Assessing the Voltage Adequacy of a Power System

A Case Study

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Scenario

- Fictitious 37-bus, 3-area system
- Proposal:
  - retire 2 aging units in a heavy-load area
- Task
  - determine the impact of retiring the units on the voltage adequacy of the system

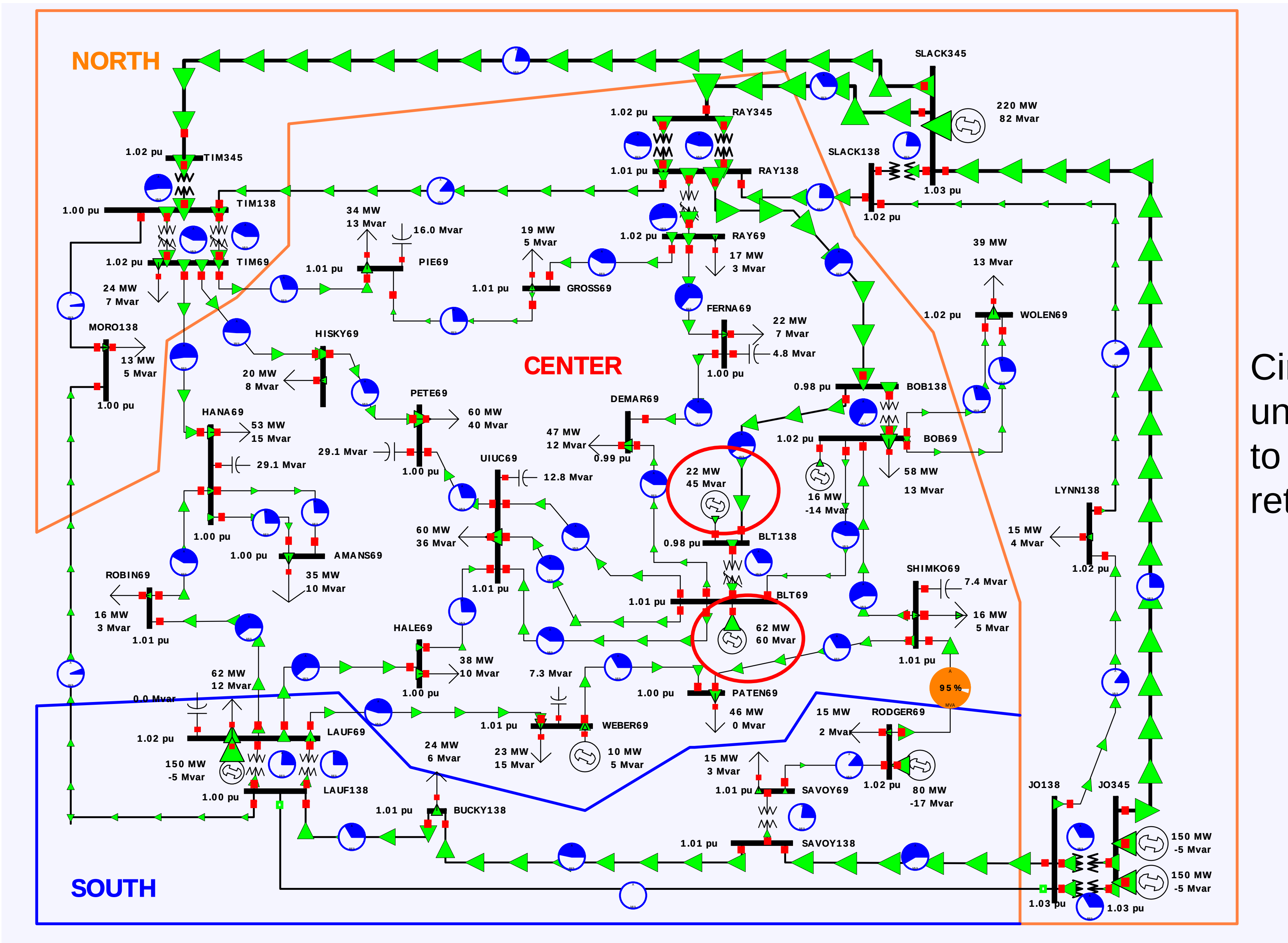
Voltage Adequacy

the ability of a system to serve present and future responsibilities without loss of load and at acceptable voltage levels for both pre- and post-contingency conditions

The Approach

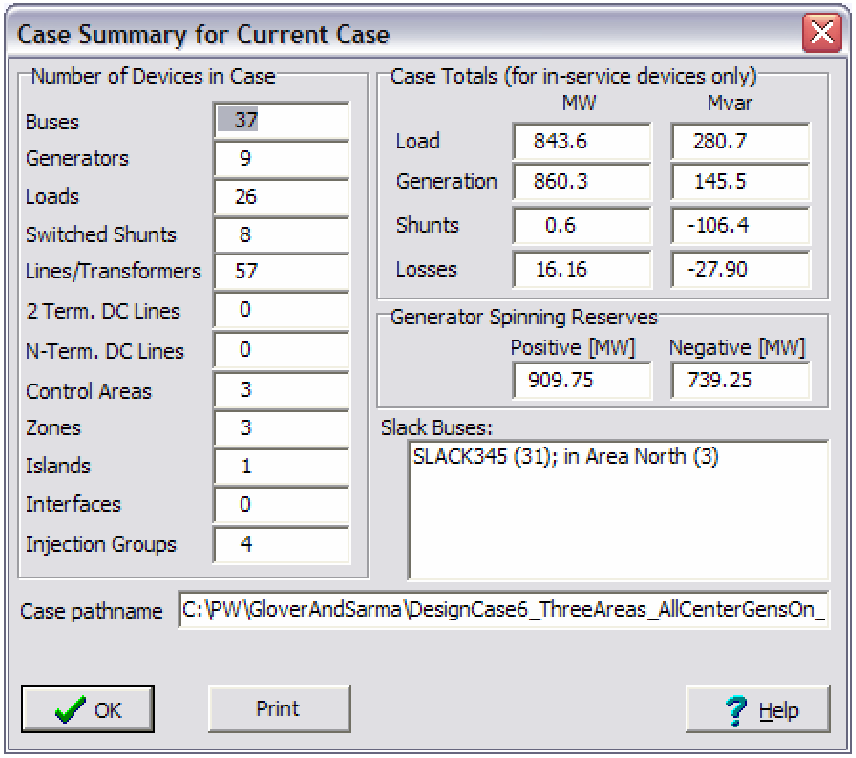
- What is the impact on the pre-contingency state of the system?
  - Contours and difference flows
    - Identifies buses of potential interest
- What is the impact on n-1 reliability?
  - Contingency analysis tool
    - Identifies troublesome contingencies and buses
- What is the impact on future security?
  - PV Curve Tool
    - Identifies new restrictions on import capability

