

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

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

Initial Mismatches.raw



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

	BusNum (*)	BusName (*)	AreaName	BusMismatchP	BusMismatchQ	BusMismatch ▼
1	80011	BOWMANVL	IMO	-3373.97	-620.15	3430.49
2	80476	CLAIRVIL	IMO	2509.05	344.55	2532.59
3	80049	BRUJ569	IMO	-1567.40	-471.51	1636.79
4	80053	BRUJ569E	IMO	1566.34	467.31	1634.56
5	80051	BRUJ561E	IMO	-1073.87	-147.56	1083.96
6	80048	BRUJ561	IMO	1073.51	146.61	1083.48
7	28283	18COVE	METC	1051.58	116.70	1058.03
8	28459	18PALISA	METC	-1051.56	-116.71	1058.01
9	70509	SB RCTOR	NEPOOL	1016.82	-233.10	1043.20
10	70708	SB PAR	NEPOOL	-1020.46	176.60	1035.63
11	80041	CLAIRVIL	IMO	-690.37	-728.98	1004.00
12	80099	MBYP560W	IMO	896.89	135.79	907.11
13	80098	MBYP560E	IMO	-896.87	-135.59	907.06
14	80016	DARLNGH2	IMO	843.58	159.77	858.58
15	80023	DARLNGH1	IMO	843.51	159.79	858.51
16	80018	DARLNGH4	IMO	843.76	151.06	857.18
17	80017	DARLNGH3	IMO	843.51	148.47	856.48
18	80006	CHERRYWD	IMO	691.37	495.10	850.36
19	47129	HARDCHAR	SEC	-640.86	-107.47	649.80
20	80165	D501P JT	IMO	-596.77	-78.09	601.85
21	80081	PINARD	IMO	596.75	78.00	601.82
22	80100	MBYP586W	IMO	553.62	-42.09	555.21
23	80097	MBYP586E	IMO	-553.61	42.00	555.20
24	80481	CLAIRV71	IMO	-525.38	-167.97	551.57
25	80003	BRUJ563	IMO	461.60	-219.08	510.95
26	80052	BRUJ563E	IMO	-462.04	218.14	510.94
27	74349	REACBUS	NYISO	-507.78	23.48	508.32
28	74348	SPRBROOK	NYISO	507.42	-27.05	508.14
29	75001	EGC PAR	NYISO	-504.96	-36.94	506.31
30	75005	EGC DUM	NYISO	504.91	36.65	506.24

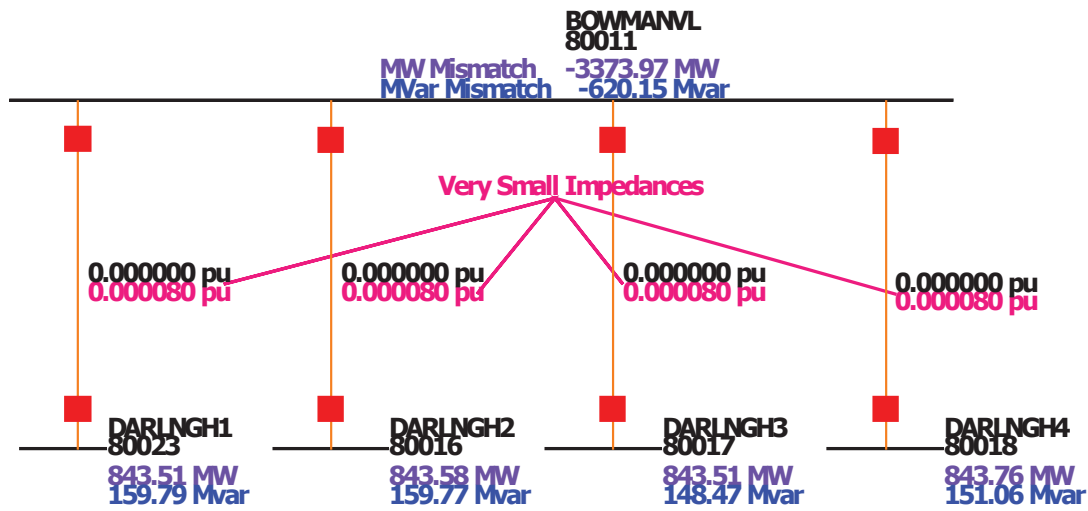
Open Oneline:

