
Unified Power System Models through Integrated Topology Processing (ITP)

For historical reasons, as well as technical reasons no longer relevant today, the software tools used for planning (off-line) simulations have used different models of the power system than the tools used to model and simulate the real-time EMS system. This has led to a situation where users are required to *change their data to meet the specifications of planning software*.

PowerWorld Corporation's Integrated Topology Processing (ITP) add-on tool completely bridges the gap between EMS models and planning simulation tools for the power system. It allows the quick and automated creation of a power flow case directly from real-time or historical EMS data. This opens to the real-time operations environment all PowerWorld Simulator's analysis and visualization tools. The ITP add-on handles all necessary model consolidation (eliminating zero impedance branches) of the full-topology system required for numerical stability of the analysis tools internally, eliminating the need for a separate planning-type model. All interaction with the model is done through the full-topology model including model updates and definition of supplemental data files such as contingency definitions, interface definitions, cost information, etc. By doing so, it solves several problems the industry is dealing with today. By creating the Integrated Topology Processing add-on, PowerWorld has *changed the software to meet the specifications of the data*.

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What Can Integrated Topology Processing Do for You?

Problem: Model Maintenance and Auxiliary Data Maintenance

Traditionally, power flow models exported from Energy Management Systems (EMS) are not very useful for off-line analysis because the bus-branch model topology varies with circuit breaker status changes. For the planning model, this means that bus numbers and transmission topology change every time a new real-time model is exported. To be clear, this is not just a problem of bus number changing. These models have differences in topology that can never be overcome through some magical bus number mapping. Off-line analysis data structures that assume consistent bus numbering and transmission topology, such as contingency definitions, interface definitions, cost data, etc. are difficult or impossible to use in this environment.

Because of these problems, any attempts to make use of EMS models in a planning environment involve a huge expenditure of person-hours to align all these data sets together. In the day-to-day practice of power engineers, this problem is so large that instead of addressing it directly, separate models are maintained for real-time and planning studies. This has its own problems because inevitably the two models will diverge even though they represent the same physical reality. In addition, while the real-time model benefits greatly from the strict feedback of trying to match reality (i.e. metered data), the planning data does not get to reap these benefits without additional manual intervention and processes.

Solution: PowerWorld's Integrated Topology Processing

PowerWorld's ITP solves this problem by utilizing the full-topology node-breaker model directly on the PowerWorld platform. Model maintenance becomes greatly simplified because there is only one model to maintain, the full-topology model. The process for a user is to simply query the EMS system model and build a PowerWorld Auxiliary File that describes the full-topology model. This is a one-time investment of staff time and is automated for future updates.

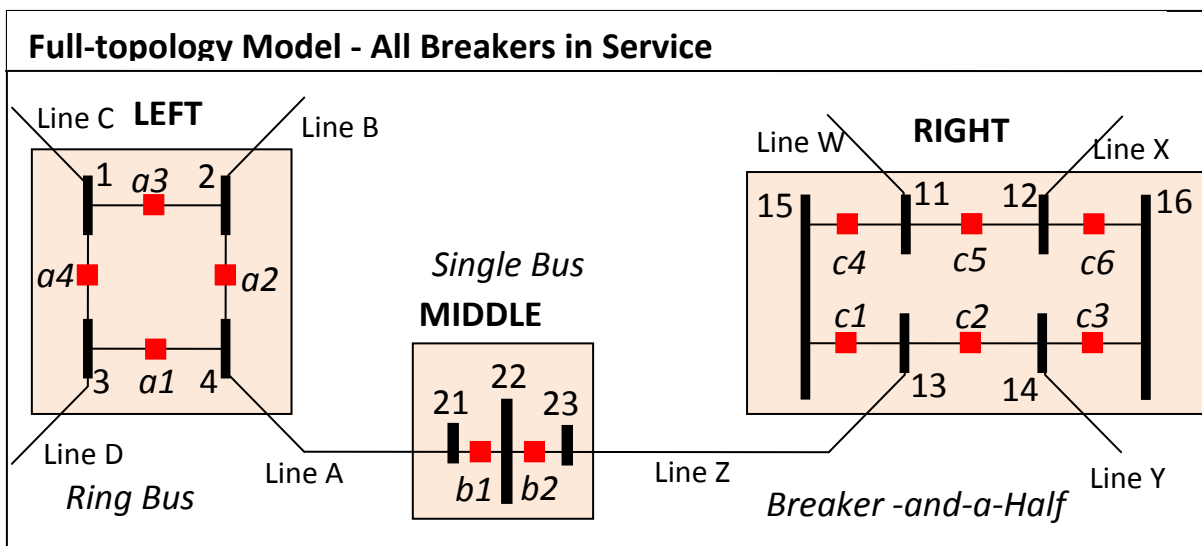
Updates must only be performed whenever the underlying node-breaker topology in the EMS changes or when considering future transmission projects. Many of these updates are already occurring for use in the real-time EMS system, so a duplication of those efforts is unnecessary.

Analysts can compile and import supplemental data such as contingency definitions, flowgate definitions, or generator cost models from spreadsheets or PowerWorld auxiliary (aux) files, based on the full-topology model. Online diagrams will also be based on the full-topology model. Such files will remain compatible with the real-time power flow model regardless of breaker status and topology of the study system.

