ECEN 615
Methods of Electric Power Systems Analysis

Lecture 12: Voltage Control, Topology Processing

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Announcements

- Read Chapter 7 (the term reliability is now often used instead of security)
- Homework 4 should be done before the first exam, but need not be turned in
- Exam 1 is during class on Oct 13
  - Closed book, notes. One 8.5 by 11 inch notesheet and calculators allowed
  - Distance education students should make arrangements with Sanjana with HonorLock one approach
  - Exam 1 from 2020 is available in Canvas; solutions will be posted as we get closer in

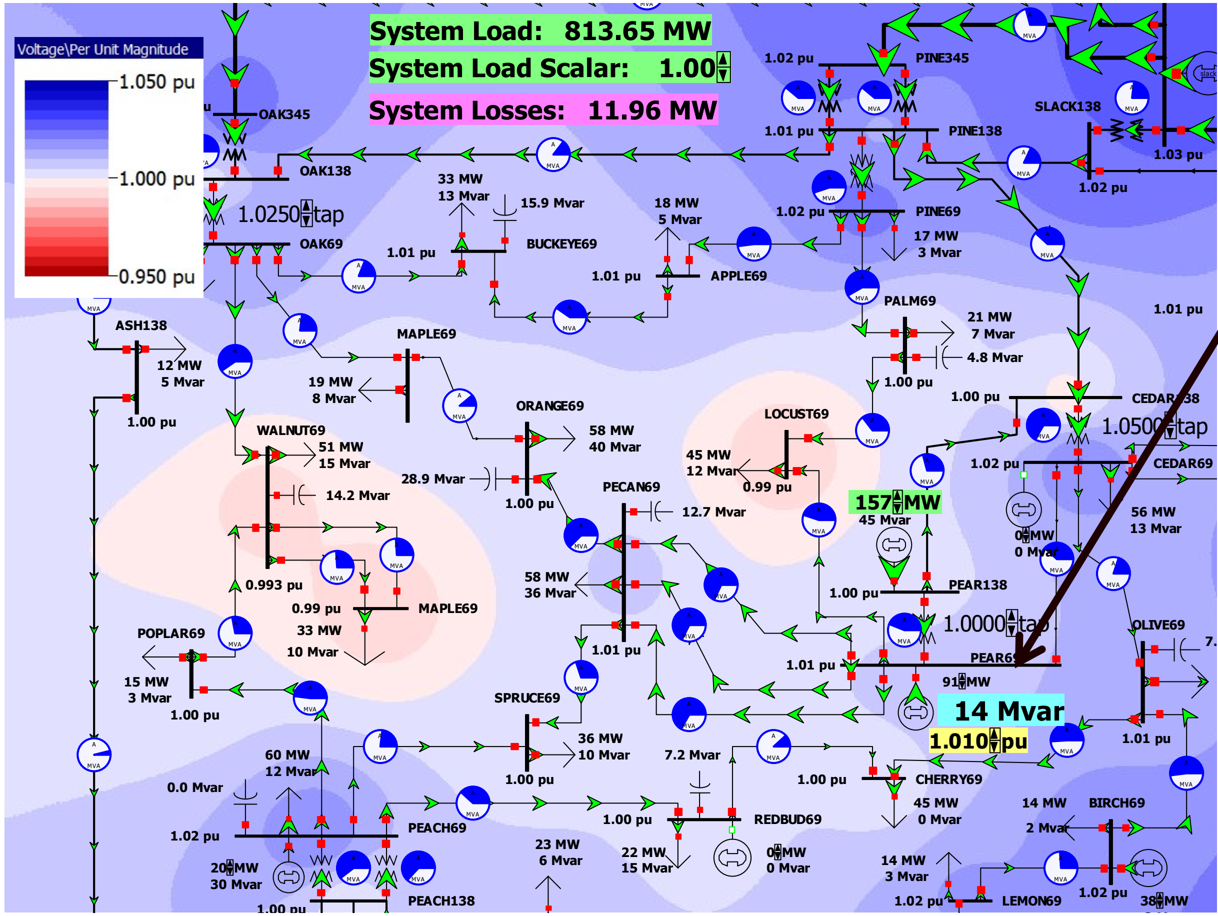
Hurricane Ian Update

- As of Monday morning the number of people without electricity in Florida has dropped to 600,000 (from 2.6 million last week)
- One of the reasons for this relatively quick recovery is over the last several years the Florida utilities have spent billions strengthening their grid, particularly the transmission line
  - Examples include replacing wooden poles with ones made of concrete or steel, putting transformers on higher ground, burying more of the distribution system
  - Florida Power and Light said they did not lose a single transmission structure after losing more than 100 during Hurricane Wilma in 2005 (a Category 3 hurricane)

Generator Volt/Reactive Control

- Simplest situation is a single generator at a bus regulating its own terminal
  - Either PV, modeled as a voltage magnitude constraint, or as a PQ with reactive power fixed at a limit value. If PQ the reactive power limits can vary with the generator MW output
- Next simplest is multiple generators at a bus. Obviously they need to be regulating the bus to the same voltage magnitude
  - From a power flow solution perspective, it is similar to a single generator, with limits being the total of the individual units
  - Options for allocation of vars among generators; this can affect the transient stability results