Initial Mismatches.raw

Bowmanvl Darlington.pwd



- ...\\S03_GettingACaseToSolve\\Bowmanvl Darlington.pwd



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

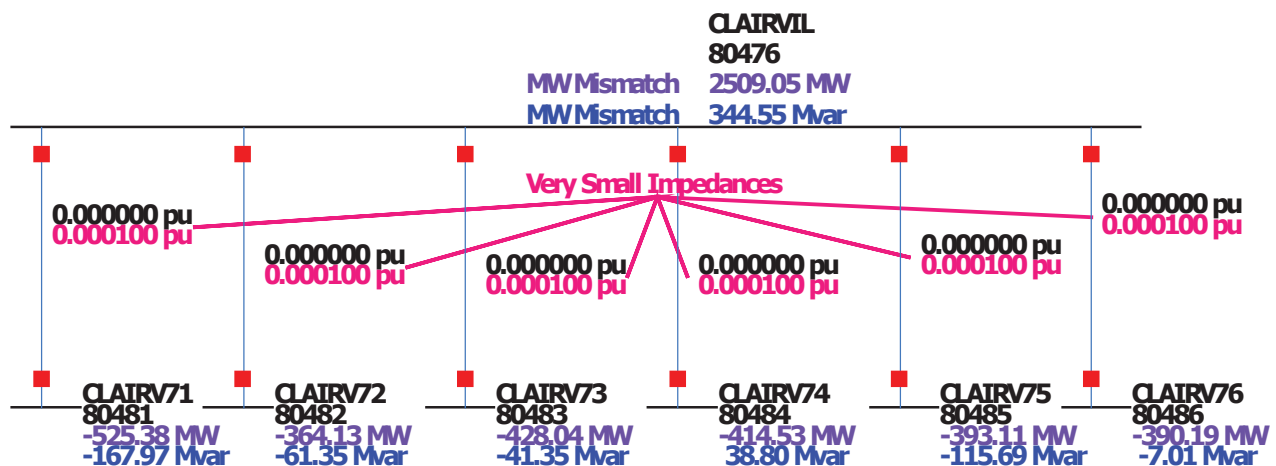
Open Oneline:

Initial Mismatches.raw

Clairvil.pwd



- ...\\S03_GettingACaseToSolve\\Clairvil.pwd



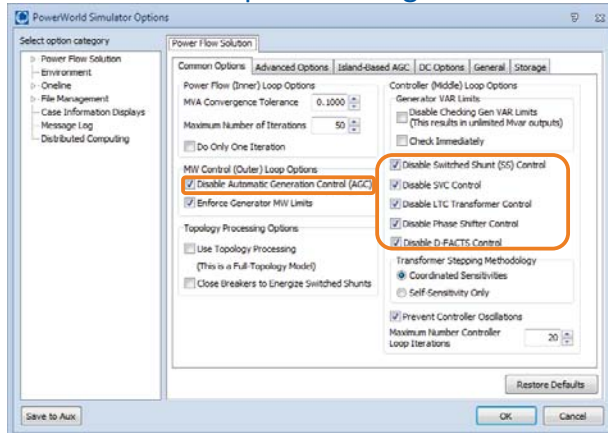
MW Mismatches sum to nearly zero
MVar Mismatches sum nearly to zero

Solve Initial Case

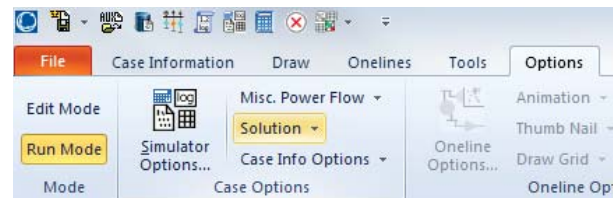
Disable All Controllers to Start

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

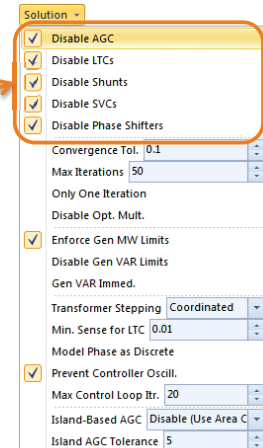
On Simulator Options dialog



Options Ribbon Tab



Disable AGC
Disable LTCs
Disable Shunts
Disable SVCs
Disable Phase Shifters



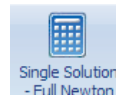
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If Initial Case was truly *Initial Mismatches.raw*
solved, Solution Will Converge Quickly

- Click **Single Solution** button

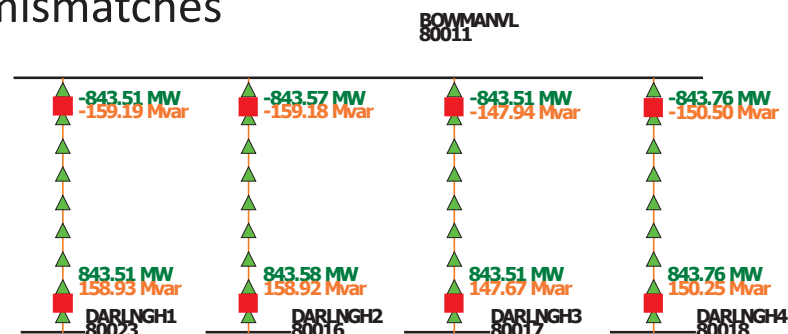


- Solution Results:

Max P: 3373.966 at bus 80011	Max Q: 719.507 at bus 80041
Max P: 78.161 at bus 2	Max Q: 273.859 at bus 23
Max P: 7.836 at bus 2	Max Q: 4.020 at bus 23
Max P: 0.003 at bus 70708	Max Q: 0.014 at bus 36314