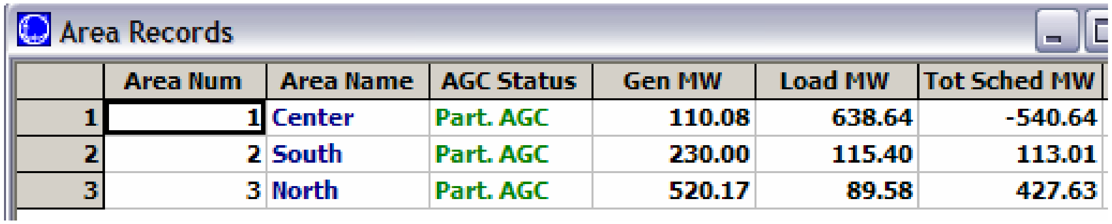
The System



Circled units to be retired

The System




Area Records

	Area Num	Area Name	AGC Status	Gen MW	Load MW	Tot Sched MW
1	1	Center	Part. AGC	110.08	638.64	-540.64
2	2	South	Part. AGC	230.00	115.40	113.01
3	3	North	Part. AGC	520.17	89.58	427.63

Impact on Base Case

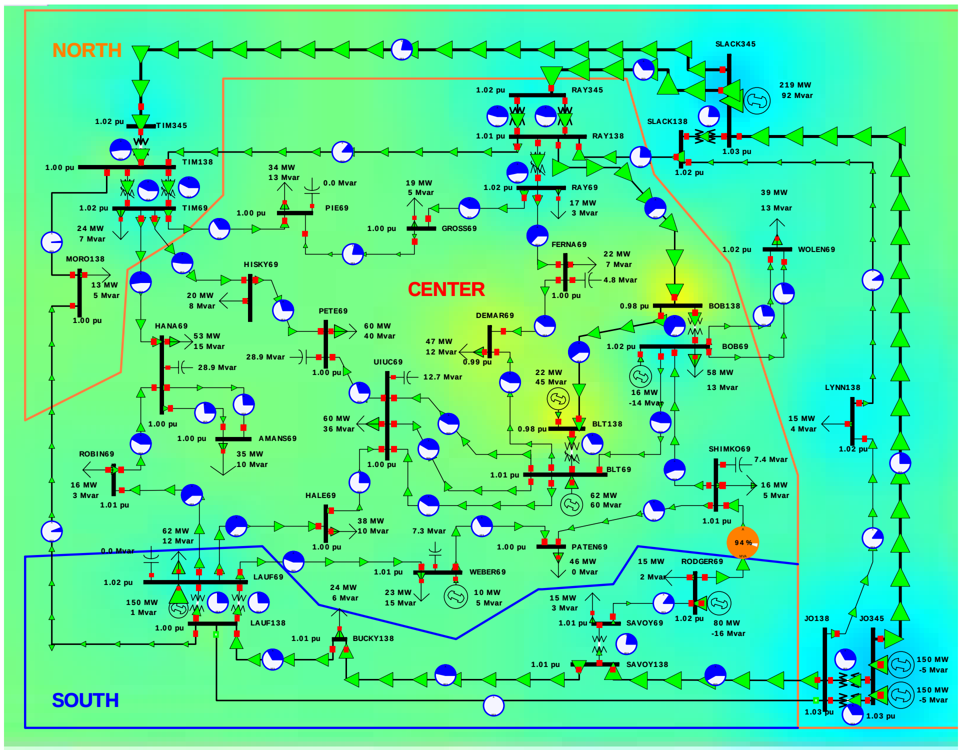
- Use difference flows to identify buses affected the most
- Use contouring to visualize the location and severity of the impact

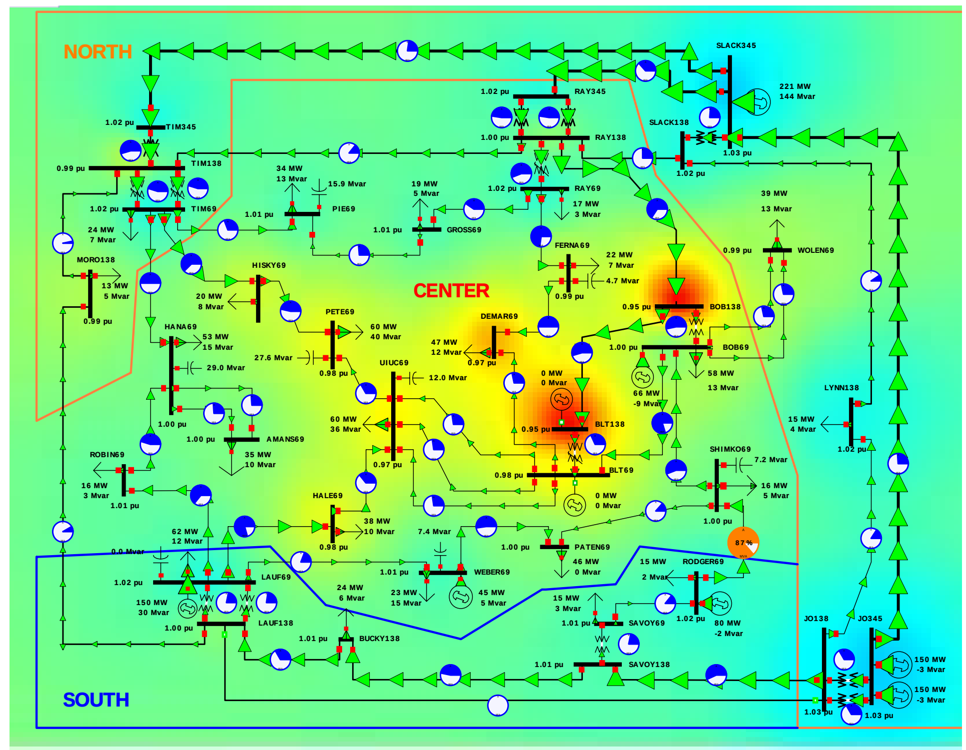
Impact on Base Case

These buses suffered the greatest voltage decrease:

