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Titre

CEI 61970-456:
Interface de programmation d'application pour système de gestion d'énergie (EMS-API) – Partie 456: Profils d'état de réseaux électriques résolus

Title

IEC 61970-456:
Energy Management System Application Program Interface (EMS-API) – Part 456: Solved power system state profiles

ATTENTION
VOTE PARALLÈLE
CEI – CENELEC
L’attention des Comités nationaux de la CEI, membres du CENELEC, est attirée sur le fait que ce projet finale de Norme internationale est soumis au vote parallèle.
Les membres du CENELEC sont invités à voter via le système de vote en ligne du CENELEC.

ATTENTION
IEC – CENELEC
PARALLEL VOTING
The attention of IEC National Committees, members of CENELEC, is drawn to the fact that this final draft International Standard (DIS) is submitted for parallel voting.
The CENELEC members are invited to vote through the CENELEC online voting system.

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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ENERGY MANAGEMENT SYSTEM APPLICATION PROGRAM INTERFACE (EMS-API) –

Part 456: Solved power system state profiles

FOREWORD

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International Standard IEC 61970-456 has been prepared by IEC technical committee 57: Power systems management and associated information exchange.

The text of this standard is based on the following documents:

FDIS	Report on voting
57/XX/FDIS	57/XX/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts of the IEC 61970 series, under the general title: *Energy management system application program interface (EMS-API)*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

The National Committees are requested to note that for this publication the stability date is 2014.

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INTRODUCTION

This standard is one of several parts of the IEC 61970 series that defines common information model (CIM) datasets exchanged between application programs in energy management systems (EMS).

The IEC 61970-3xx series of documents specify the common information model (CIM). The CIM is an abstract model that represents the objects in an electric utility enterprise typically needed to model the operational aspects of a utility.

This standard is one of the IEC 61970-4xx series of component interface standards that specify the semantic structure of data exchanged between components (or applications) and/or made publicly available data by a component. This standard describes the payload that would be carried if applications are communicating via a messaging system, but the standard does not include the method of exchange, and therefore is applicable to a variety of exchange implementations. This standard assumes and recommends that the exchanged data is formatted in XML based on the resource description framework (RDF) schema as specified in 61970-552 CIM XML model exchange standard.

IEC 61970-456 specifies the profiles (or subsets) of the CIM required to describe a steady-state solution of a power system case, such as is produced by power flow or state estimation applications. It describes the solution with reference to a power system model that conforms to IEC 61970-452 in this series of related standards. (Thus solution data does not repeat the power system model information.) IEC 61970-456 is made up of several component profiles that describe: topology derived from switch positions, measurement input (in the case of state estimation), and the solution itself.

ENERGY MANAGEMENT SYSTEM APPLICATION PROGRAM INTERFACE (EMS-API) –

Part 456: Solved power system state profiles

1 Scope

This part of IEC 61970 belongs to the IEC 61970-450 to IEC 61970-499 series that, taken as a whole, defines at an abstract level the content and exchange mechanisms used for data transmitted between control centers and/or control center components.

The purpose of this part of IEC 61970 is to rigorously define the subset of classes, class attributes, and roles from the CIM necessary to describe the result of state estimation, power flow and other similar applications that produce a steady-state solution of a power network, under a set of use cases which are included informatively in this standard.

This standard is intended for two distinct audiences, data producers and data recipients, and may be read from those two perspectives. From the standpoint of model export software used by a data producer, the standard describes how a producer may describe an instance of a network case in order to make it available to some other program. From the standpoint of a consumer, the standard describes what that importing software must be able to interpret in order to consume solution cases.

There are many different use cases for which use of this standard is expected and they differ in the way that the standard will be applied in each case. Implementers should consider what use cases they wish to cover in order to know the extent of different options they must cover. As an example, this standard will be used in some cases to exchange starting conditions rather than solved conditions, so if this is an important use case, it means that a consumer application needs to be able to handle an unsolved state as well as one which has met some solution criteria.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61970-452, *Energy Management System Application Program Interface (EMS-API) – Part 452: CIM Static Transmission Network Model Profiles*[1]

IEC 61970-453, *Energy Management System Application Program Interface (EMS-API) – Part 453: Diagram Layout Profile*[2]

IEC 61970-552, *Energy Management System Application Program Interface (EMS-API) – Part 552: CIM XML Model Exchange Format*[3]

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[1] To be published.

[2] To be published.

[3] To be published.

3 Profile information

The profiles defined in this document are based on the UML version CIM14v14.

The profiles are listed in Table 1.

Table 1 – Profiles defined in this document

Name	Version	URI	Revision date
StateVariables	1	http://iec.ch/TC57/61970-456/StateVariables/CIM14/1	2010-03-24
Topology	1	http://iec.ch/TC57/61970-456/Topology/CIM14/1	2010-03-24

4 Overview

This document describes an interface standard in which CIM/XML payloads are used to transfer results created during typical steady-state network analysis processes (e.g. state estimation or power flow solutions). Major requirements/objectives driving the design of this standard include:

- Power flow solution algorithms and output are virtually the same whether run in operations or planning contexts. State estimator output shares a common core with power flow. A single standard is desired so as to minimize software development and enable use cases that cross between environments.
- While some users of this standard might only be interested in the output state, the more general situation is that users continue to perform follow-on analyses (e.g. voltage stability) and require both the input on which the solution was based and the output result.
- Real life analytical processes often involve a series of solutions in which most of the input data remains the same from one solution to the next, and the standard must support these processes in a way that does not repeat data unnecessarily.

In order to meet these requirements, this standard depends on modularizing the potentially voluminous overall input and output data into subsets that would each be realized as smaller, separate CIM/XML payloads. An instance of one of these subsets is referred to herein as a ‘dataset’.

Two types of partitioning into datasets are utilized. In the first, the data is modularized according to what kind of data is produced (which generally corresponds with what kind of application produces the data). CIM ‘profiles’ (subsets of the complete CIM) define the classes and attributes that make up of each kind of modularization. The second type of partitioning is by ‘model authority set’ (MAS), which divides data into sets of object instances according to which utility or entity in an interconnection is responsible for the data. This partitioning occurs at the instance level and produces multiple datasets governed by the same profile that combine to form the complete set of data for that profile. Understanding the partitioning approach is critical to understanding how to use this standard to implement a particular business scenario.

This standard is flexible and designed to satisfy a wide range of analytical scenarios in the planning and operating business environments. We expect that where parties are using it to collaborate in some business process, those parties will often want to create additional business agreements that describe any restrictions and customizations of the standard that are deemed necessary for their process. In most cases, these additional agreements will be local agreements and will not be IEC industry standards.

The CIM/XML formatting of partitioned payloads is defined in IEC 61970-552. This method of formatting has the useful characteristic that valid XML describing a complete model could be achieved simply by concatenating the XML for each partition. Thus ‘merge’ and ‘extract’ of pieces of the modeling require no separate ‘stitching’ instructions and is conceptually a very simple process. IEC 61970-552 also describes how payload headers provide information as to how payloads fit together.

How to read this document:

- Clause 5, "Use cases", gives examples of business problems that this standard is intended to address.
- Clause 6, "Architecture", summarizes how the model partitioning works and describes how the parts described in this document work with parts described in other IEC 61970 series standards.
- Clause 7, "Applying the standard to business problems", describes how to go about applying the standard to your particular business problem.
- Clause 9, "Topology profile" defines the kinds of datasets controlled by this standard. (This section is auto-generated from CIMTool and is where you see the CIM modeling detail.)

5 Use cases

5.1 General

Clause 5 presents some of the business problems that were considered in the design of this standard and discusses how the standard is expected to provide value to the industry.

5.2 EMS state estimation

EMS operations typically run state estimator automatically, usually triggered either by occurrence of certain events or by a time period. Periods of 10 min or more used to be the norm, but currently many state estimator installations are running with much shorter periods approaching 5 s and nearly the same periodicity as SCADA (supervisory control and data acquisition) and consequently rendering event based triggering of state estimator important.

The state estimator’s job is to create the best view of the state of the system, based on the latest available snapshot of the SCADA measurements. The resulting steady state solution of the power system is used as input data for a number of important functions:

- A traditional EMS is usually configured by the EMS vendor with contingency analysis running on the result of the state estimator. While a standard is usually not necessary for applications from the same vendor, there is industry interest in being able to run alternate algorithms for either state estimation or contingency analysis.
- A growing number of other analytical functions that were not originally part of the EMS are also using the state estimator result as the starting point for real-time analysis (e.g. voltage stability).
- Where market systems exist, they normally require real-time exchange of state estimation result from the EMS to the market system, and these systems often are supplied by different vendors.
- Users are interested in being able to connect advanced user interface and situation awareness modules from different vendors into an EMS, and these modules need to acquire state estimator data.
- It is desirable to be able to run historical analysis as well as real-time analysis from state estimator results. This requires estimator results can be archived efficiently, and users shall be able to import results into network planning tool environments that are normally not supplied by the EMS vendor.

All of these situations require an efficient standard method of producing state estimator results and making them available to other applications.

If the complete set of input data and output data were stored for a large interconnection model running on, say, a 10 s period, it would produce a great deal of data and pose a considerable challenge to any real-time exchange. However, there are some obvious characteristics of this problem that may be exploited to reduce the data burden.