Generator Voltage Control



This example uses the case **PSC_37Bus** with a voltage contour. Try varying the voltage setpoint for the generator at PEAR69

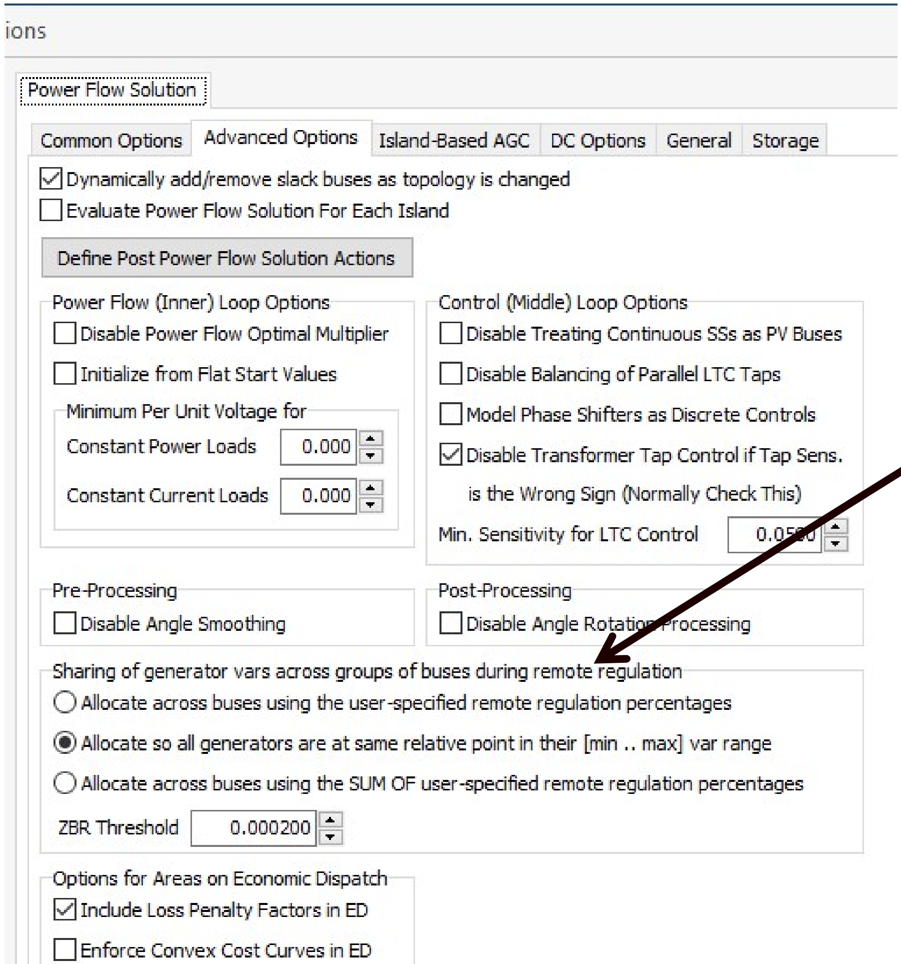
Generator Remote Bus Voltage Control

- The next complication is generators at a single bus regulating a remote bus; usually this is the high side of their generator step-up (GSU) transformer
  - When multiple generators regulate a single point their exciters need to have a dual input
  - This can be implemented in the power flow for the generators at bus j regulating the voltage at bus k by changing the bus j voltage constraint equation to be