Number	Name	Del V
54	BLT69	-0.0338
53	BLT138	-0.0331
15	UIUC69	-0.0327
47	BOB138	-0.0292
16	PETE69	-0.0262
24	HALE69	-0.0249
21	WOLEN69	-0.0247
48	BOB69	-0.0246
55	DEMAR69	-0.0238
27	HISKY69	-0.0226
13	FERNA69	-0.0139
40	TIM138	-0.0138
39	RAY138	-0.0123
20	SHIMKO69	-0.0108
3	MORO138	-0.0096

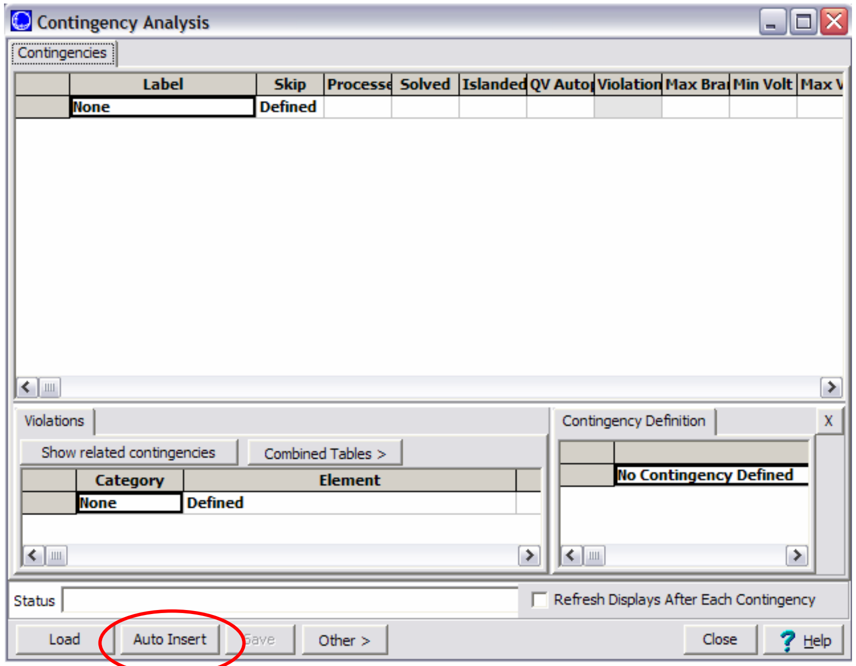
Impact on Base Case

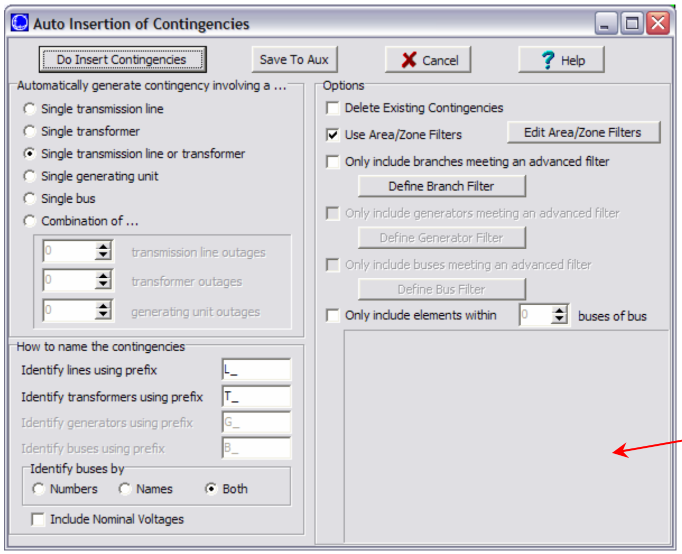




Impact on n-1 Reliability

Use contingency analysis tool to gauge condition of system for single branch and generator outages





Impact on n-1 Reliability

Violations: BLT in service

Contingency Name	Violated Element	Value	Limit
L_00010RAY69-00013FERNA69C1	FERNA69 (13)	0.93	0.95
L_00010RAY69-00013FERNA69C1	DEMAR69 (55)	0.94	0.95
L_00012TIM69-00018HANA69C1	HANA69 (18)	0.95	0.95
L_00012TIM69-00018HANA69C1	AMANS69 (37)	0.95	0.95
L_00039RAY138-00047BOB138C1	BOB138 (47)	0.95	0.95