- The network model is by far the largest part of the data. It changes infrequently and when it does change, the changes are a small set of data. Only the initialization of the system actually requires a complete large model.
- The topology of the system changes more frequently (when switching devices change position), but still is relatively infrequent and again the changes are small compared to the complete topology.
- Analog measurement input changes completely each run, but in many of the use cases, this data is not required by the consumer. Analog data may also usually be approximated from an analog history if it is not stored.
- Solution state variables change at each run.

What is required of the standard in order for each kind of business exchange to take advantage of these characteristics is that the network model and the topology may be updated only when they change. It is also valuable if updates can be represented in incremental form, rather than by re-transmission of a full model. Consumers of the data then are able to initialize themselves with a full network model and topology when they start, but only receive updates if there were changes. This reduces the data volume problem from Gbytes/solution and Tbytes/day to a more manageable Mbytes/solution and Gbytes/day.

5.3 ENTSO-E[4] Process: Day-ahead congestion forecast

A daily analytical operational process called day ahead congestion forecast (DACF) is currently applied in the ENTSO-E regional group continental Europe. In this process,

- each TSO prepares a power flow case covering exactly its own territory representing each hour of the following day (based on day-ahead market outcomes). These cases are transferred to a central server;
- the full set of submitted cases may be checked for mutual compatibility. (i.e. do the boundary exchange conditions match);
- once all cases are submitted, each TSO downloads from the central server the cases posted by their neighboring TSOs. These are combined with their own models to form a set of study models on which they can analyze the congestion in their region for the next day;
- congestion result cases may be exchanged among TSOs, as the situation warrants.

This work is carried out primarily with planning tools running bus-branch models (although an obvious possible variation on the process would be to generate cases with EMS tools).

Even though the DACF process is not a real-time process like state estimation, it is quite similar in that a sequence of cases is produced representing periodic intervals. The solution values will change at each case, but the network model will change rarely and the topology will change occasionally. Conserving file size is a concern, and that concern is addressed if the standard allows the network model and topology to be exchanged incrementally.

DACF raises another set of requirements, however. Unlike the state estimator scenarios, which feature complete transfer of a solution, the DACF involves a lot of merging and extracting of pieces of solutions. In Figure 1, TSO A runs power flows to develop a picture of

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[4] European network of transmission system operator-electricity.

its territory for the following day. This would be done with models that include representations of neighboring TSOs. They shall post, however, only the part of the model representing their own territory, and this shall be a stand-alone solved power flow. (In ENTSO-E, boundaries between TSOs are, by agreement, always at the mid-point of tie-lines, and single TSO cases are formed with equivalent injections at each tie-line mid-point.) At the central site, or at any TSO, submitted internal cases shall be able to be reliably and automatically re-combined to form models with coverage appropriate to whatever task is at hand.

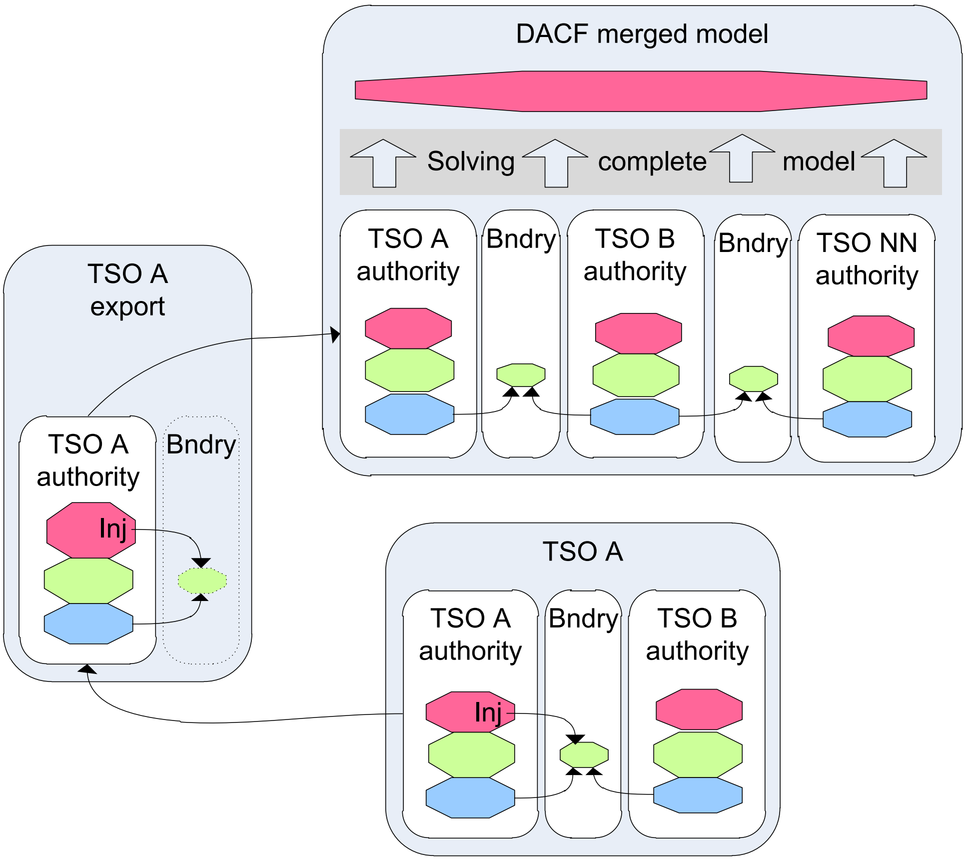

Figure 1 – TSO sends a case to be merged with the overall model

The octagons in Figure 1 represent datasets. The colors of the sets have the following meanings:

- magenta - data described by state variables profile;
- green - data described by the topology profile;
- blue - data described by the equipment profile.

Refer also to Figure 2.

5.4 System planning studies process

There are many synchronous interconnections worldwide (such as ENTSO-E discussed above) that require cooperative construction of future models by its members in order to support planning of the interconnection. Typically, “base cases” are constructed representing future time frames by combining submittals from each interconnection member, a process that closely resembles that depicted in Figure 1 for operational analysis. Instead of day-ahead, a planning case may represent years ahead; instead of daily update, a planning case must be reconstructed as plans change; instead of a known functioning power system, a planning case is not real yet. But in terms of process and in terms of data requirements, the assembly of base cases for planning is the same as in Figure 1, and it is the objective of this standard to support both construction of base cases and the exchange of solution cases that necessarily occurs among members during the analysis based on these cases.

5.5 Harmonization of planning and operations models

Network analysis is universally carried out with what is known as ‘bus-branch’ modeling, where most or all zero impedance switching devices are eliminated to form logical buses, and where load, generation and regulation parameters have been selected for a single point in time. However, there are significant differences in the way that network models are handled in operations and planning contexts.

- Planners tend to work extensively with a few selected bus-branch ‘cases’. For example, they will set up the conditions that represent a summer peak load for a future network, and then study variations on that case. Planning tools typically provide for direct entry of buses and single point in time parameters.
- Operations environments (EMS) require the ability to set up bus-branch cases automatically for any point in time. They typically begin with a network model with switching detail, and with schedules for time-varying parameters – and then the EMS will have applications that compute the bus topology from switch status, and compute specific parameters from time-varying schedules.

Our goal here is to create a standard that can support the following situations effectively:

a) power system modeling where planning and operations are managing their models independently;
b) consolidated modeling, where a single source supports both planning and operations;
c) initialization of planning cases from operations results, regardless of whether modeling is consolidated;
d) initialization of operations models from planning models;
e) construction of external operations models from models of neighboring systems;
f) construction of interconnection planning models from models of the constituent systems.

Most of the requirements derived from the above list bear more strongly on the static modeling of the power network, which is covered in IEC 61970-452. From the standpoint of solution exchange, it is simply important to remain consistent with all these requirements.

6 Architecture

6.1 General

The main architectural feature of this standard is data modularization:

- modularization by data model (CIM) profiles (usually reflects the application that produces the data);
- modularization by grouping of instance data into model authority sets (MAS) (usually reflects regional responsibility).

6.2 Profile architecture

Figure 2 shows the profiles that are covered by the IEC 61970-450 to 61970-499 series specifications and depicts the relationships between them. The profiles are defined in different IEC 61970-450 specifications where each specification defines a group of profiles:

- Static network model profiles defined in IEC 61970-452
  - equipment profile. The static modeling information describing power system physical elements and their electrical connections;
  - schedules profile. The time-varying specifications for power system quantities;

  - measurement specification profile that defines power system measurements.
- Schematic display layout exchange profiles defined in IEC 61970-453
  - Schematic layout exchange profile. Describe the elements of schematic or geographic displays that typically shall be amended when new elements are added to a network model.
- Steady-state solution profiles defined in IEC 61970-456 (this document)
  - topology profile. The bus-branch result as is produced by a topology processor;
  - state variables profile. The result of a state estimator or power flow, or the starting conditions of state variables;
  - discrete (status) measurement profile. A set of switch states at a given points in time;
  - analog measurement profile. A set of analog measurements at a given points in time.