 Etc... (generator Mvar limit checking)

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



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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
- 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*

Area Records for Case: *Initial Mismatches.raw* ACE Column



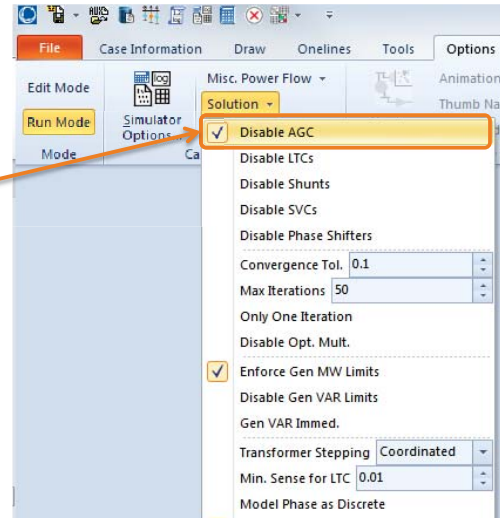
Area Num	Area Name	AGC Status	Gen MW	Load MW	Shunt MW	Tot Sched MW	Int MW	ACE MW	Lambda	Loss MW	Auto Shunts	Auto XF	Area Slack Bus	Unspec. MW Inter.
1	702 NYISO	Area Slack	30687.31	30733.25	34.41	-984.00	-1000.36	-16.36	Off Control	920.02	YES	YES	ROSE GN1 (74190)	-984.00
2	147 TVA	Off AGC	32370.66	30604.01	0.00	1180.00	1189.09	9.09	Off Control	577.56	YES	YES	N3 BFN (18137)	1180.00
3	208 CIN	Area Slack	13181.99	13278.11	0.46	-549.00	-544.75	4.25	Off Control	448.16	YES	YES	08BCKID5 (25895)	-549.00
4	356 AMRN	Area Slack	10911.62	11522.91	0.00	-821.00	-823.08	-2.08	Off Control	211.79	YES	YES	OSAGE (31400)	-805.00
5	357 IP	Area Slack	4281.18	4146.10	0.00	56.00	57.82	1.82	Off Control	77.27	YES	YES	HAVANA (32407)	56.00
6	35 DP&L	Area Slack	2924.37	3886.71	0.00	-1064.00	-1062.22	1.78	Off Control	99.88	YES	YES	IR4 (9219)	-1064.00
7	703 IMO	Area Slack	25768.36	24990.65	0.55	0.00	1.32	1.32	Off Control	775.85	YES	YES	LAKEVWGS (80900)	0.00
8	31 PSE&G	Area Slack	6906.48	10312.64	0.00	-3474.00	-3474.81	-0.81	Off Control	68.66	YES	YES	SEWARREN2 (5121)	-3474.00
9	28 JCP&L	Area Slack	3716.84	5829.86	0.00	-2365.00	-2365.65	-0.65	Off Control	252.63	YES	YES	O C GEN (2895)	-2365.00
10	707 CORNWALL	Off AGC	45.00	45.00	0.00	-45.00	-45.57	-0.57	Off Control	0.57	YES	YES		-45.00
11	146 SOCO	Area Slack	46844.58	44752.09	41.06	1180.00	1179.52	-0.48	Off Control	871.90	YES	YES	1GASTON5 (15100)	1180.00
12	37 RECO	Area Slack	0.00	419.00	0.00	-421.00	-420.62	0.38	Off Control	1.62	YES	YES	SO.MAHWA (79356)	-421.00
13	144 SC	Area Slack	4254.31	4225.04	-0.06	-73.00	-72.63	0.37	Off Control	101.96	YES	YES	1 CROSS1 (13042)	-73.00
14	704 HQTE	Off AGC	24907.65	21440.59	1.69	2615.00	2615.31	0.31	Off Control	850.07	YES	YES	BERS-1 (84033)	2615.00
15	701 NEPOOL	Off AGC	24424.71	26128.96	214.26	-2596.00	-2595.73	0.27	Off Control	677.22	YES	YES	BP #3 GN (72370)	-2596.00
16	401 FPL	Area Slack	16907.98	20705.45	0.00	-4384.00	-4383.77	0.23	Off Control	586.30	YES	YES	CAPECAN2 (40363)	-4384.00
17	25 PJM500	Area Slack	13044.48	0.00	0.00	12892.00	12892.20	0.20	Off Control	152.28	YES	YES	POBMTM 2 (34)	12892.00
18	523 GRRD	Area Slack	1251.66	761.00	0.00	467.00	467.19	0.19	Off Control	23.47	YES	YES	SALINA 5 (54486)	0.00
19	600 XEL-NSP	Area Slack	8145.16	9512.56	0.00	-1649.47	-1649.30	0.17	Off Control	281.90	YES	YES	SHERC33G (60001)	-1571.00
20	30 PECCO	Area Slack	6066.80	8136.08	-1.09	-2190.00	-2189.83	0.17	Off Control	121.64	YES	YES	EDDYSTN2 (4112)	-2190.00
21	26 PENIELEC	Area Slack	3802.16	2591.50	6.26	1106.00	1105.84	-0.16	Off Control	98.55	YES	YES	SHAWVL 1 (424)	1106.00
22	652 WAPA	Area Slack	4385.53	2954.93	0.00	1252.00	1252.14	0.14	Off Control	178.45	YES	YES	OAH 1G (66559)	1248.00
23	536 WERE	Area Slack	5842.04	5484.96	0.00	204.21	204.35	0.14	Off Control	152.73	YES	YES	LEC U5 (56663)	0.00
24	545 INDN	Area Slack	215.79	303.90	0.00	-90.00	-90.13	-0.13	Off Control	2.01	YES	YES	BLUVLY 2 (59806)	0.00
25	205 AEP	Area Slack	24244.65	23419.18	0.00	137.00	137.12	0.12	Off Control	688.36	YES	YES	05SPORNA (22987)	-113.00
26	706 NS	Area Slack	1078.44	1238.48	0.00	-200.00	-199.88	0.12	Off Control	39.84	YES	YES	TRENTON6 (89086)	-200.00
27	29 PPL	Area Slack	7416.08	6670.00	-45.60	636.00	636.11	0.11	Off Control	155.57	YES	YES	MTN CK 3 (3150)	636.00
28	140 CPLE	Area Slack	10579.76	11623.00	0.42	-1253.00	-1253.11	-0.11	Off Control	209.45	YES	YES	IROX #2 (10870)	-1253.00
29	364 ALTE	Area Slack	3596.04	2372.57	0.00	1126.51	1126.62	0.11	Off Control	96.85	YES	YES	COLL 2 (39153)	941.00
30	363 NI	Area Slack	22865.50	22203.70	0.00	196.00	196.10	0.10	Off Control	465.71	YES	YES	COLLI;1U (37526)	196.00
31	546 SPRM	Area Slack	619.53	740.59	0.00	-130.00	-130.10	-0.10	Off Control	9.05	YES	YES	JRPS#5 1 (59899)	0.00
32	680 DPC	Area Slack	1112.32	878.90	0.00	164.74	164.65	-0.09	Off Control	68.77	YES	YES	JPM (69542)	132.00
33	608 MP	Area Slack	1648.63	1603.10	0.00	-26.00	-26.09	-0.09	Off Control	71.62	YES	YES	BOSWEL3G (61774)	-26.00
34	640 NPPD	Area Slack	2934.11	2827.59	0.00	1.00	1.09	0.09	Off Control	105.43	YES	YES	GENTLM2G (64711)	-99.00