Violations: BLT out of service

L_00039RAY138-00047BOB138C1	BOB138 (47)	0.90	0.95
L_00039RAY138-00047BOB138C1	BLT138 (53)	0.90	0.95
L_00010RAY69-00013FERNA69C1	FERNA69 (13)	0.90	0.95
L_00010RAY69-00013FERNA69C1	DEMAR69 (55)	0.91	0.95
T_00010RAY69-00039RAY138C1	FERNA69 (13)	0.93	0.95
T_00010RAY69-00039RAY138C1	DEMAR69 (55)	0.93	0.95
L_00012TIM69-00018HANA69C1	AMANS69 (37)	0.93	0.95
L_00013FERNA69-00055DEMAR69C1	DEMAR69 (55)	0.93	0.95
L_00031SLACK345-00038RAY345C1	BOB138 (47)	0.93	0.95
L_00031SLACK345-00038RAY345C1	BLT138 (53)	0.93	0.95
T_00054BLT69-00053BLT138C1	BLT138 (53)	0.93	0.95
L_00039RAY138-00047BOB138C1	UIUC69 (15)	0.94	0.95
L_00039RAY138-00047BOB138C1	BLT69 (54)	0.94	0.95
T_00010RAY69-00039RAY138C1	RAY69 (10)	0.94	0.95
L_00012TIM69-00018HANA69C1	HANA69 (18)	0.94	0.95
L_00012TIM69-00027HISKY69C1	PETE69 (16)	0.94	0.95
L_00012TIM69-00027HISKY69C1	HISKY69 (27)	0.94	0.95
L_00012TIM69-00027HISKY69C1	BOB138 (47)	0.94	0.95
L_00012TIM69-00027HISKY69C1	BLT138 (53)	0.94	0.95
L_00001TIM345-00031SLACK345C1	TIM345 (1)	0.94	0.95
L_00001TIM345-00031SLACK345C1	TIM138 (40)	0.94	0.95
L_00001TIM345-00031SLACK345C1	BOB138 (47)	0.94	0.95
L_00001TIM345-00031SLACK345C1	BLT138 (53)	0.94	0.95
L_00016PETE69-00027HISKY69C1	BLT138 (53)	0.94	0.95
T_00001TIM345-00040TIM138C1	TIM138 (40)	0.94	0.95
T_00001TIM345-00040TIM138C1	BOB138 (47)	0.94	0.95
T_00001TIM345-00040TIM138C1	BLT138 (53)	0.94	0.95
T_00054BLT69-00053BLT138C1	BOB138 (47)	0.94	0.95
L_00047BOB138-00053BLT138C1	BOB138 (47)	0.94	0.95
L_00039RAY138-00047BOB138C1	DEMAR69 (55)	0.95	0.95
T_00010RAY69-00039RAY138C1	BOB138 (47)	0.95	0.95
T_00010RAY69-00039RAY138C1	BLT138 (53)	0.95	0.95
L_00010RAY69-00013FERNA69C1	BOB138 (47)	0.95	0.95
L_00010RAY69-00013FERNA69C1	BLT138 (53)	0.95	0.95
L_00012TIM69-00018HANA69C1	BOB138 (47)	0.95	0.95
L_00012TIM69-00018HANA69C1	BLT138 (53)	0.95	0.95
L_00013FERNA69-00055DEMAR69C1	BOB138 (47)	0.95	0.95
L_00013FERNA69-00055DEMAR69C1	BLT138 (53)	0.95	0.95
G_00044LAUF69U1	BOB138 (47)	0.95	0.95
G_00044LAUF69U1	BLT138 (53)	0.95	0.95
L_00031SLACK345-00038RAY345C1	RAY345 (38)	0.95	0.95
L_00031SLACK345-00038RAY345C1	RAY138 (39)	0.95	0.95
L_00030BUCKY138-00032SAVOY138C1	BOB138 (47)	0.95	0.95
L_00030BUCKY138-00032SAVOY138C1	BLT138 (53)	0.95	0.95
L_00016PETE69-00027HISKY69C1	BOB138 (47)	0.95	0.95
L_00030BUCKY138-00041LAUF138C1	BOB138 (47)	0.95	0.95
L_00030BUCKY138-00041LAUF138C1	BLT138 (53)	0.95	0.95
L_00031SLACK345-00028JO345C1	BOB138 (47)	0.95	0.95
L_00031SLACK345-00028JO345C1	BLT138 (53)	0.95	0.95
L_00024HALE69-00044LAUF69C1	BOB138 (47)	0.95	0.95
L_00024HALE69-00044LAUF69C1	BLT138 (53)	0.95	0.95
L_00021WOLEN69-00048BOB69C1	BOB138 (47)	0.95	0.95
L_00021WOLEN69-00048BOB69C1	BLT138 (53)	0.95	0.95
L_00020SHIMKO69-00048BOB69C1	BOB138 (47)	0.95	0.95
L_00020SHIMKO69-00048BOB69C1	BLT138 (53)	0.95	0.95
L_00003MORO138-00040TIM138C1	BOB138 (47)	0.95	0.95
L_00003MORO138-00040TIM138C1	BLT138 (53)	0.95	0.95
T_00039RAY138-00038RAY345C2	BOB138 (47)	0.95	0.95
T_00039RAY138-00038RAY345C2	BLT138 (53)	0.95	0.95
L_00017PIE69-00019GROSS69C1	BOB138 (47)	0.95	0.95
L_00017PIE69-00019GROSS69C1	BLT138 (53)	0.95	0.95
G_00050RODGER69U1	BOB138 (47)	0.95	0.95
G_00050RODGER69U1	BLT138 (53)	0.95	0.95
L_00039RAY138-00040TIM138C1	BOB138 (47)	0.95	0.95
L_00039RAY138-00040TIM138C1	BLT138 (53)	0.95	0.95
L_00018HANA69-00037AMANS69C1	BOB138 (47)	0.95	0.95

L_00039RAY138-00047BOB138C1	BOB138 (47)	0.90	0.95
L_00039RAY138-00047BOB138C1	BLT138 (53)	0.90	0.95
L_00010RAY69-00013FERNA69C1	FERNA69 (13)	0.90	0.95
L_00010RAY69-00013FERNA69C1	DEMAR69 (55)	0.91	0.95
T_00010RAY69-00039RAY138C1	FERNA69 (13)	0.93	0.95
T_00010RAY69-00039RAY138C1	DEMAR69 (55)	0.93	0.95
L_00012TIM69-00018HANA69C1	AMANS69 (37)	0.93	0.95
L_00013FERNA69-00055DEMAR69C1	DEMAR69 (55)	0.93	0.95
L_00031SLACK345-00038RAY345C1	BOB138 (47)	0.93	0.95
L_00031SLACK345-00038RAY345C1	BLT138 (53)	0.93	0.95
T_00054BLT69-00053BLT138C1	BLT138 (53)	0.93	0.95
L_00039RAY138-00047BOB138C1	UIUC69 (15)	0.94	0.95
L_00039RAY138-00047BOB138C1	BLT69 (54)	0.94	0.95
T_00010RAY69-00039RAY138C1	RAY69 (10)	0.94	0.95
L_00012TIM69-00018HANA69C1	HANA69 (18)	0.94	0.95
L_00012TIM69-00027HISKY69C1	PETE69 (16)	0.94	0.95
L_00012TIM69-00027HISKY69C1	HISKY69 (27)	0.94	0.95
L_00012TIM69-00027HISKY69C1	BOB138 (47)	0.94	0.95
L_00012TIM69-00027HISKY69C1	BLT138 (53)	0.94	0.95
L_00001TIM345-00031SLACK345C1	TIM345 (1)	0.94	0.95
L_00001TIM345-00031SLACK345C1	TIM138 (40)	0.94	0.95
L_00001TIM345-00031SLACK345C1	BOB138 (47)	0.94	0.95
L_00001TIM345-00031SLACK345C1	BLT138 (53)	0.94	0.95
L_00016PETE69-00027HISKY69C1	BLT138 (53)	0.94	0.95
T_00001TIM345-00040TIM138C1	TIM138 (40)	0.94	0.95