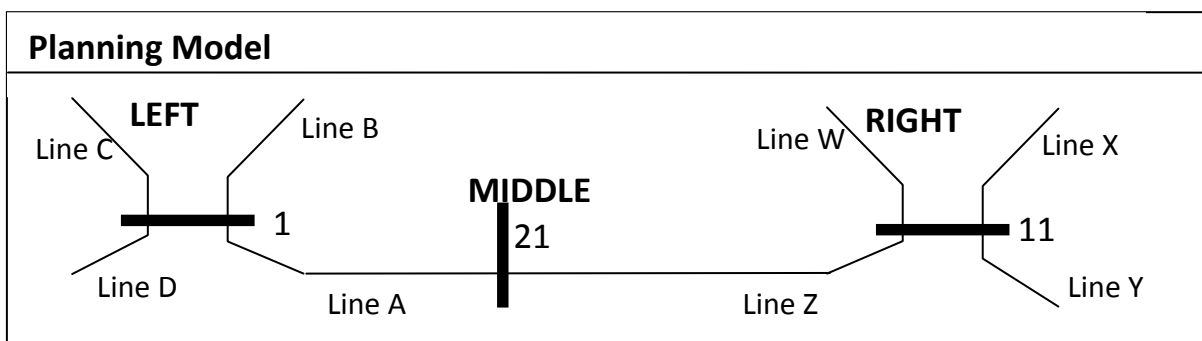
Technical limitations of the past prevented planning models from using full-topology models. Large numbers of zero-impedance branches lead to numerical instability in the solution algorithms and still would today if the solution algorithms themselves operated on the full-topology. PowerWorld's Integrated Topology Processing add-on fixes these problems by handling all the necessary consolidations to remove zero impedance branches without the user of the software needing to worry about them. User-interaction is centered on the real model (i.e. the full-topology model), while the software takes care of any issues associated with this.

Problem: Invalid Contingency Simulations Using a Planning Model

When dealing with planning models, contingency definitions directly refer to the opening of transmission elements (e.g. transmission line outages, generator outages, etc.). In addition, the planning model does not include the breakers, and the nodes at one electric point have been consolidated into one bus. Modeling in this manner will not give the correct simulation results in some breakers status configuration of the full-topology model. To provide an example of how the planning model may fail, consider a portion of a system shown in the following figure.

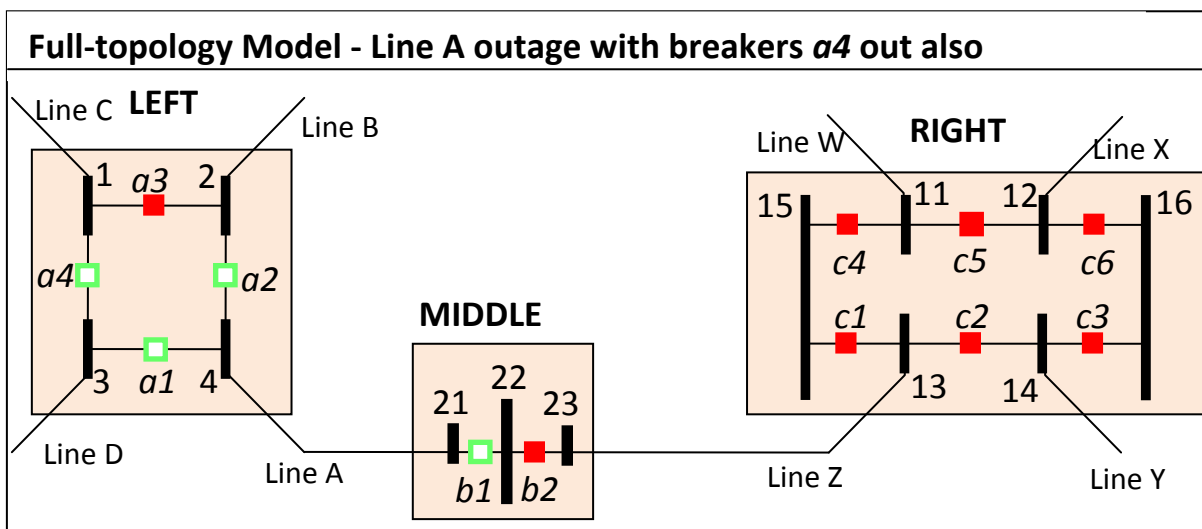


The nodes labeled LEFT form a configuration called a "Ring Bus". The nodes labeled MIDDLE form a configuration called a "Single Bus". The nodes labeled RIGHT form a configuration called a "Breaker-and-a-Half". In a typical planning model, this representation of 13 nodes will be consolidated to 3 buses as shown in the following figure.

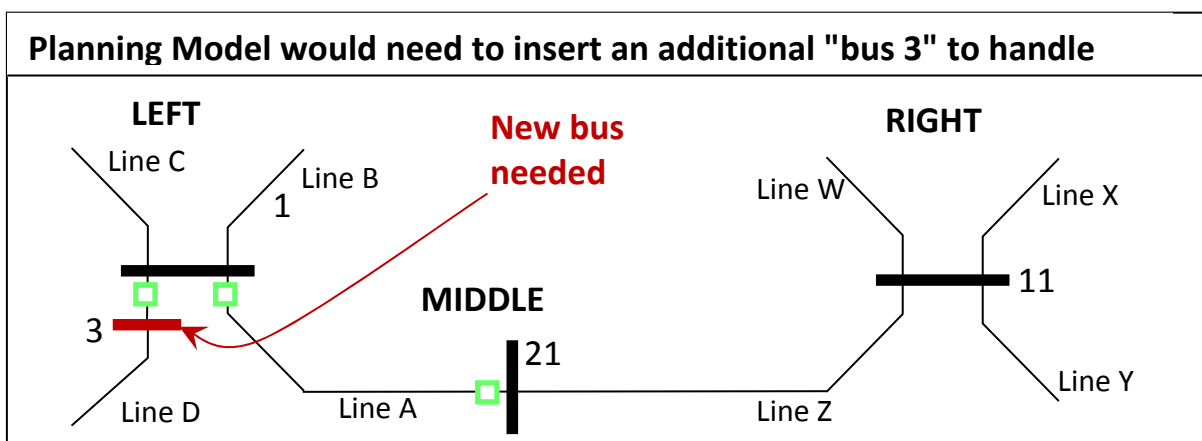


When using power system simulation software, contingency analysis (and all the tools that build on this including Security Constrained OPF, PV and QV curve tools, ATC analysis, etc.) will model the loss of a transmission line. In reality, the line itself is opened by the operation of circuit breakers. For example, to model the outage of Line A the breakers *a1*, *a2*, and *b1* would open. Similarly, to model the outage of Line Z the breakers *b2*, *c1*, and *c2* would be opened. (Note: Thousands of lines will not need to be processed manually to determine which breakers to open to isolate lines; PowerWorld has a built-in solution that is discussed shortly.)

