transmission grid that are required for producing future base cases.
- A set of all planned changes to neighboring external territory that are required for producing future base cases.

For an ISO, where all PNM data comes from external sources (either member TSOs or neighboring ISOs/TSOs) there are two subsets of PNM data:

- A model of externally-supplied components both inside and outside the ISO footprint and their connectivity, as the system is currently constructed.
- A set of externally-supplied planned changes to territory both inside and outside the ISO footprint that are required for producing future base cases.

NMM User Workspaces

A workspace is a place where an individual user can view and edit Model Parts, execute validation processes, define plans and assemble full cases for export, without interfering with other concurrent users.

The term ‘case’, as used herein, refers to the complete collection of data assembled as the basis for a given network study or network analysis process. Also referred to as a ‘base case’, because it is typical that a nominal situation is assembled and checked out (such as a current system model for an EMS or a future summer peak condition) and then that base condition is used within analytical environments to run many individual variations on the base.

NMM User Interface

The NMM user interface enables a user to view, navigate and edit network model data, as allowed by his access permissions. There are two principal functions accomplished:

- The user interface is the original entry point for any PNM data that cannot be imported from other computerized sources.
- The user interface provides assembly capability to put together the different base cases that are required by different target environments. (e.g., a node-breaker view for operations vs. a bus-branch view for planning.)

Other Components

The NMM also provides a permanent store for a variety of other artifacts that are required in order to make the NMM modeling processes work successfully. For example:

- Case Model Parts Repository (CM)
- Object registry
- Workspace save/retrieve
- Procedures

CIM Integration Services

The NMM delivers its value by integrating with other utility systems. Integration converts largely manual business processes to largely automated processes. NMM's CIM-based services are the vehicle for accomplishing this integration. Ideally, they are the sole means by which NMM communicates with other systems. CIM services provide stable, sufficiently general, supported interfaces such that integration can be implemented without requiring modification of NMM internals.

The NMM Role in Utility Network Model Management

Figure 2-2 illustrates how an NMM is expected to relate to other systems involved in network model management. In this diagram, the light green shaded boxes identify existing sources of and destinations for network model information:

- Enterprise Data Sources represent information from host TSO systems that are the original source for parts of the data required in network models. ISOs typically do not have true Enterprise Data Sources, but instead rely on information from their member TSOs.
- External Sources represent information in systems outside the host utility, such as ISOs or neighboring utilities for a TSO or member TSOs or neighboring ISOs for an ISO.
- Network Cases are analytical cases managed within network analysis systems such as EMS or planning or protection applications.

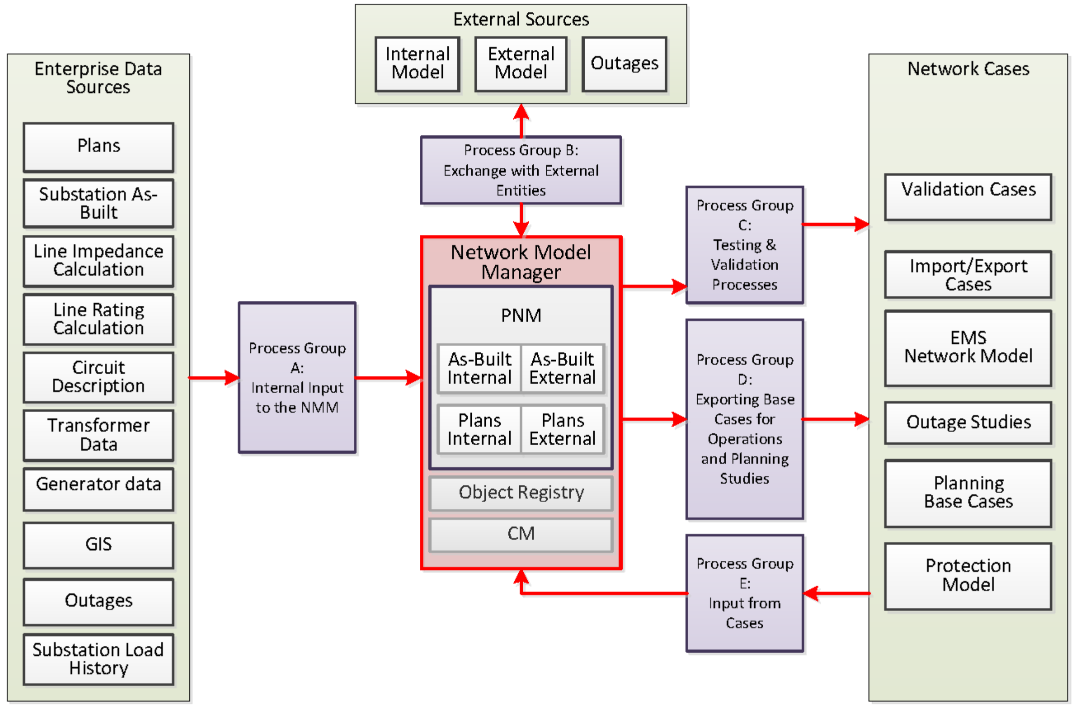

Figure 2-2
NMM role within network model management

The NMM (red-shaded) has functionality as described in the preceding section. However, the NMM is not designed to stand alone. Its real value is realized when it is connected to the data sources and case targets. When existing processes without an NMM are diagrammed, there is a tangle of paths connecting these multiple data sources to the multiple network case targets, and these information flows often involve manual steps that are not easy to automate in their present form. With an NMM system in the middle, as shown, the data management processes can be broken down into five better-organized groups (represented by the purple shaded boxes) which can be automated effectively using the NMM CIM interfaces.

Process Group A: Internal Input to the NMM

Group A processes feed information from other enterprise sources into the NMM.

- Plans define future construction activities that may add or remove equipment and change connectivity.
- Station engineering drawings define station component identities and their electrical connectivity.
- Line drawings similarly define line component identities and their electrical connectivity.
- Line impedances are calculated from circuit detail.

- Line ratings are calculated from circuit detail.
- Transformer nameplates and testing results define transformer models.
- Generator models are obtained from generator owners (or from nominal models).
- Load models are estimated based on historical loads or rated capacity.

Currently, most information is manually taken from sources (like station engineering) and entered into network models. In the initial deployment of an NMM, many Group A transfers would likely remain manual, but modelers would have the advantage of a comprehensive and state-of-the-art graphical NMM user interface. Manual entry capability will in any case always be a requirement, even if it is only used as a means of overriding an automated source.

Over time, it is expected that Group A processes will become more and more automated. The exact form of automation that is optimal may take some time to figure out. For example, consider computation of impedances and ratings from circuit detail. Utilities commonly use applications that model circuit details to a level well beyond what is needed for network analysis, but which is necessary in order to develop the net ratings and impedances used in network analysis. This detailed circuit modeling overlaps with PNM. Would it be better to just put the circuit detail into PNM so that all the data are in one consistent model? Or, should circuit detail be populated separately but be able to export line models to PNM? Or is it easier to stay manual? The costs and benefits of these and other alternatives are not completely clear. Nor will it be true that the discussion for circuits is the same as for other categories of data, as each has a different set of choices to evaluate. The one firm goal, though, is to assure that information is only entered or transferred once.

Process Group B: Exchange with External Entities

Group B processes govern the exchange of information with external entities. From a TSO perspective, these could be an ISO or neighboring utilities. From an ISO perspective, these would be member TSOs and neighboring ISOs/TSOs. In general, utilities both require modeling from other utilities and have an obligation to provide their models to other utilities. Information is exchanged bi-laterally and the end result for each utility is the population of the parts of its PNM for which some other utility is the modeling authority.

These utility-to-utility exchange processes are becoming increasingly important to the successful planning and operation of the grid. Generally speaking, they are implemented using mostly manual steps and they consume considerable engineering labor. CIM standards have outlined methods which could lead to complete automation of external exchanges, but the major obstacle is that only limited automation can be established unilaterally.

Process Group C: Testing and Validation Processes

An objective for the NMM is to consolidate a high-quality source for building all analytical cases. Quality assurance is an important objective. Group C processes carry out testing and validation of the PNM content.

Process Group D: Exporting Base Cases for Operations and Planning Studies

Group D processes are where the payoff occurs. They allow engineers to create the base cases required for operations, planning and protection analysis by combining master PNM data with appropriate case (CM) information to generate base cases for analysis. The scope of base cases produced varies with the purpose of the analysis, but wherever a given PNM network element is used, it will be represented in the same way.

Process Group E: Input from Cases

Group E processes reflect the fact that network applications themselves will often be the source of physical network model information (needed corrections discovered by State Estimator, for example) or case part information (assumptions used in ad hoc cases, for example) which is fed back into the NMM.

Section 3: A Quick Word About Cases, as Viewed by IEC CIM Working Groups

This section is provided to establish a common vocabulary that will be employed by the descriptions of the "Use Case Sketches for Network Model Management" section that follows.

There are two basic aspects of input to any power flow study: the first is the physical network model (the configuration of equipment and connectivity) and the second is a steady-state (or operating) hypothesis for the study (the operating condition to be studied). The output is a set of values for the network variables (primarily flows and voltages) that satisfy the laws of physics at one instant in time. Together, the input and output make up a case – where we define a 'case' as being the data (input and optionally output) associated with a power flow or state estimator for one instant in time.

Figure 3-1 shows the specific components that make up a case, as defined by CIM standards. In the diagram, rounded-corner rectangles are used to represent sets of data and square-corner rectangles are used for processes.

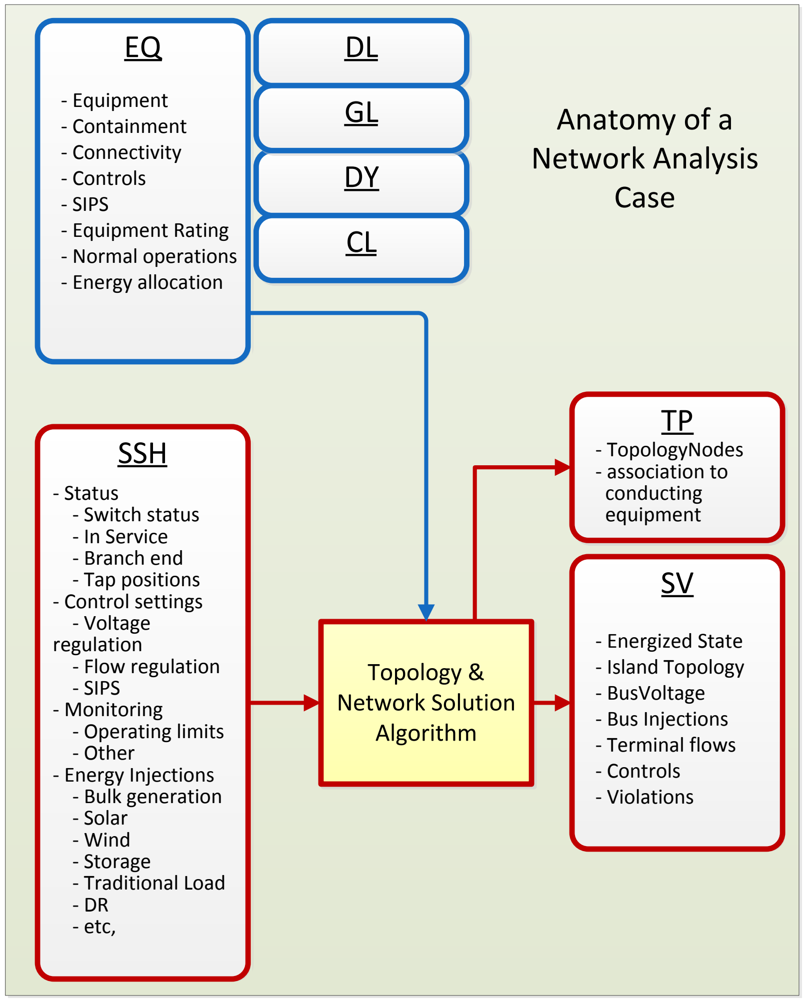

Figure 3-1
Parts of a network case

The components outlined in blue contain the physical network model data. They include the following kinds of information contained in the following CIM Dataset Types:

- EQ – Describes the steady-state electrical characteristics of the equipment and describes how the equipment is connected together (connectivity).
- DL – Describes any Diagram Layouts that are used. (Optional)
- GL – Describes any Geographic Location data. (Optional)
- DY – Describes Dynamic Modeling. (Required only if the case is going to be used for dynamic analysis.)
- CL – Describes Contingency List. (Required only if the case is going to be used for contingency analysis.)

The components outlined in red describe the operating condition under study. They include the following information contained in CIM Dataset Types:

- SSH – Describes the input data that defines the Steady-State Hypothesis. This includes device status, load and generation, control settings, operating limits, etc.
- TP – Describes the Topology that results from processing closed switching devices into traditional power flow 'buses'.
- SV – Describes the State Variables that are produced by the network analysis solution algorithm.

The IEC CIM Working Group philosophy is to maintain strict segregation between input and output, even if the values don't change. Thus, for example, a regulated voltage input in SSH would be the same as the resulting voltage in SV, provided the algorithm was able to hold voltage.

Different target functions (consumer applications) need different amounts of case information:

- EMSs require all physical network model information and variants of other operating hypothesis information (normal breaker states or circuit limit sets, for example) to support the internal building of its wide variety of cases.
- Planning applications could utilize complete case input information (physical network model and operating hypothesis), though such applications often have scripting languages that could also supply/modify operating hypothesis information prior to case analysis.
- Protection applications need a complete physical network model and selected operating hypothesis information.
- Outage scheduling systems require only select parts of the physical network model.

In the use cases of the following section, the phrase "model assembly" is more often used in relation to the EMS and the phrase "case assembly" more often in relation to planning applications, but both are understood to mean the construction of a set of network analysis information which is complete from the perspective of the consumer application.

Section 4: Use Case Sketches for Network Model Management

In this section, a number of typical use case outlines are presented, organized by Process Group. It is important to understand that these use cases are only developed in overview, and, while they are representative of important model maintenance activities, they are both incomplete and overlapping when taken as a set. Less important use cases are omitted and duplicate use cases exist which express alternate ways of accomplishing the same general task.

The purpose of the use cases is to capture the most common and significant ways in which an NMM tool might be used in facilitating effective model management, so that the functionality requirements for an NMM can be identified. While these use cases could help provide a starting point for a utility NMM implementation or a vendor product development, they will not be complete or necessarily correct for those purposes. More detailed use case analysis is required in order to develop detailed requirements.

The use cases explored in the section are:

Process Group A: Internal Input to the NMM

- Use Case A1 – Update a Project to As-It-Will-Be-Built
- Use Case A2 – Establish Identity of Public Objects
- Use Case A3 – Update the PNM Baseline to Reflect Newly Commissioned Work
- Use Case A4 – Create a New Planned Project
- Use Case A5 – Update Content or Timing of a Planned Project

Process Group B: Exchange with External Entities

- Use Case B1 – TSO Updates its Footprint in ISO EMS Model
- Use Case B2 – TSO Notifies ISO of New TSO Baseline
- Use Case B3 – TSO Provides Planned Project to ISO
- Use Case B4 – TSO Receives External Planned Project
- Use Case B5 – TSO Receives EMS Model Update from ISO

- the new work is in the planning phase Use Case B6 – TSO Sends Contribution to a Regional Planning Case
- Use Case B7 – TSO Receives Complete Planning Base Case
- Use Case B8 – TSO Imports ISO Study Case for Comparison
- Use Case B9 – ISO Receives Generator Information from Generator Owner or Agent
- Use Case B10 – TSO Receives Generator Information from ISO
- Use Case B11 – ISO Receives Planned Project from TSO
- Use Case B12 – ISO Receives Update to Planned Project from TSO
- Use Case B13 – ISO Receives Notification of New Baseline from TSO
- Use Case B14 – TSO Updates its Information for ISO Market System Model

Process Group C: Testing and Validation Processes

- Use Case C1 – Validate Modeling of Newly Commissioned Work
- Use Case C2 – Ongoing Validation of As-Built Model
- Use Case C3 – Validation of Future Projects

Process Group D: Exporting Base Cases for Operations and Planning Studies

- Use Case D1 – Update the EMS Model
- Use Case D2 – Build a New Planning Base Case of Type X
- Use Case D3 – Script New Physical Model Assembly
- Use Case D4 – Script New Case Assembly
- Use Case D5 – Update Outageable Equipment in Outage Scheduling Application
- Use Case D6 – Create, Update or Baseline PSS®MOD Project
- Use Case D7 – Provide New, Updated or Baseline Project to Protection Software
- Use Case D8 – Update ISO Market System Model
- Use Case D9 – Build a Post-Event Analysis Case

Process Group E: Input from Cases

- Use Case E1 – Online EMS Changes/Corrections into NMM

Additional Use Cases Enabled by NMM

- Use Case X1 – Add/Update Outage Schedule
- Use Case X2 – Provide Outage Schedules to EMS

- Use Case X3 – Provide Outage Schedules to Planning Study

As an aid in understanding the use cases, Figure 4-1 and Figure 4-2 below show how the described use cases might interrelate in support of projects and outages.