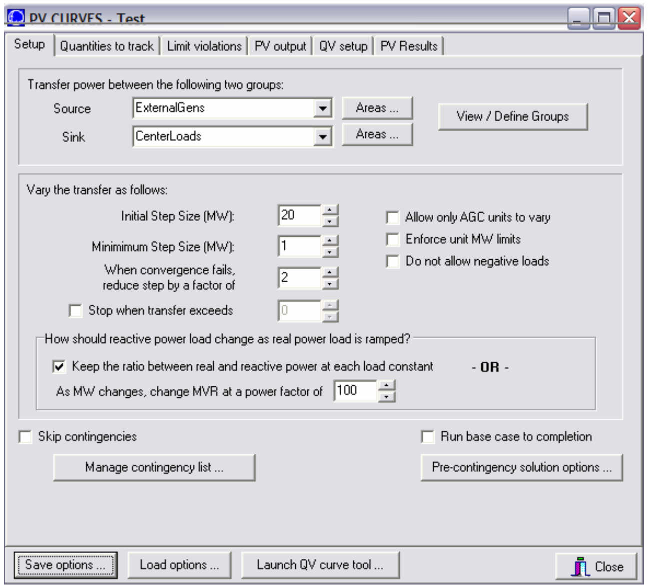
Impact on Future Conditions

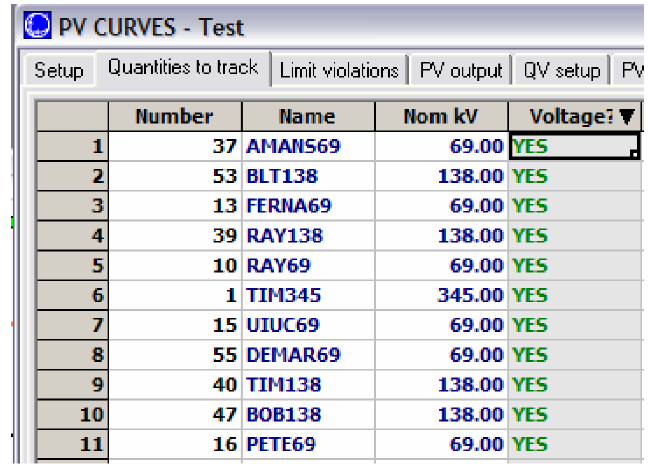
- PV Curve tool can model gradual changes
  - load growth
  - generation shifts
- Typically study transfers across several interfaces
- Monitor bus voltages as transfers grow

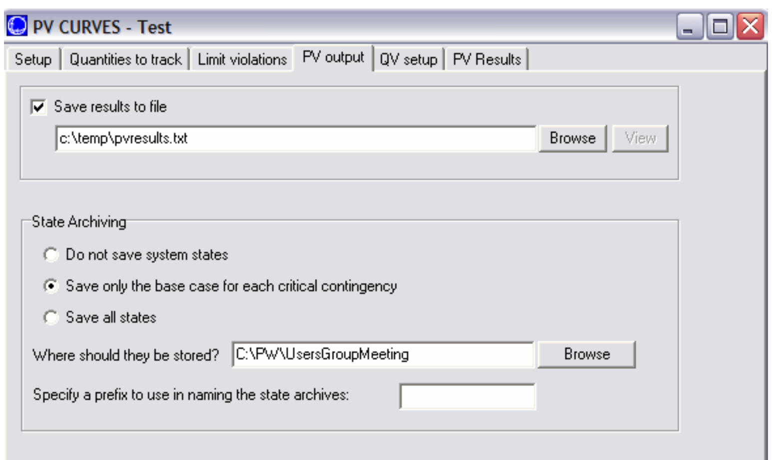
PV Curve Study Requirements

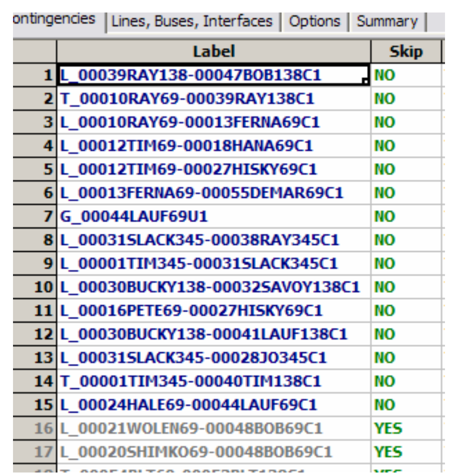
- Transfer directions
- Contingencies
- Quantities to monitor
- For this case study
  - Transfer
    - North & South Gens to increasing Central Load
  - Contingencies
    - Those that caused violations at base load
  - Monitored buses
    - Those whose voltage were violated at base load for base and contingency topologies

