

Steady-State Power System Security Analysis with PowerWorld Simulator



S3: Techniques for Conditioning Hard-to-Solve Cases



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Example Cases



- Solving Real Power Flow Cases
 - Low impedance mismatches
 - ...*S03_GettingACaseToSolve\Initial Mismatches.raw*
 - Controller Settings, Area Control
 - ...*S03_GettingACaseToSolve\Unspecified Interchange.raw*
- Make use of the **Check Immediately** option for **Generator MVar Limits**
 - ...*S03_GettingACaseToSolve\Check Var Immediately.pwb*
- Loss of reactive support, Voltage Collapse, and Low-Voltage Solutions
 - ...*S03_GettingACaseToSolve\Voltage Collapse.pwb*
- Use of the Robust Solution Process
 - ...*S03_GettingACaseToSolve\Voltage Collapse.pwb*

Reading a Solved Text-File, Public Power Flow Formats



- You receive a case from someone that is supposed to be solved, but it won't solve
- Issues with initial case
 - Large mismatches from low impedance lines
 - Voltage Controllers
 - Transformers
 - Switched Shunts
 - Area Interchange Control
- These are not errors with the case or with Simulator, but should be understood
 - May require you to turn off some controllers

Very Large Initial Mismatches



- Very large initial mismatches
 - Primarily caused by “low-impedance” branches
 - Other software treats branches below a threshold impedance as exactly zero
 - The buses at either end of the branch are then merged and the transmission line is ignored
 - PowerWorld never merges buses this way
 - We do have minimum R and X of values however
 - » Minimum R = $0.0000001 = (1/1,000,000)$
 - » Minimum X = $0.00001 = (1/100,000)$
 - » Simulator will not let you set the values lower than this

Example Case with Large Initial Mismatches

Initial Mismatches.raw



- Choose **File** → **Open Case**
 - ... \S03_GettingACaseToSolve\Initial Mismatches.raw
- Open the Model Explorer
 - Navigate to the case information display
Network\Mismatches
- You will notice that there are very large initial mismatches

Initial Large Mismatches



- Notice mismatches come in oppositely signed “pairs”
 - -1567 MW,
 - +1566 MW
- MORDOR is more complicated
- LIVERPOOL is more complicated

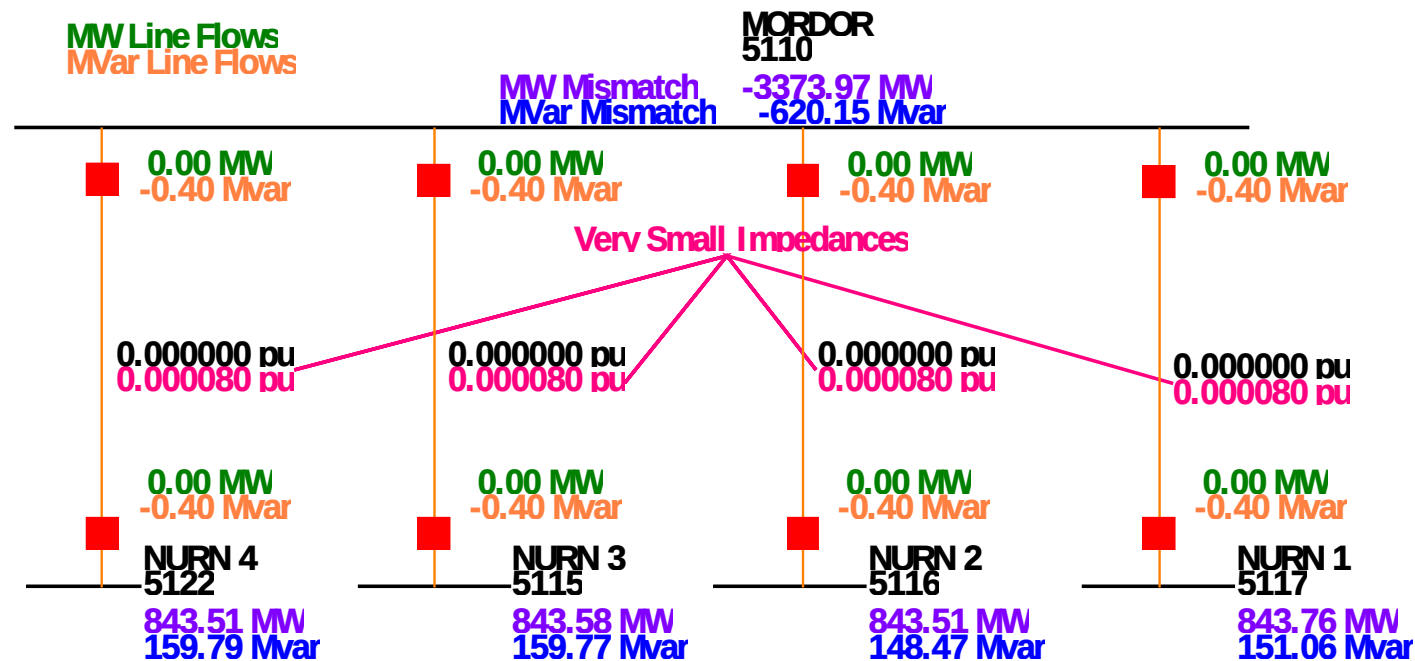
	Number	Name	Area Name	Type	Mismatch MW	Mismatch Mvar	Mismatch M ▼
1	5110	MORDOR	Area 5	PQ	-3373.97	-620.15	3430.49
2	5460	LIVERPOOL	Area 5	PQ	2509.05	344.55	2532.59
3	5148	BUS 5148	Area 5	PQ	-1567.40	-471.51	1636.79
4	5152	BUS 5152	Area 5	PQ	1566.34	467.31	1634.56
5	5150	BUS 5150	Area 5	PQ	-1073.87	-147.56	1083.96
6	5147	BUS 5147	Area 5	PQ	1073.51	146.64	1083.48
7	269	BUS 269	Area 1	PQ	-1053.99	-122.37	1061.07
8	93	BUS 93	Area 1	PQ (Re	1051.58	116.70	1058.03
9	1281	BUS 1281	Area 3	PQ	1016.82	-233.10	1043.20
10	1443	BUS 1443	Area 3	PQ	-1020.46	176.60	1035.63
11	5140	BUS 5140	Area 5	PQ	-690.37	-728.98	1004.00
12	5198	BUS 5198	Area 5	PQ	896.89	135.79	907.11
13	5197	BUS 5197	Area 5	PQ	-896.87	-135.59	907.06
14	5115	NURN 3	Area 5	PQ	843.58	159.77	858.58
15	5122	NURN 4	Area 5	PQ	843.51	159.79	858.51
16	5117	NURN 1	Area 5	PQ	843.76	151.06	857.18
17	5116	NURN 2	Area 5	PQ	843.51	148.47	856.48
18	5105	BUS 5105	Area 5	PQ	691.37	495.10	850.36
19	5259	BUS 5259	Area 5	PQ	-596.77	-78.09	601.85

Open Oneline: Mordor Nurn.pwd

Initial Mismatches.raw



- ...\\S03_GettingACaseToSolve\\Mordor Nurn.pwd



MW Mismatches sum to nearly zero

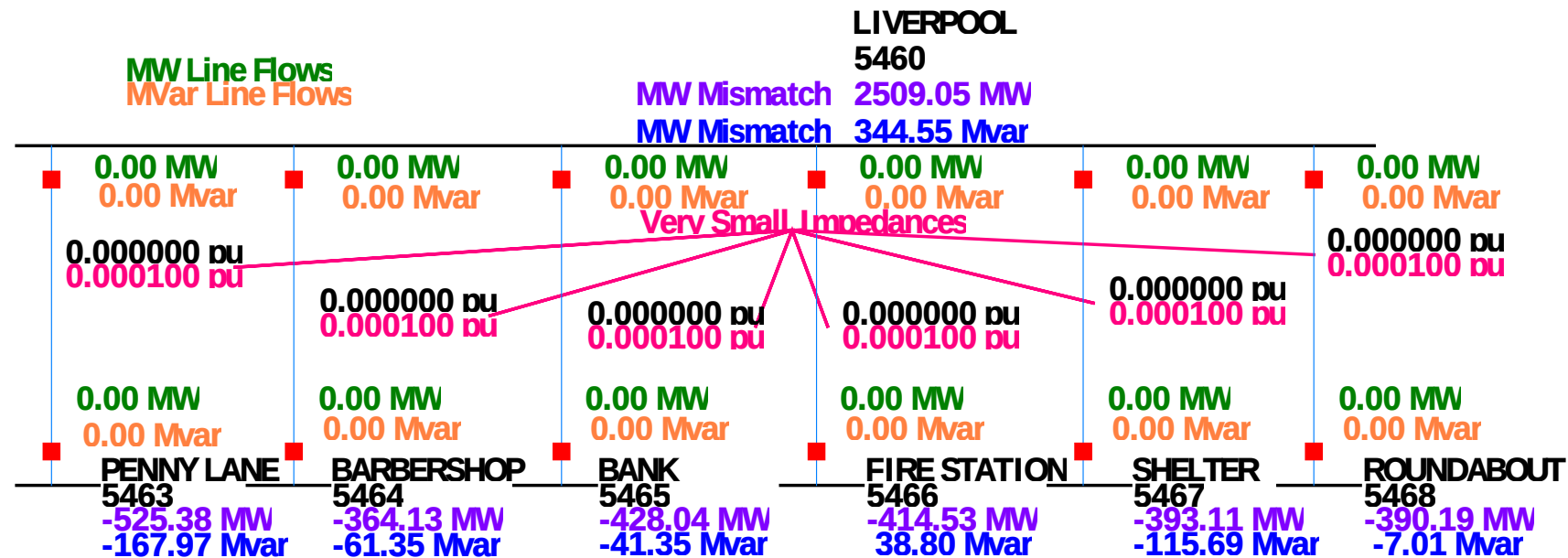
MVar Mismatches sum nearly to zero

Open Oneline: Liverpool.pwd

Initial Mismatches.raw



- ...\\S03_GettingACaseToSolve\\Liverpool.pwd



MW Mismatches sum to nearly zero
MVar Mismatches sum nearly to zero

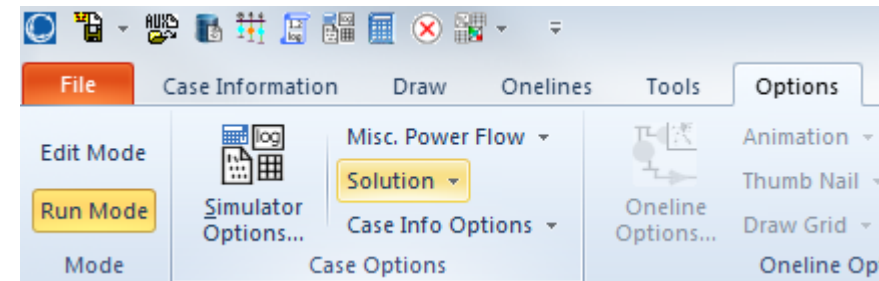
Solve Initial Case

Disable All Controllers to Start

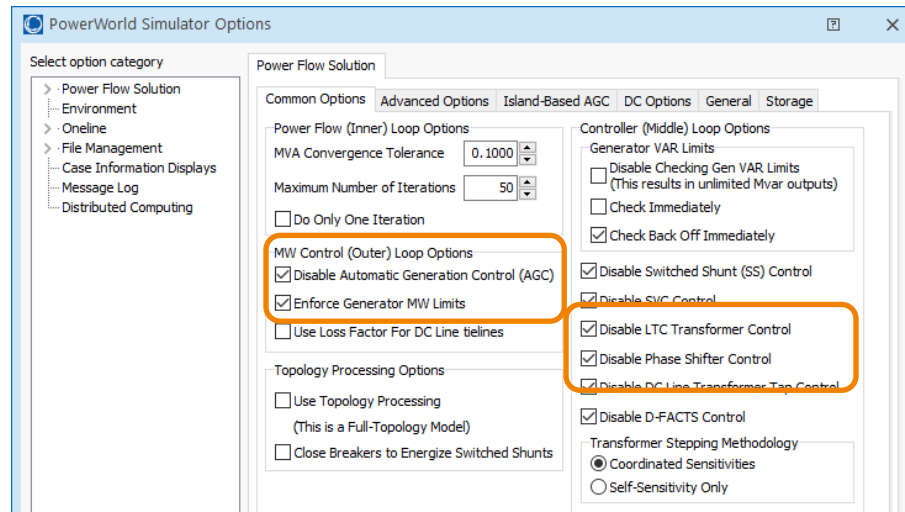


- First remove mismatches due to the low-impedance branches without moving any controllers