As long it is assumed that all the breakers have the same status as in the original configuration, then taking a line out of service in the planning model is equivalent to opening the breakers as described in the previous paragraph. If however some of the breakers are either out-of-service for maintenance or some other reason, it is possible that the simulation results will be incorrect. Consider the situation of breaker *a4* being out-of-service for maintenance. Now modeling the outage of Line A on the full-topology model looks as follows.



Note that unlike in the previous line outage, Line D has been isolated from Line B and Line C as a result of the contingency. If the planning model is used to perform contingency analysis, then only Line A is opened and the results would be invalid because the "bus split" that has occurred is not captured. Looking at this case through the lens of the old planning case, a new planning model as shown in the following figure would be needed.



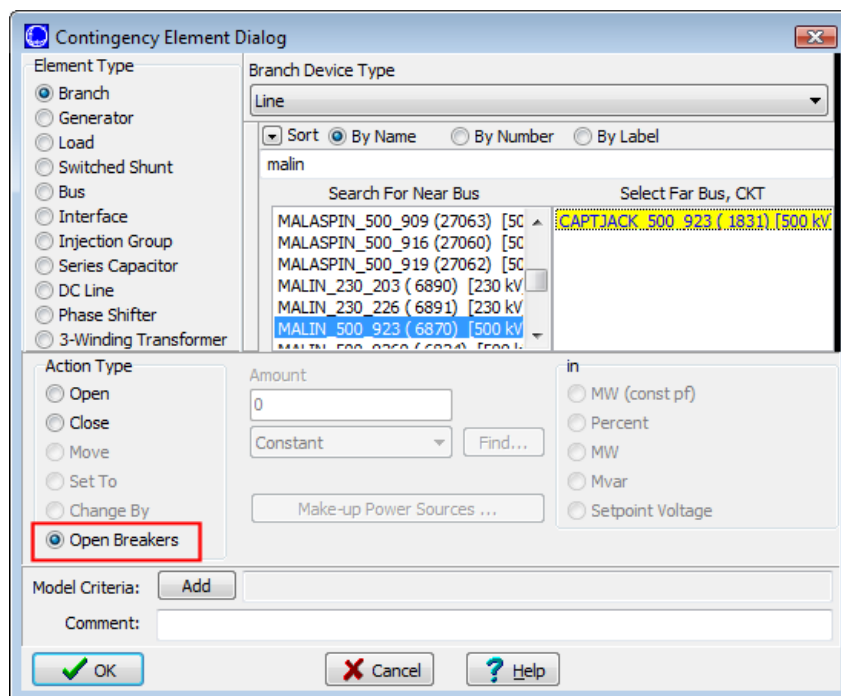
In the old planning case, every time there is an outage of one of these circuit breakers that form a loop, many tasks must be undertaken. A new contingency list to match the new bus numbers is needed; possibly a redo of some injection group or interface definitions, etc. Generally dozens of person-hours of effort by a few engineers is needed, and this may be repeated every week, if not every day. Alternatively, these effects might be ignored completely and incorrect contingency results generated without any knowledge this is occurring.

Solution: PowerWorld's Integrated Topology Processing

When using PowerWorld's ITP this will not be a problem. The full-topology model is maintained; therefore Simulator's contingency analysis and all others tools that build from this recognize these situations automatically. ITP will use the knowledge of the breaker status in the full-topology to appropriately maintain buses in the solution algorithms as needed. Again, all this will be done by the software itself and no user-intervention or the dozens of person-hours per topology change will be needed.

Coming from the traditional planning case world, it may appear that a complete rethinking of the way contingencies are defined is required. It may appear that the modeling of a line outage must be achieved using separate breaker open contingency actions. This will not be necessary though, because PowerWorld's contingency analysis tool contains a special contingency action called "Open with Breakers" that allows the user to open a device using nearby breakers instead of just changing the status of the transmission line, generator, load, or switched shunt as is done in the traditional planning case.

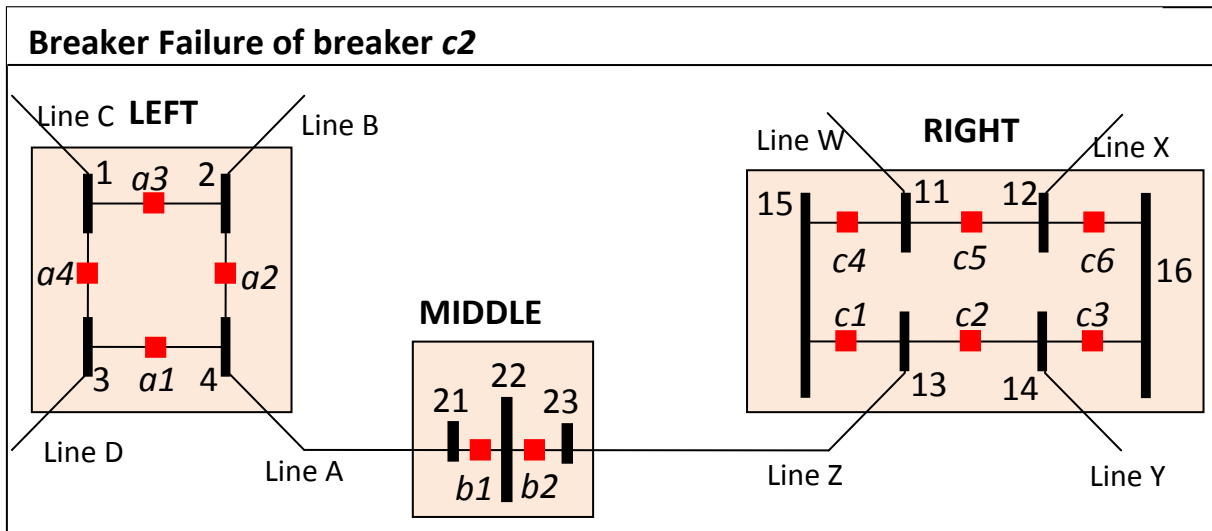
When using the "Open with Breakers" option, PowerWorld's contingency analysis will automatically identify the breakers that need to be opened to isolate an element. The appropriate breaker statuses will be changed during the contingency, and this will ensure that accurate modeling of the real-time system is achieved. This new feature is available on the Contingency Element Dialog in Simulator as shown in the following figure.