$$\left|V_k\right| - V_{k,set} = 0$$

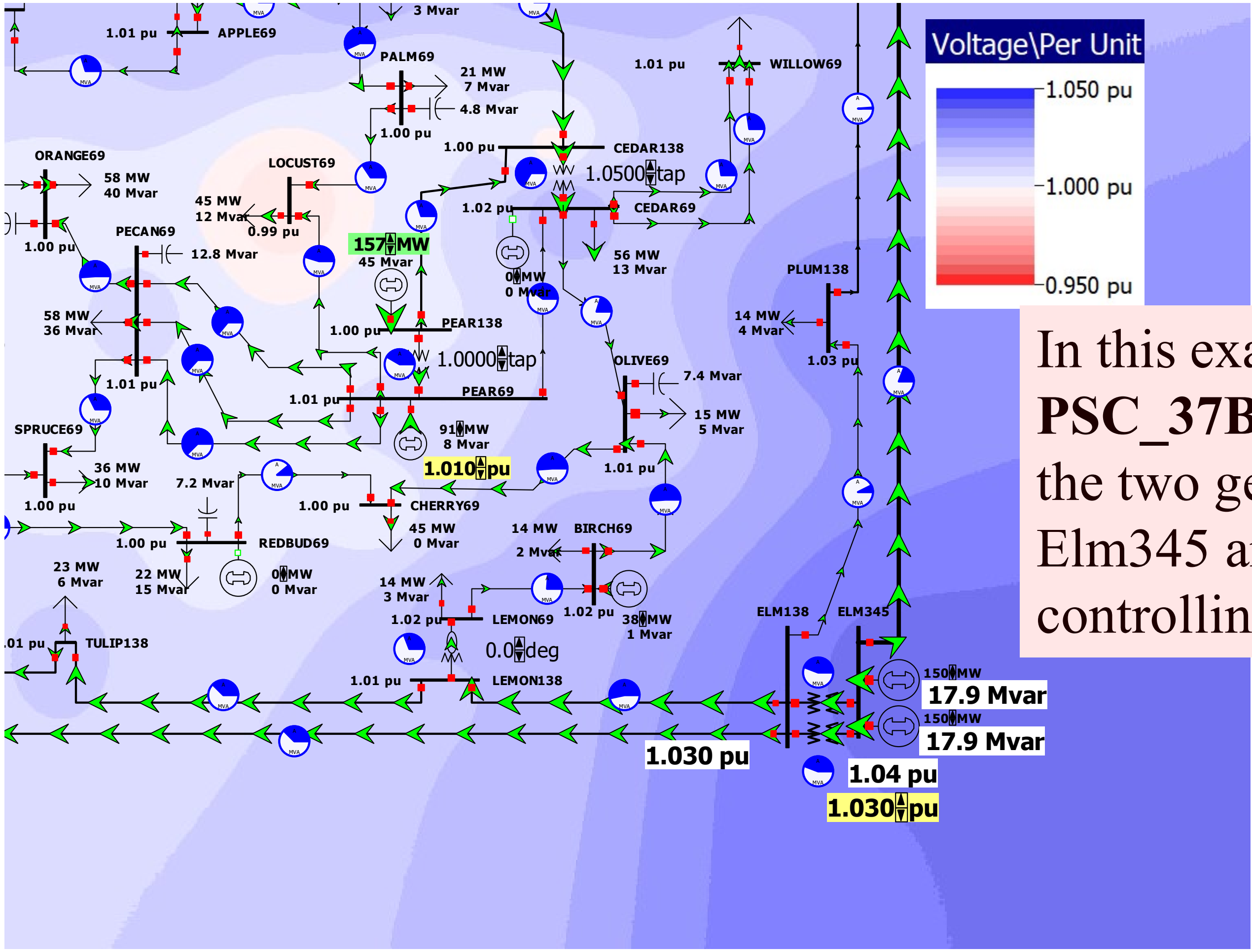
    (however, this does create a zero on the diagonal of the Jacobian)
  - Helps with power system voltage stability

Reactive Power Sharing Options



Different software packages use different approaches for allocating the reactive power; PowerWorld has several options.

Reactive Power Sharing

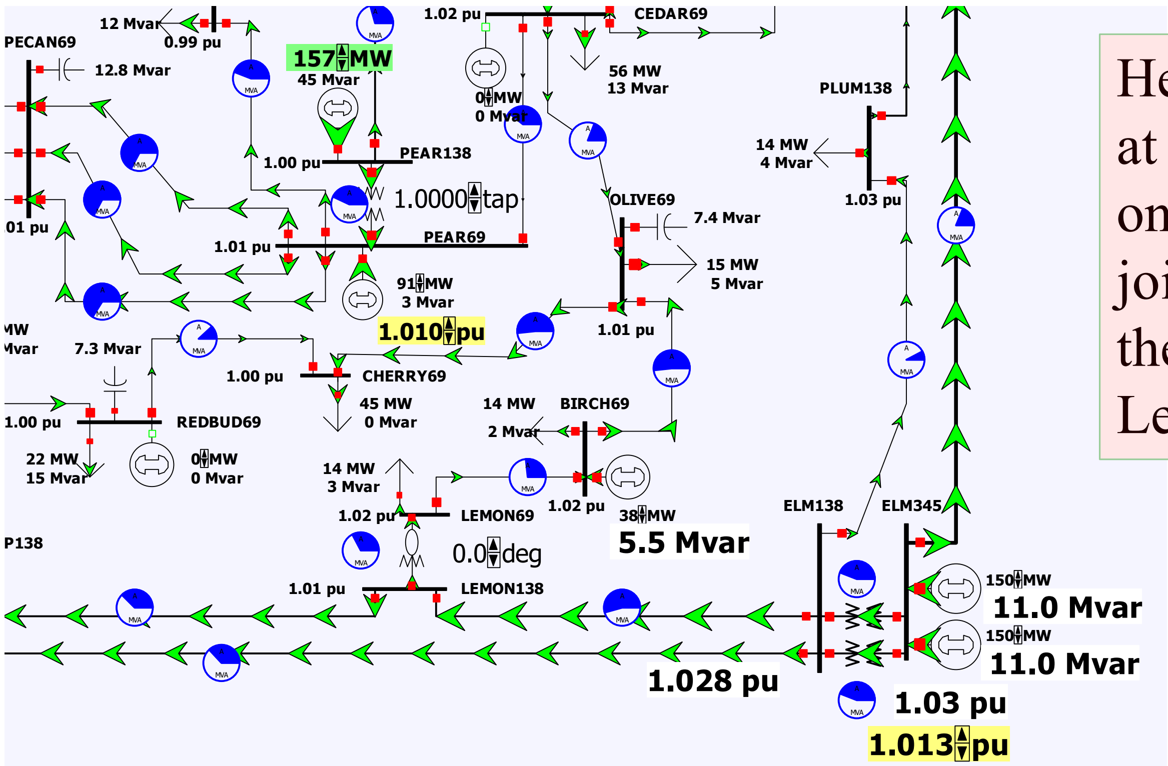


In this example, case **PSC_37Bus_Varsharing**, the two generators at Elm345 are jointly controlling Elms138

