# Methods of Converting CIM Power System Models into Bus-Branch Formats Utilizing Topology Processing Algorithms and Minimal Schema Modifications to IEC 61968/70

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*Abstract*—**This paper describes the design of the ERCOT topology processor algorithms, used in conjunction with modeling extensions to IEC 61968/70 standards, that are employed to convert CIM representations of balanced three-phase power system models used in real-time operational energy management applications into standardized bus-branch models used in transmission system planning applications (a flat file format used by PSS/e and Powerworld applications). By using such algorithms, ERCOT is able to utilize a single, unified, highly granular data model source to support all real-time operations and steady-state planning processes, thus removing a primary area of discrepancy that has historically existed between the electrical power industry's planning and operational departments that has long been associated with staging these two modeling environments independently.**

*Index Terms*—**CIM, ERCOT, Topology**

## I. Introduction

HISTORICALLY, real-time operations of the electric transmission and distribution grids and the long-term planning functions for the same grids have not used the same base model data source. This disassociation comes primarily from the way in which the individual models evolved.

Real-time operations models were derived initially from SCADA systems, where real-time telemetry of equipment was mapped to static status boards. As computing power increased and the ability to bring new operational functionality on-line (Security Constrained Dispatching, State Estimation, etc.) was improved, the newer application functionalities were developed by leveraging the existing SCADA infrastructure (primary reasoning for this choice being that SCADA systems already contained elements such as electrical breaker statuses, and generation telemetry that would easily serve as a foundation for the newer functionality). The summation of this development approach is that, for steady-state three-phase models, generally, operations models now tend to have a higher granularity of modeling than their planning counterparts for transmission level topology.

By contrast, planning models were created for simulating real-time and future grid conditions, primarily for performing N-1 contingency analysis used in the determination of proposed transmission system improvements (new transmission lines, etc.). Given the limitations of computing power at the time, a number of simplifications were employed to reduce the size of the model and the calculation time. This included ignoring a number of pieces of topologically significant equipment such as electrical circuit breakers and disconnects, modeling equivalent distribution feeders as transmission level equipment, and for the most part, just collapsing all equipment of the same voltage level within a substation down to a single node (referred to a "bus").

Since planning model representations of the electrical transmission grids were restricted in their granularity, limitations in the certainty of the power flow analysis were imbedded. A commonly cited limitation involves simulations requiring the loss of a transmission line. For example, both a substation with a ring bus configuration (Figure 1) and a substation with a breaker-and-a-half configuration (Figure 2) would, in general, have the same representation in planning models (Figure 3). However, the loss of a transmission line in connected ring bus would have a different post-contingency power flow result as compared to the result of a loss of a transmission line connected in the breaker-and-a-half configuration, since the ring-bus configuration would sectionalize in such a way that the load at the substation would remain energized (Figure 4) and served by the generation, while the same loss of a transmission line in the breaker-and-a-half substation would result in the loss of either the load or the generation (Figure 5). The prior case will be captured by the planning model representation in Figure 3 but the latter case will not.

This limitation was, in general, acceptable for planning studies, since in most cases, the power flow simulation of leaving all equipment in service except for the single transmission line was defined such that it corresponded to the most limiting contingency. Yet, as can be seen in this case, if the load was large, the sectionalizing of the breakers-and-a-

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half bus and the resulting loss of the generation would lead to a post contingency overload of the remaining transmission line that would not be visible in the planning model-based studies.