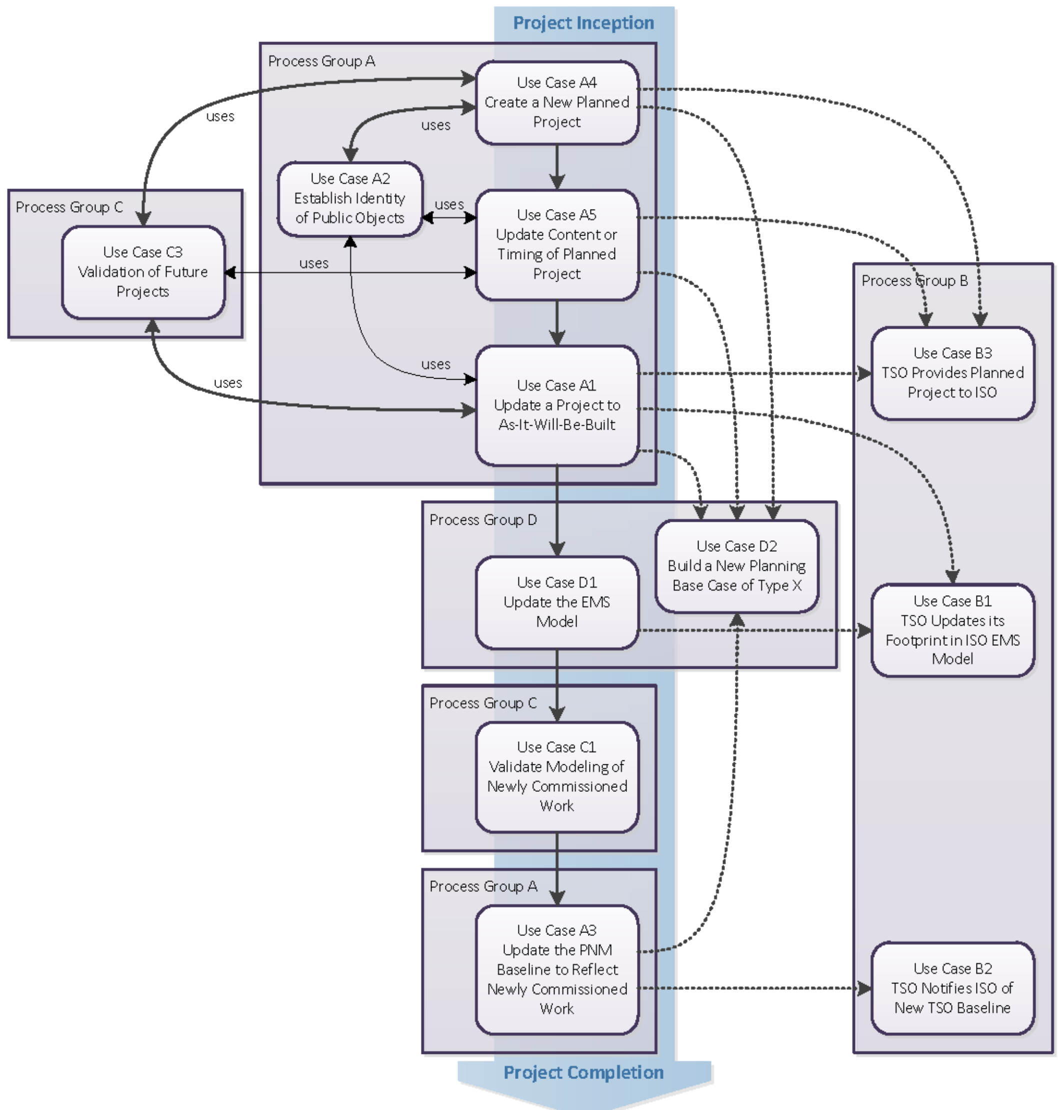

Figure 4-1
Possible flow of Use Cases during project lifecycle

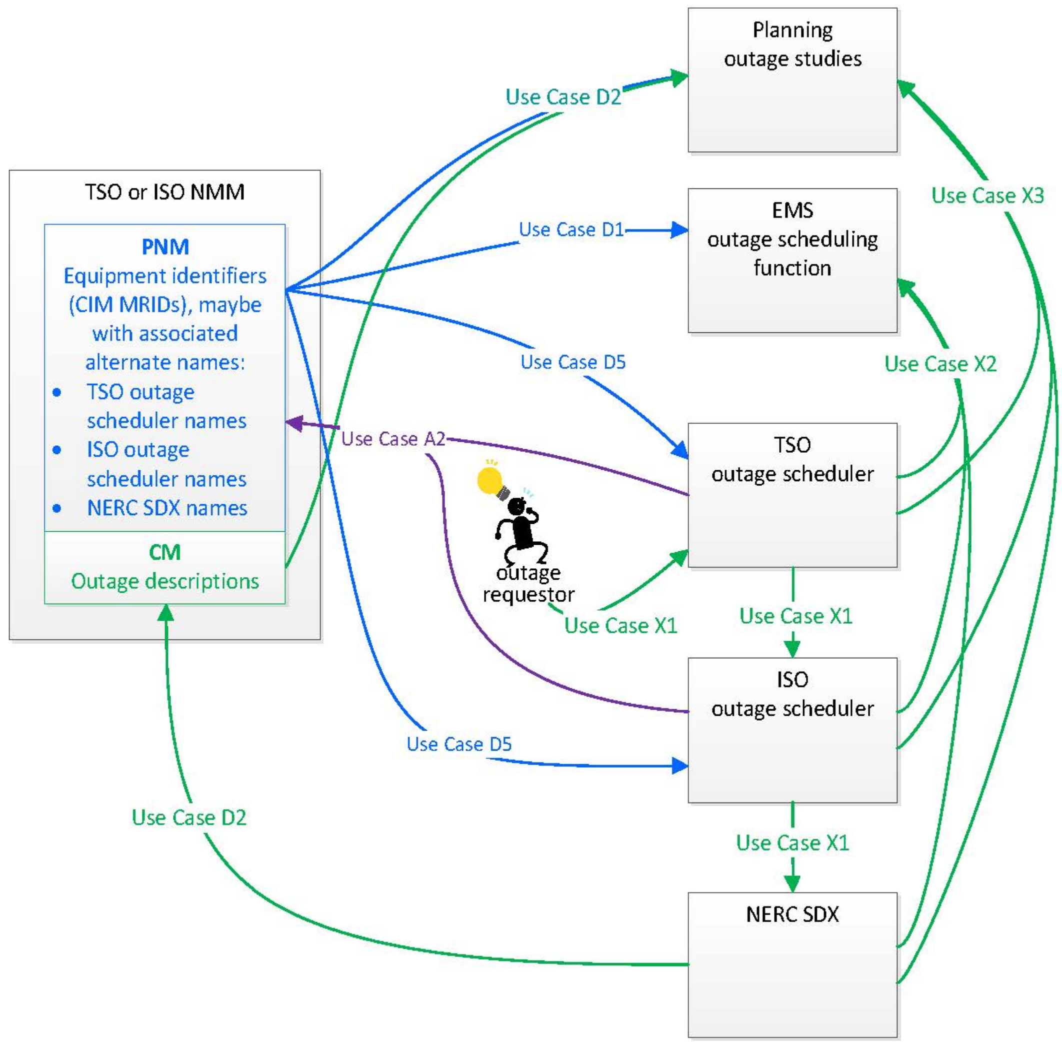

Figure 4-2
Possible Use Cases participating in outage schedule information flow

Process Group A: Internal Input to the NMM

1. Use CaseA1 – Update a Project to As-It-Will-Be-Built
   a. Pre-conditions:
      i. Basic description of planned changes has likely already been built as planned project in PNM. (See "Create a New Planned Project" and "Update Content or Timing of a Planned Project" use cases.)
      ii. Now detailed construction data are available and a new 'as-it-will-be-built' version of the project needs to be created.
      iii. This probably occurs before actual commissioning of the work in the field, and might need to be revised during and after completion of the activity.

b. Scenario:

   i. From station engineering drawings:

      1. Enter components, connectivity and geography graphically in PNM.
      2. Enter measurement placements.
      3. Develop schematics in PNM as needed.

   ii. From circuit drawings:

      1. Enter components, connectivity and geography graphically in PNM.
      2. Enter measurement placements.
      3. Develop schematics in PNM as needed.

   iii. In the foregoing two steps, when new power system components are added, component identity is established. (Refer to "Establish Identity of Public Objects" use case.)

   iv. Add component properties:

      1. Enter basics (location, grouping relationships, asset relationship, etc.)
      2. Import or enter impedance and rating detail.
      3. Import or enter transformer models.
      4. Import or enter generator steady-state data.
      5. Import or enter generator dynamic data.
      6. Import or enter relay/protection data.
      7. Import or enter data about other components (cap banks, HVDC, FACTS, storage, etc.)
      8. Import or enter load data (both steady state load distributions or injection data and dynamic data).

   v. Documentation (.pdfs, drawings, spreadsheets, notes, emails) related to the project is attached to the project

   vi Validate project modeling as individual addition to the most recent PNM baseline (unless it is dependent on another project)

   vii Notification of new 'as-it-will-be-built' project is sent to registered parties

c. Comments:

   i. There are many possible ways to import information, which are not explored in specific detail here.

   ii. For this use case, the new work is in the planning phase, so it is still maintained as a project and is not yet incorporated into a PNM baseline. It may, however, be used to generate a new EMS model, if the EMS needs to see a forward view.

iii. It might vary who would perform this work, but one scenario would be:

1. EMS modelers are responsible for connectivity, schematics and other EMS data.

2. Other groups (planning modelers, protection engineers, etc.) would add any detail for which they are the most knowledgeable source (ratings, impedances, relaying, etc.).

3. Planners/protection engineers review the result to assure that modeling will work for planning and protection in addition to operations.

iv. EMS workload should not be significantly changed. It is just shifted to the NMM environment.

v. Planning and protection modelers should be able to reduce their modeling effort significantly.

vi. All systems are coordinated in terms of modeling. Content is consistent and there is a single master reference source for load distributions, ratings, impedances, etc.

vii. Multiple work groups entering different, but potentially related, information creates the need for access control strategies and requires support of business process flow.

2. <u>Use Case A2 – Establish Identity of Public Objects</u>:

a. Pre-conditions:

i. A 'public object' is basically one that is registered for use in data exchange payloads.

ii. NMM objects (like breakers or line segments or limits or circuit definitions or load distributions) are all public objects, but the public object services could also be used for objects defined elsewhere.

iii. This use case begins when a public object needs to be created.

iv. Any system that needs to register an alternate identifier or to generate name translation tables has registered to receive notifications.

b. Scenario:

i. Primary registration of a public object by its source is accomplished as follows:

1. A unique identifier (an MRID in CIM terms) is generated for the object.

2. The existence of the object is registered in a public object registry, (which is anticipated to be part of the NMM) with the following type of information :

a. MRID

b. Public name

c. Class

d. Object owner or source

3. Notification of registration is sent to registered parties.

ii. Secondary registrations by other parties occur as follows:

1. Notification is received.

2. The receiving system (or a proxy within the primary registrant) executes a procedure to get a user to create or confirm an alternate identity.

3. The secondary registration is attached to the primary in the public object registry.

c. Comments:

i. MRIDs tied to secondary identifications allow an object in any context to be recognized as representing a particular real thing. Thus when thousands of network cases are produced and exist in many places, some of which may have different names for the thing due to local naming restrictions or conventions, the thing can still be recognized and compared in each context.

ii. Registration also enables automated maintenance of name translation tables that are often needed to enable interoperability.

iii. The ability to "retire" objects from active use will likely need to be supported. (Object "deletion" isn't a concept that matches the goal of maintaining a model history over time.)

3. <u>Use Case A3 – Update the PNM Baseline to Reflect Newly Commissioned Work:</u>

a. Pre-conditions

i. One or more PNM projects reflecting completed work or model corrections need to be incorporated into a new version of the PNM baseline model.

ii. The EMS model has been updated and state estimation confirms that changes are modeled correctly. (See "Validate Modeling of Newly Commissioned Work" and "Update the EMS Model" use cases.)

b. Scenario:

i. A new version of the PNM baseline is officially created by adding the projects that have been used to populate the EMS.

ii. The projects are removed from the active project repository and added to the audit trail for the baseline.

iii. Notification of the new baseline version is sent to registered parties.

c. Comments:

i. This use case reflects one possible approach to the sequencing of model validation and baselining. There are others.

ii. State estimation provides quantitative feedback on accuracy before the update (project) is considered as completed in PNM.

iii. Planning and export cases can be monitored for potential impact and regenerated as necessary.

iv. A generally accessible and accurate record of project completion is produced.

4. Use Case A4 - Create a New Planned Project:

   a. Pre-conditions:

      i. A new planned project needs to be entered into the PNM in order to make it generally accessible.

      ii. A version of the plan may have been created in another application, such as a planning suite or TSO project management application.

   b. Scenario:

      i. The plan may be entered into PNM using the same process that is used to enter an as-it-will-be-built project, but typically, advanced planned projects are much less detailed. PNM schematics can be created and used to illustrate planned changes.

      ii. Alternatively, the planned project may be imported from another source.

      iii. Documentation (.pdfs, drawings, spreadsheets, notes, emails) related to the planned work is attached to the project.

      iv. The planned project is annotated with author, purpose, effective date, work status, etc.

      v. The planned project is validated individually as an addition to the most recent baseline (unless it is dependent on another project, in which case the collection of all required projects is validated) (see "Validation of Future Projects" use case). Combinations of planned projects can also be validated.

      vi. Notification of the new planned project is sent to registered parties.

   c. Comments:

      i. All model-related information for each plan is consolidated in one location.

      ii. Planned projects are held separate from the baseline model.

      iii. Automated business processes tracking submission, review, approval of plans can be implemented.

5. Use Case A5 - Update Content or Timing of a Planned Project:

   a. Pre-conditions:

      i. The planned project in question already exists in PNM.

      ii. Plans are reviewed, revised, analyzed and approved/rejected according to a TSO business process.

   b. Scenario:

      i. Content and/or timing of the planned project is updated in PNM.

      ii. PNM maintains full audit trail of changes.

iii. Case assembly-related audit trails include planned project identification and can be checked to identify cases impacted by the changes.

iv. Notification of the planned project change is sent to registered parties.

c. Comments:

i. Greatly improves likelihood that studies maintain an accurate view of plans.

ii. Ensures that planning and protection are aware of need to update study cases when plans change and reduces the labor to do the updates.

iii. Changes to plans over time are documented.

Process Group B: Exchange with External Entities

1. <u>Use Case B1 – TSO Updates its Footprint in ISO EMS Model</u>:

a. Pre-conditions:

i. As the TSO creates as-it-will-be-built project definitions, the changes need to be reflected in the ISO models where the TSO is a member.

b. Scenario:

i. Project completion date in PNM falls inside ISO-required lead time range which triggers generation of PNM notice to send change information to ISO. There is likely a validation function that is performed before project publication.

ii. Export of changes can be accomplished in different modes, ranging from manual to semi-automated to fully automated. In a fully automated scenario,

1. Models at the ISO and the TSO are coordinated using CIM MRIDs and formal boundary definitions.

2. PNM schematics are included.

3. Projects that work at the TSO EMS should work at the ISO if they apply to a part of the TSO that the ISO models.

i. ISO validates the project and may request that the TSO make corrections/changes to the project and resubmit it.

c. Comments:

ii. As projects proceed through commissioning, the ISO update may be repeated as appropriate.

iii. When new TSO models are installed in the TSO EMS, a complete new TSO model may also be delivered to the ISO.

iv. Some labor savings should be realized under any degree of automation, but if the ISO and member TSO processes are fully synchronized, then separate ISO modeling is eliminated, object identities are mutually understood and results of studies conducted at the ISO and at the member TSO are easily related to one another.

   v. In a real-world implementation, some TSOs will likely be fully automated well before others.

2. Use Case B2 – TSO Notifies ISO of New TSO Baseline:

   a. Pre-conditions:

      i. A new version of the PNM baseline has been created (see "Update the PNM Baseline to Reflect Newly Commissioned Work" use case).

   b. Scenario:

      i. Notification of TSO creation of new baseline is communicated to ISO, which indicates to ISO that model changes have been tested by TSO and are considered complete and correct.

      ii. Depending on degree of alignment between TSO and ISO EMS model management practices, different actions would be taken by ISO, ranging from simple acknowledgement to initiation of new baseline creation at ISO. (See "ISO Receives Notification of New Baseline from TSO" use case.)

   c. Comments:

      i. This process is uncommon in TSO/ISO interactions today, but could provide significant model quality benefits to the ISO if updated baseline models were utilized by the ISO planning function.

3. Use Case B3 – TSO Provides Planned Project to ISO:

   a. Pre-conditions

      i. Here it is hypothesized that an ISO maintains a set of projects representing the plans that its members have published and are available to others.

      ii. A plan has reached a state of review/approval where it is appropriate to make it available to the ISO and/or to other members of the ISO.

   b. Scenario:

      i. Export the project representing the plan to the ISO for posting there.

      ii. Depending on business processes and ISO technology, posted projects could be used in a variety of ways. (See "ISO Receives Planned Project from TSO" and "ISO Receives Update to Planned Project from TSO" use cases.)

   c. Comments:

      i. As planned projects proceed through commissioning, the provided project information may be updated as appropriate.

      ii. Depending on the interconnection operating agreements about shared data, this could be restricted in various ways, but to the extent plans are posted, it should facilitate the accurate assembly of planning cases at both the ISO and its member TSOs.

4. Use Case B4 – TSO Receives External Planned Project:
   a. Pre-conditions
      i. Here it is hypothesized that an ISO maintains a set of projects representing the plans that its members or other adjoining entities have published and are available to others.
      ii. Contractual agreements and business process rules exist that govern the sharing of planned project information.
      iii. The NMM is maintained current with the posted planned projects.
   b. Scenario:
      i. Import and store the posted planned project from the ISO.
      ii. Notification of the planned project receipt is sent to registered parties.
   c. Comments:
      i. Affected studies may be revised as necessary.
5. Use Case B5 – TSO Receives EMS Model Update from ISO:
   a. Pre-conditions:
      i. EMS systems require models of the network external to TSO.
      ii. Generally, these models must represent the higher voltage facilities which have a significant impact on the host TSO's system.
      iii. The source for such a model could be either the neighbor TSO directly or the ISO, but the ISO has the advantage that it can provide a complete set of external modeling.
      iv. This use case assumes the ISO is not doing coordinated network model management and is not supplying the TSO with projects through their lifecycles.
   b. Scenario:
      i. ISO modelers notify the TSO that new external models are available for download.
      ii. The import of changes can be accomplished in different modes. The primary difference is based on whether the ISO and TSO models are synchronized using CIM MRIDs and formal boundary definitions.
         1. If they are, changes can be downloaded either as projects or as complete replacements of regions and directly incorporated in PNM.
         2. If not, a new external model version can be downloaded into a workspace and diffed against the previously received version to determine what has changed. The changes can

then be reviewed and modifications manually made as necessary to the PNM's version of the external.

iii. Updates to external models are then validated and exported to the EMS in the same manner as internal updates are handled. (See "Update the EMS Model" use case.)

c. Comments:

i. ISO state estimation validates the accuracy of the external modeling.

ii. If fully automated, updates of external models can occur more frequently – out-of-date external models are a very common problem for EMS today.