Generator Remote Bus Voltage Control

- The next complication is to have the generators at multiple buses doing coordinated voltage control
  - Controlled bus may or may not be one of the terminal buses
- There must be an a priori decision about how much reactive power is supplied by each bus; example allocations are a fixed percentage or placing all generators at the same place in their regulation range
- Implemented by designating one bus as the master; this bus models the voltage constraint
- All other buses are treated as PQ, with the equation including a percent of the total reactive power output of all the controlling bus generators

Remote and Coordinated Var Control Example



Here the generators at Elm345 and the one at Birch69 are jointly controlling the voltage at the Lemon138 bus.

Case is **PSC_37Bus_Varsharing_MultipleBuses**

Power Flow Topology Processing

- Commercial power flow software must have algorithms to determine the number of asynchronous, interconnected systems in the model
  - These separate systems are known as Islands
  - In large system models such as the Eastern Interconnect it is common to have multiple islands in the base case (one recent EI model had nine islands)
  - Islands can also form unexpectedly as a result of contingencies
  - Power can be transferred between islands using dc lines
  - Each island must have a slack bus

Power Flow Topology Processing

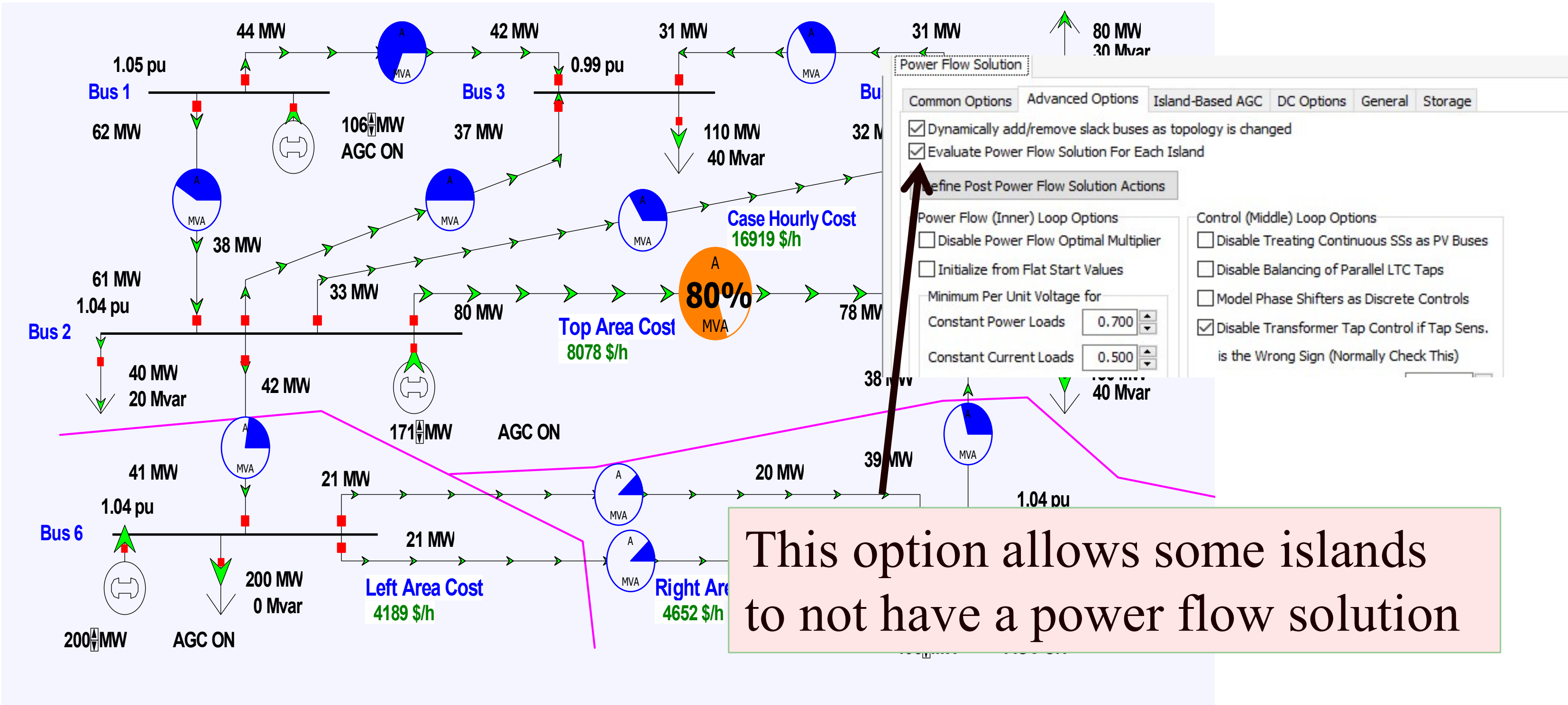
- Anytime a status change occurs the power flow must perform topology processing to determine whether there are either 1) new islands or 2) islands have merged
- Determination is needed to determine whether the island is "viable." That is, could it truly function as an independent system, or should the buses just be marked as dead
  - A quite common occurrence is when a single load or generator is isolated; in the case of a load it can be immediately killed; generators are more tricky