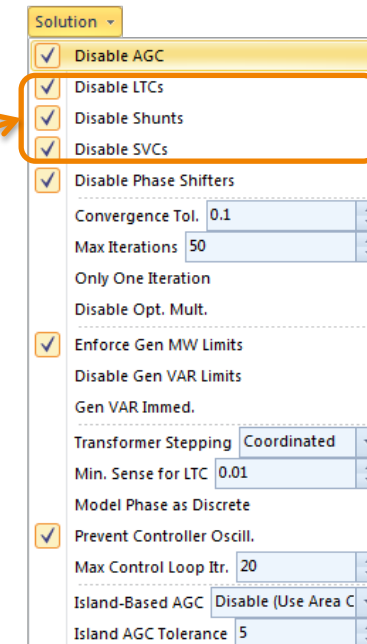
Options Ribbon Tab



On Simulator Options dialog



Disable AGC
Disable LTCs
Disable Shunts
Disable SVCs
Disable Phase Shifters
Disable DC Line Taps
Disable D-FACTS



If Initial Case was truly *Initial Mismatches.raw* solved, Solution Will Converge Quickly



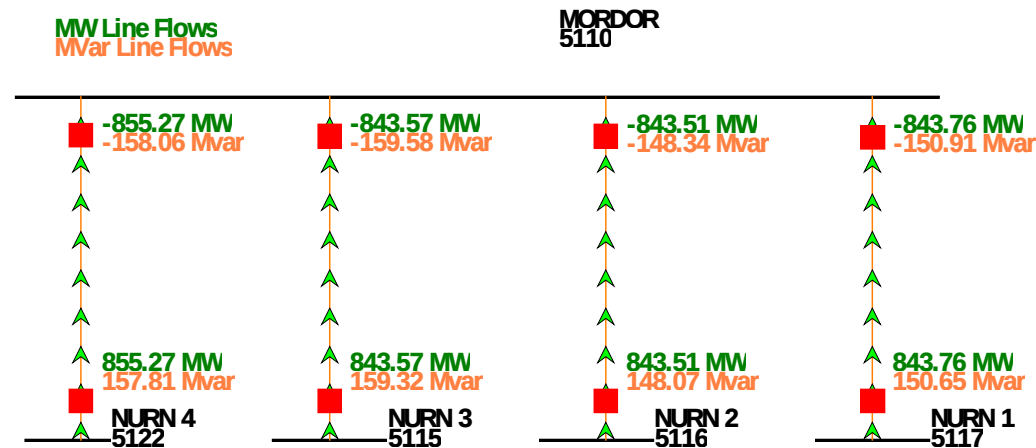
- Click **Single Solution** button



- Solution Results:**

Max P: 3373.966 at bus 5110 Max Q: 728.978 at bus 5140
Max P: 1555.962 at bus 5110 Max Q: 335.451 at bus 5140
Max P: 374.296 at bus 5110 Max Q: 81.281 at bus 5140
Max P: 3.776 at bus 1433 Max Q: 11.993 at bus 1443
Max P: 0.034 at bus 1443 Max Q: 0.025 at bus 1318
Etc... (generator Mvar limit checking)

- Flows on low-impedance branches are the same as the original mismatches



Now Restore the Voltage Controllers



- Turn on the Switched Shunt Controllers First
- Solve Power Flow
- Turn on SVCs
- Solve Power Flow
- Then the LTCs
- Solve Power Flow
- Then the Phase Shifters
- Solve Power Flow
- Then DC Line Transformer Tap and D-FACTS
- Why would problems occur?
 - Depends on the controller settings in the other software package
 - Controller settings are not included in some of the text file formats
 - RAW format has not solution parameters
 - EPC format has some solution parameters

Solution ▾

- ☒ Disable AGC
- ☒ Disable LTCs
- ☒ Disable Shunts
- ☒ Disable SVCs
- ☒ Disable Phase Shifters

Convergence Tol. 0.1

Max Iterations 50

Only One Iteration

Disable Opt. Mult.

- ☒ Enforce Gen MW Limits

Disable Gen VAR Limits

Gen VAR Immed.

Transformer Stepping Coordinated ▾

Min. Sense for LTC 0.01

Model Phase as Discrete

- ☒ Prevent Controller Oscill.

Max Control Loop Iter. 20

Island-Based AGC Disable (Use Area C) ▾

Island AGC Tolerance 5

What Happens for this Example?



- Switched Shunts
 - Very little movement is noticed (a few move)
- Tap Changing (LTC) Transformers
 - Error Checking Occurs
 - Many transformers are set off control because no regulated bus is specified
 - Many parallel transformer have their taps balanced automatically
 - Transformers that regulated the same bus which have different Regulation Ranges are modified
 - Many LTC transformers are not meeting their regulation requirements
 - Solution is achieved, but obviously the initial file did not represent a case solved with transformer tap switching enabled
- Phase Shifting Transformers
 - Some phase-shifting transformers are not meeting their regulation
 - Again solution is achieved, but obviously the initial file did not represent a case solved with phase-shifter switching enabled



Area Generation Control (AGC)

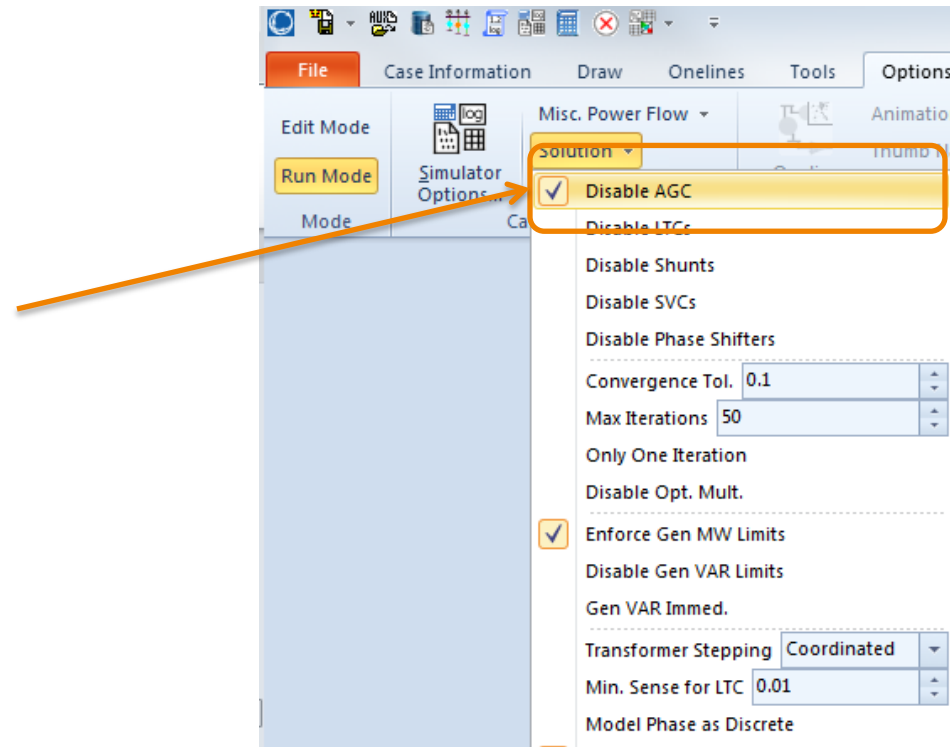
- Before you try to enable the AGC, ensure that the case was truly solved while on AGC control
- The best way to check this is to do following
 - Open Model Explorer
 - Go to **Aggregations\Areas**
 - Look at the **ACE MW** column
 - If values are very large, the original case was not solved using area control
 - They look OK for case *Initial Mismatches.RAW*

X Areas X DC Lines X Generators X Buses X Balancing Authorities X Owners X Zones X Mismatches X Islands															
Filter Advanced Area Find... Remove Quick Filter															
	Area Num	Area Name	AGC Status	Gen MW	Load MW	Shunt MW	Dist MW	Tot Sched MW	Int MW	ACE I	Lambda	Loss MW	Auto Shunts	Auto Xf	A
1	5	Area 5	Off AGC	25795.84	24990.65	-162.93	0.00	115.95	144.03	28.08	Off Control	824.09	YES	YES	5
2	4	Area 4	Area Slack	30687.31	30733.53	-176.29	0.00	-1225.33	-1248.65	-23.32	Off Control	1378.72	YES	YES	3
3	1	Area 1	Area Slack	10673.83	9576.97	-1063.87	0.00	1900.50	1896.61	-3.89	Off Control	264.13	YES	YES	6
4	2	Area 2	Area Slack	12036.43	12154.99	300.09	0.00	-665.61	-667.23	-1.62	Off Control	248.57	YES	YES	8
5	3	Area 3	Area Slack	24642.79	26065.96	-1985.24	0.00	-126.35	-124.81	1.54	Off Control	686.87	YES	YES	2

When Case is Not Solved with AGC



- Choose **File** → **Open Case**
 - ... \S03_GettingACaseToSolve\Unspecified Interchange.raw
- Go to **Options** Ribbon Tab
 - Choose the **Solution** menu
 - Check **Disable AGC**
- Click **Single Solution**
- Solution successful
- Open Model Explorer
 - **Aggregations\Areas**



Area ACE MW, Unspecified MW Transactions

Unspecified Interchange.Raw



- Large ACE Values
- Unspecified MW interchange does not sum to zero

Areas																	
X Areas X Buses X Zones X Owners X Balancing Authorities X Mismatches																	
Records Geo Set Columns Options																	
Filter Advanced Area Find... Remove Quick Filter																	
	Area Num	Area Name	AGC Status	Gen MW	Load MW	Shunt MW	Dist MW	Tot Sched MW	Int MW	ACE MW	Lambda	Loss MW	Auto Shunts	Auto XF	Area Slack Bu	Unspec. MW Inter.	AGC Tolerance
1	10	Area 10	Off AGC	202.00	273.06		0.00	0.00	-73.90	-73.90	Off Control	2.84	YES	YES		0.00	10.00
2	11	Area 11	Off AGC	63.44	108.12		0.00	0.00	-45.39	-45.39	Off Control	0.71	YES	YES		0.00	10.00
3	12	Area 12	Off AGC	319.14	525.77		0.00	0.00	-214.02	-214.02	Off Control	7.40	YES	YES		0.00	10.00
4	13	Area 13	Off AGC	177.71	273.80		0.00	0.00	-97.43	-97.43	Off Control	1.34	YES	YES		0.00	10.00
5	14	Area 14	Off AGC		4.64		0.00	0.00	-4.84	-4.84	Off Control	0.20	YES	YES		0.00	10.00
6	15	Area 15	Area Slack	1702.83	1628.80	0.00	0.00	0.00	58.05	58.05	Off Control	15.98	YES	YES	5451	0.00	1.00
7	16	Area 16	Area Slack	46.00	10.00		0.00	36.00	35.99	-0.01	Off Control	0.01	YES	YES	3630	36.00	1.00
8	17	Area 17	Off AGC	80.00	253.00	0.00	0.00	0.00	-173.86	-173.86	Off Control	0.86	YES	YES		0.00	0.00
9	18	Area 18	Off AGC	395.00				0.00	393.76	393.76	Off Control	1.24	YES	YES		0.00	10.00
10	19	Area 19	Off AGC	320.75	404.00	0.00	0.00	0.00	-110.11	-110.11	Off Control	26.85	YES	YES		0.00	0.00
11	20	Area 20	Off AGC	462.00	0.00	0.00	0.00	0.00	454.91	454.91	Off Control	7.09	YES	YES		0.00	10.00
12	21	Area 21	Off AGC	1726.30	2166.89	0.00	0.00	0.00	-493.87	-493.87	Off Control	53.28	YES	YES		0.00	0.00
13	22	Area 22	Off AGC	2500.00				0.00	2458.96	2458.96	Off Control	41.04	YES	YES		0.00	0.00
14	23	Area 23	Area Slack	1289.30	2234.23	0.00	0.00	0.00	-990.79	-990.79	Off Control	45.86	YES	YES	5143	0.00	1.00
15	24	Area 24	Area Slack	5719.95	6297.81	0.00	0.00	0.00	-753.53	-753.53	Off Control	175.67	YES	YES	4853	0.00	1.00
16	25	Area 25	Area Slack	6444.80	3080.31	0.00	0.00	497.44	3259.31	2761.87	Off Control	105.18	YES	YES	4247	497.44	1.00
17	26	Area 26	Area Slack	3601.65	4137.50	0.00	0.00	-700.00	-575.01	124.99	Off Control	39.16	YES	YES	3348	-700.00	1.00
18	27	Area 27	Off AGC	16729.67	18080.03	0.00	0.00	0.00	-1557.94	-1557.94	Off Control	207.59	YES	YES		0.00	0.00
19	28	Area 28	Off AGC		94.34		0.00	0.00	-94.34	-94.34	Off Control	0.01	YES	YES		0.00	10.00
20	29	Area 29	Off AGC	76.00	459.57		0.00	0.00	-384.71	-384.71	Off Control	1.14	YES	YES		0.00	10.00
21	30	Area 30	Area Slack	23835.60	24258.93	0.00	0.00	0.00	-1091.25	-1091.25	Off Control	667.92	YES	YES	3116	0.00	1.00