ACE values are reasonable

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



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

Area Num	Area Name	AGC Status	Gen MW	Load MW	Shunt MW	Tot Sched MW	Int MW	ACE MW	Lambda	Loss MW	Auto Shunts	Auto XF	Area Slack Bus	Unspec. MW Inter.
1	ONCORTSP	Area Slack	23835.60	24258.93	0.00	0.00	-1091.25	-1091.25	Off Control	667.92	YES	YES	THSE 2 G (3404)	0.00
2	RYBRNTSP	Off AGC	76.00	459.57		0.00	-384.7	-384.71	Off Control	1.14	YES	YES		0.00
3	TEXLATSP	Off AGC	3601.65	4137.50	94.34	0.00	-94.34	-94.34	Off Control	0.01	YES	YES		0.00
4	HLP TSP	Off AGC	16729.66	18080.03	0.00	0.00	-1557.95	-1557.95	Off Control	207.58	YES	YES		0.00
5	CPS TSP	Area Slack	3601.65	4137.50	0.00	-700.00	-575.0	124.99	Off Control	39.16	YES	YES	VHB3 (5028)	-700.00
6	LCRA TSP	Area Slack	6444.80	3080.31	0.00	497.44	3259.3	2761.87	Off Control	105.18	YES	YES	FERGUSG1 (7000)	497.44
7	AEP TSP	Area Slack	5719.95	6297.81	0.00	0.00	-753.53	-753.53	Off Control	175.67	YES	YES	DAV #1 (8459)	0.00
8	AEN TSP	Area Slack	1289.30	2234.23	0.00	0.00	-990.79	-990.79	Off Control	45.86	YES	YES	DECKR G2 (9001)	0.00
9	STP	Off AGC	2500.00			0.00	2458.96	2458.96	Off Control	41.04	YES	YES		0.00
10	BEPC TSP	Off AGC	1726.30	2166.89	0.00	0.00	-493.87	-493.87	Off Control	53.28	YES	YES		0.00
11	TMPA TSP	Off AGC	462.00	0.00	0.00	0.00	454.9	454.91	Off Control	7.09	YES	YES		0.00
12	STEC TSP	Off AGC	320.75	404.00	0.00	0.00	-110.11	-110.11	Off Control	26.85	YES	YES		0.00
13	SANMIGUL	Off AGC	395.00			0.00	393.76	393.76	Off Control	1.24	YES	YES		0.00
14	BPUB TSP	Off AGC	80.00	253.00	0.00	0.00	-173.86	-173.86	Off Control	0.86	YES	YES		0.00
15	DCEAST	Area Slack	46.00	10.00		36.00	35.99	-0.01	Off Control	0.01	YES	YES	DCEAST (5925)	36.00
16	TNMP TSP	Area Slack	1702.83	1628.80	0.00	0.00	58.05	58.05	Off Control	15.98	YES	YES	TNPONE #1 (39960)	0.00
17	SHRY TSP	Off AGC		4.64		0.00	-4.8	-4.84	Off Control	0.20	YES	YES		0.00
18	DENTNTSP	Off AGC	177.71	273.80		0.00	-97.4	-97.43	Off Control	1.34	YES	YES		0.00
19	GRINDTSP	Off AGC	319.14	525.77		0.00	-214.02	-214.02	Off Control	7.40	YES	YES		0.00
20	GRNVLTSP	Off AGC	63.44	108.12		0.00	-45.39	-45.39	Off Control	0.71	YES	YES		0.00
21	BRYN TSP	Off AGC	202.00	273.06		0.00	-73.90	-73.90	Off Control	2.84	YES	YES		0.00