Topology Processing Algorithm

- Since topology processing is performed often, it must be quick (order n ln(n))!
- Simple, yet quick topology processing algoritm
  - Set all buses as being in their own island (equal to bus number)
  - Set ChangeInIslandStatus true
  - While ChangeInIslandStatus Do
    - Go through all the in-service lines, setting the islands for each of the buses to be the smaller island number; if the island numbers are different set ChangeInIslandStatus true
  - Determine which islands are viable, assigning a slack bus as necessary

This algorithm does depend on the depth of the system

Example of Island Formation



This option allows some islands to not have a power flow solution

Splitting large systems requires a careful consideration of the flow on the island tie-lines as they are opened

Bus Branch versus Node Breaker

- Due to a variety of issues during the 1970's and 1980's the real-time operations and planning stages of power systems adopted different modeling approaches

Real-Time Operations

Use detailed node/breaker model

EMS system as a set of integrated applications and processes

Real-time operating system

Real-time databases

Planning

Use simplified bus/branch model

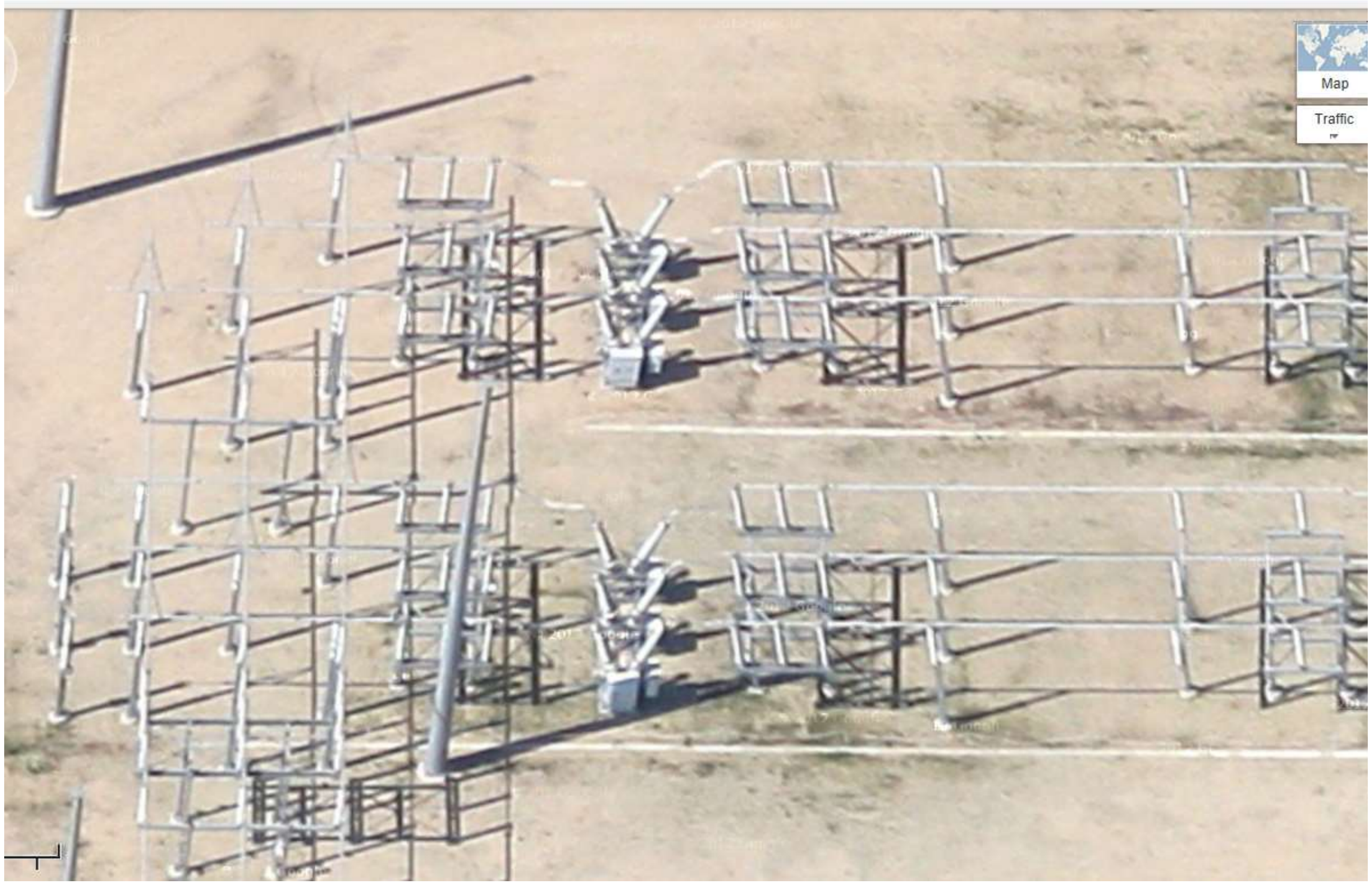
PC approach

Use of files

Stand-alone applications

Entire data sets and software tools developed around these two distinct power system models