The PV Curve Tool









PV Results

BLT In Service

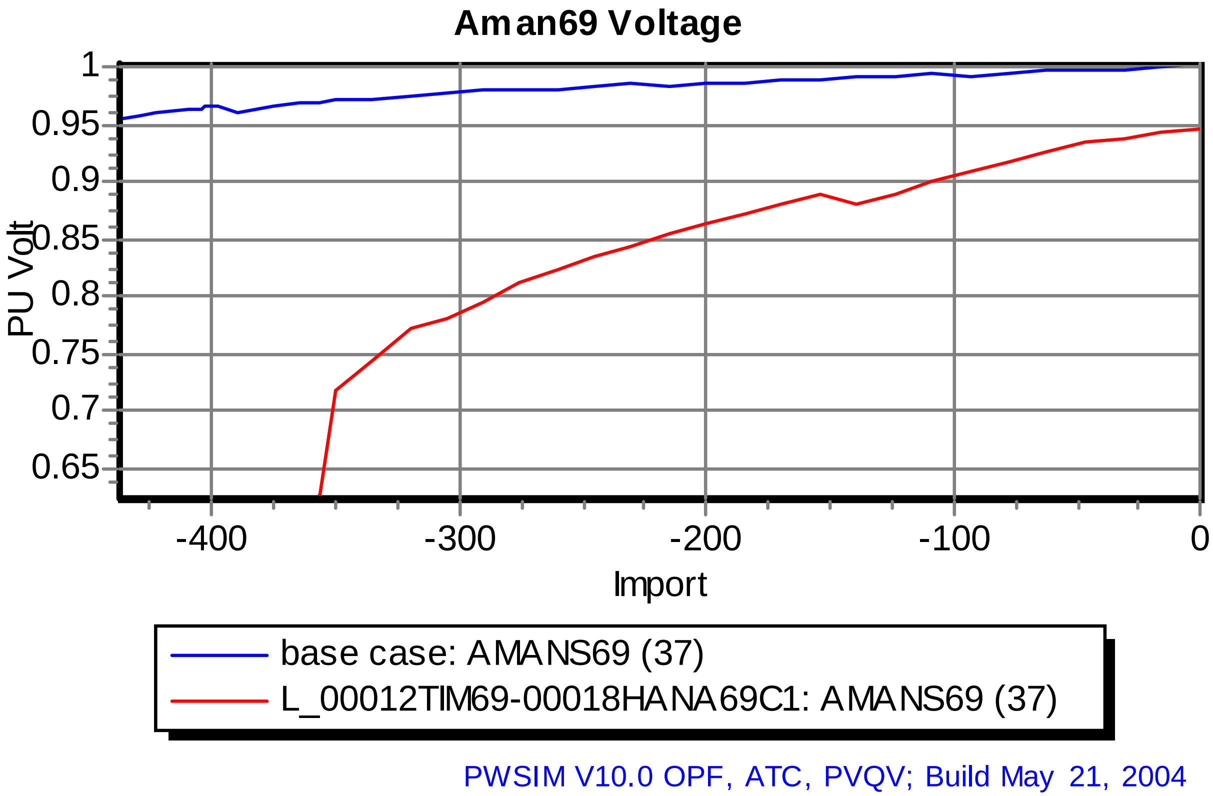
PV Scenario	Critical?	Critical Reason	Max Shift	Max Expor	Max Impor	# Viol	Worst V Vi
L_00039RAY138-00047BOB138C1	YES	Reached Nose	576	524.68	-427.81	29	0.71
L_00031SLACK345-00038RAY345C1	YES	Reached Nose	538.75	486.49	-401.3	32	0.7
L_00012TIM69-00018HANA69C1	YES	Reached Nose	475	421.22	-356.5	20	0.62

BLT Out of Service

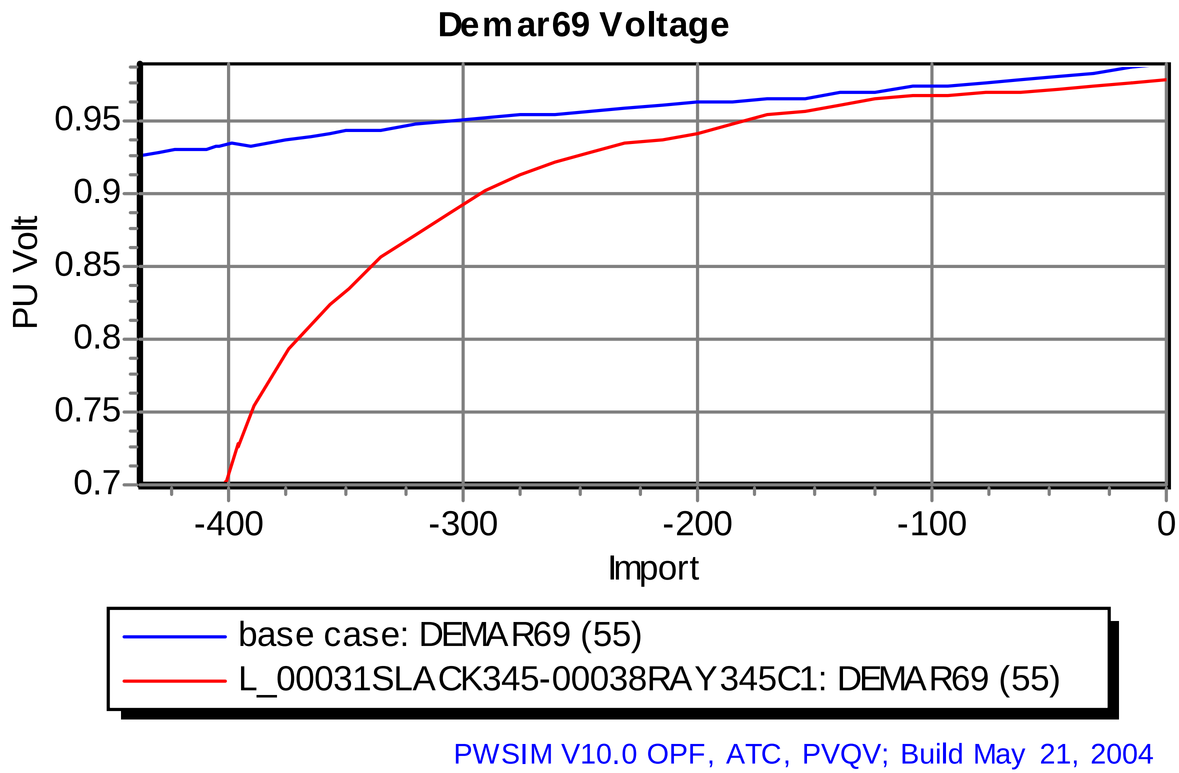
PV Scenario	Critical?	Critical Reason	Max Shift	Max Expo	Max Impor	# Viol	Worst V V
L_00039RAY138-00047BOB138C1	YES	Reached Nose	403.5	387.21	-298.63	29	0.64
L_00031SLACK345-00038RAY345C1	YES	Reached Nose	377.25	348.54	-278.59	32	0.69
L_00012TIM69-00018HANA69C1	YES	Reached Nose	437.25	385.66	-324.56	22	0.63

Outage reduces import capability by almost 80 MW!