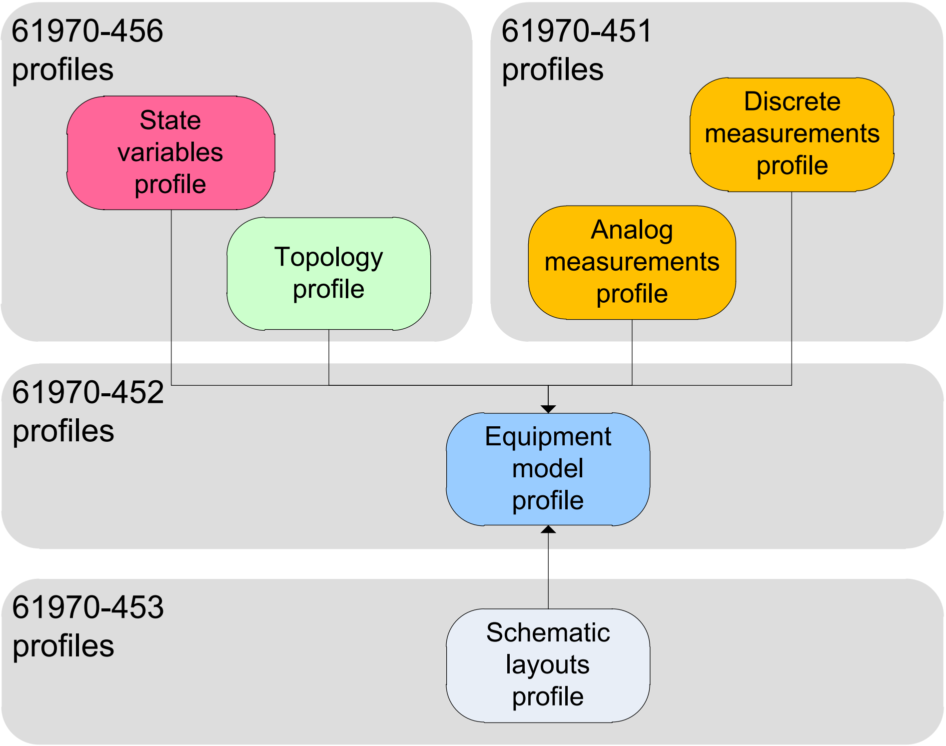

Figure 2 – Profile relationships

These modules satisfy the needs of network analysis business processes used in operations settings (with node-breaker models), in planning settings (with bus-branch models), and for transfers between operations and planning.

In Figure 2, an arrow between profiles indicates that there are relationships defined between classes in the two profiles. The directionality indicates that classes in the “from” profile depend on classes in the “to” profile. For data this means that “from” class data refers to or depends on “to” class data. Example: an instance of an equipment model may have many state variable instances that refer to that equipment model.

In IT-systems, datasets corresponding to the profiles in Figure 2, are exchanged between functions and/or applications. Some examples of applications and their dataset exchange are described below.

The equipment model has detailed substation connectivity based on the ConnectivityNode and terminal classes, refer to Figure 3. The terminal class is central in that it is used by the topology, state variables and schematic layout profiles as well as to associate ConnectivityNodes with ConductingEquipment. Hence the Terminal is an integral part of the equipment model.

It would be possible to create a connectivity profile by factoring out the ConnectivityNode and the Terminal.ConnectivityNode reference. This then introduces complexity and data duplication that mitigate the creation of the connectivity profile.

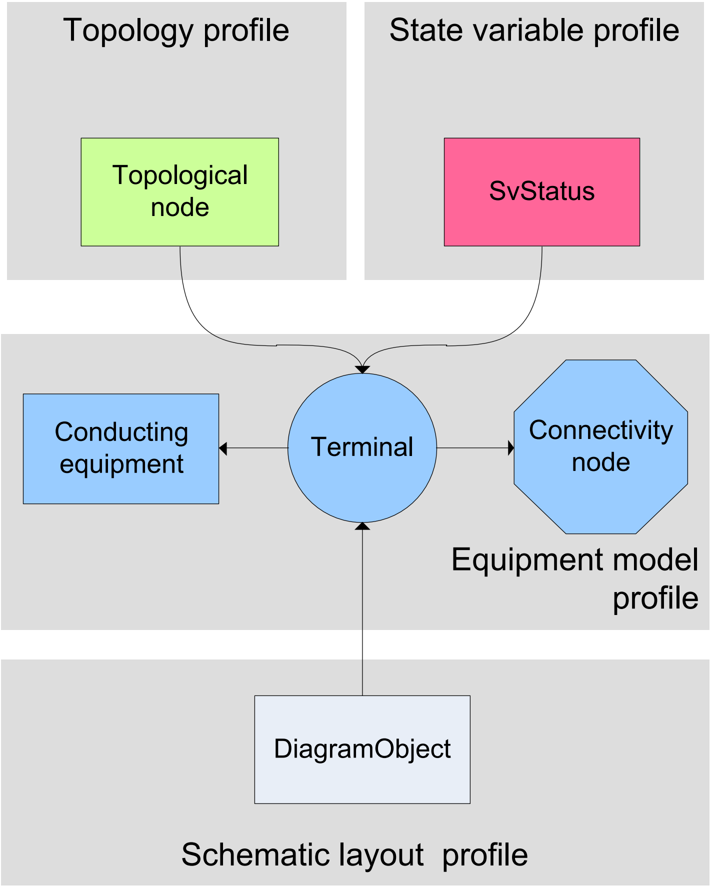

Figure 3 – Instance example of the CIM connectivity model

6.3 Profiles and datasets for EMS network analysis

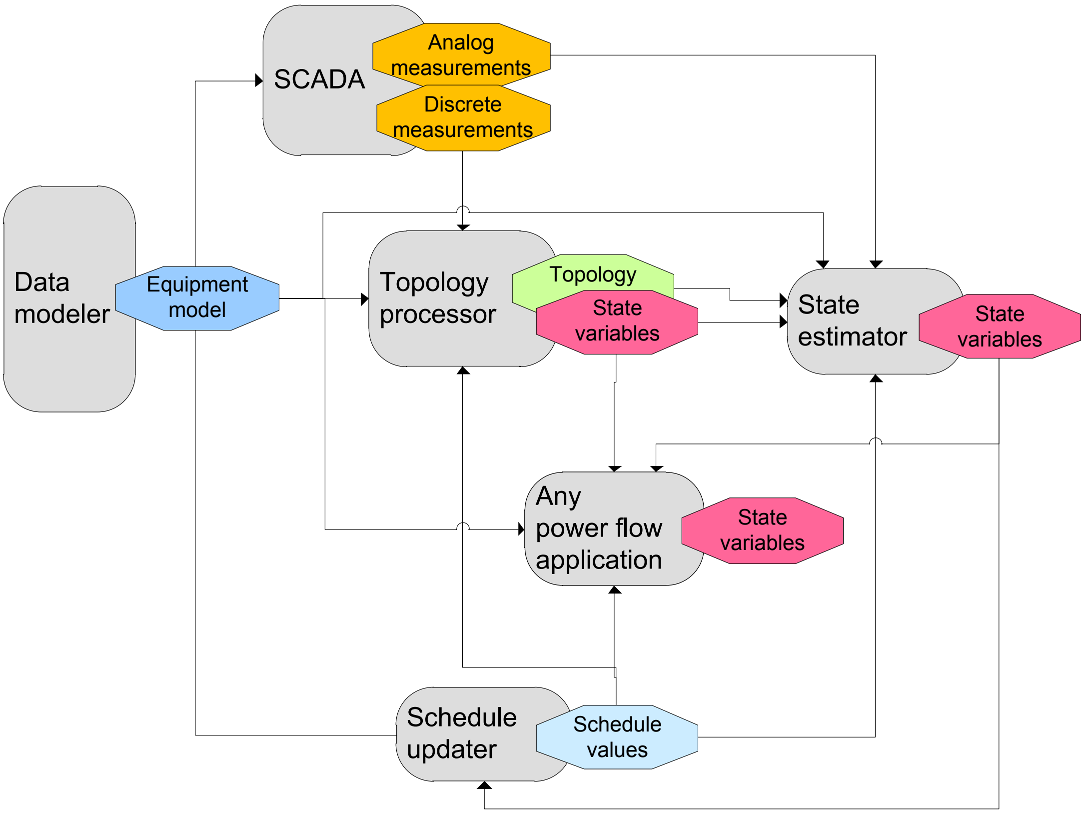

Figure 4 – EMS datasets by CIM profiles

Figure 4 shows how datasets governed by the different CIM profiles that are produced in an EMS. The octagons in the EMS show datasets that are described by the profiles. The rounded octagons represent typical application modules. Data typically flows from producers to consumers as follows. The modeler application produces the equipment model.

The SCADA application uses equipment measurement model as input and produces, periodically, new analog and discrete (e.g. status) measurements.

The topology application uses equipment model from the modeler and discrete measurements from SCADA to determine the starting conditions for a state estimation algorithm, which results in topology and state variable datasets.

The state estimation application uses the analog measurements, the equipment model, the topology and the state variable datasets as input and produces the solved state expressed as a state variable dataset. (Note here the same profile, state variables, governs a dataset used for input and a different dataset containing the solution.)

Any power flow based application, e.g. contingency analysis, uses equipment model, topology and solved state variables to produce multiple contingency solutions also expressed as state variables.

The scheduler update application uses the equipment schedules model from the data modeler with state variables datasets from other applications to create schedule values. The schedule values can be used by state estimation or any power flow application as an alternate source of input data.