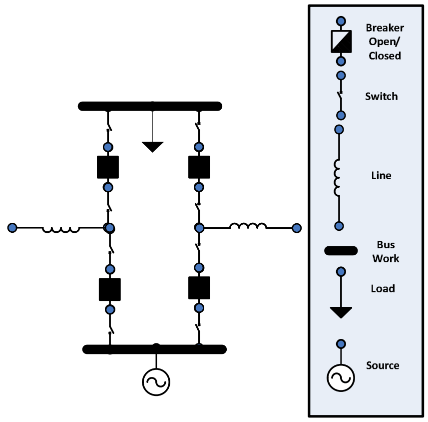


Figure 1: Operational Model Ring Bus Configuration

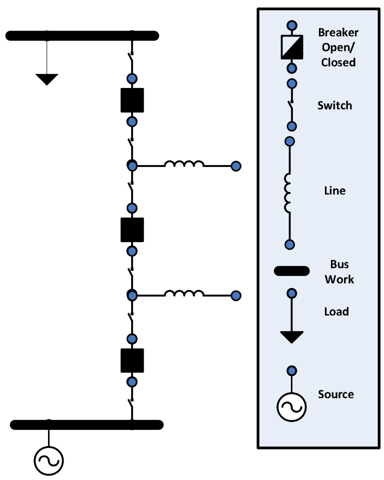


Figure 2: Operational Model Breaker-and-a-Half Configuration

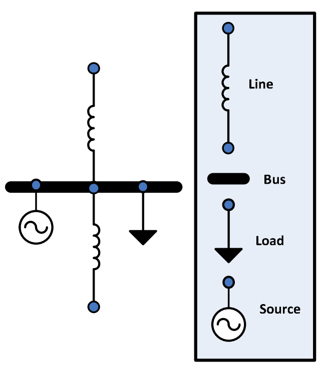


Figure 3: Planning Model for Figure 1 and Figure 2

As technology improved, the number of buses in the system no longer significantly impacted the calculation time for the power flow solutions. This allowed for additional buses and low-impedance line segments to be inserted into the model in attempts to more accurately represent the sectionalizing of the substation due to breaker switching.

However, because of this method, while operational and planning power flow results of line loading under given conditions converged closer, the underlying models producing the results diverged even farther.

In carrying forward the example from before, while a ring bus may continue to be represented in planning models using Figure 3, the substation with the breaker-and-a-half scheme could be represented using the equivalent model in Figure 6, where the removal of the low-impedance cross-connect simulated the sectionalizing of the substation.

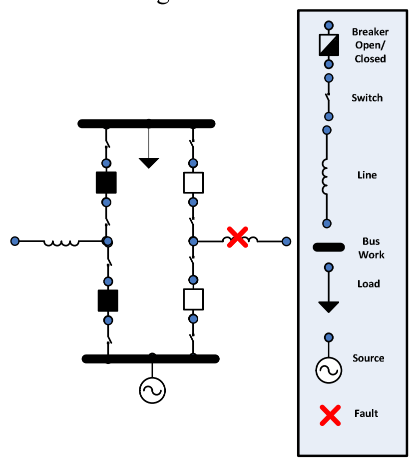


Figure 4: Post-Fault configuration for Ring Bus

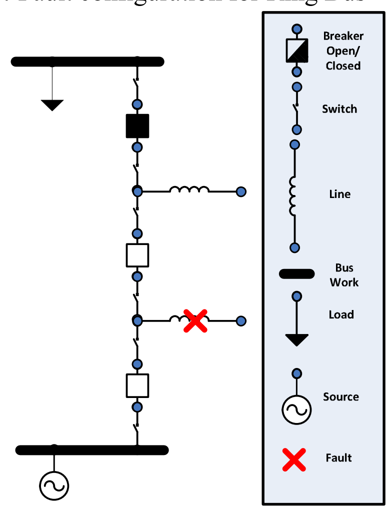


Figure 5: Post-Fault configuration for Breaker-and-a-Half Configuration

While inserting the zero-impedance line allowed for studying the sectionalizing, it increased the amount of discrepancy between the operations and planning models. This meant that when attempting to map operations data changes to planning models for the purposes of model maintenance (i.e. reconducting of existing transmission lines changing impedance) a large effort was required to first locate the same element in the planning model and then map the update.

As time progressed, and even more modeling analysis was made possible by improved computing capability and speeds, greater granularity of modeling was required for supporting the various incoming functions thus causing these models to diverge further. The amount of labor and effort required for supporting both modeling environments, as well as the amount of effort required to document and address inconsistencies between the two models also became larger and more complex with each advance in technology.