BLT Units In-Service



BLT Units In-Service



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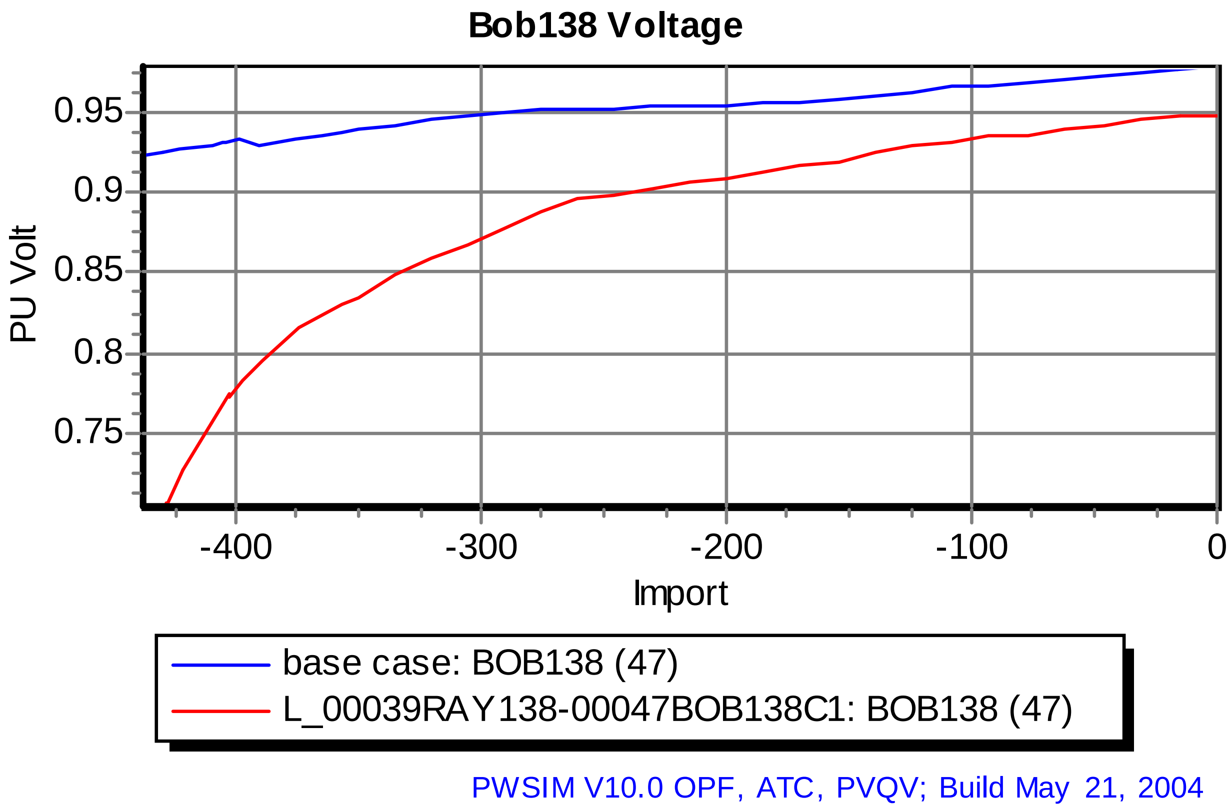
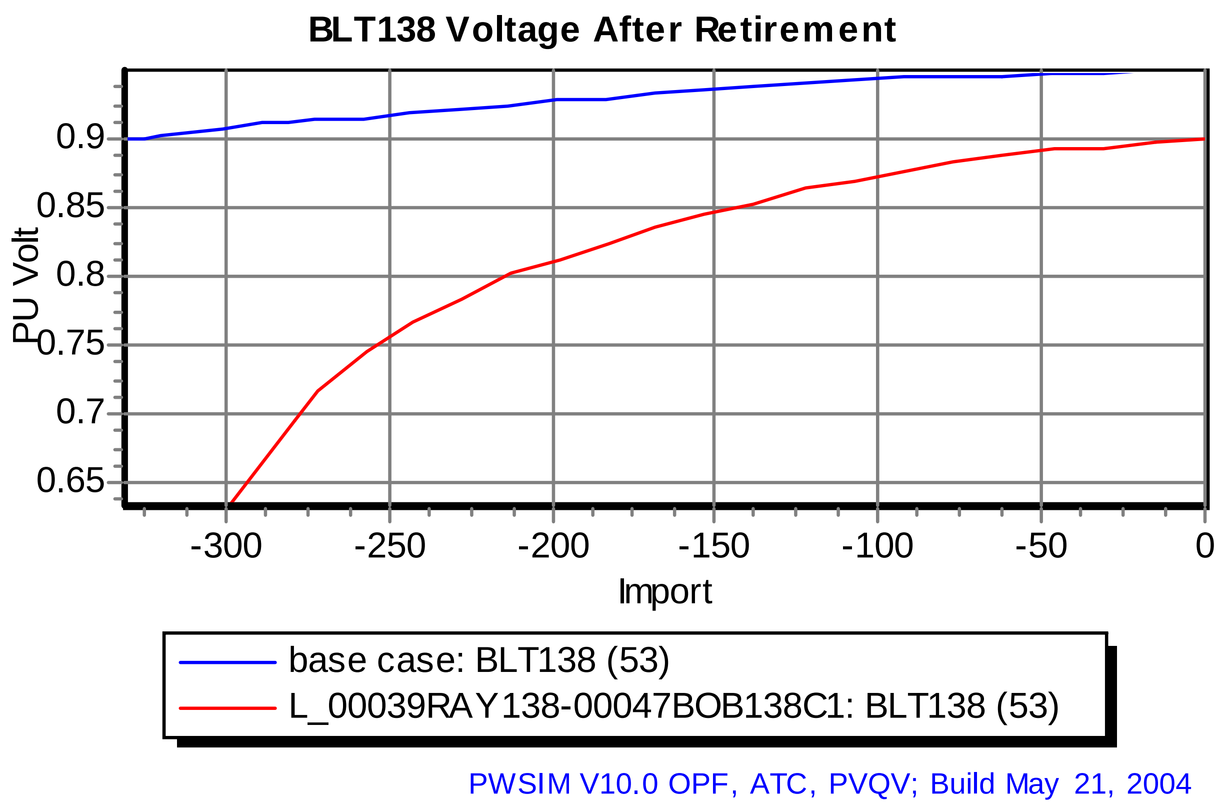
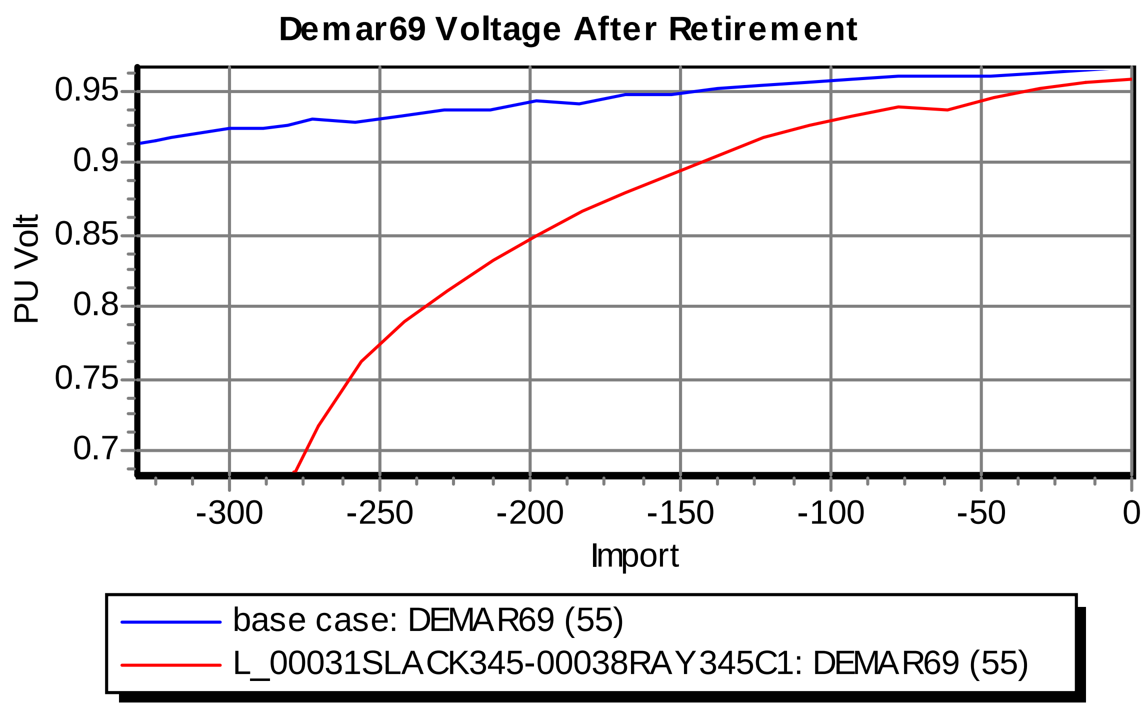