6.4 Profiles and datasets in a planning power flow

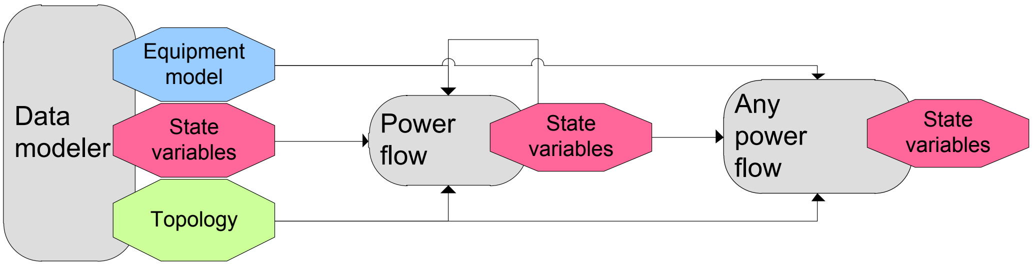

Figure 5 – Planning power flow datasets by CIM profile

Figure 5 shows this same sort of diagram for a planning power flow environment. In this situation:

- the modeling application is only used to generate cases for a single point in time, so there is no need for schedules and initial state variables are created as input;
- no state estimator exists, so measurements are not required;
- users typically enter data directly as a topology result.

These diagrams illustrate how datasets conforming to standard CIM profiles may be produced in some common configurations. The reason the standard is constructed on these profiles is so that in typical sequences of operations a complete record of input and output can be saved without duplicating information unnecessarily. Figure 6, we see what this would look like for the case of periodic execution of state estimation. In the first run, each type of dataset would be recorded completely, but in subsequent runs, only those datasets that change need to be produced, and some of those may be produced in incremental form.

In order to make use of this information, a consumer shall be able to re-assemble a complete set of input for its particular purpose. A very common example would be a bus-branch network analysis application that requires a state estimator solution as a starting point. Such an application would normally need the solved instance of state variables, plus an instance of topology representing that used in the state estimate, plus an instance of equipment representing that used in the state estimate. Referring to Figure 5, if such a consumer wanted state variable SV4, it would need topology T2 and equipment E1. Very likely, this consumer is moving from one state to the next. Very likely, when V4 is produced, it has already received and established T2 and E1 when it processed SV3. If so, the only thing it has to do is to acquire the new V4 and check that the topology and equipment datasets have not changed. The structure of datasets is designed to optimize this sort of processing.

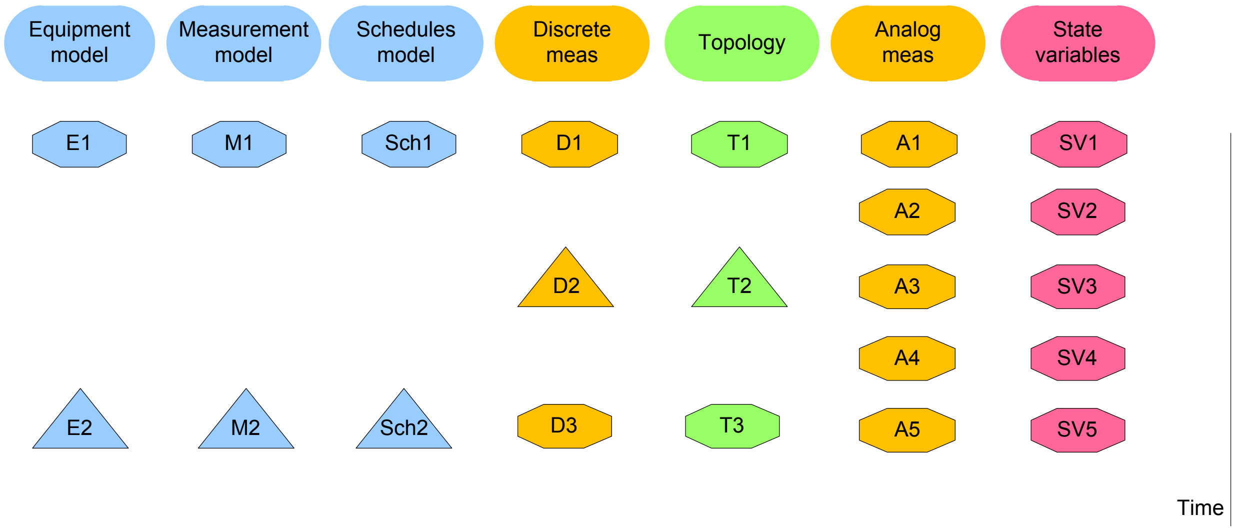

Figure 6 – State estimation case sequence

Figure 6 show two types of datasets:

- octagons that are a full dataset;
- triangles that are a differential dataset.

6.5 Model authority sets and instance level data modularization

6.5.1 General

Modularization by profiles results in modularization of a model by object instance, but each dataset contains only the kinds of objects and relationships defined in the profile to which the dataset belongs. When we use the term ‘instance level modularization’, we are talking about further partitioning within a profile. This is a technique for efficient re-use of data. It rests on some fairly simple graphical principles, which are summarized in 6.5.2.

6.5.2 EMS instance modularization

Figure 7 illustrates partitioning of models in an EMS. Octagon shapes depict datasets. Those at different vertical points conform to different profiles and those at different horizontal points are different instance modularizations.

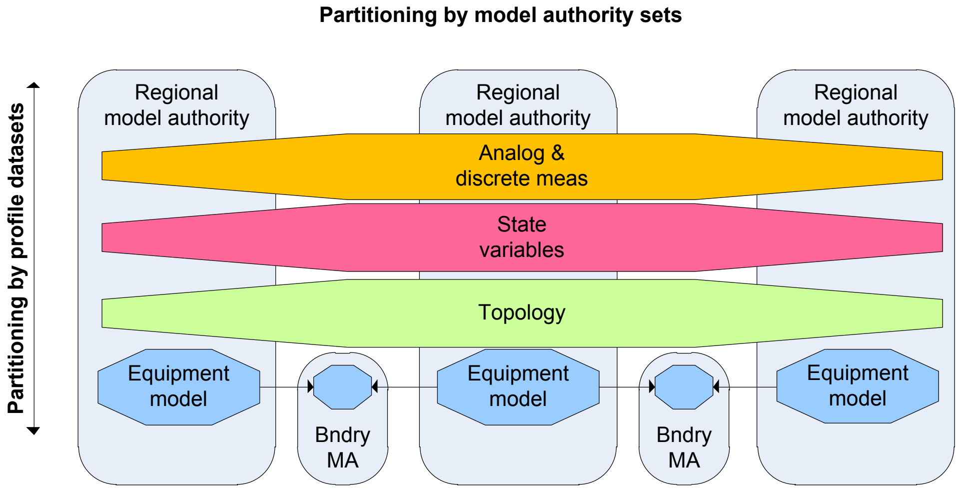

Figure 7 – Instance modularization applied in an EMS

Starting at the bottom and working up this diagram, the elements are as follows:

- Static model data from a modeler
  - equipment model dataset. As shown in Figure 7, some of the model data appears in the boundary;
  - measurement model dataset (not shown in diagram);
  - schedules model dataset (not shown in the diagram).
- Computed data
  - analog and discrete measurement datasets. These datasets contain actual measurements;
  - topology datasets. In an EMS, this is the calculated output of a topology processing application;
  - state variable dataset. In an EMS, this is either the calculated input to a state estimator or power flow (for initializing state variables) or it is the output of a network solution.

From left to right the partitioning between model authority sets is shown. Boundary objects are shared both for equipment model and topology data.

6.5.3 Planning instance modularization

Figure 8 illustrates partitioning of models in network planning applications.

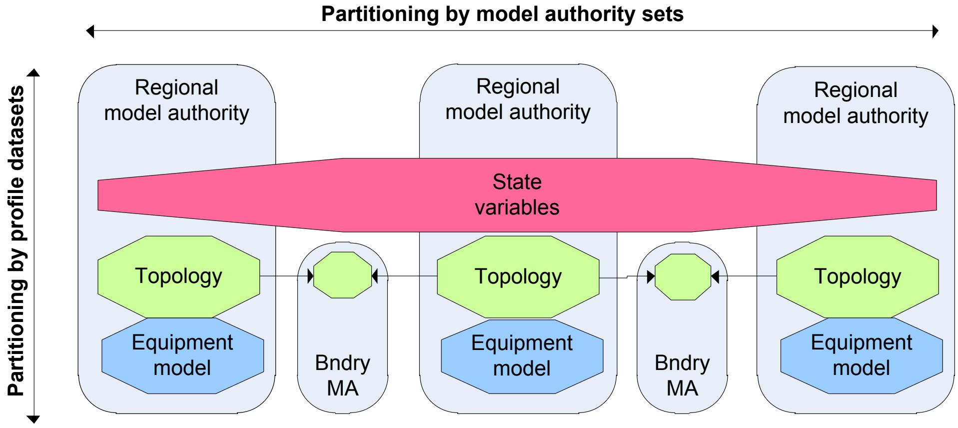

Figure 8 – Instance modularization applied to planning power flow models

Starting at the bottom and working up this diagram, the main elements are as follows:

- Static model data that defines the base case
  - equipment model dataset. As shown in Figure 8, some of the model data appear in the boundary;
  - schedules model dataset (not shown in the diagram);
  - topology datasets.
- Exchange of solved cases
  - State variable dataset.

6.6 Principles of instance modularization

Every dataset has:

- a dataset identity. This typically differentiates its purpose. Thus ‘region A as-built model’ would be different from ‘region A equivalent’, even though they occupied exactly the same position in a larger model;
- a dataset version;
- a profile reference defining the object and relationship types that are allowed in the dataset;
- an optional model authority set reference defining the association with a regional partitioning. There might be region A partitions of equipment and connectivity, for example.