6. <u>Use Case B6 – TSO Sends Contribution to a Regional Planning Case</u>:

a. Pre-conditions:

i. Regional planning cases are often constructed by having the constituent utilities submit their territory to the entity that will carry out the study.

ii. It is assumed here that the TSO is expected to submit a solved case representing its territory, with flow conditions (could be represented by an artificial generator) at each boundary to simulate tie flow.

b. Scenario:

i. The TSO receives a notice requesting their contribution for a planning case representing a certain time, with certain loading conditions and other applicable assumptions.

ii. A base case is constructed to represent the study conditions and is exported to the appropriate study tool. (See "Build a New Planning Base Case of Type X" use case.)

iii. A power flow analysis is run in the study tool to create a solved case.

iv. The solved case for the TSO territory is exported to the study entity.

c. Comments:

i. The case as constructed by NMM may include operating hypothesis information or it might include only physical network model information, with operating hypothesis information added by the study tool.

7. <u>Use Case B7 – TSO Receives Complete Planning Base Case</u>:

a. Pre-conditions:

i. A planning case has been completed by an external authority.

ii. The TSO now needs to import the case to execute studies.

iii. The TSO will have contributed the part of the case that represents its own territory, and this will have been built from the PNM source.

b. Scenario: TBD

c. Comments:

   i. This use case reflects the practice of model sharing by means of official cases being provided to the TSO by ISO or Interconnect.

   ii. This could go a number of different ways. If plans are not being exchanged up front, importing the external authority cases for a number of points in time into NMM may allow the TSO to reverse engineer planned projects by diffing. It may also work fine just to import external authority cases directly into the planning software suite for analysis.

8. <u>Use Case B8 – TSO Imports ISO Study Case for Comparison</u>:

   a. Pre-conditions:

      i. The TSO wants to be able to compare model or operating hypothesis for an ISO study to its internal model or operating hypothesis.

      ii. It is assumed here that the ISO study has been set up from TSO contributions and the MRIDs of network components have been preserved.

   b. Scenario:

      i. Case is imported into an NMM workspace.

      ii. The same situation is constructed based on PNM and CM information in another NMM workspace.

      iii. Diffs are done for each TSO territory to identify any differences in structure.

   c. Comments:

      i. Comparisons should be greatly simplified.

9. <u>Use Case B9 – ISO Receives Generator Information from Generator Owner or Agent</u>:

   a. Pre-conditions:

      i. ISO has interface on NMM to support entry of needed generator information by generator owner or agent.

      ii. A boundary (or connection) point has been defined such that generator-related data can be appropriately incorporated into the physical network model.

   b. Scenario:

      i. Responsible party (generator owner or agent) enters or updates generator data and a project is created in ISO PNM.

      ii. ISO validates data (see “Validation of Future Projects” and “Validate Modeling of Newly Commissioned Work” use cases) and notifies responsible party of any changes that need to be made.

        iii. Corrections are made to project by responsible entity.

    c. Comments:

        i. Facilitates process of validating generator information for use in multiple applications.

10. Use Case B10 – TSO Receives Generator Information from ISO:

    a. Pre-conditions:

        i. Necessary coordination has been done between generator owner or agent and TSO.

        ii. ISO has received and validated generator information from generator owner or agent.

        iii. ISO and TSO have shared information about generator boundary (connection) point.

    b. Scenario:

        i. ISO exports project containing updated generator information from its PNM to TSO PNM.

        ii. Project is available to be used in model and case assemblies in TSO NMM.

    c. Comments:

        i. Generator information is considered external model information from TSO perspective

11. Use Case B11 – ISO Receives Planned Project from TSO:

    a. Pre-conditions

        i. Here it is hypothesized that an ISO maintains a set of projects representing the plans that its members have published and are available to others.

        ii. A TSO plan has reached a state of review/approval where it is appropriate to make it available to the ISO and/or to other members of the ISO.

    b. Scenario:

        i. ISO receives the project representing the plan from the TSO.

        ii. ISO validates project and requests that the TSO correct any errors that are found.

        iii. ISO identifies any official base cases affected by the new project and recreates them using scripts as appropriate.

        iv. Notification of new project is sent to registered parties by ISO.

    c. Comments:

        i. This should facilitate the accurate assembly of planning cases at both the ISO and its member TSOs.

        ii. A variation on this use case would be the receipt of a planned project from a neighboring entity related to an outside-the-ISO portion of the grid. Case update and notification actions could be very similar to the inside-the-ISO actions described in this use case.

12. <u>Use Case B12 – ISO Receives Update to Planned Project from TSO:</u>
    a. Pre-conditions
        i. ISO has previously received a planned project from a TSO, has validated it, stored it in its PNM and is using it in case assembly as appropriate.
        ii. An update to the planned project has been made by the TSO and the revised project has been sent to the ISO.
    b. Scenario:
        i. ISO receives the updated project representing the plan from the TSO.
        ii. ISO validates project and requests that the TSO correct any errors that are found.
        iii. ISO identifies any official base cases affected by the updated project and recreates them using scripts as appropriate.
        iv. Notification of updated project is sent to registered parties by ISO.
    c. Comments:
        i. A variation on this use case would be the update of a planned project from a neighboring entity related to an outside-the-ISO portion of the grid. Case update and notification actions could be very similar to the inside-the-ISO updates described in this use case.
13. <u>Use Case B13 – ISO Receives Notification of New Baseline from TSO</u>:
    a. Pre-conditions
        i. TSO has notified ISO that a project has been baselined in the TSO PNM.
        ii. The project has previously been incorporated into the ISO EMS model and state estimation confirms that changes are modeled correctly.
    b. Scenario:
        i. A new version of the ISO PNM baseline is officially created by adding the project.
        ii. The project is removed from the active project repository and added to the audit trail for the baseline.
        iii. Notification of the new baseline version is sent to registered parties.
    c. Comments:
        i. This use case reflects one possible approach to the sequencing of model validation and baselining. There are others.

ii. Planning and export cases can be monitored for potential impact and regenerated as necessary.

iii. A generally accessible and accurate record of project completion is produced.

iv. The actions described in this use case could also apply to outside-the-ISO baseline notifications received from neighboring entities.

14. <u>Use Case B14 – TSO Updates its Information for ISO Market System Model</u>:

   a. Pre-conditions

      i. The ISO NMM contains an accurate as-built network model and appropriate future projects suitable for constructing the ISO EMS and Market System network models.

      ii. Resource Models have been read in and established in a resource data base at the ISO.

      iii. The market participant (TSO) has logged on to the ISO NMM, presented credentials, and been authenticated.

   b. Scenario:

      i. The market participant makes the following types of changes which will be captured in a project in the NMM:

         1. Uploads or enters any changes in the mapping of connectivity nodes to pricing nodes for use in the calculation of Locational Marginal Prices (LMP).

         2. Uploads or enters any changes to the aggregation of pricing nodes into aggregated pricing nodes and hubs, etc.

         3. Deletes old/uploads new nomograms for use in security constrained unit commitment.

         4. Uploads or enters any changes to the definition of transmission corridors.

         5. Uploads or enters any changes to commercial operating limits on transmission corridors.

         6. Uploads or enters any changes to generation distribution factors which distribute generation resource awards to connectivity nodes.

         7. Uploads or enters any changes to load distribution factors which distribute load distribution awards to connectivity nodes.

      ii. The market operator (ISO) validates entered data. (See "Validation of Future Projects" use case.)

   c. Comments:

      i. The assumption is made that detailed resource models required for LMP markets are in a resource data base separate from the NMM.

ii. These resource models need to be mapped to the network model connectivity nodes (as per the CIM models) in the NMM.

iii. This use case reflects one possible set of market entity roles – there are many others.

Process Group C: Testing and Validation Processes

1. Use Case C1 – Validate Modeling of Newly Commissioned Work:
   a. Pre-conditions:
      i. The work is represented in one or more projects, which have been incorporated into the EMS state estimator model.
   b. New work has been commissioned (i.e. gone live).Scenario:
      i. The project changes are accurately represented in the EMS state estimator (state estimator matches field conditions).
         1. In present EMS, this sometimes must be accomplished by artificial switching.
         2. It could also be done by an incremental model update using the project.
      ii. State estimation results are monitored.
         1. If there is a parallel state estimation test capability, results with the new model could be directly compared with results for the old model.
         2. Otherwise the new model can simply be reviewed for acceptable accuracy.
      iii. When the project is deemed successful, the NMM is notified. (See "Update the PNM Baseline to Reflect Newly Commissioned Work" use case.)
   c. Comments:
      i. This use case reflects one possible approach to the sequencing of model validation and baselining. There are others.
      ii. Accuracy of the PNM baseline model is carefully controlled.
      iii. Changes are maintained separate from the model until thoroughly checked out. (The existing paradigm is that the EMS model is the 'best' representation of as-built, but since changes are made directly to the previous EMS model and often not tracked, there is little support for audit trails or corrections of errors in changes.)
2. Use Case C2 - Ongoing Validation of As-Built Model:
   a. Pre-conditions:
      i. State estimation provides a quantitative evaluation of model accuracy through the monitoring of residuals.
      ii. It is assumed here that a new model has been received from NMM for installation.

b. Scenario:
    i. EMS sets accuracy targets.
        1. This is different from criteria for acceptable solution.
        2. It is set to trigger a need for modeling review.
    ii. State estimation results are monitored over time.
        1. Consistently high residuals usually point to a local modeling or measurement problem.
        2. Sudden increase in a residual usually points to a switching condition that is not modeled or reported properly.
    iii. Results of detective work are used to improve models in PNM.
c. Benefits:
    i. All studies benefit from a proven accurate as-built model.
    ii. Debugging time for planners is minimized for the as-built.

3. <u>Use Case C3 - Validation of Future Projects</u>:
    a. Pre-conditions:
        i. Any new project is added to the PNM which is not yet implemented in the field.
    b. Scenario:
        i. PNM validation rules inspect the project.
        ii. The project is then added to the current PNM baseline in an NMM workspace (along with any projects that it depends on).
        iii. The workspace model is run in a power flow.
            1. Setting up and running a test power flow should be quick and easy.
            2. It could be implemented by stored procedures that export to a separate power flow environment.
            3. It could be implemented by a power flow service embedded in the NMM.
        iv. Depending on the nature of the project being validated, the workspace model could be exported and validated in any of the target consuming applications (short circuit, dynamics, QA/test EMS, QA/test market system, etc.).
    c. Comments:
        i. Modelers need to be able to assess quickly that the new project seems to be able to support power flow (or other network analysis function).
        ii. Model errors discovered by this process will initiate corrections being made in the NMM.

Process Group D: Exporting Base Cases for Operations and Planning Studies

1. Use Case D1 – Update the EMS Model:
    a. Pre-conditions
        i. EMS configuration environment is able to merge physical network model and specific types of case information supplied from the NMM into the remainder of its EMS configuration (which would address areas like RTUs, alarm categories, users and consoles, etc.).
        ii. One or more PNM projects reflecting soon-to-be-completed work or model corrections need to be incorporated into the EMS.
        iii. For audit purposes and for coordination with other parts of EMS configuration, it is important to the EMS to know how the new model differs from the previous one.
        iv. The NMM audit trail of the current (and soon-to-be replaced) EMS model shows:
            1. The baseline version used as the starting point.
            2. The projects that were added to it.
    b. Scenario:
        i. Run the EMS model script in NMM to load a workspace:
            1. Select the appropriate portions of the latest baseline model which are to be used by the EMS.
            2. Select approved projects within a specified time frame.
            3. Make any specific additional project deletions or inclusions.
        ii. Compare the workspace audit trail to the previous:
            1. Verify that the projects incorporated into the baseline being used for this assembly are those that were included as projects in the previous EMS model assembly.
            2. Verify the new projects being incorporated into this assembly.
        iii. Validate the resulting model in NMM to assure that the combined projects are ok.
        iv. Export the model (which could include PNM schematics and ICCP definitions) to the EMS, where it will be incorporated into the EMS configuration environment, further tested and put on-line.
            1. If testing reveals any problems, return to NMM and make adjustments.
    c. Comments:
        i. Assembly is largely automated.
        ii. This use case currently does not deal with how the modeling of normal operating hypothesis is created for EMS – specifically whether it is created in the NMM or in an EMS tool.

iii. Audit trails of models allow detection of events that would impact the EMS model.

2. <u>Use Case D2 - Build a New Planning Base Case of Type X</u>:
   a. Pre-conditions:
      i. A set of rules for Type X studies has been defined that describes what portions of the model make up the case.
      ii. A script for Type X physical model has been created. For example:
         1. Select the portions of the latest PNM baseline which are used by Type X studies.
         2. Select all approved projects for study date.
         3. Allow user to modify project list.
      iii. If operating hypotheses are to be completed in NMM, a script for Type X case construction has been created. For example:
         1. Import or construct energy statistical forecasts.
         2. Import or construct interchange assumptions.
         3. Import or construct scheduled energy inflow or outflow.
         4. Distribute energy forecast to points of inflow or outflow.
         5. Import or construct switch, tap position assumptions.
         6. Import or construct outage schedule.
         7. Import or construct controls setup.
         8. Import or construct limits setup.
         9. Import or construct contingency specifications.
   b. Scenario:
      i. The physical model script for Type X is executed. Parameters are entered as necessary.
      ii. The case part script for Type X is executed. Parameters are entered as necessary.
      iii. Operating hypotheses are modified manually as necessary, either by creating new sets of modifications or by invoking saved modifications.
      iv. An audit trail captures all assembly steps.
      v. The workspace is exported to the desired study tool.
   c. Comments:
      i. The ability to define rules and script the selection of appropriate portions of the network model and appropriate case parts allows a wide variety of studies to be described.
      ii. The physical model assembly is universally valuable:
         1. Greatly reduced assembly time for base case creation.

        2. All cases built from single, verified as-built model and selected set of consistent plans, so data quality is assured.
    iii. The case part value is more dependent on the specific TSO circumstance:
        1. If not present, then operating hypotheses are established in the study tool.
        2. Partial setups are ok.
        3. Ability to save and re-use 'case modifications' can be valuable for re-using things like controls setup.
        4. Energy forecasting and scheduling services will probably grow in value as the energy picture continues to get more complex.
    iv. Audit trail of case assembly allows:
        1. Detection of base cases impacted by a change in a project.
        2. Automatic regeneration of cases that are impacted by a change in a project.
        3. Significant net reduction in the probability of serious planning errors.
    v. Some kinds of cases that can be scripted in this way include:
        1. Use Case - Build Annual Submission to Interconnection Planning
        2. Use Case - Provide Historic Case for Post-Event Analysis
        3. Use Case - Set up Planning Outage Study Case
        4. Use Case - Build Short Circuit Case for Annual Submission to ISO
        5. Use Case - Build Short Circuit Case for Post-Event Fault Location

3. <u>Use Case D3 – Script New Physical Model Assembly</u>:
    a. Pre-conditions:
        i. A new model assembly script is required.
        ii. There may or may not be an existing script that is a prototype.
    b. Scenario:
        i. The script first identifies the portions of the model that will be composed.
            1. e.g. 'Take the latest baseline version for regions A, B C.'
        ii. The script then describes how to add projects.
            1. An explicit list.
            2. A filter specification, such as take all approved projects from source X with in-service dates prior to a given date.
    c. Comments:

i. The script should be able to be:

1. Entered from scratch conveniently
2. Recorded from manual actions
3. Extracted from a case audit trail and edited

ii. An audit trail should always contain the script action that drove it, but where a script is an abstract action that determines specifics, the specifics are also recorded.

iii. Scripting function allows faster execution and automatic process re-execution if input changes.

4. Use Case D4 – Script New Case Assembly:

a. Pre-conditions:

i. A new case assembly script is required.

ii. There may or may not be an existing script that is a prototype.

b. Scenario:

This area needs some thinking. Case assembly can be characterized in overview by saying that there is a collection of services that may be run (e.g. 'go get a load forecast') that initialize parts of a case, but then there are also manual entries– i.e. a set of changes to the initially generated parts. Finally, it is useful to be able to grab parts of other cases.

The desirable form of a script is as a sequence of parameterized operations.

Implementation of case assembly will be probably be phased. There is no absolute requirement for completeness. The absence of a particular part of a case simply means that it is left to the receiving application to fill in the missing data.

c. Comments:

i. The script should be able to be:

1. Entered from scratch conveniently
2. Recorded from manual actions
3. Extracted from a case audit trail and edited

ii. An audit trail should always contain the script action that drove it, but where a script is an abstract action that determines specifics, the specifics are also recorded.

iii. Scripting function allows faster execution and automatic process re-execution if input changes.

5. Use Case D5 – Update Outageable Equipment in Outage Scheduling Application:

a. Pre-conditions:

i. An outage scheduling application works with lists of outageable equipment.

ii. PNM defines equipment objects at appropriate level of granularity to support outageable equipment.

b. Scenario:

i. At appropriate time in project lifecycle new or modified equipment is identified as of interest to outage scheduling.

ii. Outageable equipment is appropriately identified to support required data exchanges among outage scheduling functions at the TSO, ISO and interconnect. This could mean that outaged elements are simply identified by MRID or it might mean that ISO and interconnect outage scheduler identifiers are registered as alternate identifiers.

iii. Equipment object and all necessary alternate identifiers are supplied to EMS, planning application, TSO and ISO outage scheduling applications.

c. Comments:

i. Sourcing all required equipment object identifiers from NMM allows subsequently defined outages to be used in case assembly without any manual intervention. (See "Provide Outage Schedules to EMS", "Provide Outage Schedules to Planning Study" and "Add/Update Outage Schedule" use cases.)