Problem: Modeling Breaker Failure Contingencies

A breaker failure contingency involves modeling a situation where a breaker is expected to operate and open itself to clear a fault on the transmission system, but instead of opening the breaker remains "stuck" in the closed position. In order to clear the fault, other nearby breakers will need to operate. Breaker failure contingencies are particularly difficult to model in traditional planning models. They often require the manual modifications of planning cases with the subsequent updates of supplemental data such as contingency definitions, interface definitions, etc. Again, this consumes large amounts of staff time.

As an example, consider the failure of breaker *c2*. To properly model this failure, breakers *b2*, *c1*, *c3*, as well as any breakers at the other end of Line Y must be opened.



Solution: PowerWorld's "Open with Breakers" Contingency Action

As described in the previous solution, Simulator contains a contingency action type called "Open with Breakers". By applying this action to a breaker device itself, the breaker failure simulation is achieved. When Simulator sees a contingency element specifying that breaker *c2* be opened using breakers, PowerWorld assumes that it cannot open the breaker *c2*, but instead must treat the breaker itself as an element that must be isolated. To do this, the breaker is handled in the same way that a normal transmission branch would be, and breakers starting at both terminals are examined to determine which to open.

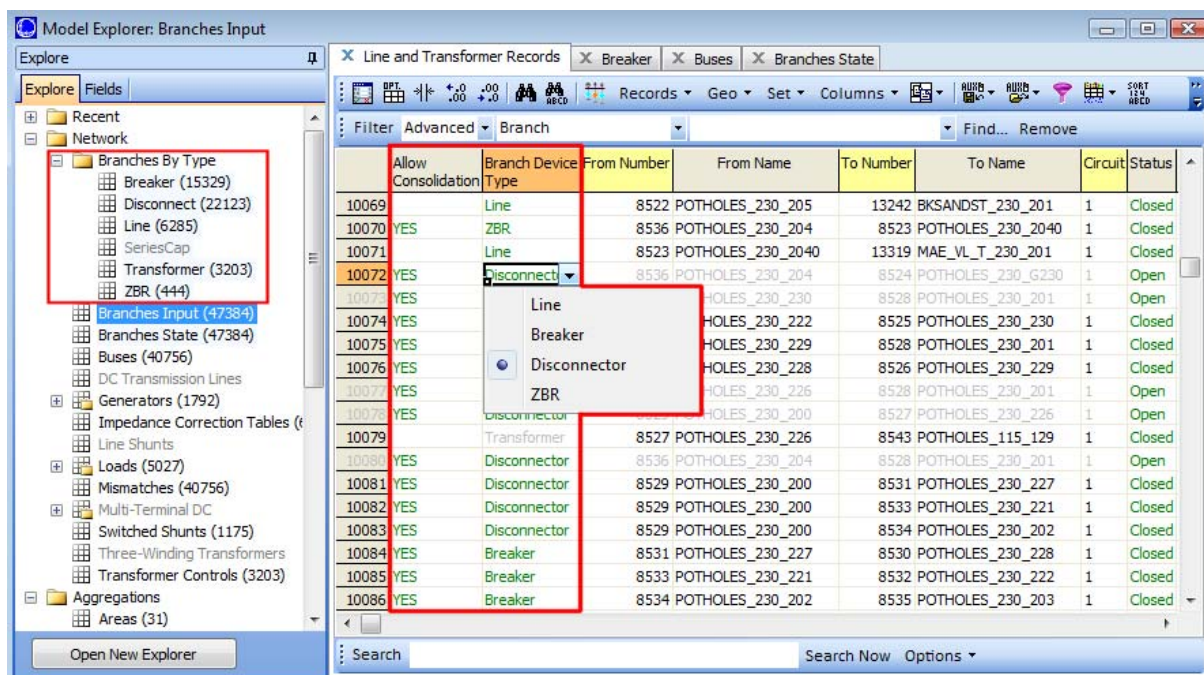
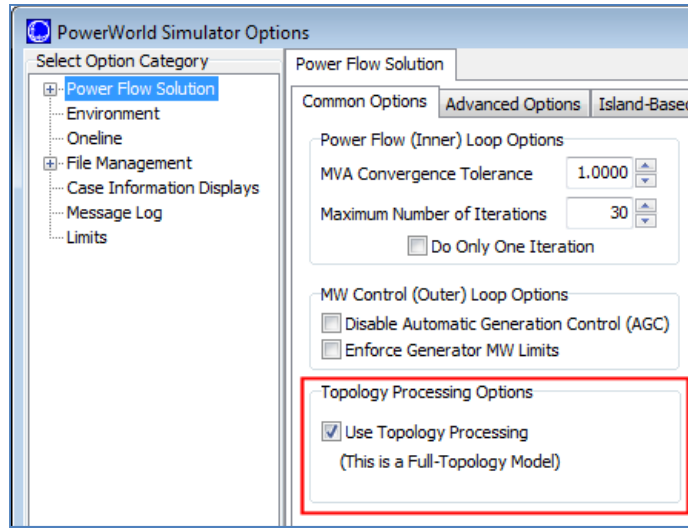
It is even possible to model the simultaneous failure of multiple breakers by specifying "Open with Breaker" contingency elements for two or more breakers for one contingency. When this is done, while determining the list of breakers that will isolate the devices desired, any breaker that is part of the contingency definition and is of type "Open with Breakers" is not allowed to open.

How Do I Make Use of These New Features?