Whereas CIM profiles are standardized when exchanged and vendors shall support datasets conforming to the standard profiles, the use of instance modularization is a matter of convenience for the business process. Although vendor applications shall support model authority sets, the manner in which they are applied is user-determined and not constrained except that model authority sets that will be merged to form models shall be disjoint – i.e. non-overlapping. Figure 9 illustrates the model merge process where models managed by different model authority sets are merged into a global model. The merge process includes datasets for multiple profiles.

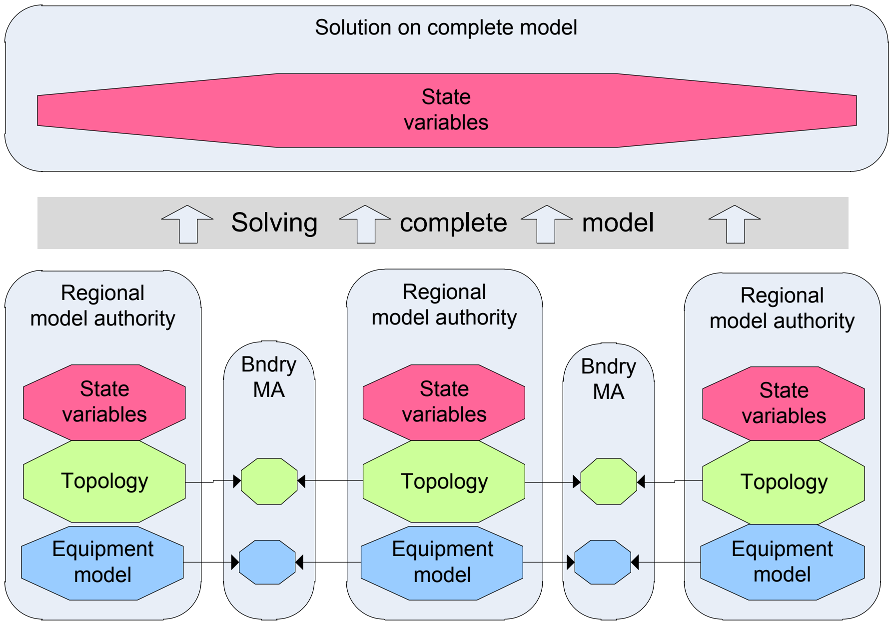

Figure 9 – Model merge process

A useful way to describe what is happening with overall modularization is to picture a complete set of data graphically (as is done in RDF), where the nodes of the graph are object instances and where the arcs of the graph are relationships between object instances. A modularization of this complete model is defined as any partitioning of nodes into non-overlapping subsets of nodes (i.e. disjoint sets). Each subset may be described as a sub-graph. (There is no requirement that such a sub-graph is connected – i.e. that its nodes are connected internally to the sub-graph.)

There are obviously a great many possible modularizations of any large model. Power systems have specific objectives, however:

- modularization according to the producer application;
- modularization according to responsibility for data. This facilitates the exchange of regional models and assembly of whole models from contributed parts – hence the term 'model authority set';
- modularization according to functional building blocks. This optimizes business processes where one subgraph is re-used in many situations – as is true with the power system equipment modeling.

A relationship between two sub-graphs means that the applications or users that manage the datasets (i.e. add, delete or modify objects) shall be aware of the potential for invalidating the relationship. The reason these relationships are important is that many related business problems may be solved by re-using sub-graphs in different situations, and the external connections of the sub-graphs must plug together in order to make this work.

Relationships in CIM UML are (at the moment) not directional and datasets (i.e. sub-graphs) in CIM/XML are typically made directional in the profile specifications. Specifying the relationship from one end is used if the referred-to dataset is created at one step in a process, and then referring dataset is created later, e.g.

- an equipment model datasets are created in a power system modeling tool and made available for applications. The modeler should not have to know what this equipment dataset will be used for. As topology and various solutions are run, result datasets are created. These datasets logically relate back to Equipment model;
- boundary data sets are agreed upon between two or more parties. Once defined and existing, the boundary datasets can be imported into data modeler tools where its objects can be referenced when building regional model authority set datasets. Boundary datasets act as isolation layers that keep the regional model authority set datasets mutual unaware of its internal data. Hence it is important that the boundary datasets are created early on;
- in power systems, for example, the boundary set contains nodes either in the middle of or at one end of each tie line. Since ties change rarely and are very well known, it is usually easy from this starting point to build regional sets that correspond to the territory of one transmission owner.

7 Applying the standard to business problems

7.1 EMS network analysis integration with external consumers

An architecture for transfer of data from a SCADA/EMS to an external client is shown in Figure 10.

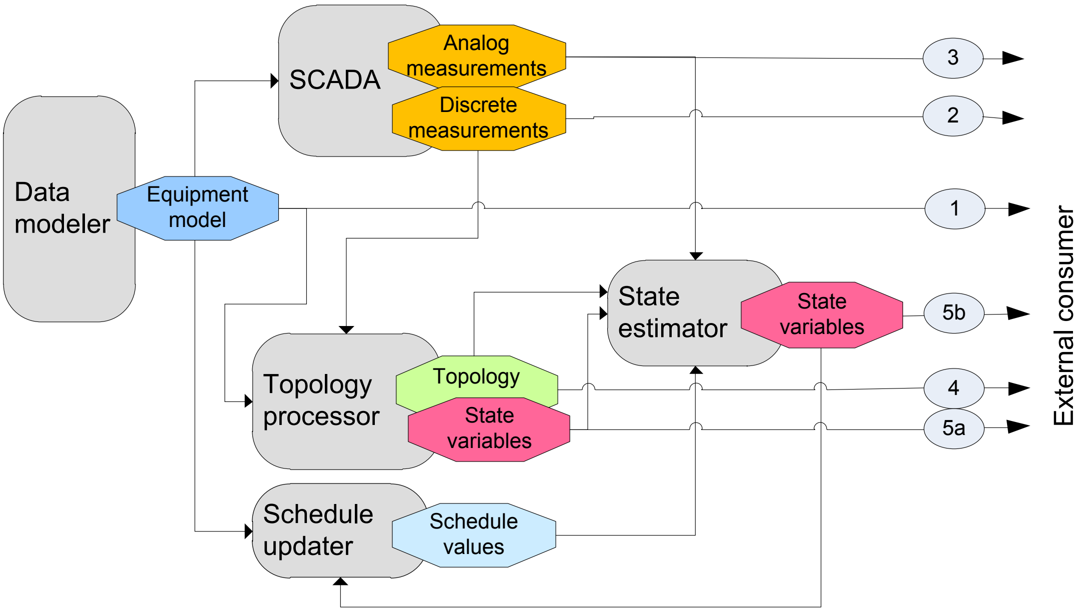

Figure 10 – EMS datasets to an external client

The following interfaces are shown in Figure 10:

– network model data as described in IEC 61970-452;

– network discrete measurements dataset;

– network analog measurements dataset;

– topology processor result dataset;

– state variables a) input values and b) state estimator results.

Different consumers may be interested in different combinations of these interfaces.

- Interfaces 1, 4, 5b would support an external contingency analysis.
  - Add interface 2 if contingencies are defined in terms of switch data.
- Interfaces 1, 4, 5b would support voltage stability analysis.
- Interfaces 1, 3, 4, 5a would support an external state estimator.
- Interfaces 1, 4, 5 (a or b) would support external planning-type power flows (which typically operate in bus-branch models for a single point in time).
  - Add interface 2 if topology processing is supported to enable switch data input.
  - Add interface 3 if measurements are desired for study state estimation.

Figure 11 show how the boundary dataset tie together two regions MAS1 and MAS2.

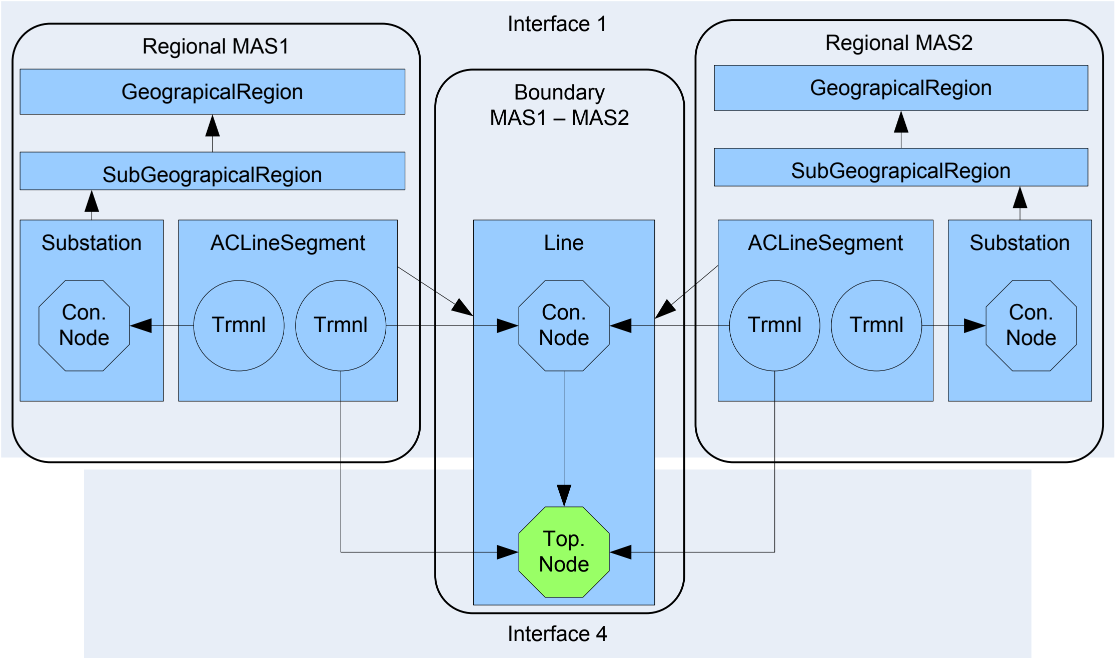

Figure 11 – EMS boundary dataset example

Figure 11 follows the colour conventions for profiles/datasets defined earlier. The following shorted CIM class names are used:

- Con.Node = ConnectivityNode;
- Top.Node = TopologicalNode;
- Trmnl = Terminal.