Google View of a 345 kV Substation



Example of Using a Disconnect to Break Load Current

Substation Configurations

- Several different substation breaker/disconnect configurations are common:
- Single bus: simple but a fault anywhere requires taking out the entire substation; also doing breaker or disconnect maintenance requires taking out the associated line

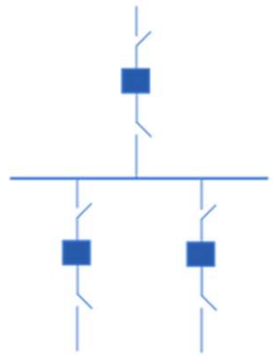


Fig B: Single Bus

Source: http://www.skm-eleksys.com/2011/09/substation-bus-schemes.html

Substation Configurations, cont.

- Main and Transfer Bus:
  Now the breakers can be taken out for maintenance without taking out a line, but protection is more difficult, and a fault on one line will take out at least two
- Double Bus Breaker:
  Now each line is fully protected when a breaker is out, so high reliability, but more costly

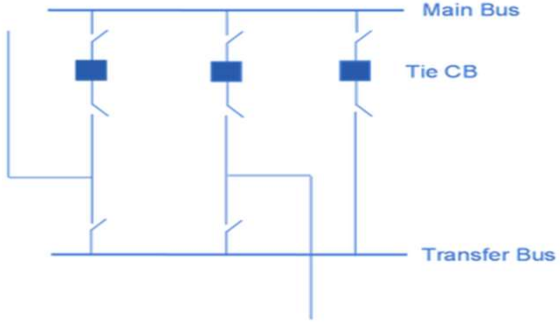


Fig C: Main and Transfer Bus

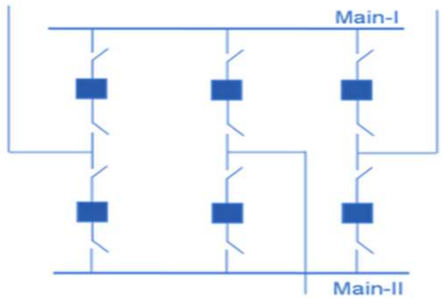


Fig D: Double Bus Double Breaker

Source: http://www.skm-eleksys.com/2011/09/substation-bus-schemes.html

Ring Bus, Breaker and Half

- As the name implies with a ring bus the breakers form a ring; number of breakers is same as number of devices; any breaker can be removed for maintenance
- The breaker and half has two buses and uses three breakers for two devices; both breakers and buses can be removed for maintenance

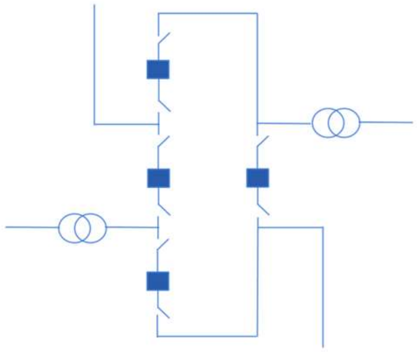


Fig F: Ring Bus

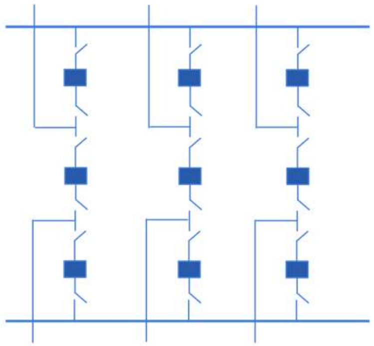
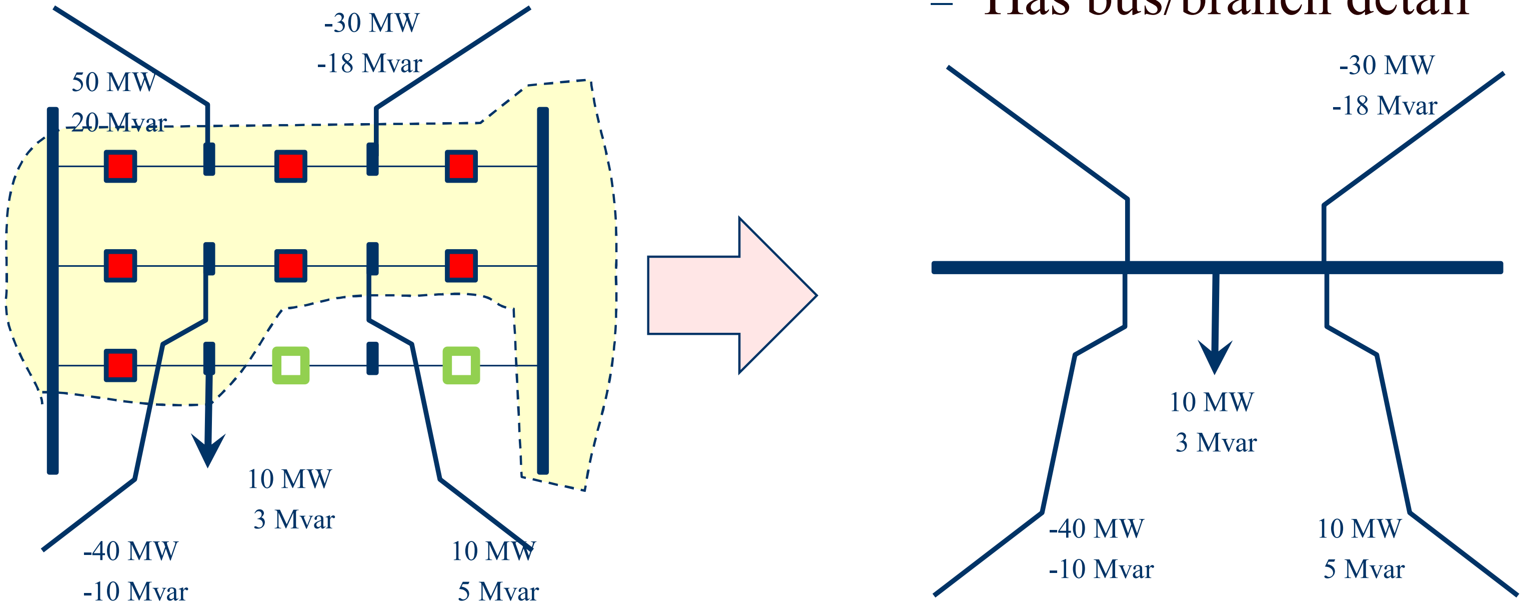