6. Use Case D6 – Create, Update or Baseline PSS®MOD Project:

a. Pre-conditions

i. Projects representing plans are maintained in PSS®MOD where they are managed and used in the creation of power flow cases.

ii. A plan has reached a state of review/approval where it is appropriate to add it to the projects managed in PSS®MOD.

b. Scenario:

i. NMM exports the project or updated version of the project to PSS®MOD.

ii. Project is added to project library in PSS®MOD.

iii. NMM creates new baseline

iv. NMM notifies PSS®MOD when a project has been incorporated into a new baseline.

v. PSS®MOD takes appropriate local action to include project that has been completed in its baseline.

c. Comments:

i. Exported project needs to be at the level of detail appropriate for project managed by PSS®MOD, which is likely bus/branch.

7. Use Case D7 – Provide New, Updated or Baseline Project to Protection Software

a. Pre-conditions

i. Some protection software (like CAPE or Aspen) supports model updates via mechanisms analogous to projects (groups of equipment that have in-service and out-of-service dates, for example). An adapter is available to transform project-based changes into the protection software's local change handling approach.

ii. An NMM plan has reached a state of review/approval where it is appropriate to export it to the protection software tool.

b. Scenario:

i. Export the project or updated version of the project to the protection software.

ii. Adapter translates project into protection software's local change definition format.

iii. NMM creates new baseline

iv. NMM notifies protection software when a project has been incorporated into a new baseline.

v. Protection software takes appropriate local action to include project that has been completed in its baseline.

c. Comments:

i. Exported projects needs to be at the level of detail appropriate for protection software.

8. <u>Use Case D8 – Update ISO Market System Model</u>:

a. Pre-conditions:

i. A set of changes affecting the Market System has been entered as one or more projects in the NMM and needs to be put into production.

ii. Resource Models are populated in a resource data base separate from the NMM.

iii. Mappings to pricing nodes and aggregated pricing nodes have been created in the NMM.

b. Scenario:

i. Run the Market System model script in NMM to load a workspace:

1. Select the appropriate portions of the latest baseline model which are to be used by the Market System.

2. Select the appropriate projects.

ii. Compare the workspace audit trail to the previous:

1. Verify that the projects incorporated into the baseline being used for this assembly are those that were included as projects in the previous Market System model assembly.

2. Verify the new projects being incorporated into this assembly.

iii. Validate the resulting model in NMM to assure that the combined projects are ok.

iv. Export the model to the Market System, where it will be incorporated into the Market System configuration environment, further tested and put on-line.

c. Comments:

i. Part of the Market System testing mentioned under iv. above would be the validation of network model to resource data base mapping.

ii. This is one way that Market System update could be done. The Market System model might also be created directly from the EMS model.

9. <u>Use Case D9 - Build a Post-Event Analysis Case</u>:

a. Pre-conditions:

i. The environment exists in the NMM to build cases of different types (see "Build a New Planning Base Case of Type X" use case).

ii. Pointers to real-time data points (measurements) are maintained as part of the PNM and real-time data history is stored in a data historian.

iii. A grid event has occurred and there is a need to perform studies using planning applications.

b. Scenario:

i. A physical model script is executed to assemble a network model for the planning application for the appropriate time in history.

ii. The case part script is executed that retrieves needed historic real-time information (breaker states, loads, generation levels) from the real-time data historian based on the measurement pointers in the assembled physical network model.

iii. Other operating hypotheses are modified manually as necessary, either by creating new sets of modifications or by invoking saved modifications.

iv. An audit trail captures all assembly steps.

v. The workspace is exported to the planning application.

c. Comments:

i. The ability to associate historic real-time information with planning models should greatly simplify creation of post-event study cases.

Process Group E: Input from Cases

1. <u>Use Case E1 – Online EMS Changes/Corrections into NMM</u>:

a. Pre-conditions:

    i. Changes to limits, impedances, non-telemetered loads, normal device states, etc. can be made between database updates in the EMS online environment
    ii. EMS is capable of tracking corrections/changes and filtering and supplying them to NMM
  b. Scenario:
    i. EMS creates list of changes entered between database updates and supplies them to PNM as a project
  c. Comments:
    i. Corrections are accurately and consistently applied to source data and are available for use by all consumer applications

Additional Use Cases Enabled By NMM

1. <u>Use Case X1 – Add/Update Outage Schedule</u>:
  a. Pre-conditions:
    i. Outages are defined in TSO outage scheduling application based on lists of potentially outageable equipment which have been populated from PNM. (See "Update Outageable Equipment in Outage Scheduling Application" use case.)
  b. Scenario:
    i. Outages are requested by field or other personnel using TSO outage scheduling application and are described in part by identification of clearance point equipment.
    ii. Outages at a certain stage of approval are shared with the ISO outage scheduling application an appropriate amount of time in advance (using the TSO to ISO equipment object mapping provided by the PNM).
    iii. The ISO studies the request and approves (or rejects) and, in turn, may share the outage into an interconnect-wide outage system like NERC SDX (leveraging the interconnect equipment object identification mapping provided by the PNM).
    iv. TSO, ISO and interconnect outages are available to be shared with EMS (see "Provide Outage Schedules to EMS" use case) and for use in planning study case construction (see "Provide Outage Schedules to Planning Study" use case).
  c. Comments:
    i. Correlation of equipment identifiers across EMS, planning applications and outage scheduling applications significantly reduces labor for building outage studies.
    ii. Another possibility is that outages are stored in the NMM itself, as part of the case parts repository and are shared from there with the EMS and planning applications (see "Build a New Planning Base Case of Type X" use case).

2. Use Case X2 – Provide Outage Schedules to EMS:
    a. Pre-conditions:
        i. PNM stores equipment object identifiers and related EMS, TSO outage scheduler, ISO outage scheduler and interconnect-wide outage system names/identifiers as appropriate. Alternate names/identifiers are shared with EMS and outage schedulers as needed.
        ii. EMS has an outage scheduling function, with a CIM-based API, that receives and stores outages which can be included in setup of study cases based on outage start/stop times.
    b. Scenario:
        i. Outages from the TSO outage scheduler, ISO outage scheduler and the interconnect outage system (like NERC SDX), as applicable, are automatically transferred to EMS outage scheduling function when they reach a certain level of approval and are subsequently updated if they change.
        ii. Equipment object identifiers are accurately and automatically translated, using the PNM-provided mapping, either by the scheduling function before sending the outage or by the EMS after receiving the outage.
        iii. Internal and external outages are available for use in EMS outage studies.
    c. Comments:
        i. Outage definitions automatically supplied to EMS with useable identifiers, which will significantly reduce labor in setting up EMS study cases.
        ii. As noted in other outage-related use cases, there are alternative solution strategies. The objective is to assure that the EMS has access to the same view of schedules as planning, and that the identifiers are consistent with the EMS model.
3. Use Case X3 – Provide Outage Schedules to Planning Study:
    a. Pre-conditions:
        i. PNM stores equipment object identifiers and related planning application, TSO outage scheduler, ISO outage scheduler and interconnect-wide outage system names/identifiers as appropriate. Alternate names/identifiers are shared with planning application and outage schedulers as needed.
        ii. Planning application has translation interface (populated from the PNM) that allows outages from TSO and ISO outage schedulers and interconnect-wide outage system (like NERC SDX) to be mapped to planning application equipment identifiers.
    b. Scenario:
        i. Applicable outages from the TSO outage scheduler, ISO outage scheduler and the interconnect outage system (like

NERC SDX) are requested and processed by the translation interface when needed to construct outage study cases in the planning application.

ii. Equipment object identifiers used in describing outages are accurately and automatically translated, using the PNM-provided mapping, so that internal and external outages are available for use in planning outage studies.

c. Comments:

i. Accurate correlation of equipment identifiers across planning application and outage scheduling applications significantly reduces labor for building outage studies.

ii. As noted in other outage-related use cases, there are alternative solution strategies (see the "Build a New Planning Base Case of Type X" use case as an example).

Section 5: Summary of Benefits

The benefits of fully realized centralized network model management are substantial and far-reaching. The use cases of the preceding section identified many of them. The following list summarizes the major areas where improvements appear likely to occur:

Existence of a generally-accessible, single source of model data.

- Features:
  - Understood as "the" reference model for current as-built model and for project changes
  - Model contains "best" known information from most reliable source
  - All model updates and case creation are generated from the single source
  - Data model is well-designed and data are well-organized leading to replicable model and case assembly processes and the opportunity for automation through scripting
  - Model content is consistent among consumer applications and need for manual comparisons is eliminated
- Benefit: Modeling time cut substantially, as changes are entered only once and all consumer applications receive the information they need.

Model accuracy is improved for all applications.

- Features:
  - Validated as-built model forms the basis for construction of all cases
  - Plans are centrally managed and maintained
    - Completeness of data is easier to ensure
    - Each case using a project gets an accurate, up-to-date version of the project
  - Changes to projects trigger re-creation of affected cases
- Benefit: Quality of study results is improved and labor spent identifying/correcting problems is reduced.

Quantitative validation of modeling is facilitated.

- Features:
  - Since data entry points are well defined, clear validation rules can be implemented
  - Data are validated at multiple points:
    - Upon entry in PNM (proper structure and value range)
    - Internally when collection of data is complete (automatic reasonability cross checks)
    - Externally when case can be created
      - as-built model exported to EMS for state estimation
      - Future cases assembled and validated by power flow
    - Visual confirmation of model or project accuracy is provided by PNM schematics
- Benefit: Confidence in study results is improved.

Model maintenance work flow processes are enhanced.

- Features:
  - Updates (including commissioning) are communicated accurately and in a timely fashion to all target functions (consumer applications)
  - Need for source data is identified and communicated at appropriate point in project lifecycle
  - Business processes supporting data integrity are understood and facilitated and ongoing improvement is possible
- Benefit: Data completeness and quality are improved and labor spent correcting errors or oversights is reduced.

Model and case information exchange is streamlined.

- Features:
  - Model and case information produced in CIM standard form
  - Data exchange interface requirements for consumer applications can be concisely specified
  - Data exchanged in standard form is agnostic as to consumer product, facilitating arms-length communication and reducing dependency on any one vendor
- Benefit: Forward-looking solution positions utility to effectively deal with future process or application changes (both internal and external).

History is maintained.

- Features:

- Versions of as-built model through time are stored, allowing case reconstruction for past points in time
- Project status and content changes are tracked
- Audit trail of case assembly provides clear understanding of case assumptions and the ability to accurately re-create cases after model changes

▪ Benefit: Ability to support post-event analysis greatly increased. Labor to manage model changes effectively over time is significantly decreased.

Documentation is improved.

▪ Features:
  - Scope of projects can be better communicated through use of schematics
  - Case assumptions and assembly process steps are documented for each case
  - Completion of each project is recorded

▪ Benefit: Labor spent communicating and managing changes is reduced.

Section 6: NMM Core Requirements

This section defines a core set of requirements which a commercial NMM product would be expected to meet. These requirements cover the product only. Any utility that implements an NMM will also have a major effort to integrate the NMM product with the other systems that are involved with network analysis. The requirements of that integration are not covered here, because they typically vary quite a bit from one utility to the next based on a utility's specific configuration of product choices, physical sites, organizational choices and business processes. The boundary drawn here is to define an NMM product that is required to be 'integration ready'; that is, with the right features so that it can fit cost-effectively into any utility's CIM-based integration project.

Requirements Principles

The rationale behind including or excluding a given requirement in NMM requirements is based on the NMM goal, which is to define a product that would be useful to enough utilities such that it would be worthwhile for vendors to compete in developing, selling, maintaining and enhancing such a product.

- For vendors, the requirements explain a core set of features and functions that an NMM product will be expected to meet.
- For utilities, the requirements provide a basis for evaluating and ultimately purchasing a product offering, as well as for planning an integration project.

With these purposes in mind, the principles upon which these requirements are based are as follows:

- Requirements are stated in a manner that leaves as much latitude as practical for vendor competition. Thus, for example, even though something like a graphical editing capability is an extremely important factor in selecting a good NMM, here the requirements are expressed in a minimal form, precisely in order to encourage vendor competition. (It follows that where requirements are less specific, it is a signal to utilities that comparative evaluation of products in this area is probably important.)
- Usually the degree of detail in requirements is dictated by the role a particular capability plays in the goal of establishing workable consolidation of network analysis modeling. Thus, for example, the requirement for creating and managing model building blocks gets attention, because that is seen as critical to being able to supply many different kinds of analytical environments from common sources.

- The most specific requirements are given where the NMM must interoperate according to specific industry standards. Usually, though, in this area there is simply a reference to IEC standards.
- Requirements here never dictate specific implementation techniques or technologies. Thus, for example, if a utility wants an Oracle DB implementation of an NMM, then it would be up to the utility to look for a vendor that had chosen that approach.

Glossary of Terms

The tables in this section define terms relevant to the NMM. Table 6-1 gives some relevant generic CIM terms. Table 6-2 is specific to power grid network modeling.

Table 6-1
Generic CIM terms

Term	Definition
CIM	Depending on context, 'CIM' can refer broadly to the standards and processes created by IEC TC57 WGs that share the use of a canonical data model, or it can refer to the canonical data model itself.
Canonical Data Model Canonical Model CDM	An information model defining the agreed common semantics within some scope of integration. In CIM standards, the canonical model is the CIM UML model. In CIM integration efforts, the canonical model is usually an extension of the CIM UML.
CIM Canonical Object	CIM standards build interoperability around the use of Master Resource Identifiers for objects in data exchanges. A CIM Canonical Object is a thing (like a circuit breaker) or concept (like a circuit breaker role in the network) that has been assigned a CIM MRID with the intent that this MRID will be used wherever CIM Data Objects refer to the thing or concept.
MRID (Master Resource Identifier)	An MRID is a CIM Canonical Object identifier. The preferred data type is an UUID, which virtually assures global uniqueness.
Object Registry	A facility where Canonical Objects may be registered, and which can maintain an arbitrary number of alternate names used by different systems.
CIM Data Object	A CIM Data Object is a basic unit of concrete data in a CIM Dataset, describing selected properties of a CIM Canonical Object. • Identified by MRID and based structurally on a class of the Canonical Model. • Contains selected properties as defined by the UML for the CIM Dataset in which the data object appears.

Figure 6-1 (continued)
Generic CIM terms

Term	Definition
CIM Dataset	A CIM Dataset is a set of CIM Data Objects that share some common purpose. Content may include data objects from multiple canonical classes with relationships between them – i.e. these may be complex structures. • CIM Dataset contents and structure are defined by an information model derived from the CIM UML. In effect, this information model 'types' the CIM Dataset. • A CIM Dataset may be stored somewhere or transported as part of a data exchange. • Relationships expressed by CIM Data Objects in a CIM Dataset may target CIM Data Objects that appear in other CIM Datasets. These are called 'dangling references'. • A CIM Dataset is characterized by its information content and is considered the same regardless of how it is serialized or stored.
CIM Dataset Type	A dataset information model (expressed in UML) which constrains the information that can be contained in a CIM Dataset.
Incremental Dataset	An Incremental Dataset is a specification of data changes. As with CIM Datasets, incrementals conform to a CIM Dataset Type. They consist of add, modify and delete operations on CIM Data Objects. While incrementals are typically defined in relation to a CIM Dataset (or two CIM Datasets, in the case of a differencing operation), they are considered to be independent data specifications that can be applied in contexts different from the one in which they were developed. Incrementals are designed to be used with the function Inc, which applies a sequence of Incremental Datasets to a target CIM Dataset.
Composition Function or Service	A function designated by U which takes a set of CIM Datasets as arguments and generates a union of the input. When CIM Data Objects appear in more than one of the input sets, the attributes are merged into one composed instance of that object but the source dataset of each property remains known.
Incremental Function or Service	A function designated by Inc which takes one or more Incremental Datasets and adds them in sequence to a CIM Dataset.

Table 6-2
Power grid network modeling terms

Term	Definition
Model Part	A container for a CIM Dataset whose CIM Data Objects make up a network modeling building block, and which is governed by a Model Part Specification. Most commonly, a Model Part is a version of an evolving sequence defined by a given Model Part Specification.
Model Part Specification	CIM network modeling is based around the idea that Model Parts are designed as building blocks for assembling complete models for various purposes. Model Parts therefore have an enduring role, even though content evolves from one version of a Model Part to the next. The Model Part Specification defines the enduring characteristics of the building block, including: • Name • Model Authority • Purpose • CIM Dataset Type A Model Part Specification may also have an association to a Framework Part. In particular Model Part Specifications with a CIM Dataset Type of EQ (Equipment) will have this association. This association defines, formally, the role a Model Part conforming to the Model Part Specification can play in the overall building block framework and how it plugs together with other Model Parts.
Model Authority	A party that is responsible for managing and maintaining a Model Part is designated as the Model Authority of that part.
Assembly or Network Model Assembly	A collection of Model Parts that have been composed, which basically means that they can be treated as a whole as well as by the parts. Composition is a process. It starts with one Model Part and ultimately creates a complete model for some purpose.
Physical Network Model Part or PN Model Part	A Model Part whose CIM Dataset describes the characteristics of the grid inherent in its construction. Physical Network Model Parts conform to Model Part Specifications which have CIM Dataset Types of: • EQ (Equipment) • DY (Dynamics) • GL (Geographic Locations) • DL (Diagram Layout)
EQ Model Part	A special type of PN Model Part whose Model Part Specification has a CIM Dataset Type of EQ (Equipment).