The arrow directions reflect the directions as defined in the profile documents. As can be seen, all references are going from the regional MAS into the boundary.

7.2 Planning network analysis integration with external consumers

A similar picture for from a source that operates with bus-branch style data is shown in Figure 12.

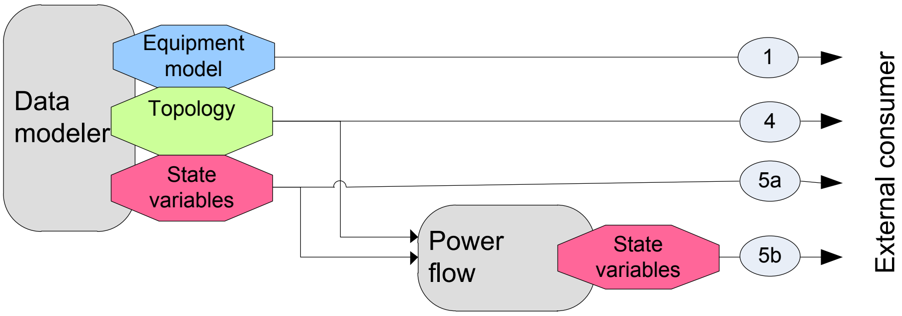

Figure 12 – Bus-branch Integration architecture

The interface specifications for 1, 4 and 5 are the same as in Figure 12, but in this system, there is no switch level detail (no connectivity dataset) and topology is managed manually instead of calculated. In situations such as simple line openings, this means that instead of opening a breaker at the end of the line, the user alters the topology status of the line terminal to open – a straightforward difference.

A more complex change, line transfer between split buses, is illustrated in Figure 13. This is accomplished as follows.

- The voltage level should be represented with two buses with a retained switch between them, even when the bus tie is closed. This will be treated as a zero impedance logical branch within the power flow.
- The bus may then be split by opening the logical branch, as shown in Figure 13.
- Transfer of a transmission line or other equipment between bus bars cannot be made with switching. Instead, the reference (in the topology dataset) between the line/equipment terminal and the TopologyNode representing bus bar is updated.

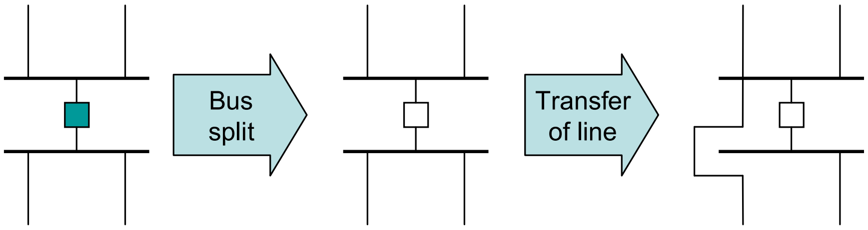

Figure 13 – Bus-branch modeling of bus coupler and line transfer

When systems model topology in this way, the results could theoretically still be transferred to a solution environment like an EMS, but the EMS would have no way to impute the underlying switch status, so it would have to be designed to operate with dual sources of topology input. Clearly, it is more natural to transfer from a node-breaker environment to a bus-branch environment than it is the other direction.

8 Data model with CIMXML examples

8.1 Measurement interfaces 2 and 3

The analog and discrete measurement interfaces are described in IEC 61970-451[5].

8.2 Topology interface 4

Interface 4 (refer to Figure 11 and Figure 12) is addressed in this document. Its purpose is to provide the bus-branch topology needed by state estimation or any other power flow based application. The topology can be created by a topology processor as indicated in Figure 14 or a tool where the bus-branch topology is manually maintained.

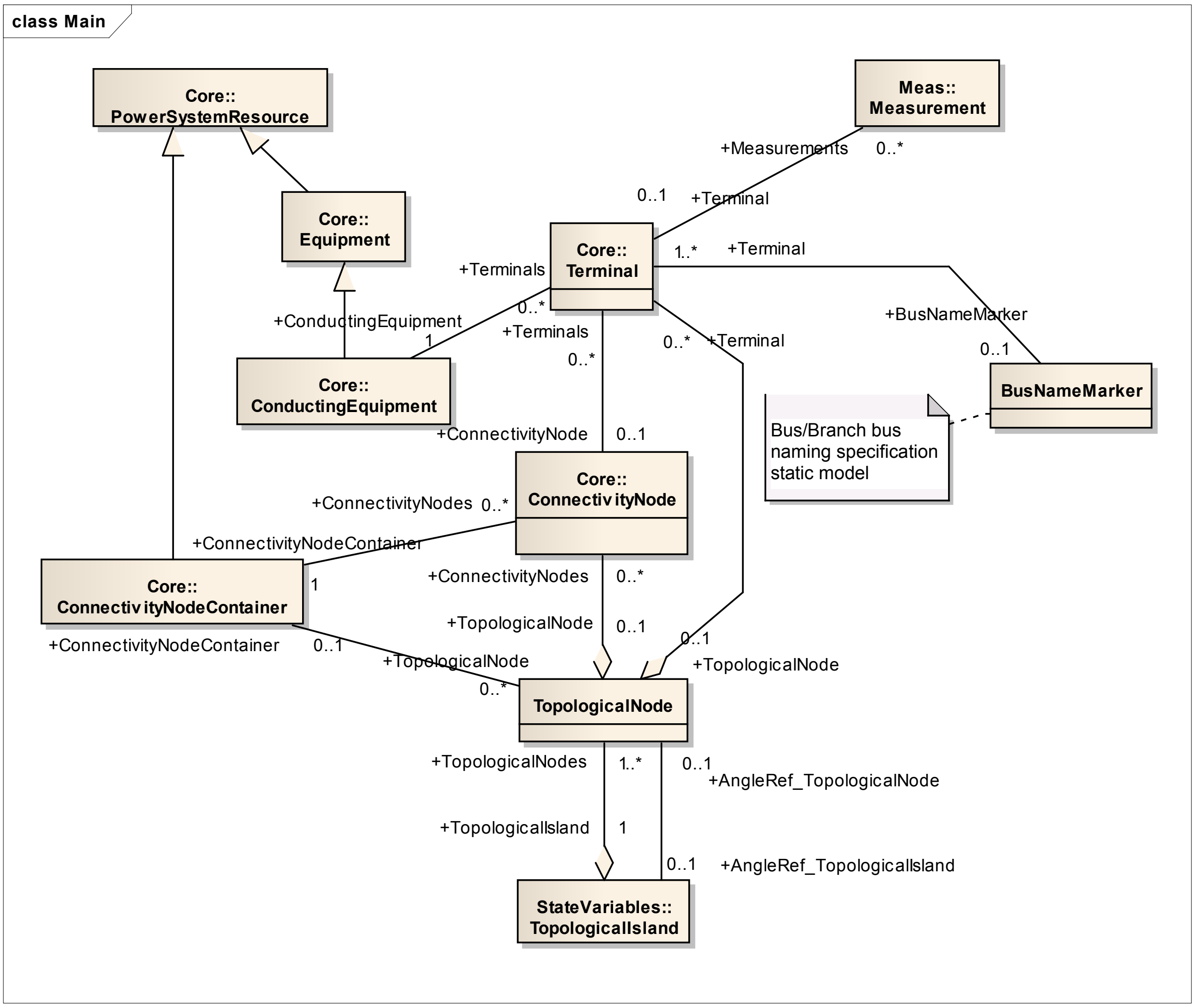

Figure 14 – CIM topology model

The topology solution is based on the classes TopologicalNode and Terminal shown in Figure 14. Disconnecting equipment (e.g. transmission lines, synchronous machines, switches, etc.) is made by setting the attribute Terminal.connected to false. The disconnecting of the coupler in Figure 13 is made this way. Transfer of a transmission line from one bus bar to another as indicated in Figure 13 is made by changing the reference Terminal.ToplogicalNode.