Fig G: Breaker and Half

Source: http://www.skm-eleksys.com/2011/09/substation-bus-schemes.html

EMS and Planning Models

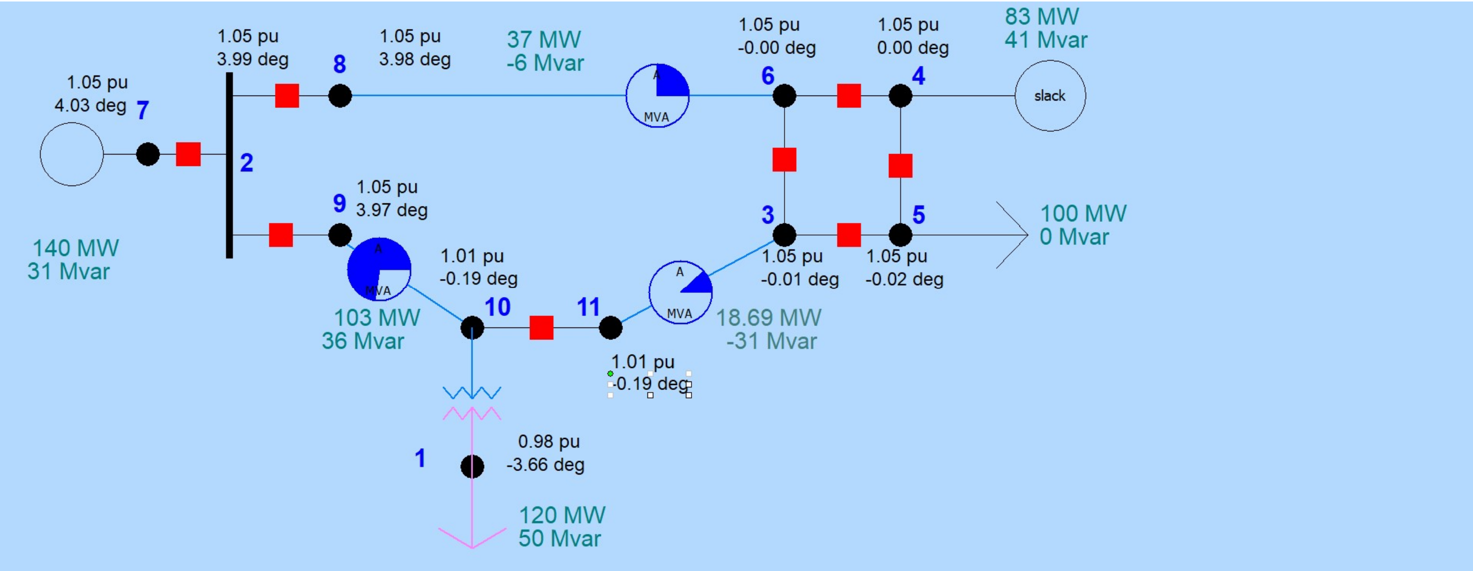
- EMS Model
  - Used for real-time operations
  - Called full topology model
  - Has node-breaker detail
- Planning Model
  - Used for off-line analysis
  - Called consolidated model by PowerWorld
  - Has bus/branch detail