Area Unspecified MW Interchange

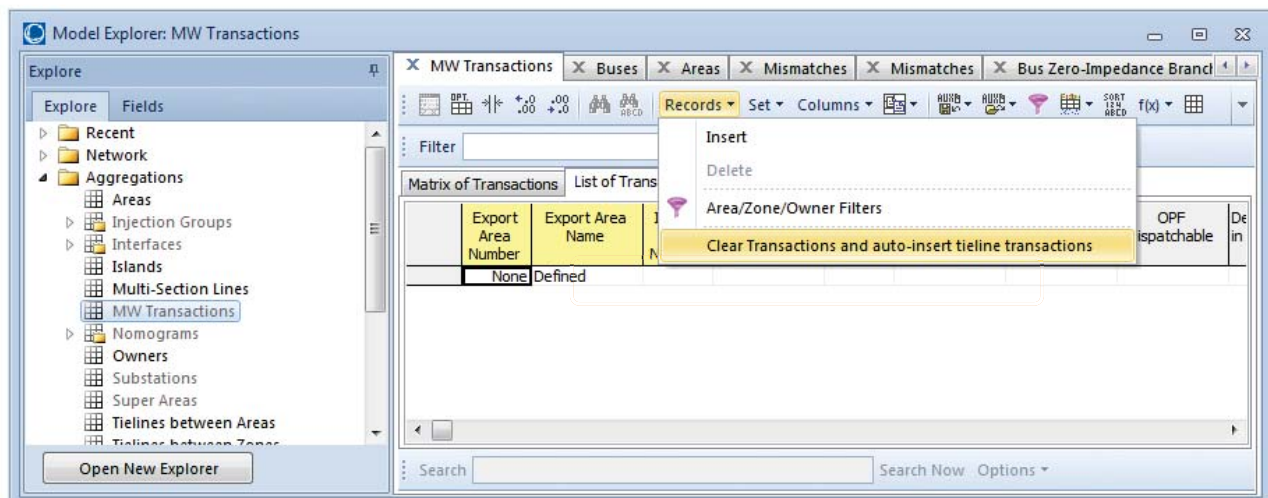


- Each area can have an export specified which does not have a “receiving” end specified
- This is called *Unspecified MW Interchange*
- These unspecified values should sum to zero
 - If they do not sum to zero, you have an “export to nowhere”
 - When this occurs, the Area with the island slack bus will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



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**

	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 2.6 (3404)	-1091.25
0	-384.71	-384.71	0.00	Off Control	1.14	YES			34.71
0	-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
0	2458.96	2458.96	0.00	Off Control	41.04	YES			58.96
0	-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
0	393.76	393.76							93.76
0	-173.86	-173.86							73.86
0	35.99	35.99							35.99
0	58.05	58.05							58.05
0	-4.84	-4.84							-4.84
0	-97.43	-97.43							97.43
0	-214.02	-214.02							14.02
0	-45.39	-45.39							45.39
0	-73.90	-73.90	0.00	Off Control	2.84	YES			73.90