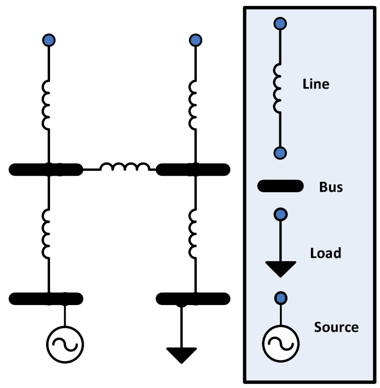


Figure 6: Planning model of Breaker-and-a-Half Configuration

## II. Common Data Souring Using CIM

It was in this environment that as part of implementing a new market system for the state of Texas, ERCOT made the decision to centralize its model information to a common single-sourced data modeling system implemented using the Common Information Model (CIM) Standard. CIM is an open standard for representing power system components originally developed by the Electric Power Research Institute (EPRI) in North America and now is a series of standards being sponsored by the International Electrotechnical Commission (IEC). When speaking of "CIM", it's commonly understood to consist of three separate IEC standards:

1. The IEC standard 61970-3011 is a semantic model that describes the components of a power system at an electrical level and the relationships between each component.
2. The IEC 61968-112 extends this model to cover the other aspects of power system software data exchange such as asset tracking, work scheduling and customer billing.
3. The CIM for Electricity Markets then extends both these models with IEC 62325-3013 to cover the data exchanged between participants in electricity markets.

The CIM standard was originally developed for exchanging power flow models between operational Energy Management Systems (EMS), and therefore is a standard that is highly granular in nature. ERCOT chose to leverage the CIM standard for a centralized data source that would support all of its model requirements.

For the vast majority of the downstream applications ERCOT employed CIM importers to read and stage XML files into databases for the use of the systems. However, for systems that required the use of a bus-branch model, this type of integration was not practical, and for the full design of the single-sourced data source to be realized, the topology was needed to process the CIM file and to produce the bus-branch representation of the model.

## III. Topology Processing

The development of a Topology Processor was a major undertaking of ERCOT as part of the market system redesign. The conversion of the ERCOT CIM model to a bus-branch model compatible with system planning needs for supporting transmission planning processes were of critical importance to a number of stakeholders that used the ERCOT created bus-branch models, most notably the ERCOT Steady State Working Group (responsible for long-term planning studies), System Protection Working Group (responsible for short circuit studies), and the Dynamics Working Group (responsible for dynamic system response studies).

### A. *Requirements*

While historically there were a number of methods associated within the energy management system (EMS) that allowed for the creation of real-time topology processed cases from a higher granularity operational base models, these models were only snapshots of the real-time EMS based on current telemetry; hence the buses were dynamically created based on switch position and therefore were not useful for the ERCOT planners and working groups who required consistent bus numbering assignments from a topology processed output file. However, the working groups also expressed the need for the CIM-based topology processing algorithm to be able to emulate the prevalent "operations methodology" of topology processing to support any forensic studies of power system excursions.

To meet the goals of the working groups for how CIM-based node-breaker model should be processed into the bus-branch model, two specific methods of topology processing logic have been deployed. One creates a bus-branch model based on the "Most-Favored" node markers; the other creates a bus-branch model based on "Connectivity Node Grouping". Most-favored node topology processing is a method preferred by operational groups in real-time environments where model-to-model consistent bus numbering/mapping is not required, while connectivity node grouping is primarily used by planning groups.

Regardless of the option employed, when processing the topology of a CIM model, there are essentially two steps for handling equipment that are not inherently supported in the bus-branch model (i.e. breakers, disconnects, etc.). First step is identifying the bus designator (name/number), and the second is aggregating the "unsupported" equipment under a single bus or node. Subsection B concentrates on describing the utilization of CIM standards to support defining bus and ZBR designators and subsections C & D describe the topology processing approach utilized within each option for identifying a bus & aggregating the equipment within a single bus.

### B. *CIM Utilization*

CIM is an expression of the Unified Modeling Language (UML), and has four basic constituent elements: Class, Attribute, Inheritance, and Association.

A Class represents a specific type of object that will be modeled; each unique instantiated object of a class type is called an instance of that class. Attributes are qualities of an instance of a class, and Association links instances of a Class together. Inheritance allows for Attributes and Associations to be shared across similar classes. For example, Breakers and Disconnects are both of type Switch, and Switch, in turn, is a type of Conducting Equipment. This allows for Attribute or Association to be placed on the parent class and then inherited by the child class.

While the standard CIM model has no concept of hierarchy, users often enforce a hierarchy for usability. Frequently, this hierarchy enforcement comes in the form of "containment", i.e. in CIM, conducting equipment has several associations, one of which is an association to VoltageLevel, and VoltageLevel in turn has several associations, one of which is an association to Substation. For usability, it's easy to think of the substation containing one or more voltage levels, and each voltage level containing one or more pieces of equipment. The design of the ERCOT Topology Processor makes use of these concepts.