Table 6-2 (continued)
Power grid network modeling terms

<table>
<tr><th>Term</th><th>Definition</th></tr>
<tr><td>Case Model Part</td><td>A Model Part that describes a steady-state input or output condition. Case Model Parts conform to Model Part Specifications which have CIM Dataset Types of:
SSH (Steady-State Hypothesis)
TP (Topology)
SV (State Variables)</td></tr>
<tr><td>SSH Model Part</td><td>A special type of Case Model Part whose Model Part Specification has a CIM Dataset Type of SSH (Steady State Hypothesis).</td></tr>
<tr><td>Base Case</td><td>A complete Assembly of Physical Network Model Parts plus Case Model Parts.</td></tr>
<tr><td>Framework Part</td><td>A Framework Part defines a role in a modeling framework. There are two fundamental kinds of parts: Frames and Boundaries. Think of panes in a window lattice. The latticework is made up of pieces that separate two panes – these are Boundary parts. The area filled by a pane of glass is a Frame part. Both kinds of Framework Parts are ‘filled’ by EQ Model Parts, but the EQ Model Parts that define Boundaries are small, consisting only of the necessary mutually agreed modeling, while the EQ Model Parts that are used to fill Frames are large.
Model Parts other than EQ Model Parts can be associated with Framework Parts, though it is EQ Model Parts which contain the CIM Data Objects with the connectivity relationships that conform to the framework.</td></tr>
<tr><td>Frame Part
or Frame</td><td>A Framework Part that defines a model building block that can be modeled unilaterally – usually corresponding to something like ‘the territory that a given utility entity will take responsibility for modeling’. A Frame Part will be ‘filled’ by an EQ Model Part.
A Frame Part is defined by the Boundary Parts that border it.</td></tr>
<tr><td>Boundary Part
or Boundary</td><td>A Framework Part that will be ‘filled’ by an EQ Model Part which contains CIM Data Objects that two framed territories have mutually agreed on as boundary objects. This bilateral agreement has two principal characteristics:
Each party agrees to follow a mutually agreed procedure for modifying boundary objects.
The objects in the boundary terminate all references between the parties.</td></tr>
</table>

Table 6-2 (continued)
Power grid network modeling terms

Term	Definition
Edge Model Part	A special type of Model Part. When large interconnected grid frameworks are used in studies, the studies often do not cover the entire framework. The simplest way to reduce study size is to exclude whole regional parts, thereby 'cutting off' the model at the boundaries that separate included regions from excluded regions. When this is done, something must represent the flow into the cut off region. A common and simple approach is to use an Edge Model Part containing equivalent generator objects at the ties. An EQ (Equipment) Edge Model Part can be defined in a standard way for each bilateral boundary.
Model Variation	A container for an Incremental CIM Dataset which is governed by a Model Variation Specification. Most commonly, a Model Variation is a version representing one point in time in an evolving sequence of Model Variations which conform to a given Model Variation Specification.
Model Variation Specification	A Model Variation Specification defines the enduring characteristics of a collection of changes to a model, including: • Name • Model Authority • Purpose • CIM Dataset Type A Model Variation Specification may also have an association to a Framework Part. This would be particularly true if the CIM Dataset Type were EQ (Equipment). If present, this locates the part of the modeling framework that the changes impact.
Physical Network Model Variation	A Model Variation that describes changes to the characteristics of the grid inherent in its construction. Physical Network Model Variations are commonly referred to as 'Projects' and conform to Model Variation Specifications which have CIM Dataset Types of: • EQ (Equipment) • DY (Dynamics) • GL (Geographic Locations) • DL (Diagram Layout)
Case Model Variation	A Model Variation that describes changes to steady-state input conditions. Case Model Variations conform to Model Variation Specifications which have CIM Dataset Types of: • SSH (Steady-State Hypothesis) • TP (Topology)
CIM Dataset Type DL	Diagram layout defined by IEC 61970-453

Table 6-2 (continued)
Power grid network modeling terms

Term	Definition
CIM Dataset Type DY	Dynamics data defined by IEC 61970-457
CIM Dataset Type EQ	Equipment and connectivity defined by IEC 61970-452
CIM Dataset Type SSH	Steady state hypothesis defined by IEC 61970-456
CIM Dataset Type SV	State variables defined by IEC 61970-456
CIM Dataset Type TP	Topology defined by IEC 61970-456

NMM Product Requirements

Physical Network Model (PNM) Requirements

The main mission for NMM overall, and PNM in particular, is to enable management of a set of core master Physical Network Model Parts (PN Model Parts), which assure that master data items have one source (the 'Model Authority'), and which may be assembled or manipulated in various ways to meet all of the important network analysis requirements for study models.

Each PN Model Part contains a CIM Dataset. Any dataset is characterized by its information model, plus the list of specific objects it contains, which usually corresponds to some logical set like 'the objects owned by a TSO'.

The PN Model Parts are the subset of information managed in NMM which represents the capabilities of grid elements as constructed (as opposed to choices about how to operate the grid). This distinction is made because the data about construction generally come via different processes from different sources (as compared to the operating choice data).

R1.

The NMM shall provide a PNM that provides a secure, redundant permanent store for PN Model Parts.

The term "parts" is significant, as the PNM is not one single model or set of models, but rather a collection of PN Model Parts that can be assembled into whole models for a particular purpose.

The PNM repository contains important master data sources that are not, in general, easy to recover if they are lost or destroyed, so data security and backup practices should be used to assure their continued integrity.

R1.1.

The PNM shall provide a directory of PN Model Parts stored which lists all attributes of each stored PN Model Part and its Model Part Specification.

A Model Part is basically a CIM Dataset plus annotation and a PN Model Part is one whose CIM Dataset includes only physical network model information. Properties of a PN Model Part shall include, but shall not be limited to:

- Name
- Version number (sequenced)
- Model Part Specification
- Date of creation
- Any other attributes that become part of the CIM standard

R1.2.

The kinds of data the master PNM is capable of managing shall correspond to the network's inherent physical electrical characteristics, as opposed to specifications of the operating hypotheses that are also required to define complete cases for power flow. This distinction shall be maintained in the same way that it is defined in IEC CIM standards.

Examples of content covered by the master PNM include:

- Equipment parameters to support steady state, short circuit and dynamics analyses
- Connectivity
- Geographic location
- Schematic diagram layout
- Access to alternate object naming (to allow mapping of objects between systems and to satisfy different applications' naming constraints)
- Measurement locations
- Asset and asset information references

CIM standards currently define the following CIM Dataset Types that PNM shall be configured to manage 'out-of-the-box':

- EQ: Equipment specifies the existence of grid power system resources, and includes modeling of steady-state electrical characteristics and electrical connectivity with other resources. Defined in 61970-452.
- DL: Diagram Layout specifies an arrangement of visualizations of objects in a space for the purpose of defining things like schematic diagrams. Defined in 61970-453.
- DY: Dynamics specifies enhancement of equipment information with dynamic models. Defined in 61970-457.
- GL: Geographic Location allows geographic location data to be specified for many different types of CIM Data Objects. Defined in 61968.

R1.3.

The kinds of data that the master PNM is capable of managing shall include all PN Model Part types plus extensions as necessary to satisfy the requirements of all network analysis functions.

What distinguishes the functions that should use the network model from other functions? A basic test is that consumers are those functions that require a system view of the grid – in other words, functions that require knowledge of how the network components are connected together and interact to deliver some capability.

- A function that analyzes an individual breaker's or transformer's history to determine appropriate maintenance action does not need the network model and therefore does not drive requirements for the PNM.
- A power flow, on the other hand, clearly has a system view and needs the PNM.
- An in-between example would be a function that calculates a circuit rating based on the circuit's component parts. It might be included as a PNM consumer on the basis that it needs a model of connectivity and PNM has that capability. On the other hand, a separate application might handle this and supply a simplified circuit model to the PNM.
- There are also applications which require subsets of PNM data (outageable collections of equipment or geo-coordinates of lines) which are not the primary drivers of PNM content but which will leverage it once it exists.

A partial list of PNM consumer functions includes:

- EMS network analysis
- RTO/ISO network analysis
- Outage management
- Interconnection planning
- Local planning
    - Short circuit and relay setting
    - Ratings calculation
    - Operations planning
    - Stability
- Geo-based visualization functions correlating line or equipment position to other information like weather, Ground Induced Current (GIC) or synchrophasor data

R1.4.

The PNM shall be designed to integrate with an asset management system using profiles derived from the CIM standard.

In CIM, a very important distinction is made between assets and the network model. Although many of the network model objects sound like they are assets (like a circuit breaker), in fact what is being described is the role in the network played by a circuit breaker. The reason for this distinction is that a role or position in the network is planned before any asset is identified, and over the role's lifetime, a number of different assets may fill the role. In some historical contexts, the history of the role is important; in others, the history of the asset is important. PNM manages the network model objects that represent roles and, critically, how these roles make up a blueprint for the grid as a whole.

The PNM shall be designed so that it can take properties from an asset system and maintain relationships between PNM objects and objects in an asset system. In a planned change to a network model, the role may acquire nominal properties from an asset system. When constructed, an actual asset is installed in the role and the role takes on the specific properties of the asset. If integrated, objects in PNM shall have associations to objects in the asset system.

R1.5.

The PNM shall be capable of managing distribution PN Model Parts, which normally requires integration (in varying degrees) with GIS systems.

While in transmission a PNM may operate without any ongoing integration with an asset source, in distribution this is much less likely. PNM is not intended as an asset management replacement. Distribution planning tools are currently often "glued" to GIS asset systems. PNM is also not intended to change this. Its value in distribution contexts is more likely to be settings like Distribution Management Systems where network analysis is a part of operating the distribution grid – e.g. in Volt-VAR analysis.

In this case, PNM needs to be able to draw from GIS any data that exists therein. However, the content of GIS is variable and the PNM will also have to be able to complete the models for the purposes of its own targets. (For example, GIS systems commonly do not model substations or feeder measurements.)

R1.6.

The PNM shall be designed to include PN Model Parts imported from other sources as well as PN Model Parts maintained by the NMM owner.

There are a number of different use cases in which PN Model Parts may be imported from external sources:

- A TSO building network models typically must model territory external to the TSO itself, and for which either the TSO's neighbors or an ISO/RTO type of organization is the logical source of data.
- For ISOs, it is common that the source for all modeling is another organization – either their members or a neighboring ISO/RTO. Since the mission of the NMM is support of network analysis, rather than just data

management internal to the entity that owns the NMM, this means that the NMM must be designed to manage imported parts as well as parts maintained internally.

- For 61850 substations (or other 61850 installations), it may be desirable to use the 61850 models as the source model, converting the 61850 information to CIM and using the result as an imported PN Model Part.
- For pure distribution, a GIS may be used as a source for network models that are completed in the PNM.
- Even though the focus of distribution analysis may involve only one feeder operating radially, a feeder typically has ties with other feeders which can be modeled by different sources and analysis sometimes needs to deal with either closed ties for networked operation or changing the location of open ties.

The PNM design should also anticipate a need to merge or at least coordinate transmission and distribution network models, so that, for example, a distribution PNM owner could import transmission models to generate energy source models at substations and a transmission owner could import distribution models to generate load models at substations.

The main difference for imported parts is the way that updates are managed. For internal PN Model Parts, updates are accomplished by adding new Projects. For external parts, although it must be possible to import Projects associated with external areas, updates are more likely to be accomplished by importing a complete new version of the PN Model Part.

R1.7.

The PNM shall be designed such that it supports the composition of Model Parts into models for various purposes. The strategy for doing so shall conform to CIM standards.

A universal need in model management (whether inside a utility or between utilities) is the ability to define parts of the physical network model that can be:

- Maintained by an entity
- Exchanged between entities
- Assembled to create complete network model instances.

In order to fit together into a single electrical grid model, parts must have defined 'connectors'. This is generally handled because there will be an object in one Model Part that has an association to an object in another part, so that the end result is that when a Model Part is viewed on its own, it may have dangling associations that are 'waiting to be completed'.

R1.7.1.

The PNM shall support the specification of a model framework consisting of Framework Parts.

A framework does not define a specific model. Rather, it defines conceptual roles that can be used to construct models from Model Parts. Model Part Specifications associate with Framework Parts to determine the role of a Model Part in constructing models. There may, however, be more than one Model Part Specification that is associated with any Framework Part.

Two types of Framework Parts shall be supported:

- Frame Parts
- Boundary Parts

R1.7.1.1.

The PNM shall support the specification of Frame Parts.

Figure 6-1 shows a pictorial of a basic framework for an interconnection model consisting of nine TSOs. The important element in this kind of framework is that each of the nine TSOs is the Model Authority responsible for providing the portion of the model that represents its territory. The goal is to allow each Model Authority to build its Model Parts as independently as possible, while still assuring that all parts will plug together without any manual intervention.

R1.7.1.2.

The PNM shall support the specification of Boundary Parts.

The framework in Figure 6-1 has twelve Boundary Parts (shown in red), which define agreements about how the TSO Model Parts will plug together.

Boundary Parts are bilateral, defining the border between exactly two Frame Parts. More precisely, a Boundary Part specifies a building block that would contain all CIM Data Objects on which the neighboring Model Authorities must agree in order that their unilaterally-defined Model Parts will fit together. In most situations, this set only includes EQ Data Objects (reflecting the fact that there is a point where adjacent areas are electrically connected). Thus the role defined by a Boundary Part is usually filled only by EQ Model Parts.

The PNM shall maintain the associations between Boundary Parts and the two Frames they divide.

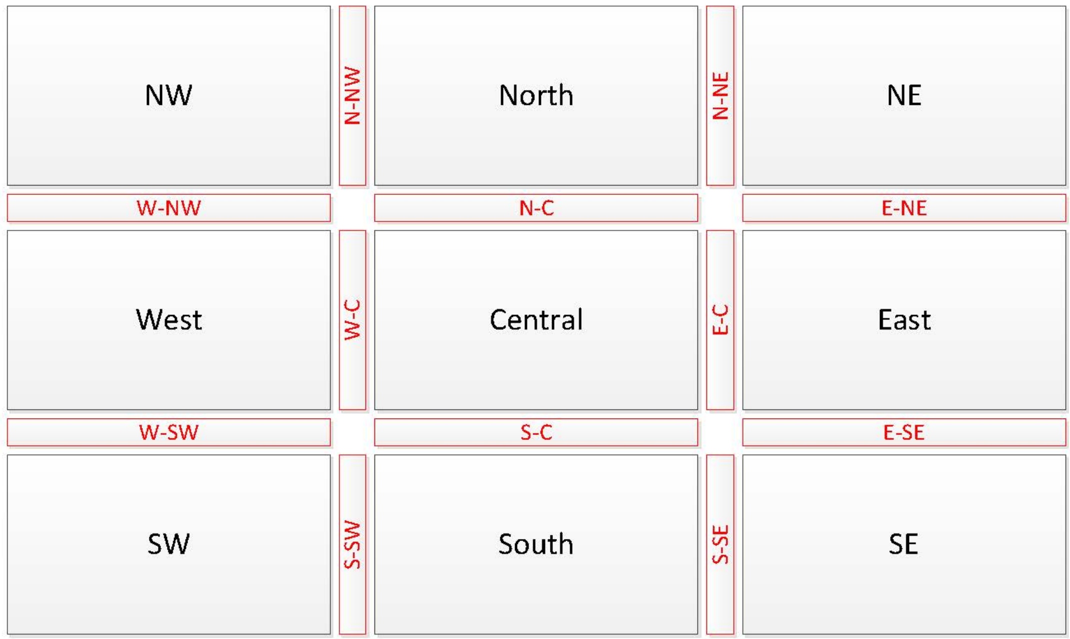

Figure 6-1
A Framework for a bulk power grid

R1.7.2.

The PNM shall be able to support network model frameworks that subdivide regions within other frameworks in order to facilitate coverage of the maximum number of study situations.

This essentially requires a recursive relationship in which a Framework Part may consist of any number of other Framework Parts.

R1.7.2.1.

The PNM shall be able to use decomposed views made up of nested Framework Parts in order to facilitate creation of simplified or equivalenced studies.

Figure 6-2 and Figure 6-3 show two approaches to Central region EQ modeling within the bulk power framework shown previously. The first is a monolithic approach, in which the intent is simply to maintain one complete EQ Model Part representing all of the Central region. In that case, there is also just one corresponding Central Frame.

In the second approach, the idea is to decompose the Central region into multiple EQ Model Parts, in order to provide more flexibility in constructing different kinds of models. The parts shown in Figure 6-3 include:

- A Central bulk power grid EQ Model Part that includes bulk power injection points

- Several 'mid-grid' EQ Model Parts, representing sub-transmission, each of which has:
  - A grid representation
  - A representation of injection points
- A set of internal boundaries between the mid-grid parts

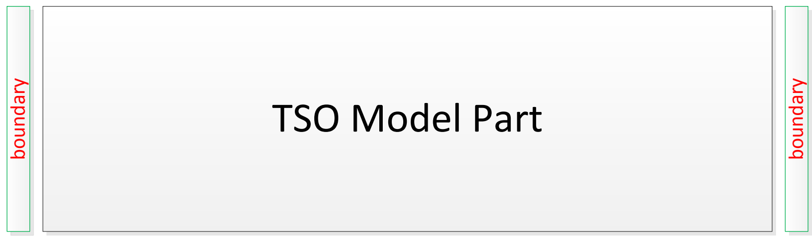

Figure 6-2
A monolithic TSO Frame and Model Part

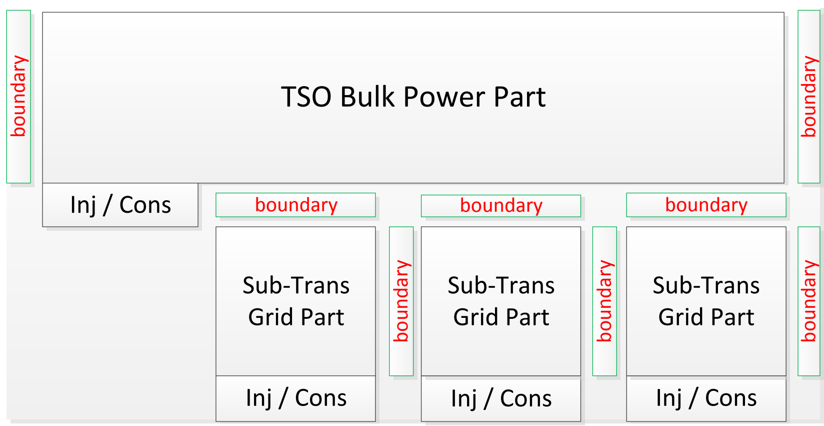

Figure 6-3
Decomposed representation of TSO as multiple Frames containing multiple Model Parts

The PNM shall be capable of defining a recursive framework describing this decomposed approach. It shall also be capable of using a monolithic framework, wherein the Central Model Part is constructed from a decomposition defined in a separate framework.