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

- 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

Check Var Immediately.pwb



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

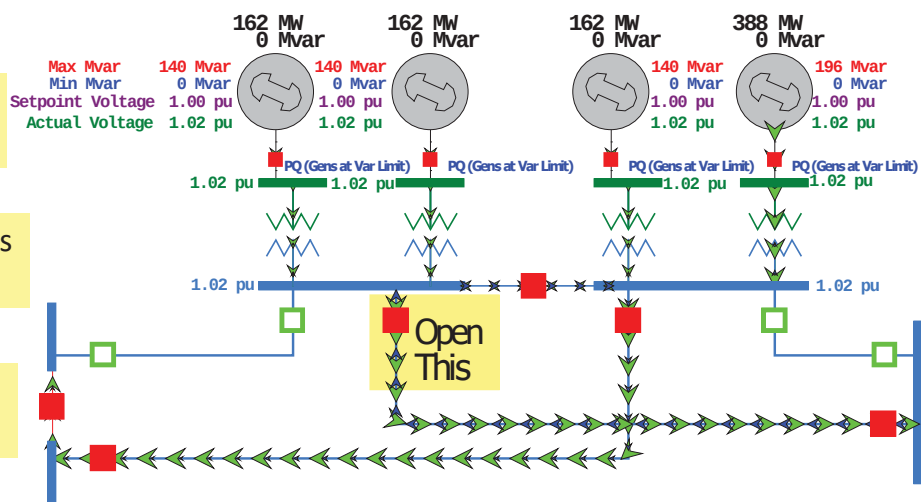


Click **Single Solution**

Setpoint voltages
are all 1.00

Terminal voltages
are all 1.02

All Generators are
stuck at Min Mvar

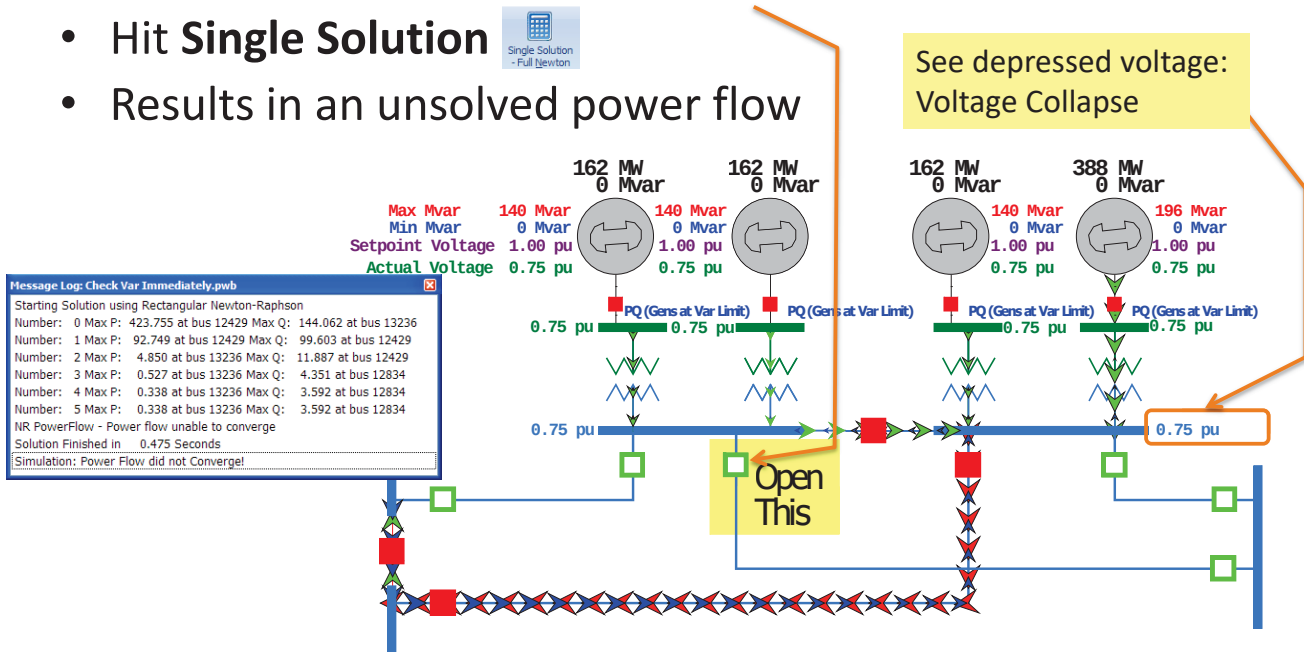


Generator MVar Modeling:

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



S3: Conditioning Hard-to-Solve Cases

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What about the Generator MVar voltage support?

Check Var Immediately.pwb

- 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

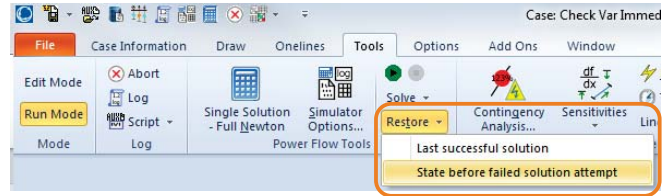
S3: Conditioning Hard-to-Solve Cases

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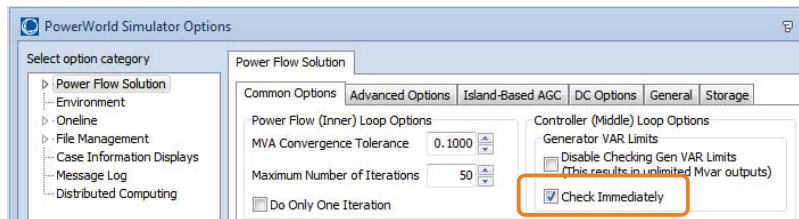
24