The Topology Processor utilizes several core CIM classes as well as several ERCOT CIM extensions. Some of the classes used include,

*a) Terminal: All CIM equipment of the type ConductingEquipment are associated with one or more Terminals. Terminals are considered the "connecting points" in CIM for equipment.*

*b) ConnectivityNode: In CIM, instances (pieces) of equipment that inherit from type ConductingEquipment are "connected" by associating each of their terminals with one and only one ConnectivityNode. PSSEBusNumber and PSSEBusName are ERCOT attribute extensions for this class.*

*c) ConnectivityNodeGroup: The ConnectivityNodeGroup is an ERCOT CIM class extension used to collect and group ConnectivityNodes together, under a common planning bus designator. PSSEBusNumber and PSSEBusName are ERCOT attribute extensions for this class.*

*d) Switch: Switch is a base class of both Breaker and Disconnect to which an ERCOT extension attribute of ZBR has been added in addition to having the NormalOpen attribute as CIM standard.*

*C. Bus Topology Option 1 (Favored Node Marker)*

Figure 7 shows a node/breaker representation of a four line ring bus. The CIM model contains PSSEBusName and PSSEBusNumber attribute extensions within the ConnectivityNode class that designate the number and name to be used to describe a bus in the Topology Processor and to be exported in the bus-branch file. Only certain ConnectivityNodes will have the PSSEBusName and PSSEBusNumber attributes entered (represented by green circle in Figure 7); these implicitly define the "favored connectivity node". The bulk of the ConnectivityNodes will have null values in the PSSEBusName and PSSEBusNumber fields (represented by yellow circle in Figure 7). When topology processing a bus that contains the "green" ConnectivityNode the defined (hence stored) bus number will be utilized, whereas when a bus doesn't contain any green ConnectivityNodes an unassigned bus number will be generated and used.

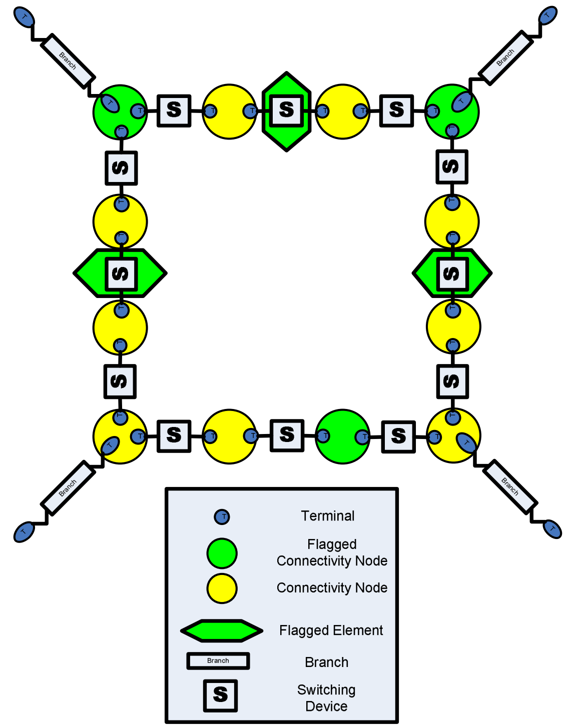


Figure 7: Graphical Representation of Most Favored Node methodology

In addition, there are certain switching devices in the station that are flagged, using the ZBR attribute on the switch record, which are to be converted into Zero Impedance Branches by the Topology Processor before distilling the connectivity nodes into the resulting bus arrangement. If the ZBR attribute is "True" then the Switching device will be converted into a Zero Impedance Branch (represented by a green hexagon around the switch in Figure 7). If the ZBR attribute is "False" then the Switching device will be left as is. These ZBR's will give the planning modelers using bus-branch models the ability to break buses up without reconfiguring their model. The equivalent bus-branch arrangement for Figure 7 is shown in Figure 9.

The Topology Processor respects switching device status to determine the bus configuration. For switching devices that have a ZBR attribute of True and NormalOpen attribute of True, the Zero Impedance Branch inserted in its place will have a status of out of service. For switching devices that have a ZBR attribute of False and NormalOpen attribute of True, then the Topology Processor will break the bus up based on the open switch devices. In the case where an open switching device splits a bus, the bus associated with the favored connectivity node will retain the bus number from the favored connectivity node, the other bus will be designated using an unassigned bus number.