Area Unspecified MW Interchange

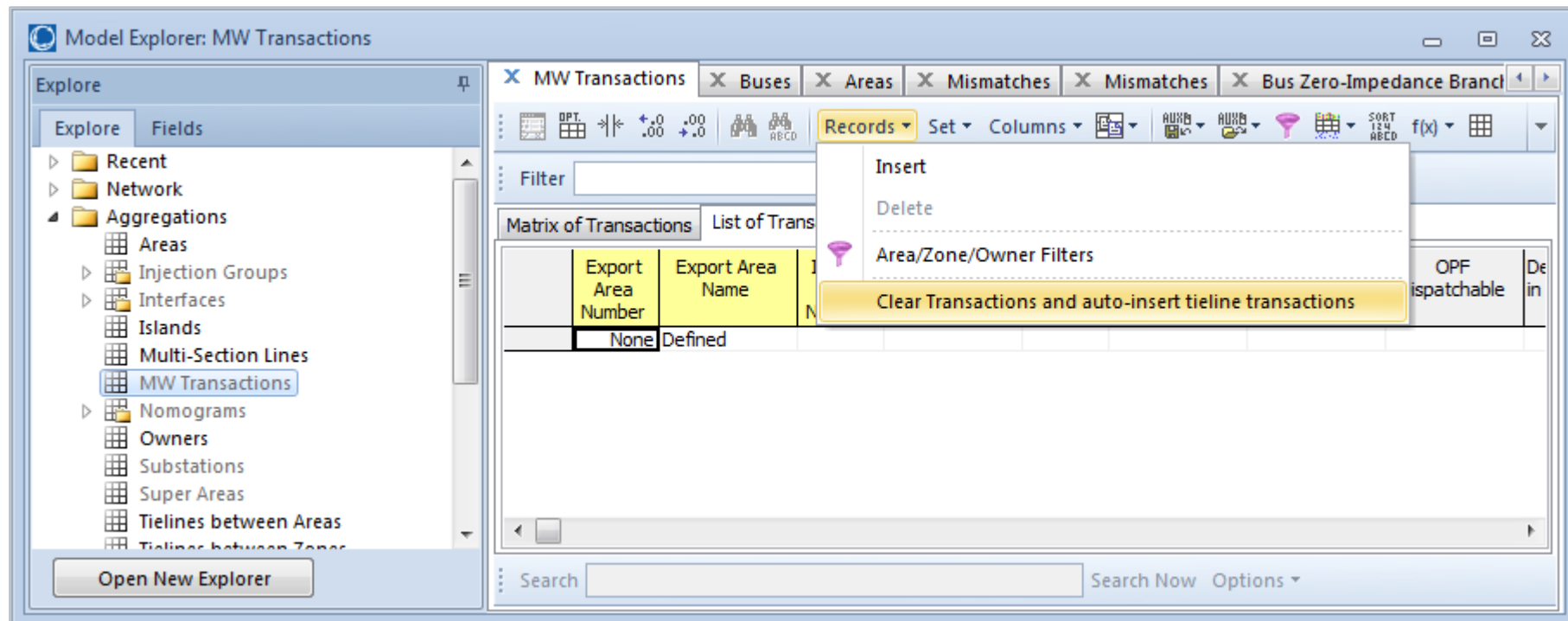


- Each area can have an export specified which does not have a “receiving” end specified
- This is called *Unspecified MW Interchange*
- These unspecified values should sum to zero
 - If they do not sum to zero, you have an “export to nowhere”
 - When this occurs, the Area with the island slack bus will be turned off AGC and all unspecified interchange will be sent to the island slack bus

What to do if Interchanges don't look right?

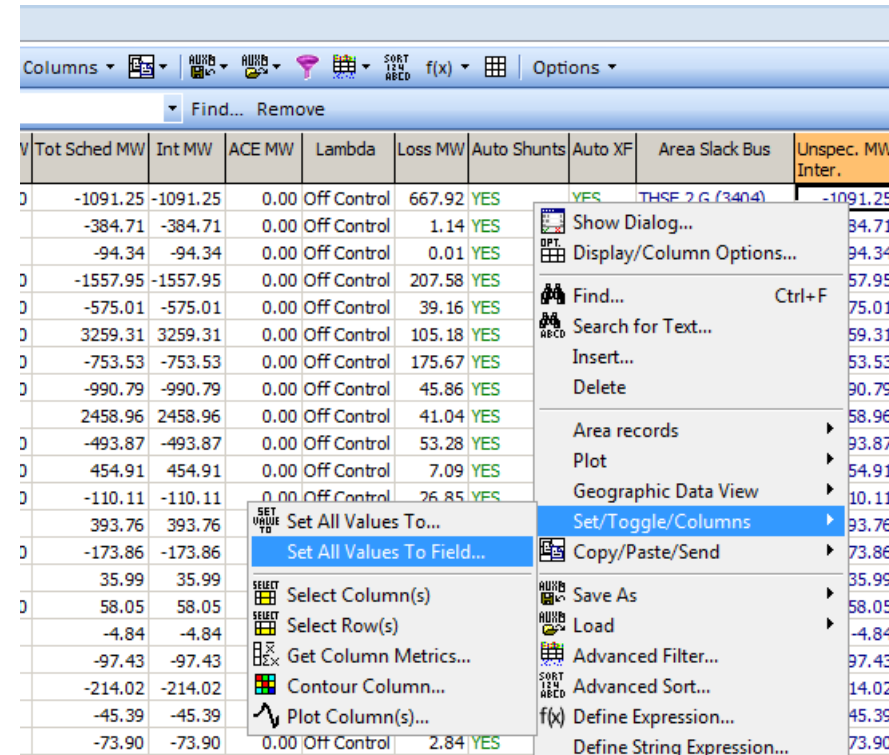


- Open Model Explorer
 - Go to **Aggregations\MW Transactions**
 - On the Case Info Toolbar, choose **Records** → **Clear Transactions and auto-insert tie-line transactions**



What to do if Interchanges don't look right?

- Another option is to set the unspecified interchange equal to the actual interchange
 - Go to Areas
 - Right-click on **Unspec. MW Inter.** field
 - Choose **Set/Toggle/Columns** → **Set All Values to Field...**
 - Choose **Interchange\Actual MW Export**



The screenshot shows a software window with a table of power system data. The table has columns: Tot Sched MW, Int MW, ACE MW, Lambda, Loss MW, Auto Shunts, Auto XF, Area Slack Bus, and Unspec. MW Inter. A context menu is open over the 'Unspec. MW Inter.' column, showing options like 'Set All Values To...', 'Set All Values To Field...', 'Select Column(s)', 'Select Row(s)', 'Get Column Metrics...', 'Contour Column...', 'Plot Column(s)...', 'Show Dialog...', 'Display/Column Options...', 'Find...', 'Search for Text...', 'Insert...', 'Delete', 'Area records', 'Plot', 'Geographic Data View', 'Set/Toggle/Columns', 'Copy/Paste/Send', 'Save As', 'Load', 'Advanced Filter...', 'Advanced Sort...', 'Define Expression...', and 'Define String Expression...'. The 'Set/Toggle/Columns' option is highlighted.

	Tot Sched MW	Int MW	ACE MW	Lambda	Loss MW	Auto Shunts	Auto XF	Area Slack Bus	Unspec. MW Inter.
0	-1091.25	-1091.25	0.00	Off Control	667.92	YES	YES	THSE 2 G (3404)	-1091.25
	-384.71	-384.71	0.00	Off Control	1.14	YES			34.71
	-94.34	-94.34	0.00	Off Control	0.01	YES			94.34
0	-1557.95	-1557.95	0.00	Off Control	207.58	YES			57.95
0	-575.01	-575.01	0.00	Off Control	39.16	YES			75.01
0	3259.31	3259.31	0.00	Off Control	105.18	YES			59.31
0	-753.53	-753.53	0.00	Off Control	175.67	YES			53.53
0	-990.79	-990.79	0.00	Off Control	45.86	YES			90.79
	2458.96	2458.96	0.00	Off Control	41.04	YES			58.96
	-493.87	-493.87	0.00	Off Control	53.28	YES			93.87
0	454.91	454.91	0.00	Off Control	7.09	YES			54.91
0	-110.11	-110.11	0.00	Off Control	26.85	YES			10.11
	393.76	393.76							93.76
0	-173.86	-173.86							73.86
	35.99	35.99							35.99
0	58.05	58.05							58.05
	-4.84	-4.84							-4.84
	-97.43	-97.43							97.43
	-214.02	-214.02							14.02
	-45.39	-45.39							45.39
	-73.90	-73.90	0.00	Off Control	2.84	YES			73.90

What does *Clear Transactions and auto-insert tie-line transactions* do?