---

[5] IEC 61970-451, *EMS-API – Part 451: SCADA Data Exchange profiles*

A dataset example based on the model in Figure 14 is shown in Figure 15.

```
<rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
xmlns:cim="http://iec.ch/TC57/2009/CIM-schema-cim14#">
        <cim:IEC61970CIMVersion rdf:ID="_301">
                <cim:IEC61970CIMVersion.version>cim6197011v09</cim:IEC61970CIMVersion.version>
                <cim:IEC61970CIMVersion.date>2007-06-12</cim:IEC61970CIMVersion.date>
        </cim:IEC61970CIMVersion>
        <cim:Terminal rdf:about="#T1">
                <cim:Terminal.TopologicalNode rdf:resource="#TN1"/>
                <cim:Terminal.connected>true</cim:Terminal.connected>
        </cim:Terminal>
        <cim:Terminal rdf:about="#T2">
                <cim:Terminal.TopologicalNode rdf:resource="#TN1"/>
                <cim:Terminal.connected>true</cim:Terminal.connected>
        </cim:Terminal>
        <cim:Terminal rdf:about="#T3">
                <cim:Terminal.TopologicalNode rdf:resource="#TN1"/>
                <cim:Terminal.connected>true</cim:Terminal.connected>
        </cim:Terminal>
        <cim:Terminal rdf:about="#T4">
                <cim:Terminal.TopologicalNode rdf:resource="#TN2"/>
                <cim:Terminal.connected>true</cim:Terminal.connected>
        </cim:Terminal>
        ...
        <cim:TopologicalNode rdf:ID="TN1">
                <cim:IdentifiedObject.name>BLOO400SUBNET_7048</cim:IdentifiedObject.name>
        </cim:TopologicalNode>
        <cim:TopologicalNode rdf:ID="TN2">
                <cim:IdentifiedObject.name>BLOO220SUBNET_7067</cim:IdentifiedObject.name>
        </cim:TopologicalNode>
        <cim:TopologicalNode rdf:ID="TN3">
                <cim:IdentifiedObject.name>BLOO220SUBNET_7082</cim:IdentifiedObject.name>
        </cim:TopologicalNode>
        ...
</rdf:RDF>
```

Figure 15 – Topology solution interface

A topology dataset always references (depends on) an equipment dataset. Normally, any topology instance will, in its header, refer to the equipment instance on which it was based, and in most use cases, this is the equipment instance that the consumer will want to use. This does not prevent its attempted use with other equipment instances, which may make sense in some use cases. Basically, the only software requirement is that all the external references from the topology set resolve to objects in the equipment dataset that it is being plugged into. If a consumer wants to recover the status set that was used as input to the topology, this may be referenced in the header and retrieved as well; however, there are no references from the topology to the status set, so this is not required.

TopologicalNodes are calculated objects, and the exact set of objects that will result depends on the status input. However, there are many use cases where results of network analyses of potentially different topologies need to be related or compared to one another. This makes sense because the power system stays in a recognizably similar configuration almost all the time, even though it theoretically could reach a very different state occasionally. In general, the key to these use cases is to get the identity associated with the main buses of each substation to be the same. CIM modeling allows the modeler to provide input data to identify the main buses and provide direction as to how bus identity is to be created in the topology processing algorithm. If modelers a) provide such identity direction, and b) establish multiple main buses separated by retained logical devices wherever bus splits are common, then the TopologicalNodes can have consistent identifications (rdf:IDs) from one topology dataset to another.

NOTE This does not mean identical – what it means is that the normal set of buses will be found with the same identifiers, even though occasionally there will be some TopologicalNodes that do not match.

A topology processor or a system may update the bus branch model incrementally, i.e. only recalculate the changed TopologicalNodes and terminals as a result of breaker changes or manual updates. Such a change may be exchanged as an incremental update. In this case, the rdf:IDs in the increment shall correlate to the ones in the previous messages.

Interface 4 may include all model authorities or just a subset. In case just a subset is included, the TopologicalNodes in the boundary shall use the stable identifications. The <cim:Terminal rdf:about= ...> in Figure 15 means that this is an update to an existing cim:Terminal object defined by interface 1. Hence it is possible to merge interface 1 and interface 4 files and the merged file will validate correctly.

8.3 State variables interfaces 5a and 5b state estimation

Interface 5 (refer to Figure 11 and Figure 12) is addressed in this document. Its purpose is to make a steady state solution, such as is created by state estimator or power flow, available to other applications. The state variables model is shown in Figure 16.

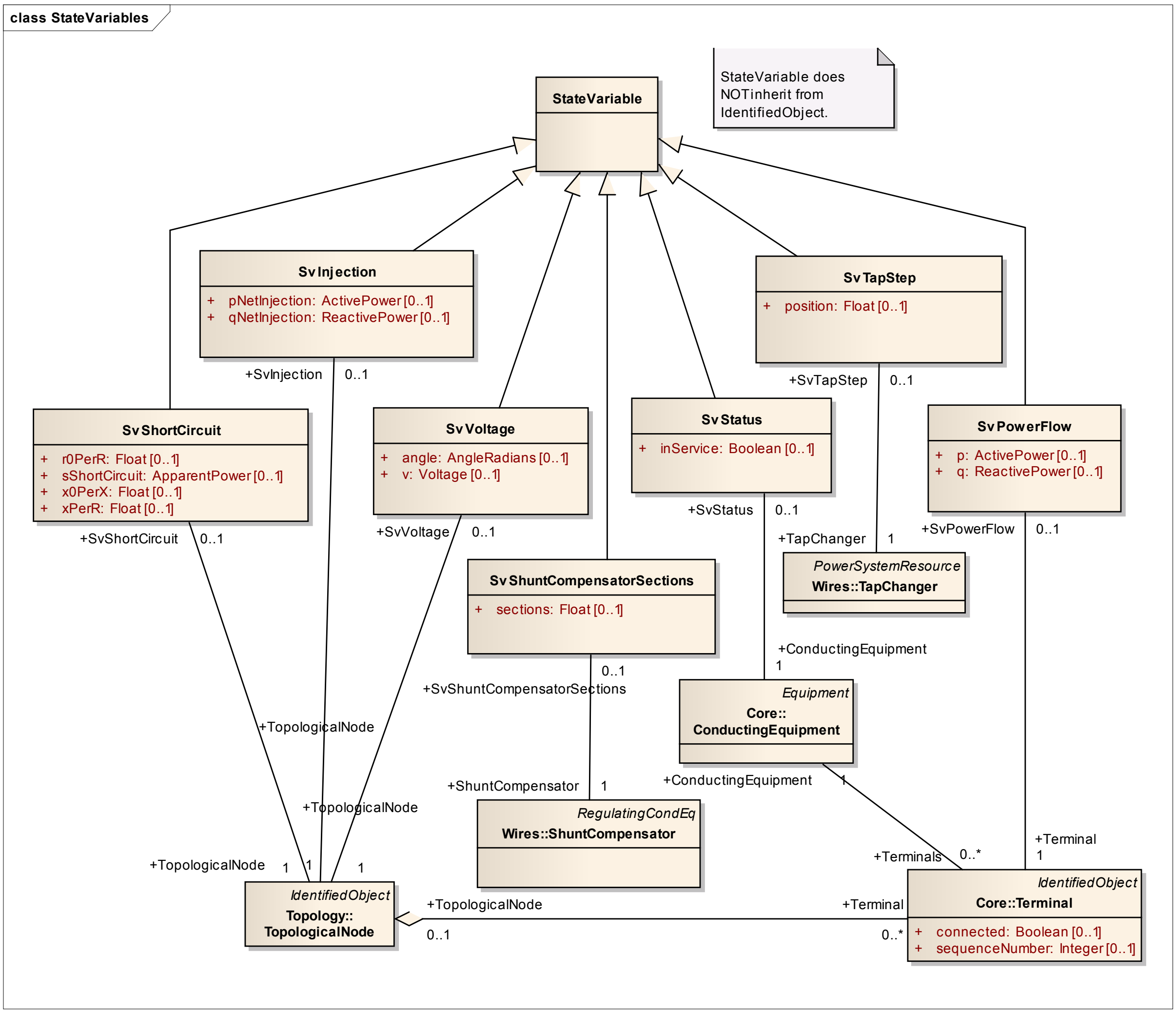

Figure 16 – CIM state variable solution model

The steady state solution is based on the class StateVariable that is specialized into a set of state variables as shown in Figure 16. Note that StateVariable does not inherit from IdentifiedObject as it is fully identified by the object it is attached to.

SvPowerFlow represents the flow into a terminal of any conducting equipment. When initial conditions are being described, it would represent the values of single terminal injections such as load and generation. When solved states are being described, the final values of real equipment injections are provided, and depending on the circumstance, the solved flows in branch terminals may be provided. The SvInjection represents the total injection at a TopologicalNode, i.e. it is the sum of all injecting SvPowerFlows.

SvInjection defines a non-physical additional injection at a TopologicalNode. In other words, this is an injection that has not been associated with a particular piece of conducting equipment. SvInjection may be assigned to every TopologicalNode but this is not required. If it is supplied in a solved case, it represents the balancing term in the bus equation. In other words, SvInjection equals the sum of the flows into all terminals connected to the TopologicalNode. For most solved power flow buses, these values would always be less than the solution tolerance and may be omitted simply because they are insignificant. There are, however, other circumstances where the SvInjection terms are significant:

- SvInjection may be used to represent the flows at the edge of solved region. In this sort of use case, regions of an interconnection solution may be reported individually, with the SvInjection term representing flows into the other parts of the interconnection. (If a receiving party tries to piece the whole solution back together, they would normally check the SvInjections on both sides of a boundary point for consistency, and then ignore both in further analysis.)

- In a state estimator result, SvInjection may report the injection residual. This can be used to avoid the heuristic assignment of injection residual to loads and generators, and provides a place to report residuals at zero injection buses.
- In unsolved power flows, SvInjection can report the buses at which there is mismatch above tolerance.