Building the Model

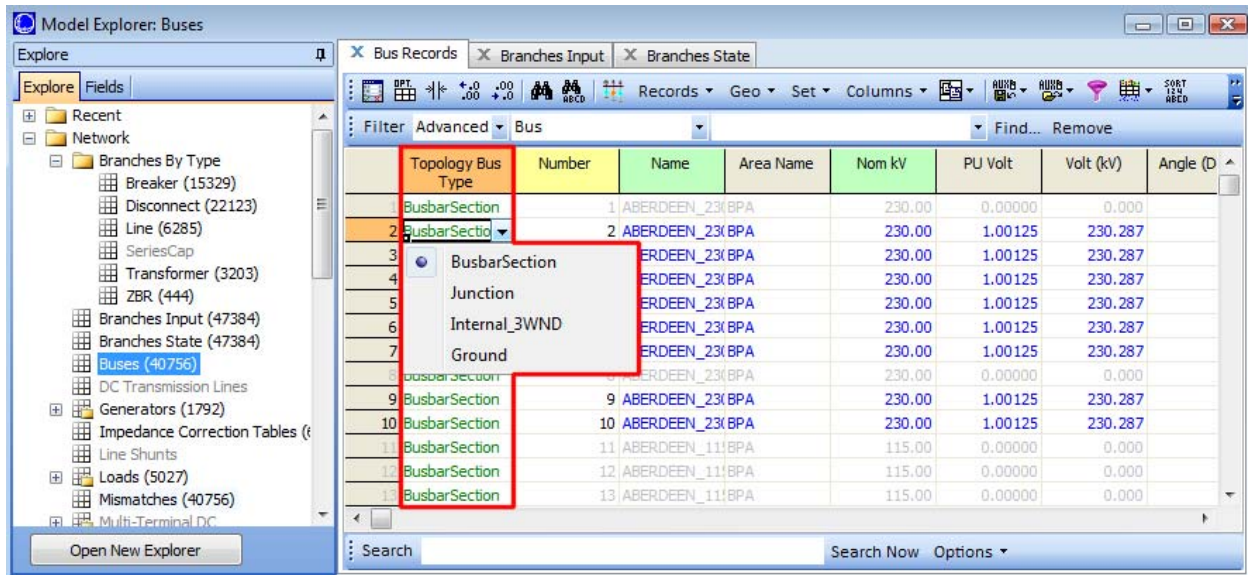
The data required for building the power system model is mostly identical to building existing planning models. There are two additional fields that need to be specified for each transmission branch: *Topology\Branch Device Type* and *Topology\Allow Consolidation of Branch*. In addition, there is one check-box that specifies to *Use Topology Processing* which is located on the PowerWorld Options Dialog and looks as shown below.

If a branch is a transformer or a series capacitor, the field *Branch Device Type* will not be enterable and will state the type of branch. Otherwise, the *Branch Device Type* may be specified as either Line, Breaker, Disconnecter, or ZBR. If a branch is a Breaker, Disconnecter or ZBR, then the *Allow Consolidation* field must also be specified. Setting *Allow Consolidation* to YES tells the software to eliminate closed switching devices from the network model when performing numeric solutions. If a branch is set not to be consolidated, it will be preserved in the model and its default impedance value will be used in the power flow equations. These fields are shown in the follow Model Explorer screen shot. In addition, there is a folder under Network which lists the Branches by Type.



If the two fields are defined properly and the option is chosen to *Use Topology Processing*, PowerWorld will automatically perform all numeric calculations by dynamically creating a consolidated model that exhibits the numerical stability of the traditional planning model without the user needing to interact with the ever-changing model.

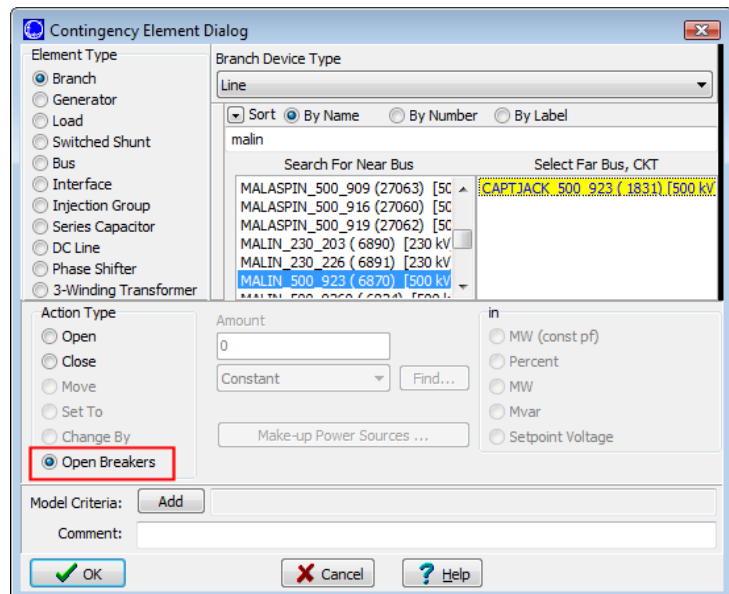
For information purposes, a field called *Topology\Topology Bus Type* may also be specified for each bus in the model. This field is not presently used by PowerWorld directly, but the user could make use of it to help build drawings or to filter against when setting up data. The options for the field are BusbarSection, Junction, Internal_3WND, and Ground. This field is shown in the following figure.



Define Contingencies Using "Open with Breakers"

Once a model is created by denoting breakers using *Branch Device Type*, the contingency definitions can be greatly simplified by using the "Open with Breakers" Action Type.

Contingency analysis will identify the breakers automatically that need to be opened to isolate an element. The appropriate breaker statuses will be changed during the contingency, and this will ensure that accurate modeling of the real-time system is achieved. This new feature is available on the Contingency Element Dialog in Simulator as shown in the following figure.