Unspecified Interchange.Raw



- All MW transactions in the case will be deleted
- All Unspecified MW transactions for each area will be set to zero
- New MW transactions will be created between each pair of areas directly connect to one another
 - The amount of the new MW transactions will be set equal to the actual sum of the flow on the tie-lines between the connected areas

Use of Generator Mvar Check Immediately



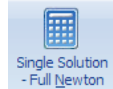
- Normally inside the **Inner Power Flow Loop**, the choice about whether a bus is a PV or a PQ bus is not changed
 - If a bus is considered PV, it is allowed to inject/absorb unlimited Mvar
 - If a bus is considered PQ, its Q output is fixed
- The choice to switch between a PV and PQ bus is normally made in the **Voltage Control** loop.
- The **Check Immediately** option for the **Generator VAR Limits** changes this
 - Choosing this means that buses with voltage-controlling generators (or continuous switched shunts) will check whether they hit or back-off a limit after each inner loop iteration
 - This may help in some situations with solution
 - However, this will slow down the solution process

Generator Mvar Modeling:

Example Check Immediately



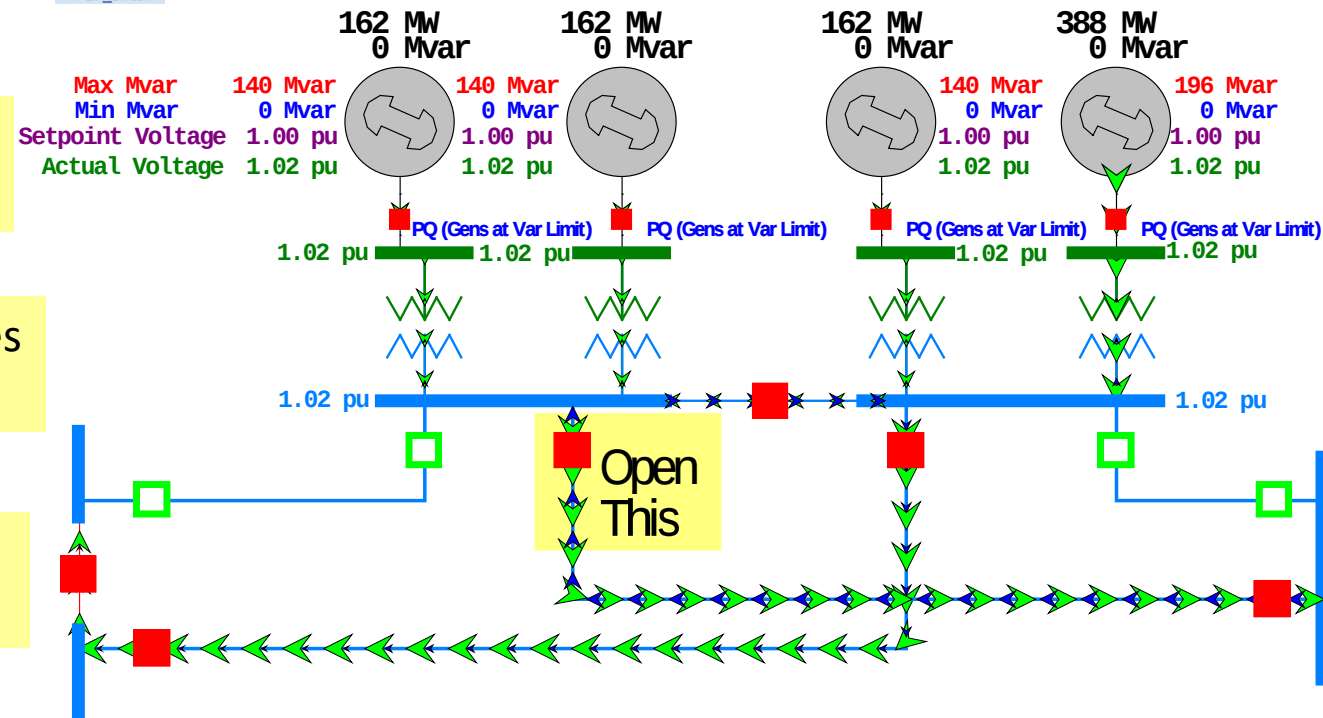
- Choose **File** → **Open Case**
 - ... \S03_GettingACaseToSolve\Check Var Immediately.pwb
- Click **Single Solution**



Setpoint voltages
are all 1.00

Terminal voltages
are all 1.02

All Generators are
stuck at Min Mvar



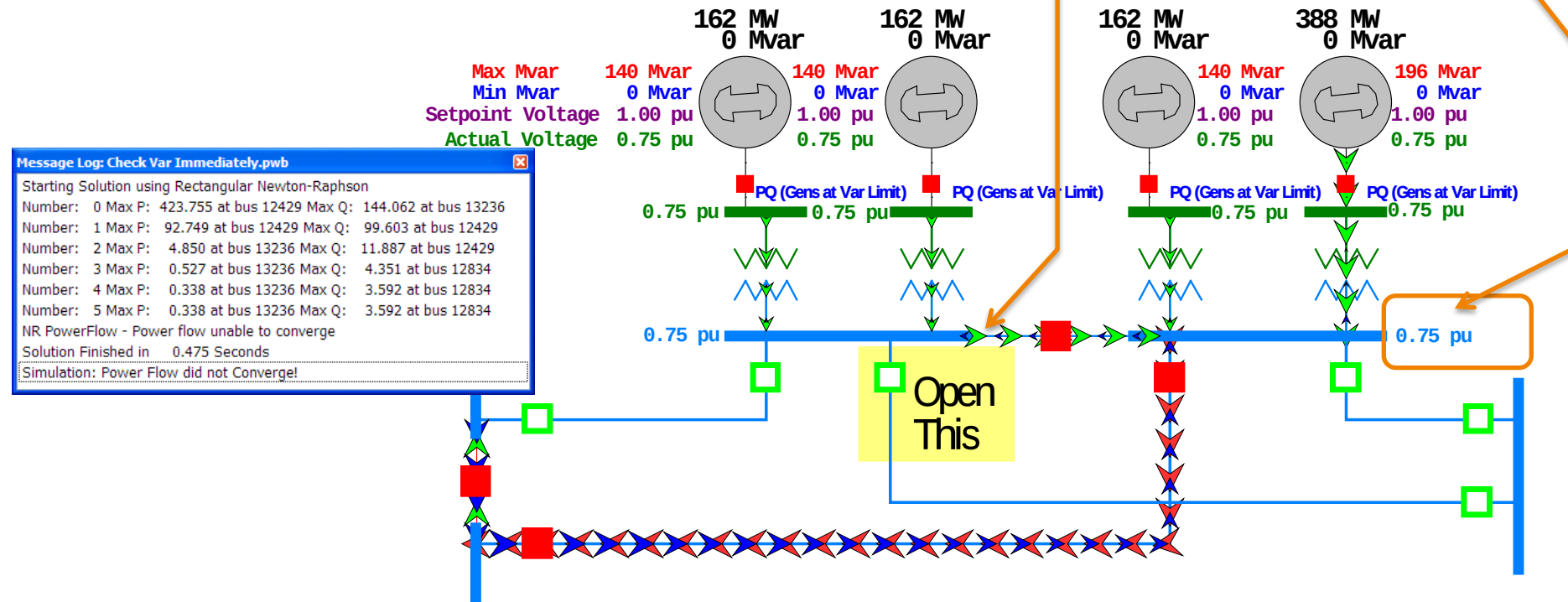
Generator MVar Modeling:

A branch outage occurs

Check Var Immediately.pwb



- Take the branch labeled “Open This” out-of-service
- Hit **Single Solution** 
- Results in an unsolved power flow



What about the Generator MVar voltage support?



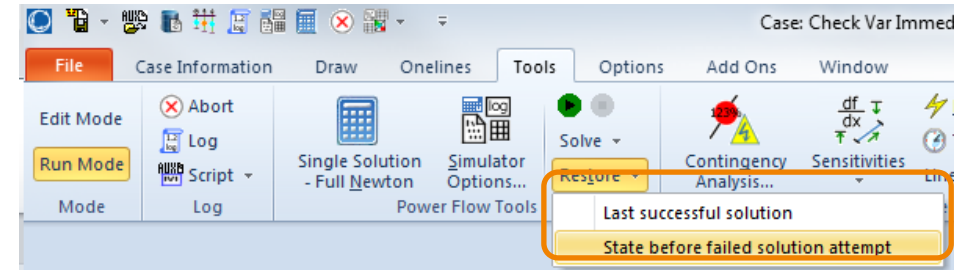
- Notice that the generators are all still operating at 0 Mvar output in the system
 - The power flow started with the generator buses flagged as PQ buses because they started at their minimum Mvar
- If they were operating with more Mvars providing more support, they might have prevented the collapse
 - The **Inner Power Flow Loop** did not achieve solution, thus the generators didn't have an opportunity to enter the **Voltage Control Loop** and switch to a PV bus (and thus provide the Mvar support)
- We can use the **Check Immediately** option on the **Simulator Options** to achieve a solution in this situation

Redo Solution while *Check Var Immediately.pwb* Checking Mvar Limits Immediately



- Go to the **Tools** Ribbon Tab, **Restore** menu

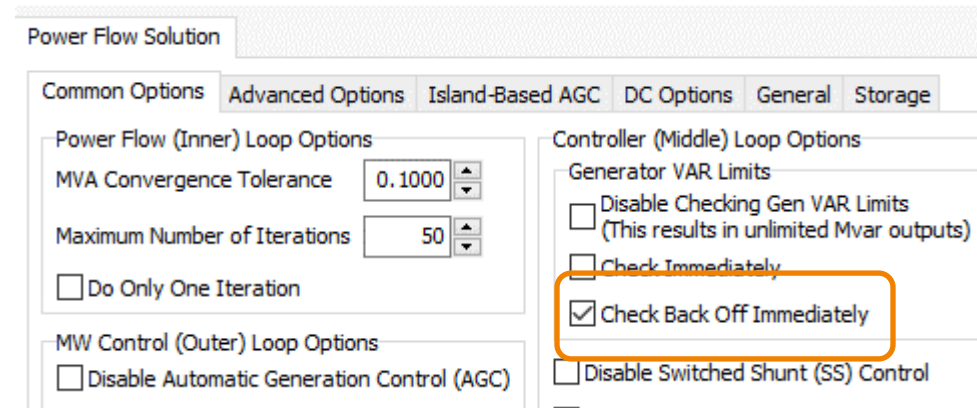
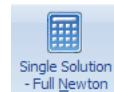
- Choose **State before failed solution attempt**



- Open **Simulator Options, Power Flow Solution, Common Options**

- Choose **Check Back Off Immediately**

- Hit **Single Solution**

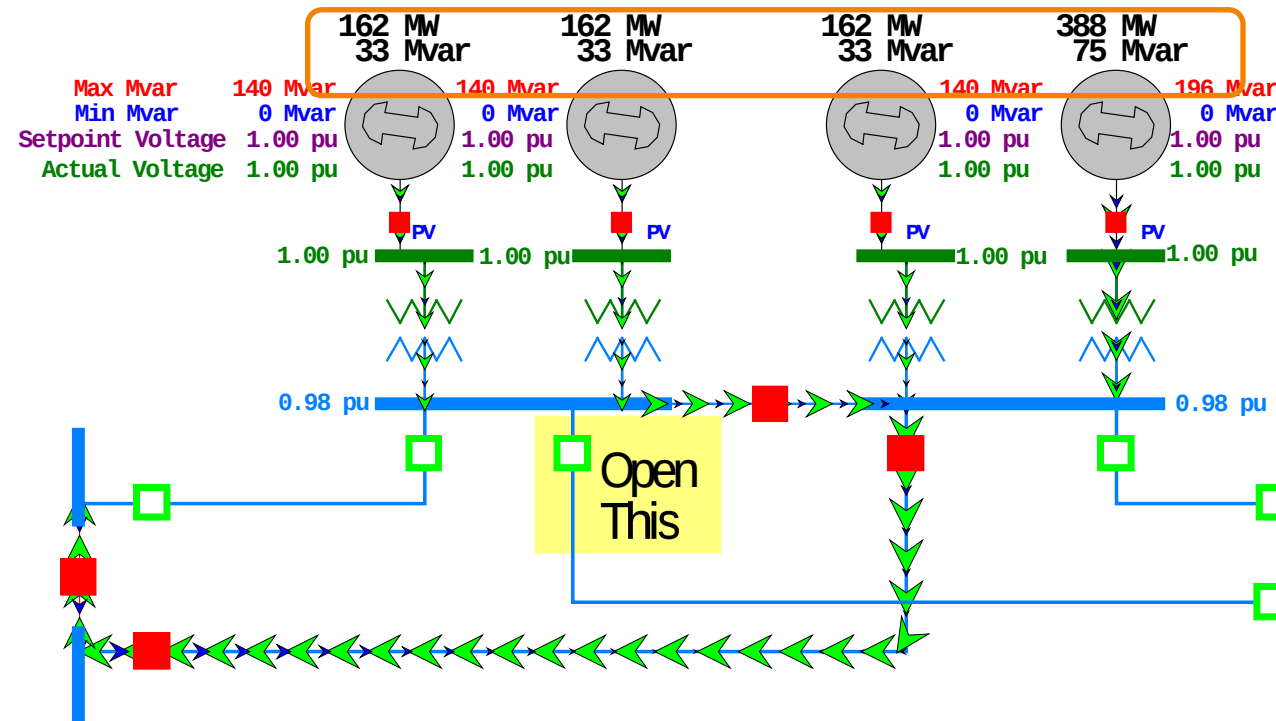


Successful Solution using Check Immediately Mvar solution option

Check Var Immediately.pwb



- A successful solution is achieved
 - Note that generators all back-off their minimum limit and are now providing support



Message Log Comparisons



Voltage Collapse

Starting Single Solution using Rectangular Newton-Raphson	
Number: 0	Max P: 423.806 at bus 10383 Max Q: 145.311 at bus 10000
Number: 1	Max P: 43.263 at bus 10383 Max Q: 91.818 at bus 10383
Number: 2	Max P: 2.940 at bus 10292 Max Q: 9.099 at bus 10292
Number: 3	Max P: 1.047 at bus 10292 Max Q: 6.477 at bus 10292
Number: 4	Max P: 1.028 at bus 10292 Max Q: 6.414 at bus 10292
Number: 5	Max P: 1.028 at bus 10292 Max Q: 6.414 at bus 10292
Number: 6	Max P: 1.028 at bus 10292 Max Q: 6.414 at bus 10292
NR PowerFlow - Power flow unable to converge	
Single Solution Finished in 0.0089 Seconds	
Simulation: Power Flow did not Converge!	