A CIM XML example based on the model in Figure 16 is shown in Figure 17.

```
<rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
xmlns:cim="http://iec.ch/TC57/2009/CIM-schema-cim14#">

        <cim:IEC61970CIMVersion rdf:ID="_301">

                <cim:IEC61970CIMVersion.version>cim6197011v09</cim:IEC61970CIMVersion.version>

                <cim:IEC61970CIMVersion.date>2007-06-12</cim:IEC61970CIMVersion.date>

        </cim:IEC61970CIMVersion>


        <cim:TopologicalIsland rdf:ID="TI1">

                <cim:IdentifiedObject.localName>_1001</cim:IdentifiedObject.localName>

                <cim:TopologicalIsland.TopologicalNodes rdf:resource="#TN1"/>

                <cim:TopologicalIsland.TopologicalNodes rdf:resource="#TN2"/>

                <cim:TopologicalIsland.TopologicalNodes rdf:resource="#TN3"/>

        </cim:TopologicalIsland>

        ...


        <cim:SvInjection rdf:ID="SvI1">

                <cim:SvInjection.TopologicalNode rdf:resource="#TN1"/>

                <cim:SvInjection.pNetInjection>123</cim:SvInjection.pNetInjection>

                <cim:SvInjection.qNetInjection>456</cim:SvInjection.qNetInjection>

        </cim:SvInjection>

        <cim:SvInjection rdf:ID="SvI2">

                <cim:SvInjection.TopologicalNode rdf:resource="#TN2"/>

                <cim:SvInjection.pNetInjection>123</cim:SvInjection.pNetInjection>

                <cim:SvInjection.qNetInjection>456</cim:SvInjection.qNetInjection>

        </cim:SvInjection>

        ...

        <cim:SvVoltage rdf:ID="SvV1">

                <cim:SvVoltage.TopologicalNode rdf:resource="#TN1"/>

                <cim:SvVoltage.v>400</cim:SvVoltage.v>

                <cim:SvVoltage.angle>0.1</cim:SvVoltage.angle>

        </cim:SvVoltage>

        <cim:SvVoltage rdf:ID="SvV2">

                <cim:SvVoltage.TopologicalNode rdf:resource="#TN2"/>

                <cim:SvVoltage.v>400</cim:SvVoltage.v>

                <cim:SvVoltage.angle>0.1</cim:SvVoltage.angle>

        </cim:SvVoltage>

        ...

        <cim:SvPowerFlow rdf:ID="SvPF1">

                <cim:SvPowerFlow.Terminal rdf:resource="#T1"/>
```

```
                <cim:SvPowerFlow.p>123</cim:SvPowerFlow.p>
                <cim:SvPowerFlow.q>456</cim:SvPowerFlow.q>
        </cim:SvPowerFlow>
        ...
</rdf:RDF>
```

Figure 17 – State solution interface example

The state variables are identified by the objects they belong to and their life time depends on that object, i.e. the objects TopologicalNode, ConductingEquipment, Terminal, TapChanger, etc. State variable rdf:IDs are required to be unique within a message only and their rdf:IDs cannot be correlated between messages.

9 Topology profile

9.1 General

Clause 9 lists the profiles that will be used for data exchange and the classes, attributes, and associations that are a part of each profile. Included are all the classes that a data consumer would be expected to recognize in the data being consumed. Additional classes are referenced in Clause 9, when the classes to be exchanged inherit attributes or associations. For instance, many classes inherit attributes from the class IdentifiedObject. However, no instances of the class IdentifiedObject would exist in the data exchanged, so IdentifiedObject has not been included in the set of CIM classes for exchange.

Profile namespace: http://iec.ch/TC57/61970-456/Topology/CIM14/1#

9.2 Concrete classes

9.2.1 Terminal

Core

An electrical connection point to a piece of conducting equipment. Terminals are connected at physical connection points called "connectivity nodes".

Native members

connected	0..1	boolean	The connected status is related to a bus-branch model and the TopologicalNode-Terminal relation. True implies the Terminal is connected to the related TopologicalNode and false implies it is not. In a bus-branch model the connected status is used to tell if equipment is disconnected without having to change the connectivity described by the TopologicalNode-Terminal relation. A valid case is that ConductingEquipment can be connected in one end and open in the other. In particular for an ACLineSegment where the charging can be significant this is a relevant case.
TopologicalNode	1..1	TopologicalNode	The topological node associated with the terminal. This can be used as an

			alternative to the connectivity node path to topological node, thus making it unnecessary to model connectivity nodes in some cases. Note that if connectivity nodes are in the model, this association would probably not be used.

9.2.2 TopologicalNode

Topology

For a detailed substation model a TopologicalNode is a set of connectivity nodes that, in the current network state, are connected together through any type of closed switches, including jumpers. Topological nodes change as the current network state changes (i.e., switches, breakers, etc. change state).

For a planning model switch statuses are not used to form TopologicalNodes. Instead they are manually created or deleted in a model builder tool. TopologialNodes maintained this way are also called "busses" native members.

Native members

BaseVoltage	1..1	BaseVoltage	The base voltage of the topologocial node.
ConnectivityNodes	0..unbounded	ConnectivityNode	Several ConnectivityNode(s) may combine together to form a single TopologicalNode, depending on the current state of the network.

Inherited members

description	0..1	string	See IdentifiedObject
name	1..1	string	See IdentifiedObject

9.3 Abstract classes – IdentifiedObject

Core

This is a root class to provide common naming attributes for all classes needing naming attributes.

Native members

description	0..1	string	The description is a free human readable text describing or naming the object. It may be non-unique and may not correlate to a naming hierarchy.

name	1..1	string	The name is a free text human readable name of the object. It may be non-unique and may not correlate to a naming hierarchy.

10 StateVariables profile

10.1 General

Clause 10 lists the profiles that will be used for data exchange and the classes, attributes, and associations that are a part of each profile. Included are all the classes that a data consumer would be expected to recognize in the data being consumed. Additional classes are referenced in Clause 10, when the classes to be exchanged inherit attributes or associations. For instance, many classes inherit attributes from the class IdentifiedObject. However, no instances of the class IdentifiedObject would exist in the data exchanged, so IdentifiedObject has not been included in the set of CIM classes for exchange.

Profile namespace: http://iec.ch/TC57/61970-456/StateVariables/CIM14/1#

10.2 Concrete classes

10.2.1 TopologicalIsland

StateVariables

An electrically connected subset of the network. Topological islands can change as the current network state changes (i.e. switch or Terminal.connected status changes).

Native members

AngleRef_TopologicalNode	1..1	TopologicalNode	The angle reference for the island. Normally there is one TopologicalNode that is selected as the angle reference for each island. Other reference schemes exist, so the association is optional.
TopologicalNodes	1..*	TopologicalNodes	A topological node belongs to a topological island.

Inherited members

description	0..1	string	See IdentifiedObject
name	1..1	string	See IdentifiedObject

10.2.2 SvInjection

StateVariables

Injection state variable

Native members

pNetInjection	1..1	ActivePower	The active power injected into the bus at this location. Positive sign means injection into the bus.
qNetInjection	0..1	ReactivePower	The reactive power injected into the bus at this location. Positive sign means injection into the bus.
TopologicalNode	1..1	TopologicalNode	The topological node associated with the voltage state.

10.2.3 SvPowerFlow

StateVariables

State variable for power flow

Native members

p	1..1	ActivePower	The active power flow into the terminal.
q	1..1	ReactivePower	The reactive power flow into the terminal.
Terminal	1..1	Terminal	The terminal associated with the power flow state.

10.2.4 SvShortCircuit

StateVariables

State variable for short circuit

Native members

r0PerR	1..1	float	The ratio of zero sequence resistance to positive sequence resistance.
sShortCircuit	1..1	ApparentPower	The short circuit apparent power drawn at this node when faulted.
x0PerX	1..1	float	The ratio of zero sequence reactance per positive sequence reactance.
xPerR	1..1	float	Ratio of positive sequence reactance per positive sequence resistance.
TopologicalNode	1..1	TopologicalNode	The topological node associated with the short circuit state.

10.2.5 SvShuntCompensatorSections

StateVariables

State variable for the number of sections in service for a shunt compensator

Native members

continuousSections	0..1	float	The number of sections in service as a continuous variable.
sections	0..1	integer	The number of sections in service.
ShuntCompensator	1..1	ShuntCompensator	The shunt compensator for which the state applies.

10.2.6 SvTapStep

StateVariables

State variable for transformer tap step. This class is to be used for taps of LTC (load tap changing) transformers, not fixed tap transformers.

Native members

continuousPosition	0..1	float	The floating point tap position.
position	0..1	integer	The integer tap position.
TapChanger	1..1	TapChanger	The tap changer associated with the tap step state.

10.2.7 SvVoltage

StateVariables

State variable for voltage

Native members

angle	1..1	AngleRadians	The voltage angle in radians of the topological node.
v	1..1	Voltage	The voltage magnitude of the topological node.
TopologicalNode	1..1	TopologicalNode	The topological node associated with the voltage state.

10.3 Abstract classes

10.3.1 StateVariable

StateVariables

An abstract class for state variables

10.3.2 ActivePower

Product of RMS value of the voltage and the RMS value of the in-phase component of the current

XSD type: double

10.3.3 AngleRadians

Phase angle in radians

XSD type: double

10.3.4 ApparentPower

Product of the RMS value of the voltage and the RMS value of the current

XSD type: double

10.3.5 ReactivePower

Product of RMS value of the voltage and the RMS value of the quadrature component of the current

XSD type: double

10.3.6 Voltage

Electrical voltage

XSD type: double

Bibliography

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