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**



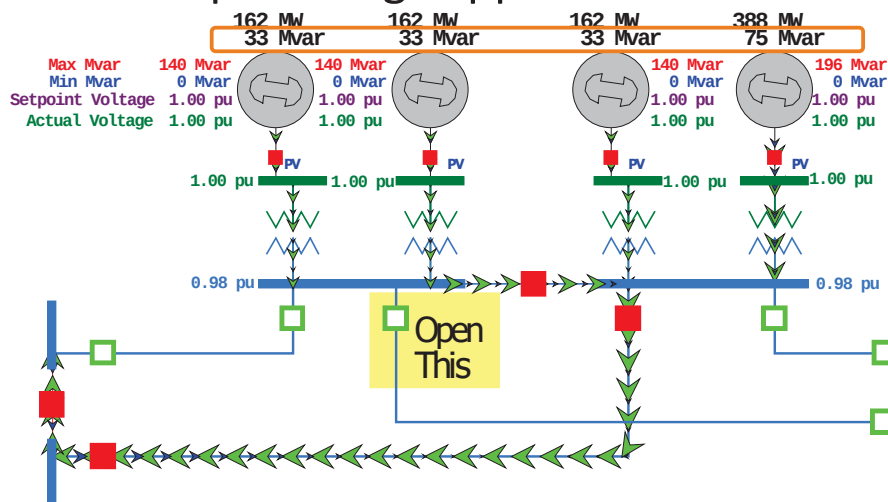
- Open **Simulator Options, Power Flow Solution, Common Options**
 - Choose **Check Immediately**



Hit Single Solution

Successful Solution using *Check Var Immediately.pwb* Immediately Mvar solution option

- 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
Warning - Total of case transactions do not sum to zero -
Case has 332.00 MW more imports than exports

Number: 0	Max P: 424.429 at bus 6JASPER (12429) Max Q: 144.033 at bus 6PURRYSB (13236)
Number: 1	Max P: 93.170 at bus 6JASPER (12429) Max Q: 99.728 at bus 6JASPER (12429)
Number: 2	Max P: 4.865 at bus 6PURRYSB (13236) Max Q: 11.950 at bus 6JASPER (12429)
Number: 3	Max P: 0.532 at bus 6PURRYSB (13236) Max Q: 4.336 at bus 1JASPST1 (12834)
Number: 4	Max P: 0.337 at bus 6PURRYSB (13236) Max Q: 3.565 at bus 1JASPST1 (12834)
Number: 5	Max P: 0.337 at bus 6PURRYSB (13236) Max Q: 3.565 at bus 1JASPST1 (12834)

NR PowerFlow - Power flow unable to converge
Simulation: Power Flow did not Converge!
Single Solution Finished in 3.047 Seconds

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

Check Immediately Enabled

Starting Single Solution using Rectangular Newton-Raphson
Warning - Total of case transactions do not sum to zero -
Case has 332.00 MW more imports than exports

Number: 0	Max P: 424.428 at bus 6JASPER (12429) Max Q: 144.033 at bus 6PURRYSB (13236)
Number: 1	Max P: 93.225 at bus 6JASPER (12429) Max Q: 99.736 at bus 6JASPER (12429)

Gen(s) at bus 1JASPGT1 (12831) has backed off var limit
Gen(s) at bus 1JASPGT2 (12832) has backed off var limit
Gen(s) at bus 1JASPGT3 (12833) has backed off var limit
Gen(s) at bus 1JASPST1 (12834) has backed off var limit

Other Gen Var Changes

Number: 2	Max P: 1.860 at bus 6JASPER (12429) Max Q: 3.816 at bus 12JEFFH6 (13028)
-----------	---

Other Gen Var Changes

Number: 3	Max P: 0.163 at bus 6JASPER (12429) Max Q: 2.064 at bus 12JEFFH6 (13028)
Number: 4	Max P: 0.002 at bus 6JASPER (12429) Max Q: 0.015 at bus 12JEFFH6 (13028)

Other Gen MW Changes

Generation Adjustment Completed.

Number: 0	Max P: 3.056 at bus 1AMW (12800) Max Q: 0.015 at bus 12JEFFH6 (13028)
Number: 1	Max P: 0.017 at bus 1VOGTLE2 (15102) Max Q: 0.026 at bus 1AMW (12800)
Number: 0	Max P: 0.017 at bus 1VOGTLE2 (15102) Max Q: 0.026 at bus 1AMW (12800)

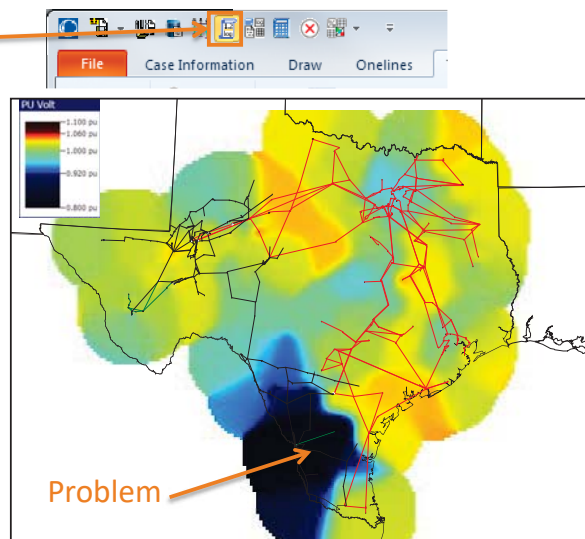
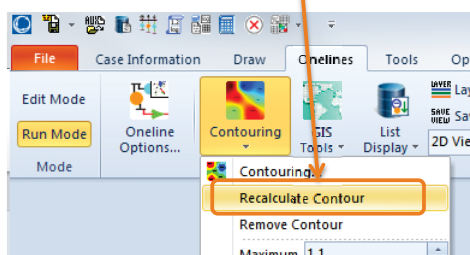
Simulation: Successful Power Flow Solution
Single Solution Finished in 2.516 Seconds