Node-Breaker Consolidation

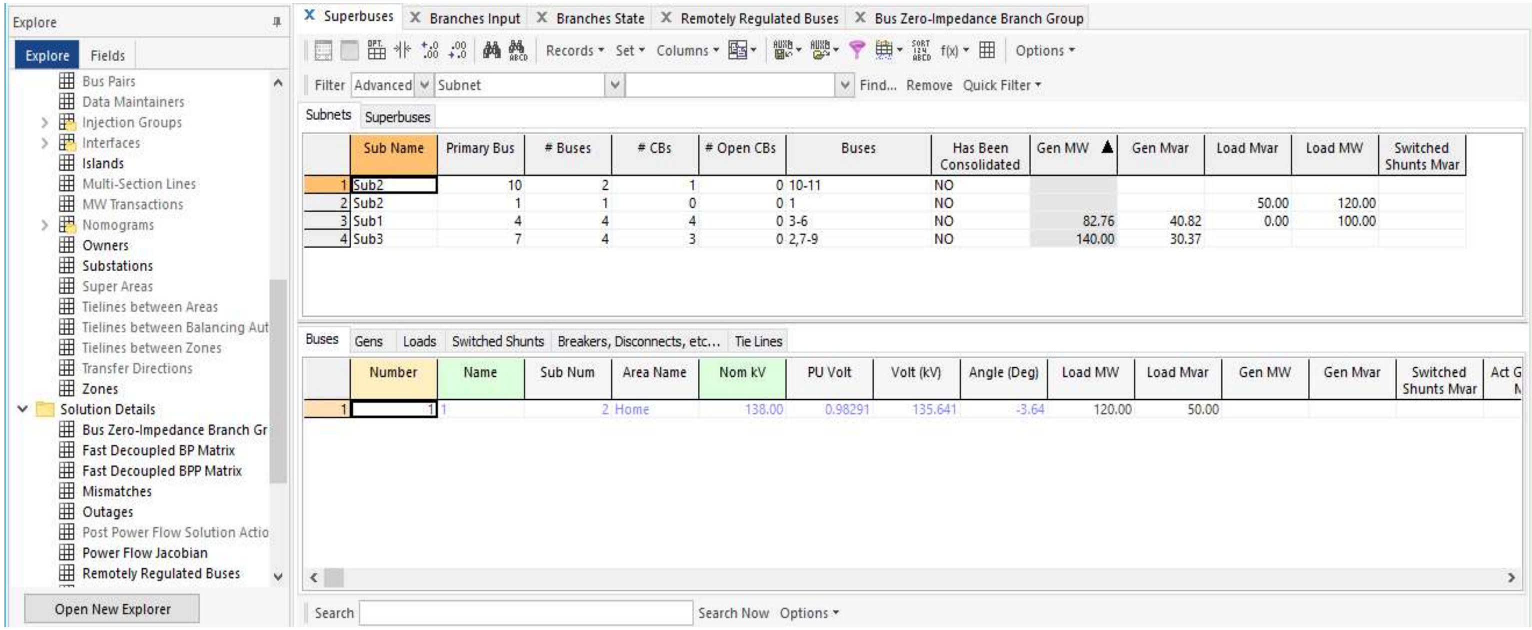
- One approach to modeling systems with large numbers of ZBRs (zero branch reactances, such as from circuit breakers) is to just assume a small reactance and solve
  - This results in lots of buses and branches, resulting in a much larger problem
  - This can cause numerical problems in the solution
- The alterative is to consolidate the nodes that are connected by ZBRs into a smaller number of buses
  - After solution all nodes have the same voltage; use logic to determine the device flows

Node-Breaker Example



Case name is **FT_11Node**. PowerWorld consolidates nodes (buses) into super buses; available in the Model Explorer: Solution, Details, Superbuses.

Node-Breaker Example



	Sub Name	Primary Bus	# Buses	# CBs	# Open CBs	Buses	Has Been Consolidated	Gen MW	Gen Mvar	Load Mvar	Load MW	Switched Shunts Mvar
1	Sub2	10	2	1	0	10-11	NO					
2	Sub2	1	1	0	0	1	NO			50.00	120.00	
3	Sub1	4	4	4	0	3-6	NO	82.76	40.82	0.00	100.00	
4	Sub3	7	4	3	0	2,7-9	NO	140.00	30.37			

	Number	Name	Sub Num	Area Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)	Load MW	Load Mvar	Gen MW	Gen Mvar	Switched Shunts Mvar
1	1	1	2	Home	138.00	0.98291	135.641	-3.64	120.00	50.00			

Note there is ambiguity on how much power is flowing in each device in the ring bus (assuming each device really has essentially no impedance)

Contingency Analysis

- Contingency analysis is the process of checking the impact of statistically likely contingencies
  - Example contingencies include the loss of a generator, the loss of a transmission line or the loss of all transmission lines in a common corridor
  - Statistically likely contingencies can be quite involved, and might include automatic or operator actions, such as switching load
- Reliable power system operation requires that the system be able to operate with no unacceptable violations even when these contingencies occur
  - N-1 reliable operation considers the loss of any single element

Contingency Analysis

- Of course this process can be automated with the usual approach of first defining a contingency set, and then sequentially applying the contingencies and checking for violations
  - This process can naturally be done in parallel
  - Contingency sets can get quite large, especially if one considers N-2 (outages of two elements) or N-1-1 (initial outage, followed by adjustment, then second outage
- The assumption is usually most contingencies will not cause problems, so screening methods can be used to quickly eliminate many contingencies
  - We'll cover these later

Contingency Analysis in PowerWorld

- Automated using the Contingency Analysis tool