Voltage Collapse Occurs – This is seen by the fact that the Reactive Power Equations can not converge

Check Back Off Immediately Enabled

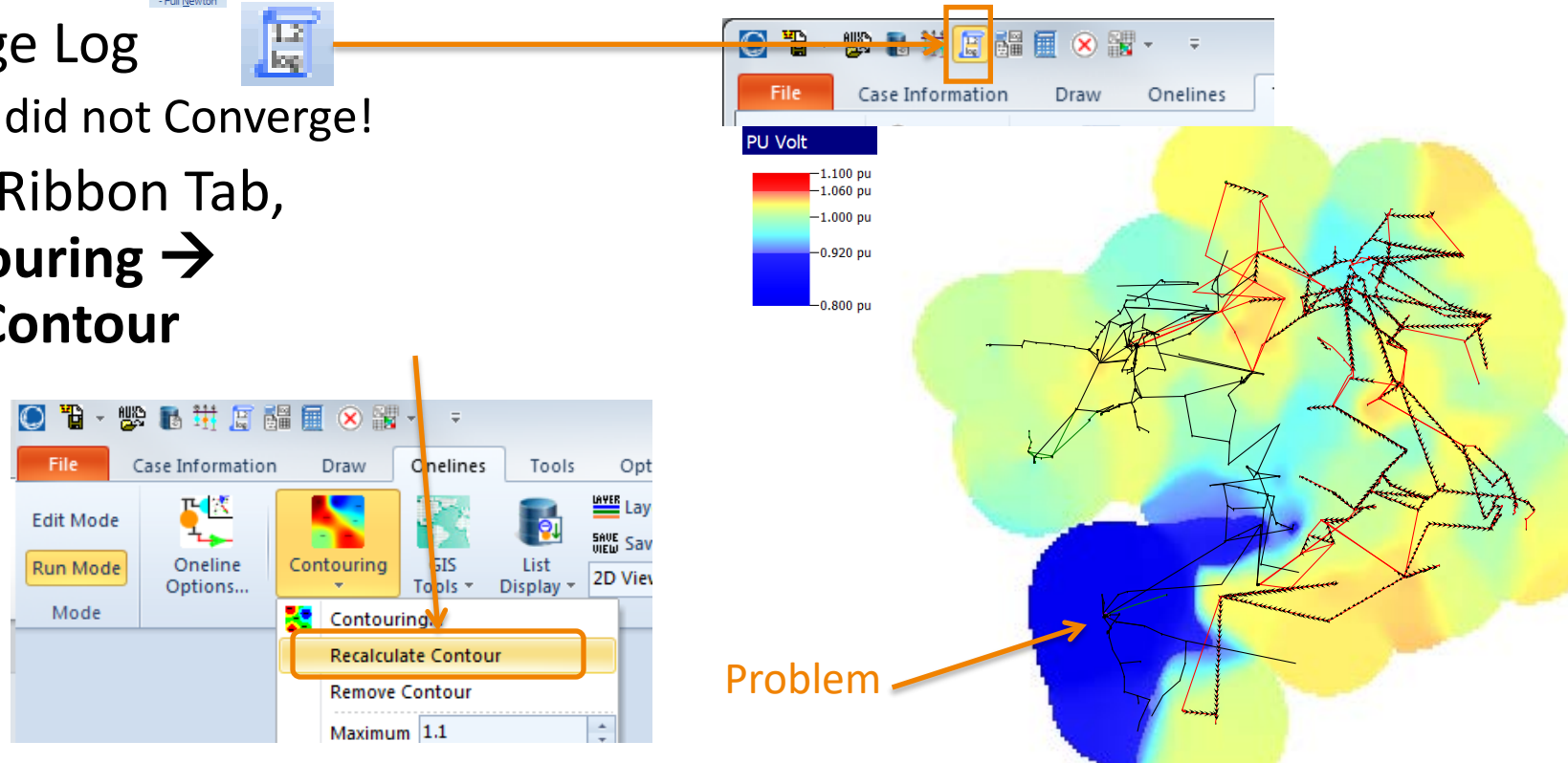
Starting Single Solution using Rectangular Newton-Raphson	
Number: 0	Max P: 423.806 at bus 10383 Max Q: 145.311 at bus 10000
Number: 1	Max P: 43.263 at bus 10383 Max Q: 91.818 at bus 10383
Gen(s) at bus 10203 has backed off var limit max Gen(s) at bus 10292 has backed off var limit min Gen(s) at bus 10293 has backed off var limit min Gen(s) at bus 10294 has backed off var limit min Other Gen Var Changes	
Number: 2	Max P: 2.627 at bus 10383 Max Q: 2.024 at bus 10000
Number: 3	Max P: 0.002 at bus 10383 Max Q: 0.003 at bus 10383
Transformer, Gen Var, AGC Changes, etc.	
Number: 0	Max P: 0.020 at bus 10313 Max Q: 0.008 at bus 10315
Number: 1	Max P: 0.020 at bus 10313 Max Q: 0.008 at bus 10315
Finished voltage control loop iteration: 1	
Solution Finished in 0.0941 Seconds	
Simulation: Successful Power Flow Solution	

Solution sees the voltages begin to fall and backs off the minimum MVar limits to provide voltage support

Voltage Collapse Example



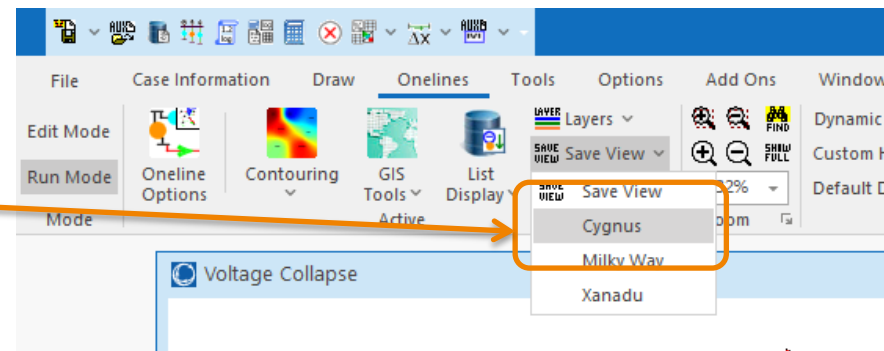
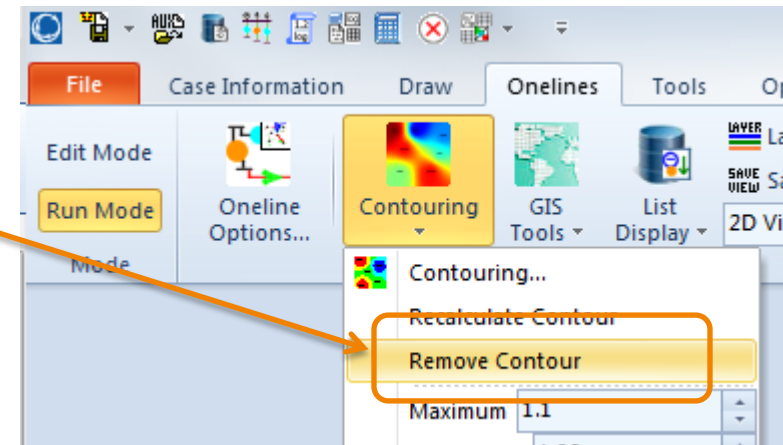
- Choose **File** → **Open Case**
 - ...\\S03_GettingACaseToSolve\\Voltage Collapse.pwb
- Hit **Single Solution** 
- Open Message Log 
 - Power Flow did not Converge!
- On **Onelines** Ribbon Tab, choose **Contouring** → **Recalculate Contour**



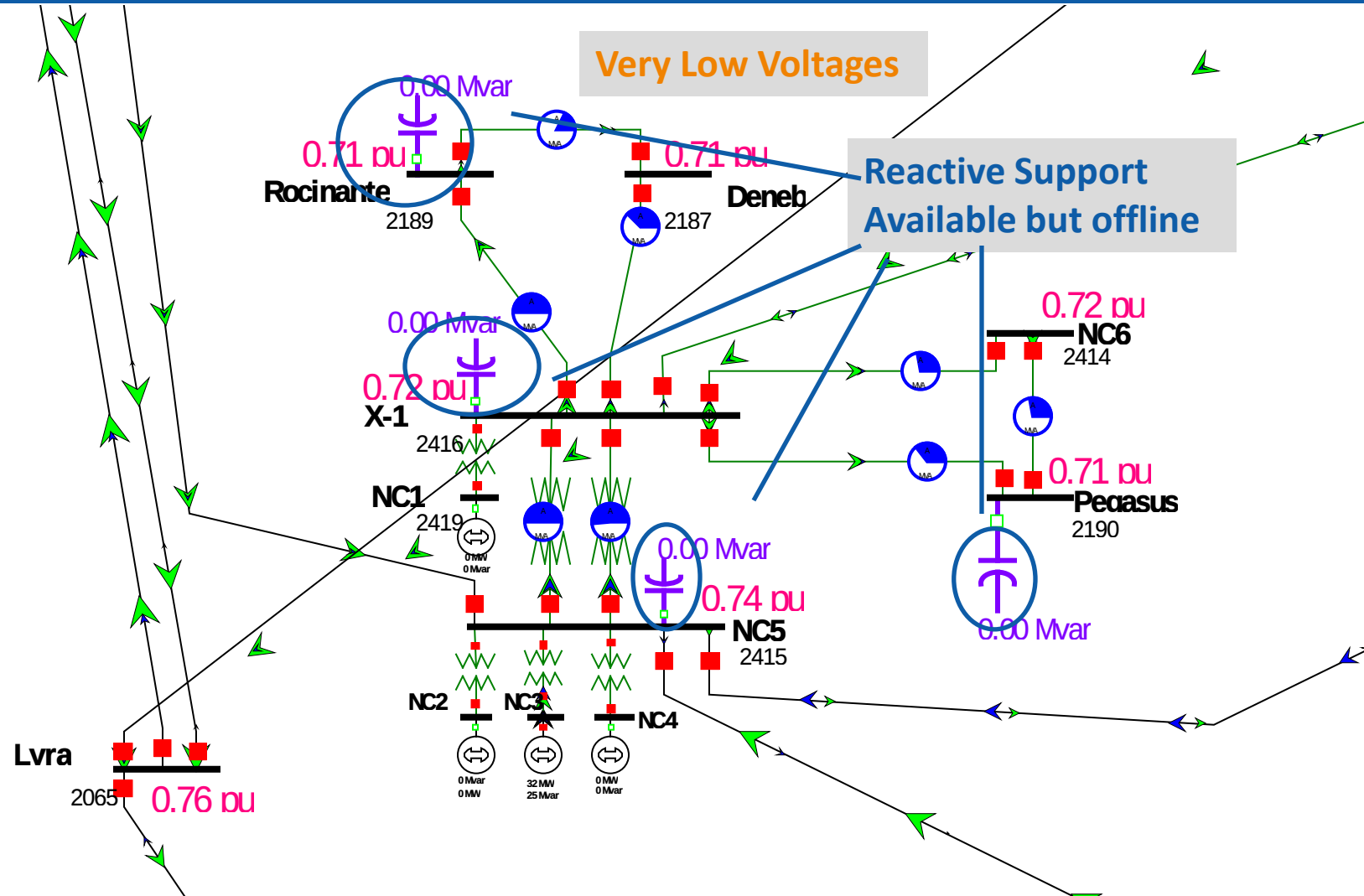
Look at the Problem Area



- Close the Message Log
- Remove the Contour
 - On **Onelines** Ribbon Tab, choose **Contouring** → **Remove Contour**
- A Saved View is available for Cygnus
 - On **Onelines** Ribbon Tab, choose **Save View** → **Cygnus**