Some studies require that the TSO be modeled fully. Other studies only want a bulk power view. One intent in decomposing the Central region is that the latter kind of study could use only the bulk power parts and throw away the mid-grid parts (replacing them with net injection Edge Model Parts).

R1.7.2.2.

The PNM shall be able to use decomposed views in order to facilitate continuous transmission-to-distribution modeling.

The decomposition concept can be carried out recursively, as illustrated in Figure 6-4. This would allow continuity in modeling between all voltage levels. One specific goal of this modeling continuity would be to enable more accurate representations of injections in higher voltage studies by processing results of lower voltage analysis; another would be to enable more accurate representations of voltage sources in lower voltage studies by acquiring results from higher voltage analysis.

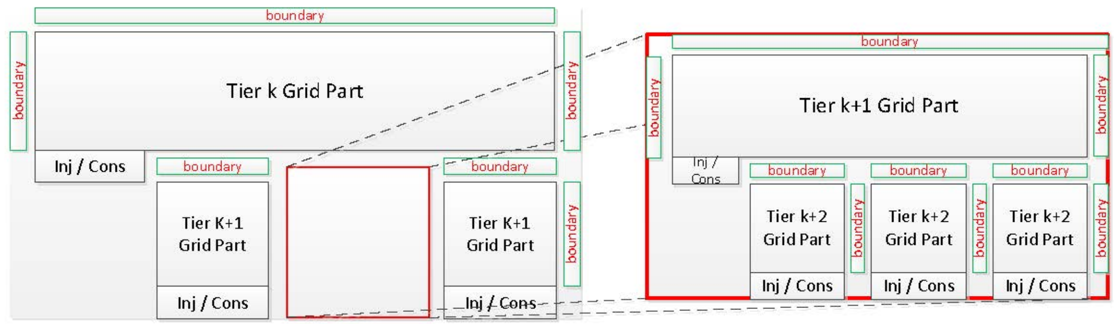

Figure 6-4
Network model Framework with recursive decomposition

R1.7.3.

The PNM shall maintain the relationship between Model Parts and Framework Parts.

R1.7.3.1.

The PNM shall be able to associate a Model Part Specification with a Boundary Part.

Boundary Parts are bilateral, separating two regions. They are 'filled' with a Model Part, containing mutually agreed-upon objects, via a Model Part Specification.

R1.7.3.2.

The PNM shall be able to associate a Model Part Specification to a Frame Part within a framework.

Frame Parts are 'filled' by Model Parts via Model Part Specifications. An example of this for EQ Model Parts is shown in Figure 6-5.

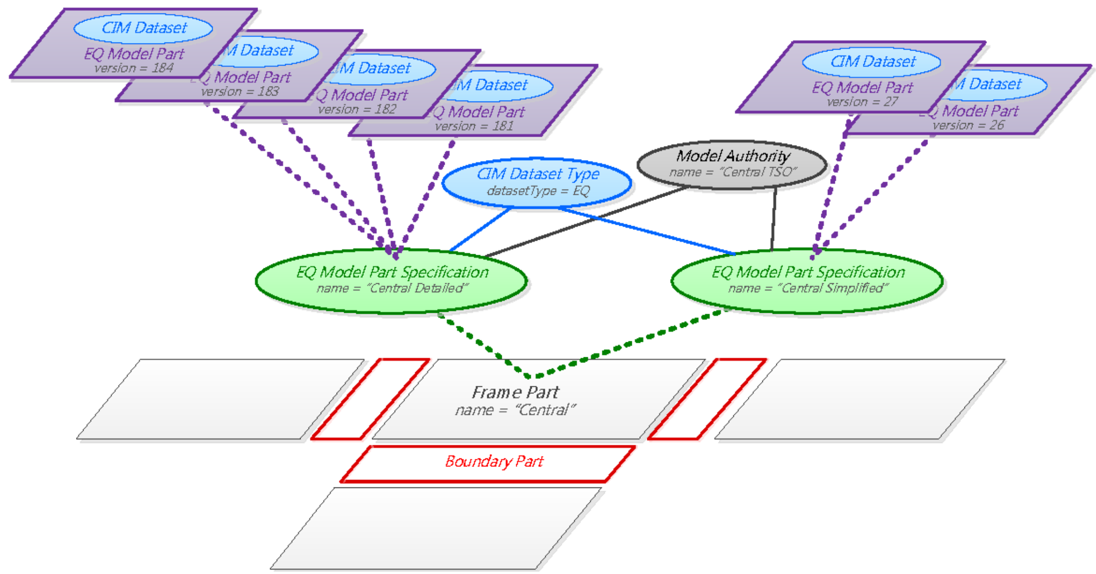

Figure 6-5
EQ Model Parts available to 'fill' a Frame Part

CIM Data Objects in Model Parts used to 'fill' Frames are unilaterally modeled by a Model Authority and can have external relationships (dangling references) only with CIM Data Objects in Model Parts of the same type that 'fill' Boundary Parts. Proper completion of dangling references can be validated by composing a Model Part related to a Frame using the Model Parts associated with the appropriate Boundary Parts.

R1.7.3.3.

The PNM shall be able to share a Model Part Specification across a framework.

It makes sense to define some CIM modeling classes, such as BaseVoltage, universally for a framework, rather than repeating them within each Model Part. The PNM shall allow a Model Part Specification to contain such objects and be 'shared', which means that other Model Parts may have references into objects in the shared Model Part (but not the other way around).

R1.7.3.4.

The PNM shall be able to associate a Model Part Specification for Edge Model Parts with a Boundary Part.

Useful network model assemblies need to include Edge Model Parts, in addition to more usual detailed PN Model Parts. Whenever one region in a framework is included in an Assembly and its counter-party region across a given bilateral boundary is not included in the Assembly, the overall model has been cut off at this boundary and needs to be terminated somehow in order to produce good results.

An Edge Model Part accomplishes this termination. A common method is simply to connect an equivalent generator/load to each boundary point. (Edge Model Parts normally can be derived directly from the CIM Data Objects in an EQ Model Part 'filling' a Boundary Part.)

Figure 6-6 depicts what an Assembly can look like for a particular kind of study.

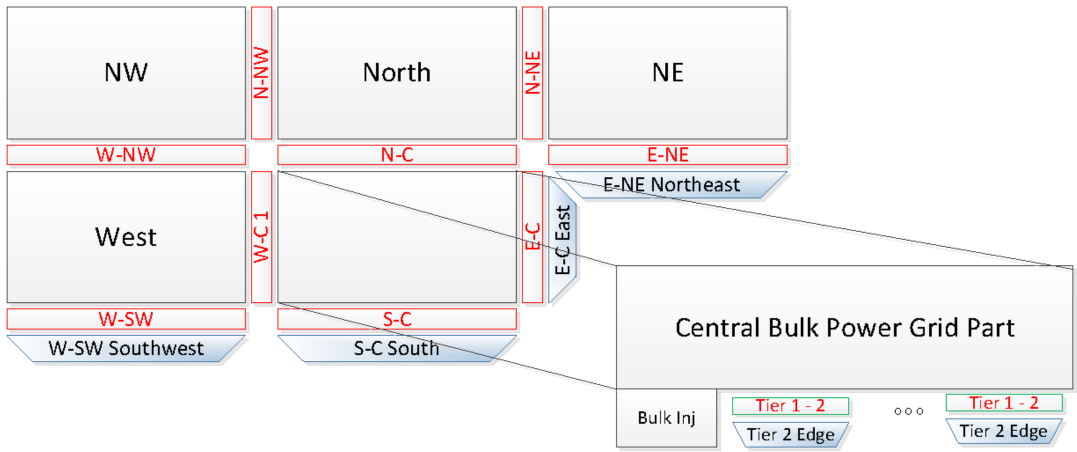

Figure 6-6
Example Assembly using Edges

Note that Edge Model Parts are used to terminate where adjacent regions are dropped out, but they also may be used, as is shown for the Central region, to represent load, if there are lower-voltage detailed Model Parts that are dropped out and simplified into injections.

R1.8.

The PNM shall manage the evolution of Model Parts over time by maintaining a sequence of versions.

While there can be any number of stored PN Model Parts that represent a particular region of the grid, certain parts are expected to serve as master data which tracks the state of the grid as it is currently constructed and from which most data management procedures begin. These parts are the heart and soul of the PNM and usually represent the grid in the greatest detail (because one can programmatically simplify a complex model where the complexity is not needed, but a program cannot usually invent detail where it does not exist).

Let's call the latest version of a master PN Model Part a 'baseline'. The baseline of a master PN Model Part would normally be kept roughly in sync with the grid as currently constructed – i.e. it represents the present or 'as-built' grid. When work is completed that changes the real grid, the changes also need to be reflected by creating a new version of a master PN Model Part.

R1.8.1.

The PNM shall support the creation of a new version of a PN Model Part by the addition of sets of changes, defined in one or more Projects, to the previous version.

When a Project is deemed to have been successfully completed, its incorporation into the previous baseline of a PN Model Part and the creation of a new baseline for that PN Model Part shall be supported.

All changes from one version to the next shall be captured in Projects.

R1.8.2.

When a new PN Model Part version is created by the addition of Projects, the Projects added to produce the new baseline shall form an audit trail documenting the version.

Once a Project has been used in the creation of a new baseline, it becomes 'frozen' and no further changes may be made to it.

R1.8.3.

The PNM shall support the creation of a new version of a PN Model Part by import from its model authority when the model authority is other than the NMM owner.

If the import makes an audit trail available, the import shall warn if the previous imported version does not match the audit trail starting point and shall capture the audit trail for the new version within the PNM.

R1.8.4.

The PNM shall maintain accessibility to past versions of PN Model Parts until they are explicitly deleted by authorized personnel.

PN Model Part versions form a sequence. Model versions are accessible by specific version or by asking for the latest version. Most NMM operations will use the latest version of any PN Model Part.

When a new release is created, there may be many studies out and in use which were based on previous versions. (The audit trails associated with these studies will identify the specific versions used.) Past versions therefore remain of interest as long as any active studies are based on them, or as long as there may be a need to create new studies of past events.

R1.8.5.

Projects in an audit trail of a Model Part version shall remain individually accessible.

Even after being merged into a Model Part version, Projects should remain accessible until explicitly removed.

R1.9.

The PNM shall maintain a set of projected or possible modifications to the system as Physical Network Model Variations (Projects) from which hypothetical or future PN Model Parts may be constructed.

Many of the important base cases that we are trying to support are supposed to represent future or hypothetical conditions. Future conditions are inherently uncertain. For physical network model data, they correspond to plans or ideas that evolve from concept through approval, construction and commissioning. Since plans can change, there is no fixed time line of the future: there are just sets of changes that can occur.

The PNM is the master source for physical network model information forward through time, as well as for the present.

The Projects capability needs to be able to function in several different roles:

- In transmission planning, where projects may stretch years into the future, PNM is intended to serve as the enterprise master data source for plans until engineering initiates detailed design.
- For transmission planning and operations in the near term, PNM is the master for network analysis, but engineering will develop more detailed plans. If engineering is integrated with PNM, then engineering can become the source for PNM Project versions.
- For transmission plans from other entities, PNM Projects are always imported from those sources (which may be other installations of an NMM product).
- For distribution, if PN Model Parts are created in NMM, then it follows that planned changes will be as well (but both are likely to be sourced from other systems, such as GIS).

R1.9.1.

The PNM shall include the ability to store an arbitrary number of Projects, where a Project consists of a collection of proposed changes, plus annotation that includes an identifier, an effective date, and a user-configurable set of additional attributes.

A Project includes an Incremental Dataset of a CIM Dataset Type that corresponds to the kind of PN Model Part it is designed to change, plus annotations.

R1.9.2.

The PNM shall support hierarchies of Projects, stages of implementation, etc. as necessary to reflect how projects are managed in the real world.

This is one of those requirements that is very important, but is here stated in terms that are not very specific. In part this is because the intent is to encourage vendor competition in developing features. Here are some common problem areas that need to be addressed:

- Let's first assume that the lowest level of project modeling is a Project that contains only one Incremental CIM Dataset (i.e., it contains a module of changes to only one Model Part of one type). If the basic Project is limited in this way, it certainly means that some sort of container Project or recursive Project modeling must exist.
- Real projects commonly have multiple stages. If an individual Project has a single effective date, then stages would have to be grouped together.
- Real projects may span multiple Model Parts. If an individual Project modifies a single Model Part, then these related Projects would need to be grouped together.
- Real projects sometimes have alternatives – that is, mutually exclusive Projects might express alternate sets of changes where only one Project would ever be incorporated in a given study.

This area is currently under consideration by the IEC CIM Working Groups, however, because they need to define standards for exchanging Projects. To the extent that the IEC CIM Working Groups set standards, of course, NMM products will be expected to conform.

R1.9.3.

The PNM shall support versioning of Projects.

Projects evolve, generally getting more complex. The name of a Project shall remain the same as it is revised. Revisions are designated by a version. Versions are sequential.

R1.9.3.1.

Versions of Projects shall remain accessible until explicitly deleted by an authorized user.

R1.9.3.2.

Access to Projects shall be supported by specifying an explicit version or by requesting the latest version.

R1.9.4.

The PNM shall support the notion of a Project lifetime governed by business procedures.

Projects may originate as ideas or as requests from grid participants. There are commonly formal procedures for moving them through various stages of review, approval, detailed design, construction and commissioning. These procedures may be manually governed, but they may also be automated to varying degrees. The PNM is, as a minimum, the place where the statuses of Projects are tracked so that any party building a future network study can design queries to select those Projects that are relevant. The PNM could also function as a platform for implementing business procedures for managing projects, but at this time, that is a somewhat open area of discussion.

Two product features are regarded as essential at this time:

- A status attribute with a default set of values that are customer modifiable. (E.g. private, proposed, approved, in-construction, commissioned, incorporated into baseline, cancelled, etc.)
- The ability for customers to add other attributes as necessary.

R1.9.5.

The PNM shall support an effective date for the changes specified in a Project.

A very common criterion for including or excluding a Project in a given model Assembly is whether the Project is scheduled to be in place prior to the date that the Assembly is supposed to represent.

R1.9.6.

The PNM shall support association of an arbitrary number of additional documents with a Project.

Related documentation includes spreadsheets, drawings, emails, etc.

Object Registry Requirements

R2.

The NMM shall support object registry services to manage the names of network modeling Canonical Objects in different contexts.

The Object Registry registers CIM Canonical Objects. The NMM can either support object registry services internally or integrate with an external provider of such services.

The primary purpose of the Registry is to manage object identity in exports. Exports that go from the NMM (a CIM environment) to another CIM environment can typically just use each object's MRID as its identity. In many integration situations, however, CIM MRIDs must be transformed into identification structures local to the target. This requires a mapping of identifiers and the Object Registry serves as a repository that supplies the mappings needed. When all mappings are managed together, it is much easier to debug mapping problems.

R2.1.

The NMM shall carry out a primary registration whenever a user saves a Model Part that contains a CIM Data Object that is not previously registered. The NMM shall carry out a primary registration whenever a Project that has been declared public introduces a new CIM Data Object.

Primary registration records the MRID, the Model Authority and the name of the CIM Data Object used by its Model Authority.

R2.2.

The NMM shall allow secondary registrations by external processes (usually integration processes) which need to register alternate names.

R2.3.

The NMM shall allow parties to register interest in registration events by class of object and source of the event.

Generally, the purpose here is to allow an integration process to detect a new CIM Data Object for which a name mapping will be required, so that it can trigger its users to set up the corresponding name.

R2.4.

The NMM shall support services to generate name mappings from MRID to any name set or between any name set.

This is a key interface with the integration activity that will connect the NMM with other systems in the enterprise. Note that some mappings may be meant to support exchange of information between systems other than the NMM (for example, between an EMS and a Market). In some of these cases, it will be unacceptable for those exchanges to access the NMM in real time, because that could make a key business exchange dependent on the availability and performance of the NMM. The design of the mapping services shall therefore not require NMM presence, except to accomplish updates when the mappings need to change.

Workspaces Requirements

The term 'workspace' is used conceptually here to mean an NMM facility for one user that allows the user to work with Model Parts and Model Variations without impacting what other concurrent users of NMM are doing. A workspace behaves like a private modeling space for the user.

R3.

The NMM shall support multiple Workspaces for carrying out NMM operations in parallel.

R3.1.

The NMM shall support concurrent activity by multiple users.

The system shall enable multiple users to perform normal user tasks in their own workspaces without interfering with one another. For example, multiple users shall be able to develop Projects against the same PN Model Part at the same time.

R3.2.

An NMM Workspace contains exactly one Network Model Assembly which is the end result of workspace operations such as creating and loading Framework Parts of interest, loading Model Parts, adding stored Variations, creating and saving Variations, etc.

Within a Workspace, the identity of Model Parts used in an Assembly is maintained, but the organization is essentially that of an assembled model where any CIM Canonical Object referenced by CIM Data Objects from more than one Model Part is viewed as a single composed data object.

R3.3.

An NMM Workspace contains sets of changes which are in the process of being developed prior to saving them as a Model Variations.

These sets of changes are the result of editing or other invoked functions (like **Diff**). They are not saved or available to any other party until a user explicitly saves them.

R3.4.

An NMM Workspace shall support a core set of standard service functions which operate on the workspace content.

Functions generally take arguments which may be part of the workspace, may reference external input sources or may be parameters supplied in a particular function invocation. Function results become part of the workspace, usually as a Model Part or Model Variation.