Define Substations and Device Labels

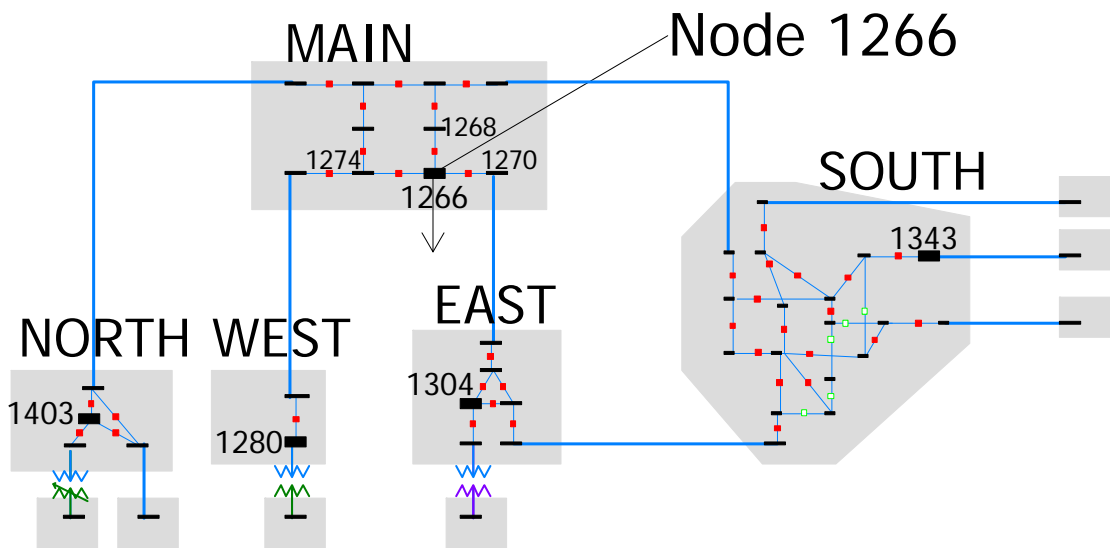
PowerWorld has had the ability to define a substation object for many years. Each bus in the model may be assigned to one substation object. It is recommended that the user make use of this designation because it will aid filtering, creating or modifying oneline diagrams, and many other activities. In addition, specifying the geographic latitude and longitude information with the substation can be a great benefit.

PowerWorld has also had the ability to define a label for devices for many years. A label can be assigned to a device such as a bus, transmission line, generator, switched shunt, load, DC line, etc. The label may then be used as an identifier for the device instead of the traditional planning identifiers related to bus numbers or name/kV combinations. These labels may be then utilized throughout all the supporting files such as contingency definitions, interfaces definitions, etc.

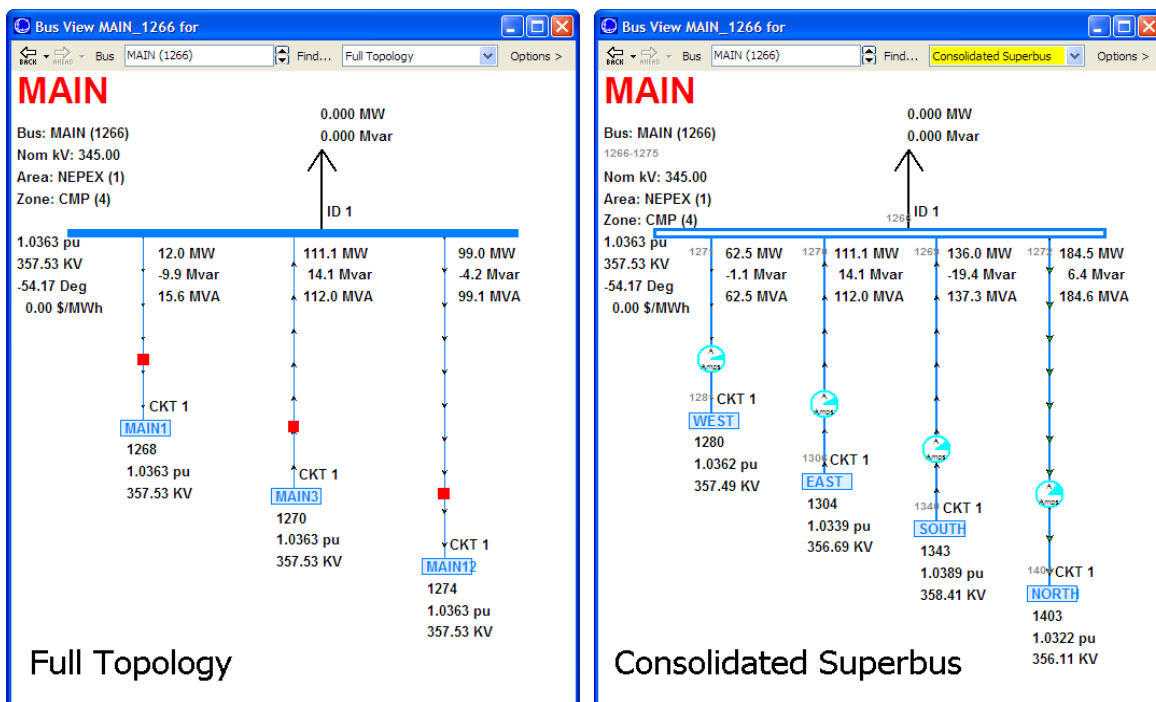
Interacting with the Model: Bus View and Branch Chooser

By switching to full-topology models, another concern lies in the interaction of the user with this full-topology model. Users accustomed to smaller planning models will now need to interact with a more complete model that contains many devices with which they are not traditionally concerned. While the numeric calculations can easily handle this difficulty, the user interaction with a much larger model must be addressed.

To this end, additional user-interface features have been created to allow the user to navigate the full-topology model representation in a manner similar to the experience of navigating the legacy planning cases. To this end, the Bus View has been modified. The Bus View is an automatically generated diagram that shows a single bus and all devices connected to that bus. In full-topology models, however, there are normally very few devices connected to each node and the majority of the model consists of circuit breakers and disconnects. This makes navigating the model in the traditional Bus View cumbersome. The following figure shows a small part of a sample full-topology model.