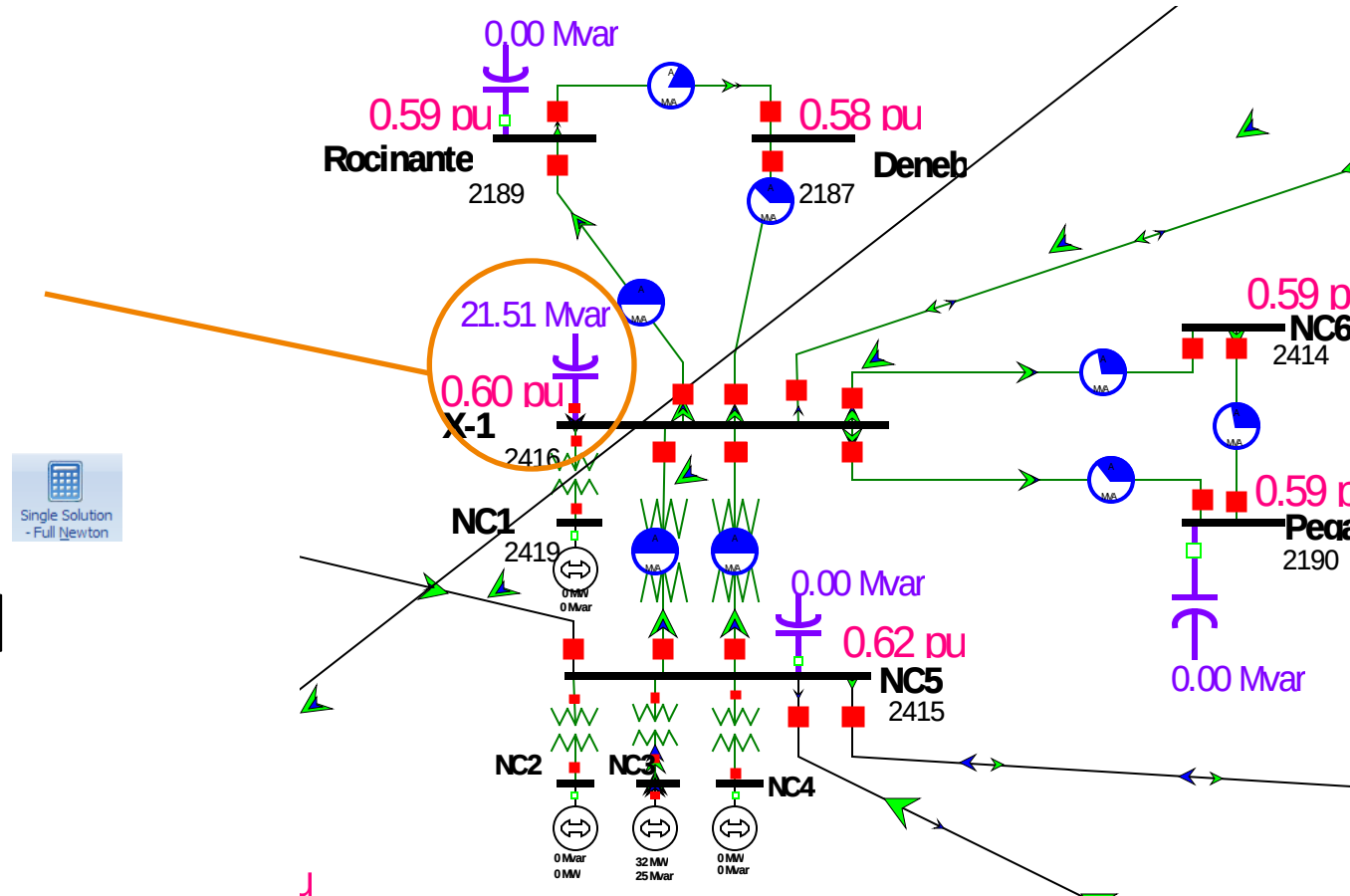
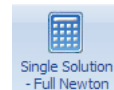
Saved View: Cygnus



Close in Capacitor at Bus X-1 (2416)

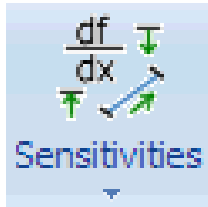


- Close the Switched Shunt at X-1 (2416)
- Hit **Single Solution**
- Solution Successful
 - Bus voltages are at 0.60 per unit!
 - This is a “low voltage” solution

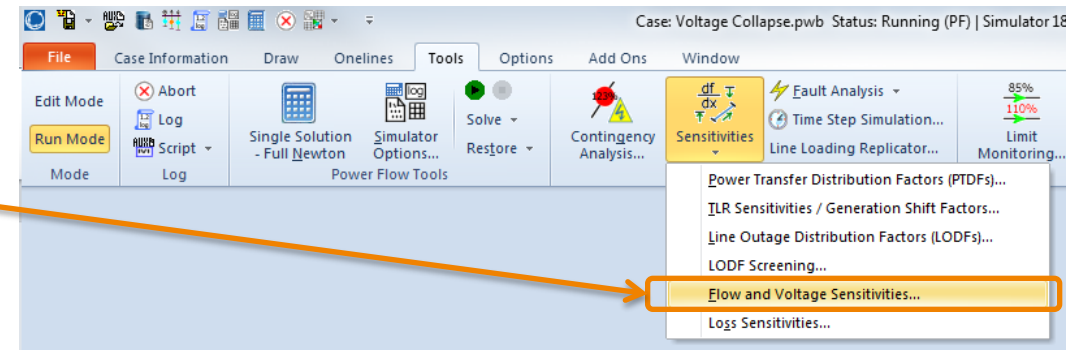


Verify Low Voltage Solution

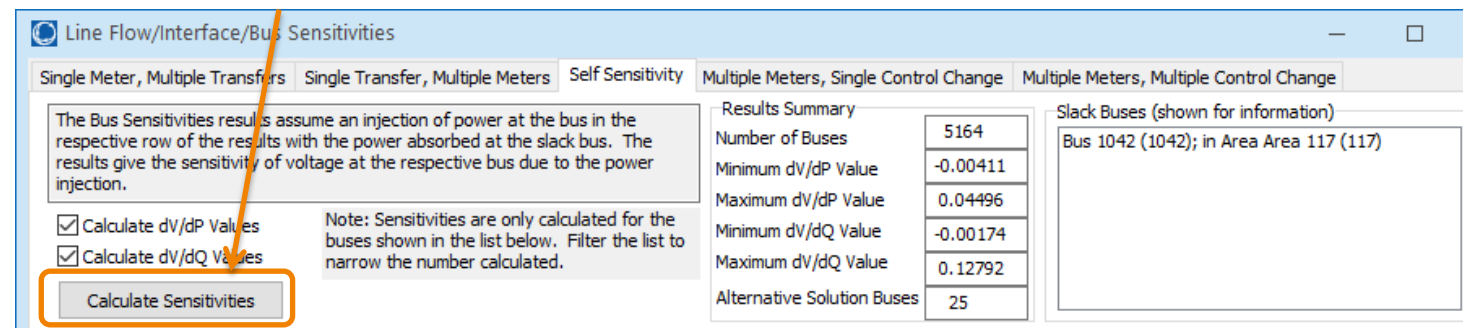
- Calculate the voltage sensitivity with respect to a change in reactive power $\left(\frac{dV}{dQ}\right)$



On **Tools** Ribbon Tab, choose **Sensitivities** → **Flow and Voltage Sensitivities**



- Go to the **Self Sensitivity** tab
- Click the **Calculate Sensitivities** button



Negative Values of dV/dQ



	Number	Name	Nom kV	Area Num	Area Name	dV/dP	dV/dQ ▲	Negative reactance lines	Li
1	2415	NC5	138.00	114	Area 114	-0.00281922	-0.00173926	NO	YI
2	2185	Bus 2185	138.00	114	Area 114	-0.00280306	-0.00164082	NO	YI
3	2416	X-1	69.00	114	Area 114	-0.00374903	-0.00162337	NO	YI
4	2059	Bus 2059	138.00	114	Area 114	-0.00262481	-0.00161184	NO	YI
5	2183	Bus 2183	138.00	114	Area 114	-0.00271964	-0.00155650	NO	YI
6	2186	Bus 2186	138.00	114	Area 114	-0.00241818	-0.00151128	NO	YI
7	2181	Bus 2181	138.00	114	Area 114	-0.00260238	-0.00146718	NO	YI
8	2182	Bus 2182	138.00	114	Area 114	-0.00253934	-0.00140442	NO	YI
9	2180	Bus 2180	138.00	114	Area 114	-0.00244979	-0.00138295	NO	YI
10	2065	Lyra	138.00	114	Area 114	-0.00198874	-0.00135069	NO	YI
11	2412	Bus 2412	138.00	114	Area 114	-0.00254295	-0.00134795	NO	YI
12	2413	Bus 2413	138.00	114	Area 114	-0.00240206	-0.00132264	NO	YI
13	2176	Bus 2176	138.00	114	Area 114	-0.00250647	-0.00131325	NO	YI
14	2177	Bus 2177	138.00	114	Area 114	-0.00247028	-0.00130708	NO	YI
15	2178	Bus 2178	138.00	114	Area 114	-0.00249596	-0.00130260	NO	YI
16	2188	Bus 2188	138.00	114	Area 114	-0.00247336	-0.00123120	NO	YI
17	2414	NC6	69.00	114	Area 114	-0.00389243	-0.00115479	NO	YI

Negative values including at bus 2416 $\left(\frac{dV}{dQ} \right)$

Determine location of negative dV/dQ buses



- Determine Path Distances to Buses

X-1 2416

Only Closed

|Z|

Bus Field Custom\Floating Point 1 is populated with result of calculation

Determine Path Distances to Buses...

Determine Shortest Path Between...

Facility Analysis ...

Branches that Create Islands...

Distance Measure

☐ X

☒ |Z|

☐ Length

☐ Number of nodes

☐ Other

Lines to Process

☐ All

☒ Only closed

☐ Filter

☐ Selected

Bus Field to Populate

Custom\Floating Point 1

Calculate

Results

	Number	Name	Area Name	Zone Name	Cust Float 1	Sub Name	Norm kV	PU Volt	Angle (Deg)	Lo
1	2416	X-1	Area 114	Zone 123	0.000000		69.00	0.59881	-24.23	
2	2414	NC6	Area 114	Zone 123	0.04974		69.00	0.59022	-26.39	
3	2189	Rocinante	Area 114	Zone 123	0.050223		69.00	0.58600	-28.28	
4	2190	Pegasus	Area 114	Zone 123	0.062428		69.00	0.58535	-27.70	
5	2415	NC5	Area 114	Zone 123	0.076293		138.00	0.61523	-15.93	
6	2187	Deneb	Area 114	Zone 123	0.084617		69.00	0.58164	-29.01	
7	2185	Bus 2185	Area 114	Zone 123	0.086636		138.00	0.61835	-16.20	
8	2059	Bus 2059	Area 114	Zone 123	0.088455		138.00	0.61902	-14.65	
9	2183	Bus 2183	Area 114	Zone 123	0.095950		138.00	0.62135	-15.78	



Revisit Negative dV/dQ values

- Advanced Filter using *Negative dV/dQ*
- Use Display/Column Options to add **Custom\Floating Point1**
- Sort by **Cust Float 1** which is now populated with our Path Distance
- First 25 entries are very near X-1
- What about the last 6?