Core services anticipated at this time are:

- **Select.** Identifies a set of Model Parts or Model Variations based on filtering criteria.
- **Compose** selected Model Parts. Loads selected parts and composes them with existing Workspace content.
- **Inc** selected Variations. Adds incremental changes contained in Variations to the Workspace, retaining the source of the new data.
- **Autogenerate** schematic. Generates a DL Model Part from all or selected part(s) of Workspace EQ, DY, GL and/or TP content.
- **Topology**. Generates a TP Model Part (bus-branch topology) from Workspace EQ and SSH.
- **Powerflow**. Generates an SV Model Part (power flow solution) from Workspace EQ, SSH and TP.

The IEC CIM Working Groups are discussing functions currently and this requirement should be interpreted as calling for support of all network modeling functions defined by the CIM standard.

R3.5.

An NMM Workspace shall support addition of locally defined service functions which operate on the Workspace content.

The NMM shall be designed as a platform for adding customized local services. Such services shall be treated in the same way as product-supplied services.

See section 7.3.5 for more detail about the kinds of services that are expected.

R3.6.

The NMM shall support a differencing capability that will allow two Workspaces or selected contents of two Workspaces to be compared, with the differences captured as a Variation.

One of the most common questions for a user is – how is this model different from that model?

Expressing differences as a Variation is the basic way to report the result. However, it would also be desirable to be able to navigate from the Variation to the portions of the model that are changed, and to see both views of changed areas.

R3.7.

An audit trail shall always be available documenting how the Workspace reached its present state.

The audit trail shall be expressed in terms of operations on the Workspace, not just a record of data item changes. The purpose of this is so that if a function, such as network reduction, were invoked to produce a set of changes, the audit trail contains an accurate record of how the change was accomplished, as well as the result.

R3.8.

Any sequence of functions or operations that a user can perform on a Workspace shall also be capable of being executed by a Procedure.

See Requirement R5.4 for basic requirements for Procedures. The ability to create Procedures is highlighted as an important area of vendor competition.

User Interface Requirements

R4.

The NMM shall provide users the capability to browse and edit NMM content.

An effective user interface shall be available that allows users to enter original data or modify imported data as necessary to maintain quality models. This shall include, but not be limited to, effective UIs to:

- Browse and edit Workspace contents in tabular form.
- Browse and edit the Workspace network model in schematic form.
- Browse and edit Variations in a Workspace.
- Browse the audit trail of the current Workspace.
- Browse and select or define filters for the PNM and CM.
- Browse and edit Procedures.

Requirements are given here at a very high level. The intent is to leave user interface design open for vendor competition. This is especially true of schematic and geographic presentations of networks and graphical editing of network models.

R4.1.

Electrical connectivity and schematics shall be created cooperatively and assured consistent.

Schematic drawings are a vital aspect of physical network models. They are critical to allowing human beings to navigate large models and interpret analytical results. The NMM shall support any number of schematic layouts, as defined in IEC 61970-453.

The NMM shall be capable of auto-generating schematic layouts from connectivity definitions. In cases where the model connectivity is not created graphically, this is a key means of assuring that connectivity is correctly represented.

There are many different kinds of schematics that are valuable in network analysis or operations control settings. These include station one-lines, circuit one-lines, bus-branch area schematics, geographical schematics and mapboard schematics. Different layout algorithms would be appropriate for each type. Algorithms that take advantage of geographic location data are desirable.

The NMM shall be capable of defining connectivity graphically from editing of schematic presentations.

R4.2.

The NMM shall provide security and access control mechanisms such that it can be configured to meet industry requirements.

Role-based access controls governing the creation, updating and deletion of different components of the PNM and CM (including CIM Data Objects, Frame and Boundary Parts, Projects and other Variations, Model Part Specifications, etc.) and the performance of assembly and NMM administrative maintenance functions shall be provided by the NMM. It is possible that privileges might vary depending on business process flow states.

Also, the NMM shall provide the capability of meeting FERC, energy market and business agreements which specify data privacy requirements which may be at the granularity of class (or object) attribute or relationship.

In addition to access control and privacy requirements, NERC and other agencies set security standards related to patch management, port documentation, user authentication, account/password management, session management, logging and auditing, malware detection, etc., with which utilities must comply and which the NMM shall support.

More detail on general utility software security requirements can be found in an Energy Sector Control Systems Working Group (ESCSWG) document available at: http://energy.gov/sites/prod/files/2014/04/f15/CybersecProcurementLanguage-EnergyDeliverySystems_040714_fin.pdf. The NMM shall meet the applicable requirements outlined in this document.

R4.3.

The NMM shall provide the ability to save and retrieve Workspace content in whole or by part.

Model and Case Assembly Requirements

NMM activities can be broadly grouped as 1) maintaining master source data, and 2) creating base cases for analysis. In many instances, creating a base case involves creating a solved power flow case. This is true because power flows are normally the starting point anyway and because power flows are needed to validate a complex assembly of data. In this section, we discuss how the NMM is intended to support creation of base cases for different target environments and purposes.

Our overarching intent for the NMM is that it can host the network analysis processes consistent with the Case Assembly reference model conceived by the IEC CIM Working Groups, and around which CIM network model standards are specified. In light of that, while it is useful to introduce the Case Assembly reference model (shown in Figure 6-7), it is also necessary to recognize that it is still under development and a strong liaison is advisable between the IEC CIM Working Groups and product designers to maintain alignment.

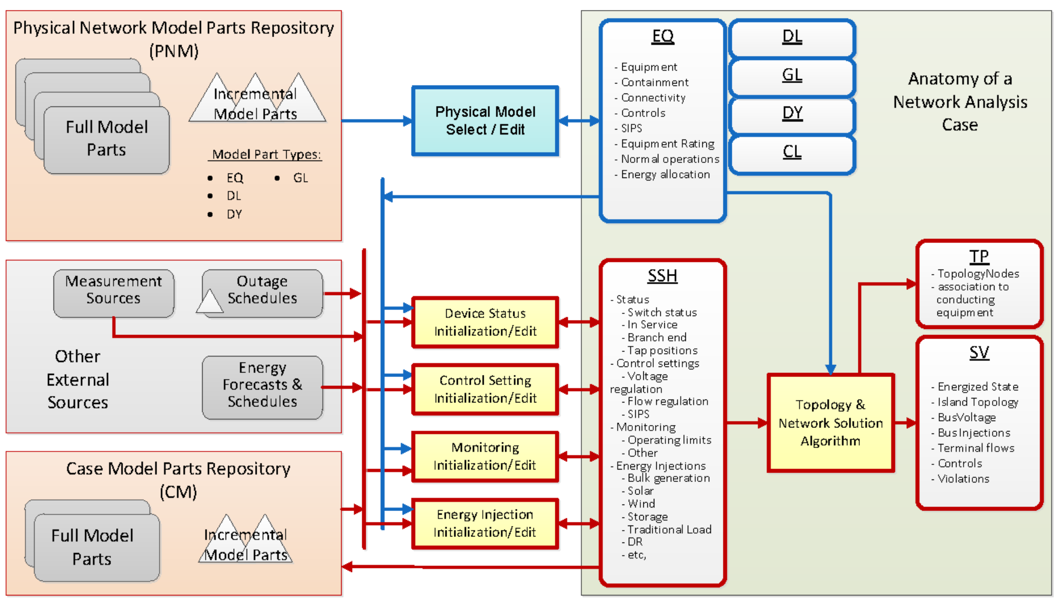

Figure 6-7
IEC CIM Working Groups reference model for Case Assembly

The right side of the reference model shows a complete Base Case Assembly in an NMM workspace. The CIM Dataset Types in blue outline reflect data contained in PN Model Parts which come from the PNM repository (or a direct import to a Workspace). The CIM Dataset Types in red outline reflect data contained in Case Model Parts that describe a particular steady-state operating hypothesis.

The left side of this diagram shows data sources that are used to assemble the right side. Two of these are NMM facilities: the PNM (Physical Network Model Parts Repository) and the CM (Case Model Parts Repository). A third area denotes other external sources. This latter could vary quite a bit in content depending on the organization into which the NMM is integrated, but here only an outage scheduler source, an energy forecast and schedule source and measurement sources are illustrated.

In between the left and right data parts are services that draw information from the left and populate the right. These services are the primary focus of this sub-section of requirements because the NMM must host these services. They are color-coded blue for physical network model services and red for case-related services.

PN Model Parts containing DL, GL, DY and CL data are shown on the right because they will be brought along with EQ Model Parts on an as-requested basis and passed on to any target that needs them. These parts may be viewed and edited in the workspace, but they are optional with respect to the process of running a base case power flow.

Notice that the EQ Model Parts must be established first, because the EQ part of the workspace determines which objects need to be set up with operating hypotheses. (This is denoted by the blue arrow feeding back from EQ into the red process boxes.)

While the NMM must host these services, only some of the services would be expected out-of-the-box in an NMM product. Others would be customized to fit different business processes in which the NMM host participates.

R5.

The NMM shall support the IEC CIM modular concept for assembling network models and network analysis base cases.

The keys to this objective are:

- Data are modularized into CIM Datasets according to CIM Dataset Types.
- Both Model Parts and Model Variations are supported as inputs.
- Assembly operations take place in NMM Workspaces.
- Services are hosted that perform all of the essential data operations.
- Procedures can be created for executing common procedures.

R5.1.

The NMM shall support services for assembling a model in a Workspace.

PN Model Parts and/or Projects are loaded into Workspaces for two reasons:

- To perform data maintenance.
- To assemble models for export to consumer applications.

In the data maintenance case, PN Model Parts or Projects to be edited are selected individually for loading and maintenance activities result in Projects.

Model assembly is more complex because of the variety of different kinds of models that could be required to be built.

- The number of different regions to be included varies.
- The detail level varies (voltage levels, simplification, style - e.g. bus-branch or node-breaker)
- The time being studied varies.

R5.1.1.

The NMM services shall provide effective means for users to select PN Model Parts for loading into a Workspace.

Examples of this are setting filters based on PN Model Part names, attributes, roles in a framework, etc.

Selection criteria should return the latest version of a PN Model Part by default, but shall allow the user to request a specific version.

In nested frameworks, either entire sub-frameworks may be selected or individual PN Model Parts may be selected.

R5.1.2.

The NMM services shall provide a service to load selected PN Model Parts into a Workspace model Assembly.

When parts are loaded into the model Assembly, both their individual and their net characteristics shall be maintained.

- Individual PN Model Part identity in the framework shall be maintained such that, for example, export and audit trails are maintained individually.
- Parts shall be composed, in the sense that a user can easily see all properties of a single object and references between loaded PN Model Parts are regarded as resolved rather than ‘dangling’.
- A report of net dangling references shall be maintained, such that it is easy to navigate to the objects.

R5.1.3.

The NMM services shall provide effective means for users to select Physical Network Model Variations (Projects) that should be included.

This should look something like a query or filter specification for stored Projects. The most important capability is to be able to supply parameters (such as date) and be able to stipulate inclusion of all Projects with effective dates prior to the date, subject to other conditions such as that the Project has been approved.

Selection criteria should retrieve the latest version of a Project by default, but shall allow the user to request a specific version.

R5.1.4.

The NMM shall provide a service to load selected Physical Network Model Variations (Projects) into the model Assembly.

Projects contain changes specifying operations on PN Model Parts. Loading Projects applies these changes to the assembled model and records the operations in the audit trails of the PN Model Parts.

R5.1.5.

The NMM shall support both out-of-the-box and customer-installed services that operate on PN Model Parts to produce simplified views.

Simplification procedures are not standardized, but are an important feature for network modeling engineers, and vendors are encouraged to offer such procedures in their standard products.

The NMM shall also support an open-ended ability to install code that will execute operations on workspaces. Examples of operations would be a heuristic for simplifying low voltage detail or a node-breaker to bus-branch converter.

Regardless of source, invocations of such operations on PN Model Parts shall be recorded in the audit trails.

R5.2.

The NMM shall support services to assemble analytical Base Cases by adding Case Model Parts and Case Model Variations (as defined in IEC CIM standards) to the assembled network models for export to consuming applications.

IEC CIM work here is evolving. The intent of the requirements articulated in this document is 1) that NMM design be consistent with IEC CIM Working Groups architecture for network CIM Datasets, and 2) that the NMM implement such parts of that architecture that have value in assembling and sharing ‘base cases’. The NMM Case Model Parts Repository is intended to store information from which case operating hypothesis information can be created during case assembly, including:

- Generation/load patterns or schedules
- Voltage schedules
- Interchange patterns
- Operating limits
- Contingency lists
- Outages
- Solved states

R5.2.1.

NMM services shall provide effective means for users to save selected Case Model Parts from a workspace to the Case Model Parts Repository.

The intention here is to be able to save subparts of SSH Model Parts from the Workspace into the CM. Studies sometimes would want to re-use an entire SSH as a starting point for editing assumptions, but often it is valuable to be able to save just the network status input, or just the generation pattern, for later re-use.

R5.2.2.

The NMM services shall provide effective means for users to select saved Case Model Parts or Variations for loading into a Workspace.

R5.2.3.

NMM services shall provide effective means to retrieve selected saved Case Model Parts or Variations into the Workspace as part of case assembly.

If a corresponding EQ Model Part(s) are already loaded, then this operation should flag any mismatch in objects – for example, any EQ objects that are missing in an SSH Model Part or any SSH objects that are missing in the EQ Model Part. Users should be allowed to repair such mismatches.

R5.2.4.

The NMM product shall include services to perform commonly-required procedures that generate SSH Model Parts.

SSH Model Part generation services are represented by the red-outlined yellow boxes in the middle of the reference diagram for case assembly (Figure 6-7). At present, there are no IEC standards that stipulate exactly what these services should do, so this is another area in which vendor competition is expected. Certain specific suggestions can be made, however:

- EQ Model Parts may contain 'normal' positions for switches, taps, capacitor banks and the like. A service to initialize SSH status from normal is recommended.
- EQ Model Parts may contain schedules for control settings. A service to initialize SSH control setting from schedules is recommended.
- EQ Model Parts may contain parameters for allocating energy from net forecasts to specific injections. Services to perform allocation based on net values are recommended.
- EQ Model Parts may contain nominal facility-rating data. Services to select ratings for use as operating limits are recommended.

R5.2.5.

The NMM shall support installation of custom services that generate SSH Model Parts. Such services will often integrate with other external applications, such as outage management or load forecasts or market outcomes, which provide source data useful in developing SSH Model Parts.

This is a critical area of capability. As the grid becomes more complex with greater reliability issues and much more diverse sources of energy, customized applications for setting up cases are going to be critical to success. These execute like any other operations performed on the Workspace to construct models, but they commonly integrate with non-NMM sources of information.

R5.3.

The NMM shall provide a means to save and retrieve complete Workspaces at any stage of work.

R5.4.

NMM functionality shall include the capability to create and execute Procedures for the assembly of common kinds of models and cases.

This is extremely important. The core idea of the NMM is to remove mastership of data from applications in order to eliminate duplication and improve overall quality. But in doing so, an extra component is added. Most setup procedures are associated with business procedures that are repeated. Gaining acceptance for the NMM requires that as much as is practical these business processes can be defined easily and executed 'one touch'. Vendor competition is encouraged to develop powerful capability in this area. The next couple of requirements set some minimum expectations.

R5.4.1.

NMM Procedure functionality shall include the ability to invoke any NMM service, either product-supplied or custom.

R5.4.2.

NMM Procedure functionality shall include the capability to supply parameters to Procedures.

Procedures shall be able to be parameterized. For example, a Procedure which loads a set of Projects with effective dates prior to some parameterized data supplied by the invoker is much more useful than if a Procedure can only be written to load a specific set of Projects. As a simple example, Procedures should be able to retrieve Projects with a date and other criteria set up as parameters.

R5.5.

The NMM shall maintain complete audit trails of Workspace activity and these audit trails shall include the record of all services invoked.

Audit trails are useful in two main situations:

- For users of the NMM to track what activity has occurred in a Workspace.
- For inclusion into model exchanges, so that the receiver of the model can understand what has been sent.

In both these cases, a trail that consists only of a log of data operations is difficult for a human to digest. It is much more useful if the audit trail communicates something like 'We started with Model Part X version 4, then added Model Project A version 2 and Model Project B version 1, then ran 'MyNetworkSimplification', then ran 'OurMarketEnergySchedule', etc.'

Validation Requirements

R6.

The NMM shall support development of a testing and validation regimen.

The electrical model of the physical grid is large and complex. It is the base around which all grid analysis takes place and is increasingly vital to successful grid operation. It is therefore increasingly important that these models be verified as accurate. An important reason for pulling together the physical model into one system is to enable a testing program to assure that consuming applications can rely on its accuracy. Such testing will involve multiple layers:

- Consistency with standard forms – assurance that user functions can process the data.
- Reasonability heuristics – review of data for unusual or suspicious conditions that modelers should check.
- Algorithm based tests – e.g., can you run a power flow?
- Feedback – e.g., state estimator residuals.

Responsiveness of validation is important to creating a positive user experience.

R6.1.

The NMM shall incorporate a topology processing service to enable modelers to test connectivity specifications.

Two goals:

- To check for disconnected network resources.
- To create bus-branch models in normal state to check bus naming.

R6.2.

The NMM shall incorporate a power flow service to enable modelers to test base cases prior to export.

Modelers need efficient, responsive access to power flows, so that power flow execution and review of power flow results can be carried out easily within the NMM environment.

Integration Requirements

R7.

The NMM shall provide CIM-based integration services that will allow the NMM to be integrated with other systems without requiring amendment of NMM product code.

The vision for network model management is to automate data connections from information sources and to network model consumers. These integrations will be implemented incrementally over time and will change as business needs evolve. Integration always involves some level of custom code, but the design of NMM shall protect the integrity of the core product. The NMM must be 'integration ready' with a combination of CIM-standard interfaces and internal services such that most integration work is external to the NMM and does not require new NMM features.

R7.1.

The PNM shall support import and export of NMM Model and Case Parts and Model and Case Variations from and to other systems that support IEC CIM model exchange standards designed for this purpose.

R7.2.

The NMM shall provide the ability to export all or any parts of a Workspace in standard CIM forms.

R7.2.1.

The export shall include the Workspace audit trails documenting each exported part.