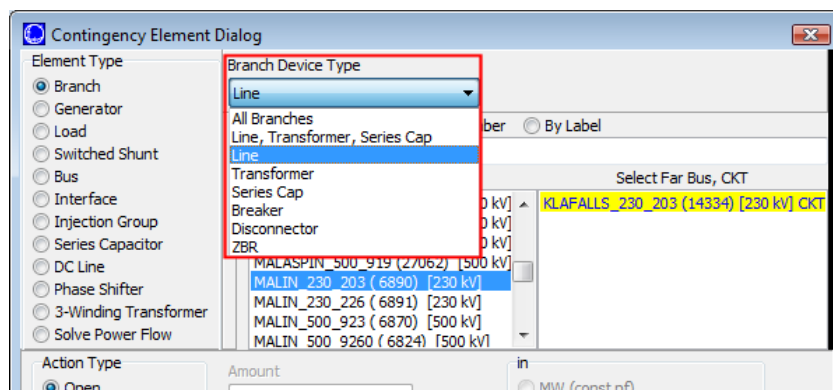


A Bus View of node 1266 would normally only show the three circuit breakers connecting it to nodes 1268, 1270, and 1274 as shown on the left of the next figure. Navigating from Node 1266 through several circuit breakers to find the North Superbus is cumbersome. However, a Consolidated Superbus View can be configured to look beyond closed circuit breakers and only show the other superbuses that connect to the superbus to which 1266 belongs. On the right side of the next figure, Node 1266 is shown connected to the superbuses 1280 (West), 1304 (East), 1343 (South), and 1403 (North).



The Consolidated Superbus View provides the same visualization with which a user of planning models is accustomed, but this view is automatically generated from the full-topology model.

Another common task done when using power system software is to search for a particular power system branch. In many locations in PowerWorld, a list of branches will now contain not only transmission lines and transformers, but also circuit breakers and disconnects. To make it easier to search for particular types of branches, the Branch Device Type will be available to filter the list. An example of this is shown on the Contingency Element Dialog as follows.

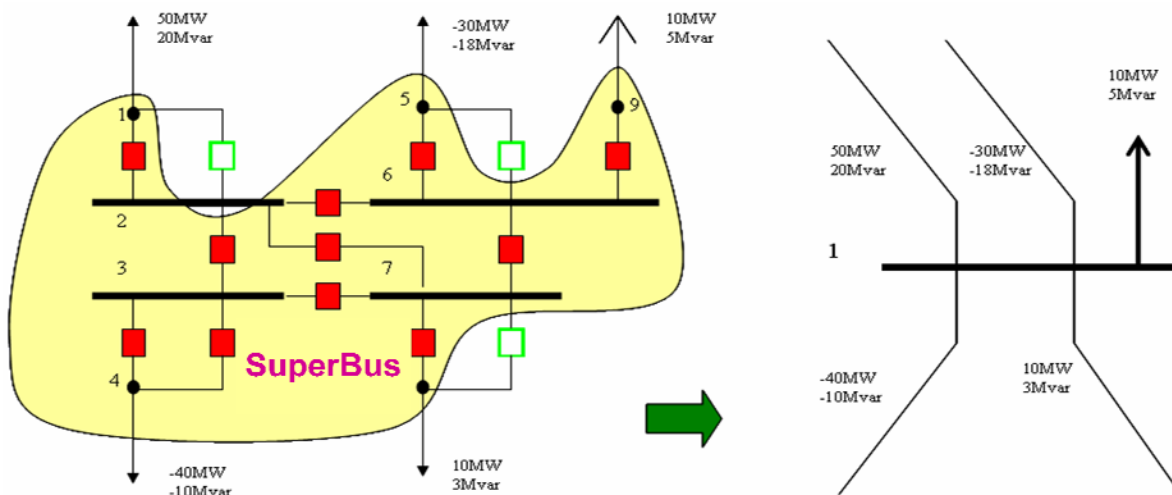


How Does Integrated Topology Processing Work?

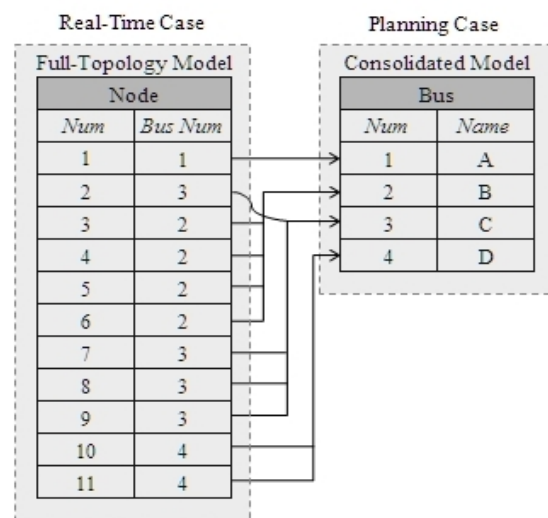
Integrated Topology Processing: Why do you need it?

Topology processing takes the full-topology node-breaker model and converts it to a consolidated bus-branch model. Zero or very low impedance branches are eliminated from the system. This is necessary for numerical stability when solving the power flow and doing other calculations necessary for power system analysis.

This process is illustrated in the figure below. The system on the left is the full-topology representation showing the nodes and connecting breakers. Based on the status of the breakers, nodes that are electrically the same can be merged into the same bus by removing the closed connecting breakers. The system on the right is the resulting consolidated planning representation of the system.



When traditional topology processing is done, a second and distinct power system model is created. Different data structures are used for each model. The full-topology data structure stores nodes while the consolidated planning model stores buses. The full-topology model knows which nodes are consolidated into which buses, but in the consolidated planning case each bus does not know from which nodes it is comprised (this is depicted in the figure to the right). Each time that the topology changes in the full-topology model, a new planning case is created and the bus numbers in the planning case change as well as the topology. This makes mapping auxiliary information (e.g. interfaces, contingencies, etc.) very difficult and in practice always requires manual intervention.



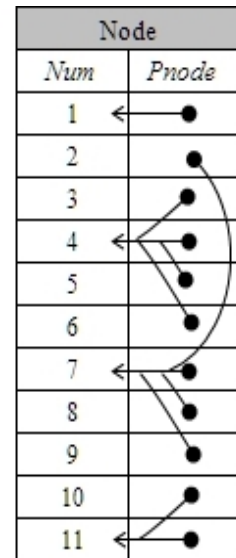
Integrated Topology Processing: Why is this what you want?