BLT Units Out-of-Service

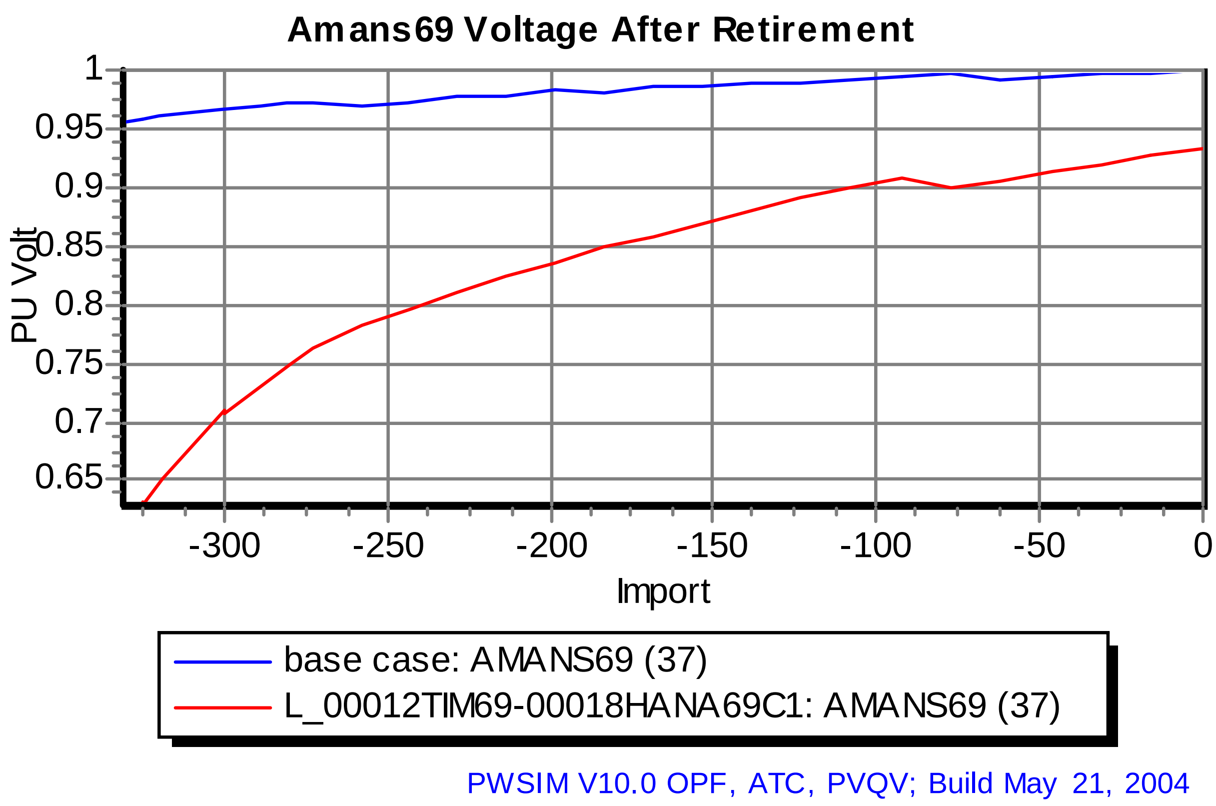


BLT Units Out-of-Service



PWSIM V10.0 OPF, ATC, PVQV; Build May 21, 2004

BLT Units Out-of-Service



Conclusion

- Difference flows, contouring, contingency analysis and the PV tool work together
- Provide an *estimate* of the ability of the system to meet
  - current demands
  - n-1 criteria standards
  - future growth
- Next step:
  - how to fortify the system