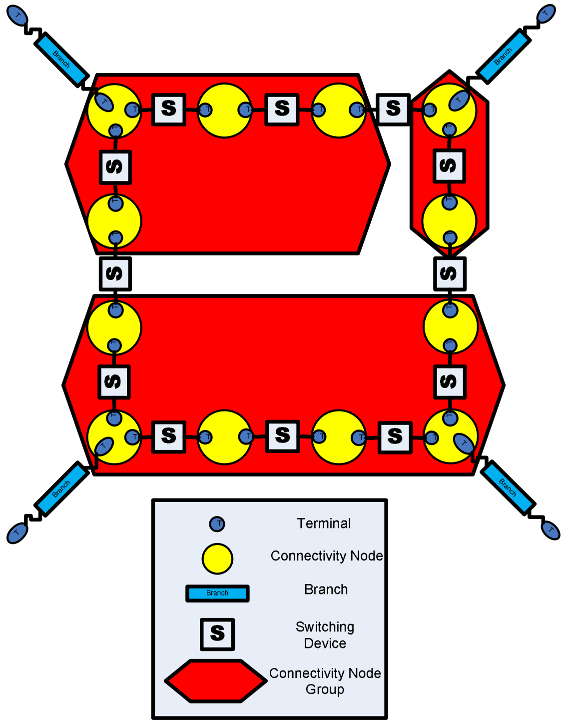


Figure 8: Graphical Representation of Connectivity Node Grouping methodology

*D. Bus Topology Option 2 (Connectivity Node Group)*

Figure 8 denotes a graphical representation for a second option for defining which ConnectivityNodes and associated equipment should aggregate to which designated buses, as well as the locations of the zero impedance branches. In this figure, a ConnectivityNodeGroup is represented by the red hexagon. All ConnectivityNodes (represented by the yellow circles in Figure 8) in each red hexagon will be compiled into the same bus. This is defined in CIM model by associating every ConnectivityNode with a ConnectivityNodeGroup via a containment grouping. PSSEBusName and PSSEBusNumber attributes on the ConnectivityNodeGroup class are used to store the number and name that is associated with the group of ConnectivityNodes.

The Topology Processor groups these nodes to the same bus and creates Zero Impedance Branches where switching devices connect the different ConnectivityNodeGroups. As in case of the previous option, the Topology Processor respects switching device status to determine the bus configuration. If one of the switching devices outside of the hexagons is marked as open, the Zero Impedance Branch inserted in its place will have a status of out of service. If there are any open switching devices within the hexagon, then the Topology Processor will break the buses up based on the open devices. In the case where an open switching device splits a bus, the Topology Processor will arbitrarily select which bus receives the designated bus number; the other bus will be designated using an unassigned bus number. The equivalent bus-branch arrangement of Figure 8 is shown in Figure 9.

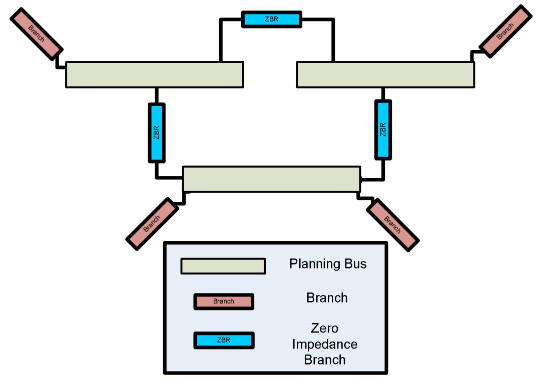


Figure 9: Planning Bus Representation

*E. Additional Topology Processor Functionality*

To study the effects of outages on future models, the Topology Processor also supports importing of outage files. The available outage definitions are base-lined on the node-breaker model rather than the bus-branch model, incorporating them into the topology processed model could result in challenges similar to the ones described in Section 1. The Topology Processor applies outage definitions prior to collapsing the CIM model down to the bus level thus providing users a mechanism for enhanced documentation of case processing since there is a high probability that an outage may split an existing bus into two or more buses (this is true regardless of which option is used).

## IV. Conclusion

By utilizing a common sourced data model in CIM, with the proper topology processing ERCOT has produced bus-branch models that are useful for planning functions. This commonality of source date has reduced discrepancies between operations and planning, and enhanced data fidelity.

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## V. Biographies

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