The screenshot shows the 'Line Flow/Interface/Bus Sensitivities' window. The 'Advanced Filter...' menu is open, showing the 'Negative dV/dQ' filter selected. The table below shows the results of the filter, with the first 25 entries having very low dV/dQ values (near 0) and the last 6 entries having higher dV/dQ values (around 0.127910 to 0.921727).

Number	Name	Num kV	Area Num	Area Name	dV/dP	dV/dQ	Cust Flo
15	2180 Bus 2180	138.00	114	Area 114	-0.00244979	-0.00138295	0.127910
16	2176 Bus 2176	138.00	114	Area 114	-0.00250647	-0.00131325	0.129501
17	2178 Bus 2178	138.00	114	Area 114	-0.00249596	-0.00130200	0.129501
18	2177 Bus 2177	138.00	114	Area 114	-0.00247028	-0.00130708	0.136751
19	2413 Bus 2413	138.00	114	Area 114	-0.00240206	-0.00132264	0.140733
20	2188 Bus 2188	138.00	114	Area 114	-0.00247336	-0.00123120	0.142196
21	2417 NC4	13.80	114	Area 114	-0.00270790	-0.00031009	0.163797
22	1016 NC2	14.40	114	Area 114	-0.00276965	-0.00021300	0.170242
23	2184 Bus 2184	138.00	114	Area 114	-0.00190352	-0.00085049	0.177120
24	2195 Bus 2195	138.00	114	Area 114	-0.00072048	-0.00008633	0.221578
25	2025 Bus 2025	138.00	114	Area 114	-0.00111881	-0.00012283	0.237962
26	2072 Bus 2072	345.00	114	Area 114	-0.00000683	-0.00015584	0.698264
27	2068 Bus 2068	345.00	114	Area 114	-0.00000674	-0.00015441	0.698364
28	2070 Bus 2070	345.00	114	Area 114	0.00000141	-0.00012416	0.717654
29	2071 Bus 2071	345.00	114	Area 114	0.00000151	-0.00012282	0.717754
30	1001 Bus 1001	1.000	114	Area 114	0.00000062	-0.00007489	0.904465
31	1004 Bus 1004	1.000	114	Area 114	0.00002389	-0.00028202	0.921727

Other Negative dV/dQ values



	Number	Name	Nom kV	Area Num	Area Name	dV/dP	Y dV/dQ	Cust Floi	Negative reactance lines
26	2072	Bus 2072	345.00	114	Area 114	-0.00000683	-0.00015584	0.6982646	YES
27	2068	Bus 2068	345.00	114	Area 114	-0.00000674	-0.00015441	0.6983646	YES
28	2070	Bus 2070	345.00	114	Area 114	0.00000141	-0.00012416	0.7176542	YES
29	2071	Bus 2071	345.00	114	Area 114	0.00000151	-0.00012282	0.7177542	YES
30	1001	Bus 1001	1.000	114	Area 114	0.00000062	-0.00007489	0.9044650	YES
31	1004	Bus 1004	1.000	114	Area 114	0.00002389	-0.00028202	0.9217271	YES

- Buses next to the branches with negative series reactances may have negative dV/dQ
 - This is normal behavior for these buses
 - Field “Negative Reactance lines” = YES
- 2068, 2070, 2071, and 2072 are next to Series Capacitors
- 1001 and 1004 are both fictitious “star” of a three-winding transformer
 - Bus View of 1001 and 1004
 - (Starting in Version 23 in April 2023, stars say NO here)

Other Helpful Fields



Negative reactance lines	Has closed gen, load or shunts	Likely Alternative Solution (First Neighbors)
NO	YES	YES

Bus Sensitivities (Filter:Negative dV/dQ)

	Number	Name	Nom kV	Area Num	Area Name	dV/dP	dV/dQ	Cust Flo:	Negative reactance lines	Has closed gen, load or shunts	Likely Alternative Solution (First Neighbors)	PU Volt
1	2416	X-1	69.00	114	Area 114	-0.00374901	-0.00162335	0.00000000	NO	YES	YES	0.59881
2	2414	NC6	69.00	114	Area 114	-0.00389242	-0.00115478	0.04974605	NO	YES	YES	0.59022
3	2189	Rocinante	69.00	114	Area 114	-0.00405262	-0.00112346	0.05022281	NO	YES	YES	0.58600
4	2190	Pegasus	69.00	114	Area 114	-0.00401255	-0.00113711	0.06242833	NO	YES	YES	0.58535
5	2415	NC5	138.00	114	Area 114	-0.00281921	-0.00173924	0.07629325	NO	YES	YES	0.61523
6	2187	Deneb	69.00	114	Area 114	-0.00411145	-0.00102099	0.08461653	NO	YES	YES	0.58164
7	2185	Bus 2185	138.00	114	Area 114	-0.00280304	-0.00164081	0.08663556	NO	YES	YES	0.61835
8	2059	Bus 2059	138.00	114	Area 114	-0.00262480	-0.00161183	0.08845481	NO	YES	YES	0.61902
9	2183	Bus 2183	138.00	114	Area 114	-0.00271963	-0.00155648	0.09595016	NO	YES	YES	0.62134
10	2186	Bus 2186	138.00	114	Area 114	-0.00241817	-0.00151127	0.09976307	NO	YES	YES	0.62371
11	2181	Bus 2181	138.00	114	Area 114	-0.00260236	-0.00146717	0.10852417	NO	NO	NO	0.62576
12	2182	Bus 2182	138.00	114	Area 114	-0.00253932	-0.00140440	0.11823810	NO	YES	YES	0.62727
13	2412	Bus 2412	138.00	114	Area 114	-0.00254294	-0.00134793	0.12134670	NO	YES	YES	0.62829
14	2065	Lyra	138.00	114	Area 114	-0.00198873	-0.00135067	0.12213808	NO	NO	NO	0.63564
15	2180	Bus 2180	138.00	114	Area 114	-0.00244977	-0.00138294	0.12791087	NO	NO	NO	0.62933
16	2176	Bus 2176	138.00	114	Area 114	-0.00250646	-0.00131324	0.12950151	NO	NO	NO	0.62890
17	2178	Bus 2178	138.00	114	Area 114	-0.00249595	-0.00130258	0.13312587	NO	YES	YES	0.62905
18	2177	Bus 2177	138.00	114	Area 114	-0.00247027	-0.00130706	0.13675024	NO	NO	NO	0.62962
19	2413	Bus 2413	138.00	114	Area 114	-0.00240205	-0.00132263	0.14073339	NO	NO	NO	0.63118
20	2188	Bus 2188	138.00	114	Area 114	-0.00247335	-0.00123119	0.14219660	NO	YES	YES	0.62928
21	2417	NC4	13.80	114	Area 114	-0.00270789	-0.00031007	0.16379711	NO	NO	NO	0.60053
22	1016	NC2	14.40	114	Area 114	-0.00276964	-0.00021299	0.17024279	NO	NO	NO	0.61523
23	2184	Bus 2184	138.00	114	Area 114	-0.00190351	-0.00085047	0.17712048	NO	YES	YES	0.64432
24	2195	Bus 2195	138.00	114	Area 114	-0.00072047	-0.00008633	0.22157881	NO	YES	YES	0.67952
25	2025	Bus 2025	138.00	114	Area 114	-0.00111880	-0.00012282	0.23796299	NO	YES	YES	0.67020
26	2072	Bus 2072	345.00	114	Area 114	-0.00000683	-0.00015584	0.69826466	YES	NO	NO	1.01543
27	2068	Bus 2068	345.00	114	Area 114	-0.00000674	-0.00015441	0.69836466	YES	NO	NO	1.01548
28	2070	Bus 2070	345.00	114	Area 114	0.00000141	-0.00012416	0.71765423	YES	NO	NO	1.01432
29	2071	Bus 2071	345.00	114	Area 114	0.00000151	-0.00012282	0.71775424	YES	NO	NO	1.01435
30	1001	Bus 1001	1.000	114	Area 114	0.00000062	-0.00007489	0.90446502	YES	NO	NO	1.02594
31	1004	Bus 1004	1.000	114	Area 114	0.00002389	-0.00028202	0.92172718	YES	NO	NO	1.01495

Negative Reactance Lines



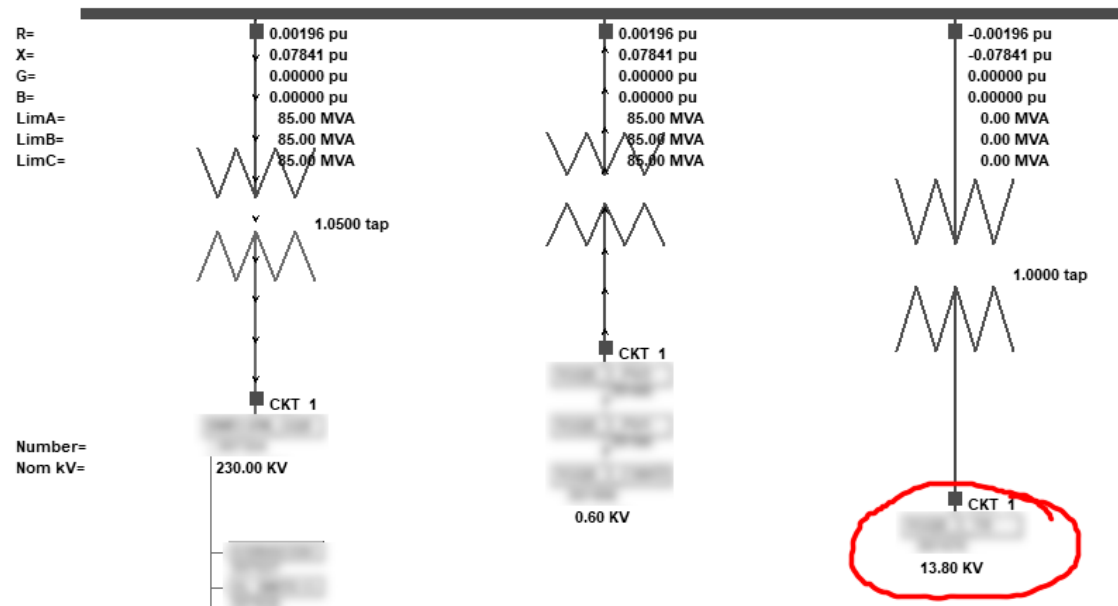
- Will return YES for the following Buses adjacent to branches with a negative Series X
 - Except for terminals of three-winding transformers which can have a negative impedance to the fictitious star bus or the star bus itself

Negative reactance lines	
NO	
NO	
NO	
NO	

Has closed gen, load or shunts



- Returns YES if there is at least one closed generator, load or shunt at a bus



Has closed gen, load or shunts	
YES	
YES	
YES	
YES	

Negative Reactance Line = NO
Because it is terminal of 3-winding transformer

Has closed gen, load shunts = NO

Likely Alternative Solution



- YES only if the 3 conditions are met
 - $dV/dQ < 0$
 - *Negative Reactance Lines* = NO
 - Terminal buses of branches with negative reactance might have negative dV/dQ for a normal solution
 - *Has closed gen, load or shunt* = YES
 - A bus without a gen, load or shunt is not going to drive the system to a low voltage solution, so ignore these
 - In a system with a low voltage solution, there will be at least one other nearby bus with a gen, load or shunt that shows YES for Likely Alternative Solution