R7.2.2

Audit trails for exports shall be sufficient to allow a receiving party to register interest in whether a particular Model Part or Model Variation referenced in the audit trail is updated.

Audit trail standards are not yet completely specified by IEC, but the NMM shall support any standards that are created.

R7.3.

The NMM shall provide the ability to import CIM-standard data into an NMM Workspace.

NMM shall support import of data expressed in compliance with standard CIM profiles. In addition, as additional CIM profiles are defined to support audit trails, support should be provided for audit trail import along with any Model Parts or Variations. It is envisioned that imported audit trails would be used to initialize the NMM Workspace into which the Model Parts or Variations are imported.

R7.4.

The NMM shall provide a set of interfaces and services that allow an external application to execute a Procedure culminating in export.

R7.5.

NMM-supported interfaces and integration with other functions shall be based on IEC CIM information modeling and profiling methods.

The NMM concept is consistent with the IEC CIM approach, which is the result of many years of collaborative information engineering by industry experts. The NMM should build on the CIM work. The CIM approach anticipates that utilities adopting the CIM may need to extend the CIM to meet local requirements, and there are techniques for managing these enhancements. CIM principles apply to the external facing services by which NMM interaction is defined, and adoption of CIM is a strategic business decision based on the judgment that CIM adoption will, over the long term, allow the utility to take advantage of future industry technology advances at the best possible overall cost/benefit ratio.

Extensibility Requirements

R8.

The data content of the NMM shall be model driven, definable by an information model and compatible with the idea that a utility may have a Canonical Data Model from which CIM Dataset Types may be derived for the NMM.

The expectation is that the productized schema would be derived from the IEC CIM, but the product would support utility modifications, which would address local requirements and could also be based on the host's own enterprise canonical model.

R8.1.

The NMM shall support processes for updating the Model Part schema from new versions of a canonical data model and for transforming NMM content from one schema version to the next.

R8.2.

The NMM shall be designed to support a phased implementation of the NMM, in which successive phases may add substantially to the schema.

Section 7: Implementation Strategy

The primary reason for viewing the network model management solution as composed of an NMM and an effort to integrate the NMM with other systems is that it makes sense to implement these two parts differently.

- The NMM is a system which should be productized. That is, it is a system that could be designed so that many utilities can also use it, and it should be commercially attractive for a vendor to develop and maintain for a community of users. Over time, such a product strategy for the NMM will yield a far higher benefit/cost ratio for the utility, because the pool of ideas driving the product would be greater and because development and maintenance costs would be distributed across more utilities.
- The integration of the NMM with other systems, however, cannot be productized in the same way. While integration techniques and toolkits can be the same, and while it may be useful to engage an outside integrator to help, the degree of customization involved in integrating with typical utility business processes is such that integration of the NMM is dominantly a customization effort that cannot be directly shared with other utilities. Furthermore, the technical skills and experience required to execute NMM integration are quite different from the skills and experience required to maintain an NMM product.

There should be two coordinated but distinct implementation efforts. The first should focus on NMM requirements and selection of an NMM vendor. The second should focus on NMM integration and how to assemble a capable integration team. The rest of this section outlines some specific considerations that are important to NMM success that go beyond the usual project concerns.

Encouraging the Market for the NMM Product

The market for an NMM is not currently established, but is getting close:

- Utilities have not converged on a network model management strategy, but the discussion is gaining visibility and momentum.
- Vendors are not convinced about what utilities will buy, although several current products are headed in the right direction.
- Standards groups have not completed all relevant standardization work, but a solid core exists and a consensus has formed that IEC CIM strategy is the right path.

While a utility could simply push ahead as a single customer looking for a vendor, the value that will be realized given the not-fully-mature market picture is closely linked to how deeply vendors believe in the NMM idea (and therefore are willing to build high quality product they are committed to maintaining).

Aligning with the IEC CIM Strategy

The NMM integration effort for network model management is based technically on IEC CIM standards. CIM standards go beyond the usual notion of interoperability standards, which have more of a point focus. The CIM idea says that the greatest long term challenge in enterprise integration is to encourage a common semantic model for exchanged information – and then to derive individual interoperability agreements using this common language. This establishes a long-term process as well as a set of specific agreements, and there is a significant learning curve associated with both the common semantic model and the methodologies and technologies involved in implementing CIM integration.

A successful NMM integration project will require expertise in CIM and CIM processes in order to be successful. A utility needs to assess the degree to which it has, or wants to achieve, in-house CIM expertise, as opposed to being dependent on an outside integration consultant.

Alignment with CIM is also not merely an NMM integration issue. CIM covers many areas beyond network models (although significantly, network modeling is the core of CIM). The value of CIM increases exponentially with the number of integration paths that are brought under the common CIM language and methodology. The utility should therefore consider whether NMM integration should be treated as an initial stage of a more general program for enterprise-wide integration that would position the utility to better meet a broad range of future challenges.

Phased, Prioritized Implementation

The inclination of organizations approaching new implementation projects is to treat them as one fixed thing that needs to be specified, budgeted, designed, implemented and commissioned. Sometimes such projects are phased, but each phase is a specific thing in the same sense.

NMM for network model management not only lends itself to phased implementation, but in some important respects actually benefits from phased implementation. Understanding these factors will be helpful in designing the best approach to implementation.

Phasing the NMM

The minimal starting point for the NMM product would be to focus on the physical network model (as opposed to the operating hypothesis components), and on the schema covering the elements required for power flow and state estimation. This starting point satisfies basic important functionality and is sufficient to assure that a solid core product architecture is established.

Candidates for later phases include:

- Schema expansion for short circuit and limit calculations.
- Schema expansion for dynamic models.
- Schema expansion for distributed energy resources.
- Management of operating hypothesis data and import/export.

Phasing the NMM Integration

Integration work is typically straightforward to implement in phases. Generally speaking, integration consists of a collection of relatively independent business process automations. One creates use cases to describe how a necessary business process can be satisfied. Each use case defines sequences of steps that involve operations in the NMM, operations in other systems, and data exchanges between systems. Each identified data exchange is an integration task and most exchanges are independent of most other exchanges in terms of implementation.

The impact of not automating a given exchange is usually just that the data needs to be carried manually, or with custom aids like spreadsheets, from one system to the other – which is usually a continuation of existing methods - until such time as automation is implemented. Use cases can be assessed in terms of relative value and prioritized based on cost, budget and value delivered.

The minimum starting point for integration is to assure support for physical network model transfer (CIM 61970-452). This achieves the basic goal of consolidating power flow modeling for operations and planning.

Why Is Phased Implementation a Good Idea?

Phasing obviously moderates staffing and budgeting requirements for NMM implementation, which is often helpful. In addition, phasing allows a number of feed-forward processes to take place that will refine and improve the overall effectiveness of the NMM implementation:

- CIM integration has a learning curve. Moderating the initial implementation goals makes it simpler to build a capable team.
- Integration is a process, not an event. Good integration is designed to accommodate the real-life reality that both business requirements and implementation technologies evolve over time, resulting in the need to upgrade versions of systems that have been integrated. Phasing is more true-to-life than is a fixed-scope project. It is good to learn this reality early.
- The thinking behind the CIM steady-state hypothesis data (operating hypothesis data) is currently less mature than for the physical network model. Flexible phasing allows individual tasks to be initiated when the time is right and the payoff is clear. Similar arguments exist in several other areas of CIM.

- NMM is a new concept. With any new idea, there is a certain amount of implement-and-learn that goes on during the process. Phasing means that there is more opportunity to take advantage of growing expertise.

Appendix A: Glossary

Consumer application (target function) – an application, system or software tool that utilizes a version of a network model or case produced by NMM. Different consumer applications have varying requirements for model complexity and scope.

EMS – Energy Management System.

IEC TC57 CIM Working Groups – International Electrotechnical Commission (IEC) Technical Committee 57 (TC57) Working Groups responsible for the maintenance of the IEC CIM Standard, which include:

- WG13 **–** responsible for the network model portion of the Common Information Model standard. The activities of this Working Group are most closely aligned with the content of this document.
- WG14 – responsible for the portion of the Common Information Model supporting 'back office' functions: asset management, work management, meters. This Working Group developed the original network model standard for distribution (61968-11, the CDPSM), but responsibility for this standard now lies with WG13.
- WG16 – responsible for the market model portion of the Common Information Model

ISO (RTO) – Independent System Operator (Regional Transmission Operator).

NMM (Network Model Manager) – a tool for maintaining information needed by power system analysis applications. An NMM contains an underlying detailed power system physical network model, a case parts repository and an object registry and manages the assembly of models and cases based on that information. An NMM provides CIM-based interfaces for data import and export and supports manual data input and model management via workspaces and a graphical user interface.

Planning suite – a collection of software functions that perform power grid analysis and are used in the utility planning environment. Typical functions of a planning suite would include: power flow, contingency analysis, transient analysis, voltage stability analysis, etc. Planning suite tools typically do not have real-time data feeds.

Protection software – an application that performs short circuit analysis/simulation and relay coordination.

Registered party – an entity that has registered to be notified when a specific event occurs. Notifications can be related to a variety of types of events: project lifecycle changes, new baseline creation, object registration.

TSO (TO) – Transmission System Operator (Transmission Operator).

Utility – An entity responsible for planning, operating or ensuring the reliability of the electrical grid. In the context of this report, both TSOs and ISOs are considered utilities.

Appendix B: Major Network Model Management Projects

Electric Reliability Council of Texas (ERCOT)

In 2009, ERCOT implemented a nodal market which relies heavily on a consolidated network model management framework called the Network Model Management System (NMMS). NMMS provides a single point of maintenance for ERCOT's network model data and supplies model information, using CIM-based interfaces, to systems and applications supporting ERCOT's planning processes, market, day-ahead operations and real-time operations. ERCOT's model management solution and practices were explored in a presentation, "The CIM and Network Model Management", given in July, 2014 as part of the CIMug Technical webcast series. A recording of the webcast can be found at: http://www.ucaiug.org/Lists/UCAIug%20YouTube%20Channel/AllItems.aspx

European Network of Transmission System Providers for Electricity (ENTSO-E)

Over the last few years, the European Commission has overseen the creation of a number of network codes which call for network model exchange among TSOs and between TSOs and DSOs. In response to these codes, ENTSO-E has adopted the CIM standard as the basis of its Common Grid Model Exchange Standard (CGMES) for network model information exchange. Specific ENTSO-E CIM standards have been defined to ensure the suitability of the CIM for ENTSO-E use and to reflect the complexity of TSO data exchanges. For more information, see: https://www.entsoe.eu/major-projects/common-information-model-cim/cim-for-grid-models-exchange/Pages/default.aspx.

Appendix C: Frequently Asked Questions

1. How is bus numbering/naming maintained when a bus/branch model is derived from a breaker/node model? Especially the split bus condition.

   The CIM has a bus name marker that contains the bus name (BusNameMarker.name) and it is associated with a Terminal in the breaker/node model maintained in the Network Model Manager. The Topology Processor uses this name when converting the breaker/node model to the bus/branch model. If you use a single bus name marker and the bus splits, the bus name will go with the part that has the bus name marker and the rest will get an assigned name. If you put in two bus name markers and a retained breaker, then the bus branch model will keep the bus tie breaker and two buses always.

2. Different systems have different names for the same 'thing' (substation, breaker, transformer). How can an NMM handle this? -or- Our utility is responsible for putting together models from several other entities and several of them have substations named 'Central'. How can an NMM handle this?

   There are several ways to handle duplicate names:

   The easiest is an Object Registry service which associates the NMM MRID of an object with the various names of the object in multiple different systems. The NMM can either support Object Registry services internally or integrate with an external provider of such services.

   If you do not have an Object Registry, then the next best thing is to maintain a cross reference table and load it into a central location that all entities can access and modify. In this case the table will contain a column for each entity that will contain the name used by that entity. The first column will contain the MRID for that object that all entities will us in the Model Manager as the primary identifier.

3. Our utility has a number of other entities that contribute updates to their portions of our model. It would be a huge challenge to get all of them (including those with less technical expertise) to provide information in a standard CIM form to our NMM. How can this situation be addressed?

   The way this was addressed at ERCOT was to provide an internet-based User Interface that allows a user at the contributing entity to edit its portion of the ERCOT model directly using a one-line diagram and dialog boxes to enter the device parameters and other information. When the user saves the work, the system *generates a CIM XML file as output that can be entered as a project to the ERCOT NMMS. The key for this interface is to present the information in a form that a Power Engineer can understand or easily interpret.*

An NMM solution offering both a manual User Interface option and an electronic CIM XML option would allow deployment of an NMM into an environment where the technology capabilities of contributing entity vary.

4. Maintaining circuit ratings across systems is really time-consuming for our utility. How can the NMM help with this?

   Equipment ratings (for individual devices) would typically be centrally maintained in the NMM as part of an EQ Model Part. Facility (circuit) ratings could be treated as a separate Rating Model Part. The NMM could store any number of Rating Model Part instances that would fit with a given EQ Model Part. This works pretty well in the situation where sets of ratings are swapped in and out, or where sets of ratings are calculated dynamically. The appropriate Rating Model Part(s) would be used during Assembly of a model or case for a given consumer application.

   At ERCOT, the NMMS uses projects for all changes to the network model. One such project will contain the circuit ratings for a specific set of devices that are present in the model. These projects will include what the ratings are or what they will be for a specific time period. These projects also provide when the ratings will be implemented and the project manager will provide information to the network model manager team (normally the person designated as the model coordinator) as to when a specific project is to be implemented. This is done with emails or pop-up dialogs. Once it is time to implement the rating, the coordinator provides the data to the model engineering for testing and implementation.

5. My utility has to provide information to our ISO's EMS without the lower voltages which we include in our EMS. Can the NMM support this?

   The NMM would model the full set of devices for all voltages. There are a couple of ways that the generation of simplified models can be supported. One is to use a service that produces a simplified Model Part for the ISO EMS that would not contain the lower voltages. Another approach is to divide the original detailed model into high voltage and lower voltage Model Parts. Then depending on the target you either include or exclude the low voltage Model Part. In either situation, this may require some type of equivalence logic to balance the retained high voltage.

6. One of our utility's biggest challenges is identifying and updating planning cases when a project completion date slips. How can NMM help with this?

   Each Project in the NMM has an effective date. The inclusion of a Project during model assembly is recorded in the audit trail of the assembled model or case. If the effective date of a Project changes, audit trails will allow the identification of those models or cases that may require recreation.

   At ERCOT, the NMMS contains a project manager that allows the user to perform searches by project number, dates, etc. When a project slips, the model *coordinator can search for all projects in that date range and enter updates based on changes to the project dates or devices that are involved. Once the projects are updated, new cases can be generated using the revised projects.*

7. The external model used for most of our planning cases is totally different from the external model used by our EMS in terms of how much of the external grid is modeled and the detail to which it is modeled. What strategies could be used in an NMM to handle this?

   Presumably, these external models come from different sources. They can then simply be imported as different external Model Parts that have the same tie points as your internals, and you use one or the other in any model or case that you assemble. If the ties don't match on the imports, Projects can be created that perform the adaption. A more sophisticated overall approach would be to treat each external TSO as a separate Model Part obtained from a source, and then you can build models by including the ones you want.

8. We receive model information from multiple outside entities (balancing authorities, TSOs, ISOs) in a variety of formats from .csv to MSAccess to vendor proprietary. What approach could be used to get this disparate information into the right place in the physical network model in the NMM?

   The NMMS used at ERCOT had this same challenge and it was resolved by providing a set of adapters for any formats that were not CIM XML. These adapters took the .csv or MSAccess or other formats and converted them to CIM XML. Once converted to CIM XML, the NMMS could easily receive the data into the NMMS repository. An Object Registry (name service) can also come in very handy here, if the external sources are not using the CIM identifiers.

9. NERC MOD-033 is going to require "comparison of a Planning Coordinator's portion of the existing system in a planning power flow model to actual system behavior, represented by a state estimator case or other Real-time data sources". How might an NMM be used to help implement strategies to address this requirement?

   One of the primary requirements and functions of the NMM is the basic principle that both Planning and Operations will use the same base model to generate their power flow solutions. This means that even if the planning and operations base cases have different scope, wherever they have the same scope, the equipment in their models will carry the same CIM MRID. This makes it straightforward to write comparison code. If both systems are using the same base model (with a few differences due to bus/branch vs breaker/node) the system behavior should be close to the same for a Planning or an Operations model. There will, of course, be a few differences but the general system behavior should be similar.

10. NERC FAC-008 requires that "The Transmission Owner and Generator Owner shall keep its current, in force Facility Ratings and any changes to those ratings for three calendar years". Can an NMM help with this?

    Yes. Whether ratings are managed as Projects or Model Parts, the NMM would provide a repository that could maintain copies of source data as long as was *required and it will also provide a means via the model assembly process to reproduce a specific model. However, this alone would not be proof of what was in use in an EMS at any particular point in time. The intent of NMM as an integration vehicle is that assembled models for target systems (like EMS) have audit trails attached that identify the source data Projects and Model Parts. If the EMS system also maintains a record of received models and installation in the EMS, then the documentation is complete.*

11. Our market system views a set of multiple generators as a single resource, whereas the network analysis functions in our EMS require physical modeling of each of the individual generators. How could an NMM handle this?

    There are several possibilities:

    The first question is whether network analysis done by the market is done in the physical view, and then that result is related to the commercial view, or alternatively whether the market is required to run its analysis with the commercial view. In the former case, the network models would be the same as for EMS, but it would be good to add a commercial generator class to the NMM schema so that a mapping from physical to commercial can be exported as well (probably along with instructions for how a market schedule should be allocated among the physical units).

    In the latter case, where market network analysis must take the commercial view, some processing would be required to produce a revised network representation that substituted the commercial view of generation, producing a modified set of Model Parts. One option would be to store the conversion to market representation as Projects. Another would be to do the schema additions in NMM, and then write logic to generate the market version of a Model Part prior for export.

    At ERCOT, the situation would be handled by having the NMMS model the physical generators and the adapter that produces the Market model combine the generators into a single resource.

Program:

IntelliGrid

3002003053

Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com