PowerWorld's Integrated Topology Processing removes the difficulty of dealing with two separate models for the real-time and planning environments. As opposed to traditional topology processing, integrated topology processing maintains only ONE power system model which is a representation of the full-topology model. Inside of this one model, the integrated topology processing internally maintains the consolidated representation of the system dynamically. All uses of the consolidated model are made transparent to the user so that they need not concern themselves with the numerical stability issues related to the breakers and disconnectors.

Integrated Topology Processing: How does it work?

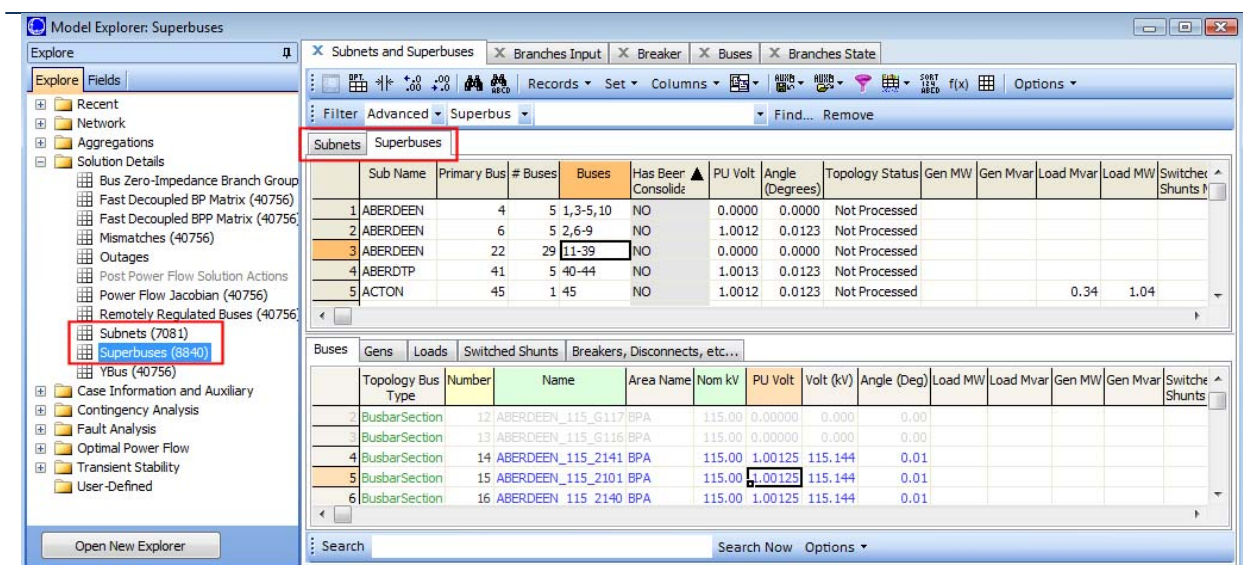
In order to achieve this level of integration, PowerWorld introduces a new object type called a superbuses with which the user of the software does not directly interact (i.e. the software maintains the structures automatically and the user is not required to worry about them at all). A superbuses is a group of buses connected through closed switching devices represented by branches with *Allow Consolidation* set to YES. As the statuses of switching devices change, the software automatically recalculates the superbuses groupings, often resulting in superbuses merging or splitting.

All the buses in a superbuses have the same voltage phasor, i.e., they correspond to the same electric point. Each superbuses chooses a primary node or pnode, and when calculations are performed on the system all devices connected to a bus will behave as though they are connected to the primary node of the superbuses to which they belong instead of the actual bus. A superbuses in the Full-Topology Model would correspond to a bus in the electrically equivalent bus-branch planning case.



In addition to the superbuses, PowerWorld also introduces the subnet object. A subnet represents a group of buses connected through branches with *Allow Consolidation* set to YES regardless of their status (open or closed). Subnets represent what the superbuses would be if all switching devices were closed. A subnet can contain one or more superbuses. A superbuses belongs to only one subnet. Subnets are bounded by transmission line and transformer terminals. As a result, subnets on a system do not depend on the status of breakers, but only on the presence of devices. Subnets do not change unless equipment is added or removed from the physical model and thus remain static as seen by all of PowerWorld's solution algorithms.

Superbuses and subnets are set automatically when the case is read from the binary or aux file, or when modifications are made to the system topology in Edit Mode. In addition superbuses are updated at the beginning of a power flow solution or sensitivity calculation to capture possible changes in the status of switching devices. The details of the superbuses and subnet records are available in the Model Explorer under Solution Details > Superbuses or Subnets as shown in the following figure.



The user will interact with superbuses on occasion such as in the Consolidated Superbus View inside the Bus View, however generally they need not worry about them. The user will generally not use the subnets extensively except for possibly some filtering activities. They are, however, used extensively internally by the contingency analysis algorithms when using a full-topology model. The subnet object is the key piece of data used by the incremental topology processing in contingency analysis.

Special Case of Contingency Analysis: Incremental Topology Processing

PowerWorld has already worked extensively with and performed contingency analysis on very large cases utilizing the Integrated Topology Processing (ITP) add-on. One feature that was added immediately in that testing was the ability to use Incremental Topology Processing. Every contingency inherently changes the topology of the system. Although testing on very large systems showed that the internal consolidation process was very fast (in 2008 it took 0.2 seconds to consolidate an 80,000 node full-topology model down to 10,000 buses), adding an additional 0.2 seconds to every contingency solution was increasing solution time.

To overcome this, incremental topology processing was added. Because the number of contingency actions in each contingency is small (less than 10), only a small number of subnets are affected. The topology of all the other subnets remains unchanged. When this option is used, PowerWorld does a full consolidation before the first contingency, and then for each contingency, the topology of just the affected subnets is re-processed (determining superbuses and primary buses, and updating the connection pointers). Incremental Topology Processing provides a more robust solution and should be used whenever possible. The speed to process the small number of subnets affected by a contingency was found to be around 0.001 seconds and so does not affect solution speed at all.