Likely Alternative Solution (First Neighbors)
--

YES

YES

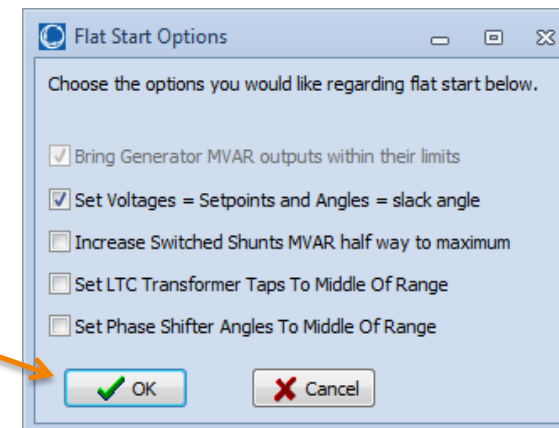
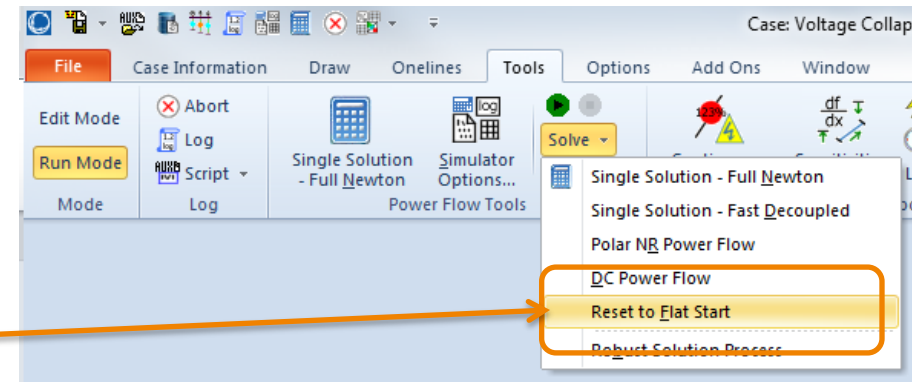
YES

YES

Robust Solution Process



- Sometimes a Flat Start followed by the Robust Solution Process can achieve a successful solution
- Apply Flat Start to Case
 - Go to **Tools** Ribbon Tab
 - Choose **Solve** → **Reset to Flat Start**
 - Click **OK** on dialog that appears

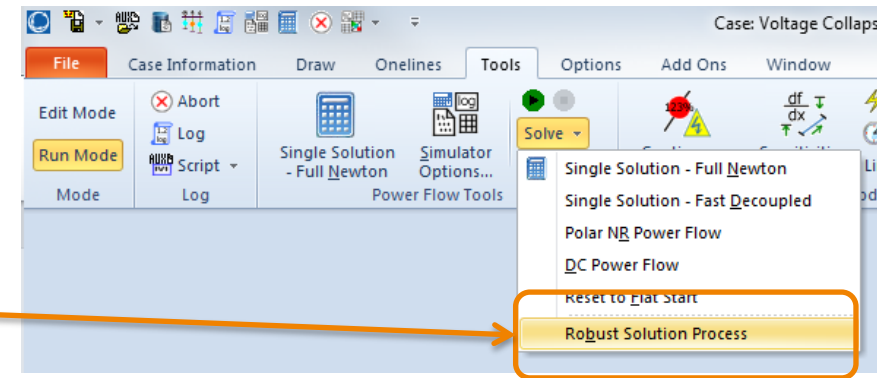


Robust Solution Process



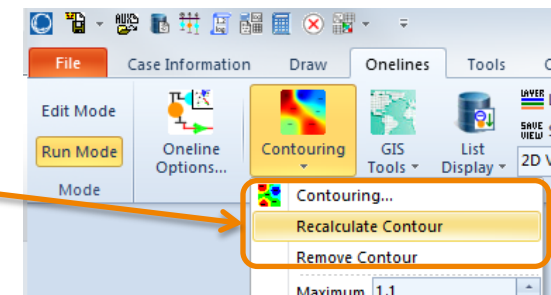
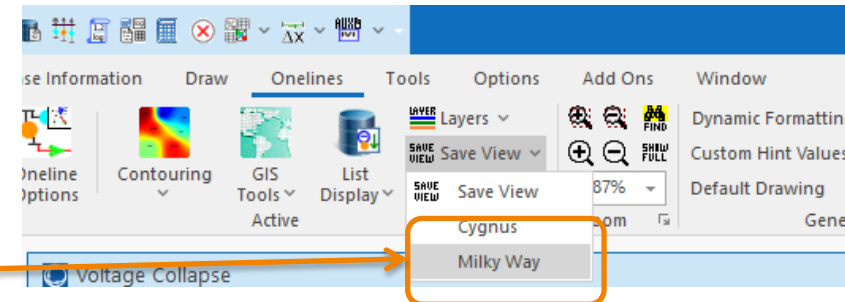
- Now Perform the Robust Solution Process

- Go to **Tools** Ribbon Tab
 - Choose **Solve** → **Robust Solution Process**



- Successful Solution is achieved, but let's look at the bus voltage contour

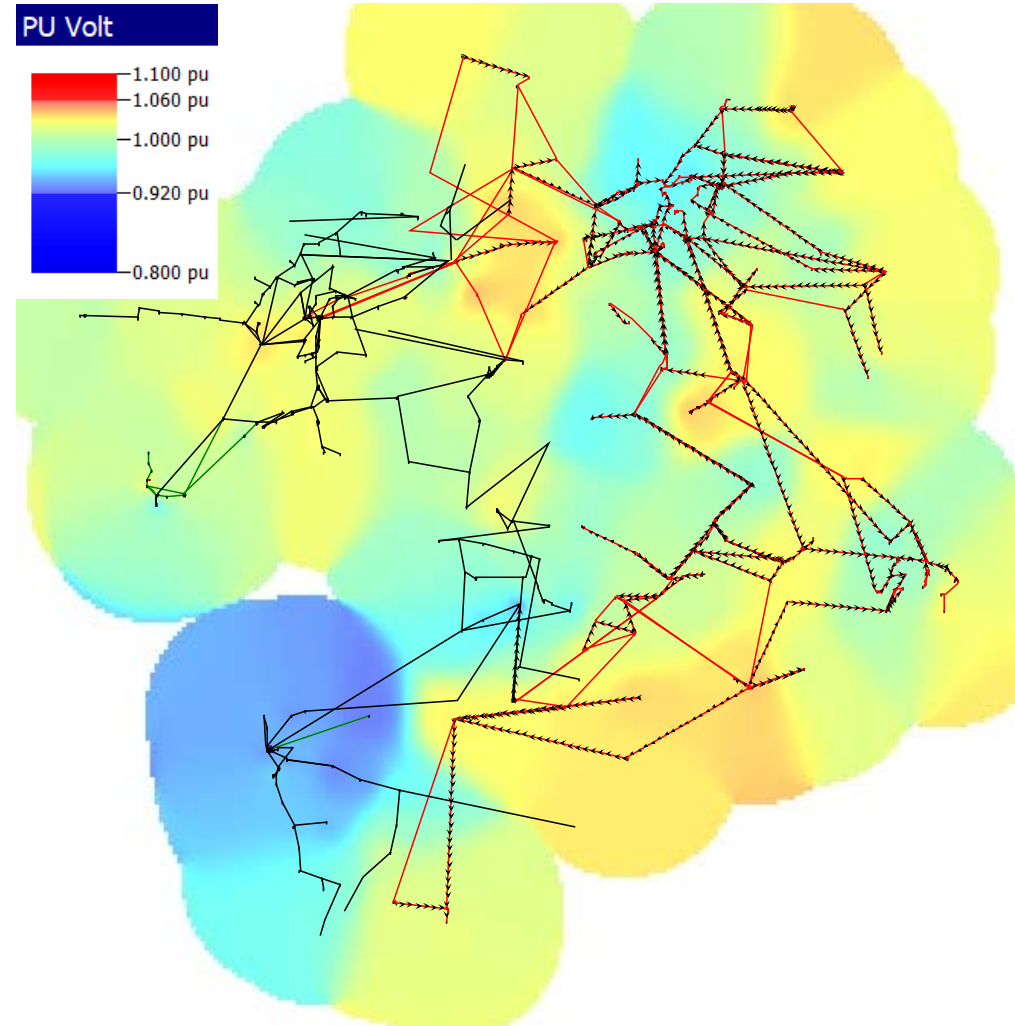
- On **Onelines** Ribbon Tab, choose **Save View** → **Milky Way**
- On **Onelines** Ribbon Tab, choose **Contouring** → **Recalculate Contour**



Result after: Robust Solution Process



- Solution is achieved!



What does the Robust Solution Process do?



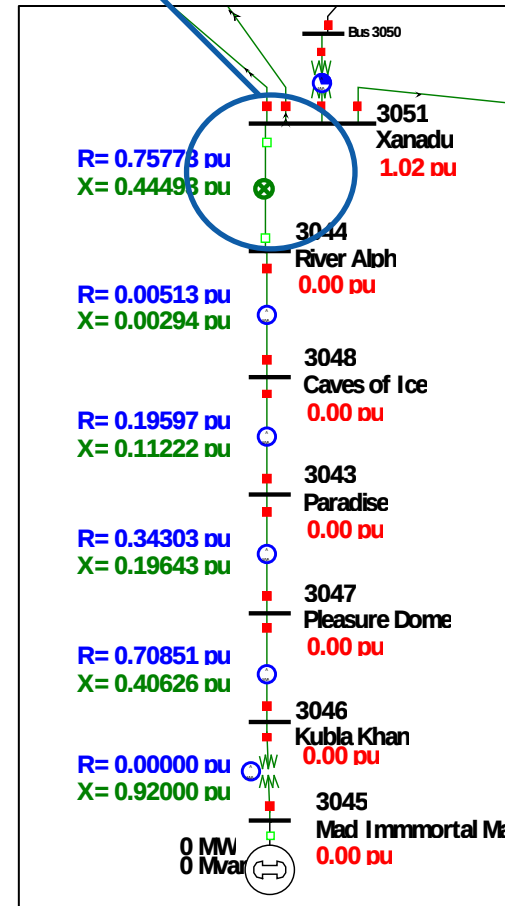
- Starts by disabling all controls
 - Disable LTC, Phases, Switched Shunts, SVCs, AGC, Gen MVar Limit Enforcement
- Solve using a Decoupled Power Flow
- Solve using the Rectangular Newton
- Enable Gen MVar Limits
- Enable Shunts, Solve Newton
- Enable SVCs, Solve Newton
- Enable LTCs, Solve Newton
- Enable AGC, Solve Newton
- Enable phase shifters one at a time and solve

Problems with Decoupled Power Flow Solution

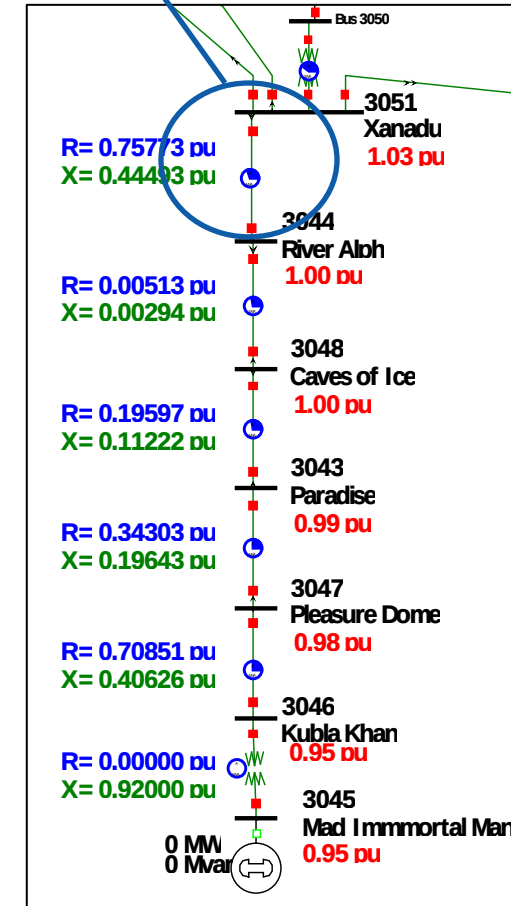


- Decoupled Solution has trouble with transmission lines with high R/X ratios
- For the Xanadu Region
 - R/X values are very large!
 - Normal Value about 0.2
 - These are 1.5 and higher.
- This can be resolved
 - Opening the Line
 - Single Solution 
 - Closing the line
 - Single Solution 

Open Line and Solve



Close Line and Solve



Newton solution has no trouble with R/X ratios

Other Problems with Decoupled



- The Robust Solution Method often works great in the WECC and the ERCOT cases, so do not hesitate to use it there
- However, we have not had great success on extremely large cases of the Eastern Interconnect

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