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

Voltage Collapse Example

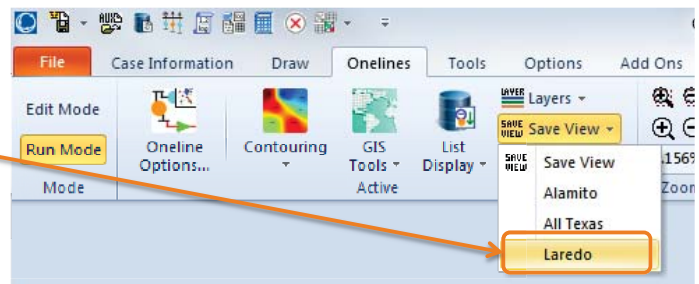
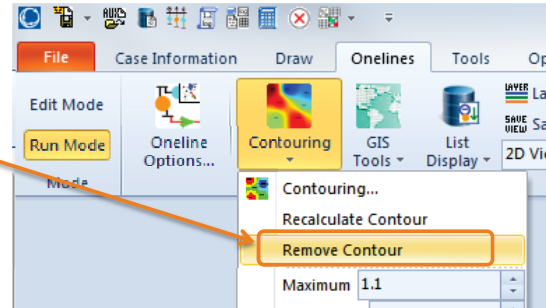


- Choose **File** → **Open Case**
 - ... \S03_GettingACaseToSolve\Voltage Collapse.pwb
- Hit **Single Solution**
- Open Message Log
 - Power Flow did not Converge!
- On **Onelines** Ribbon Tab, choose **Contouring** → **Recalculate Contour**

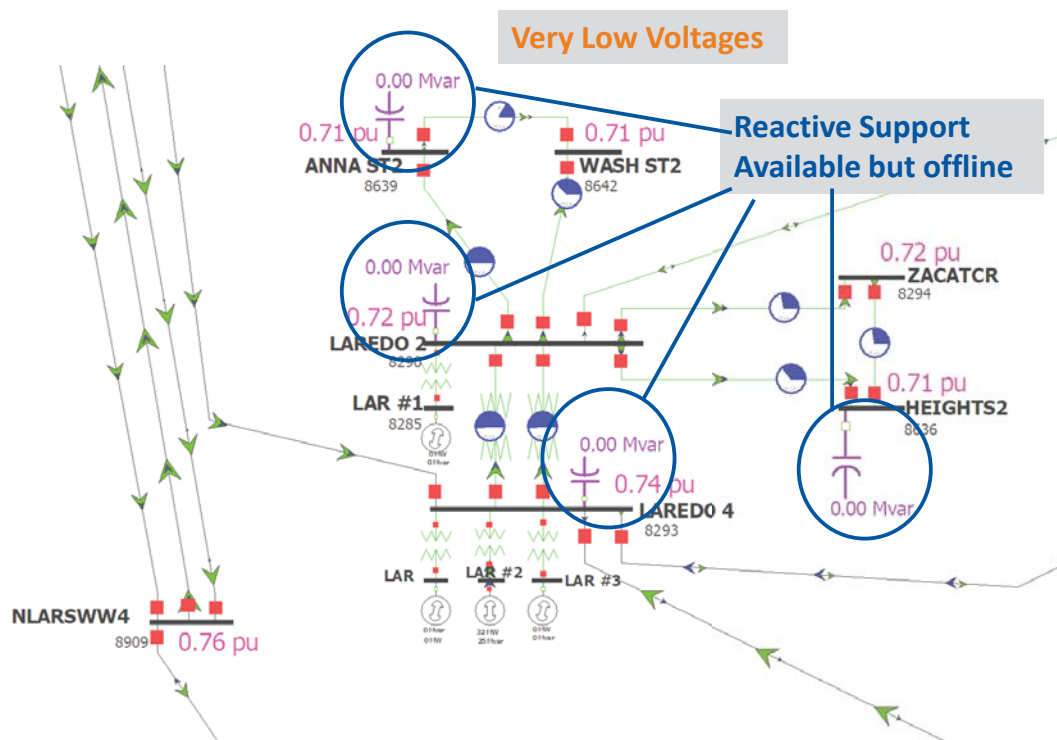


Look at the Problem Area

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



Saved View: Laredo



Close in Capacitor at Bus LAREDO 2 (8290)

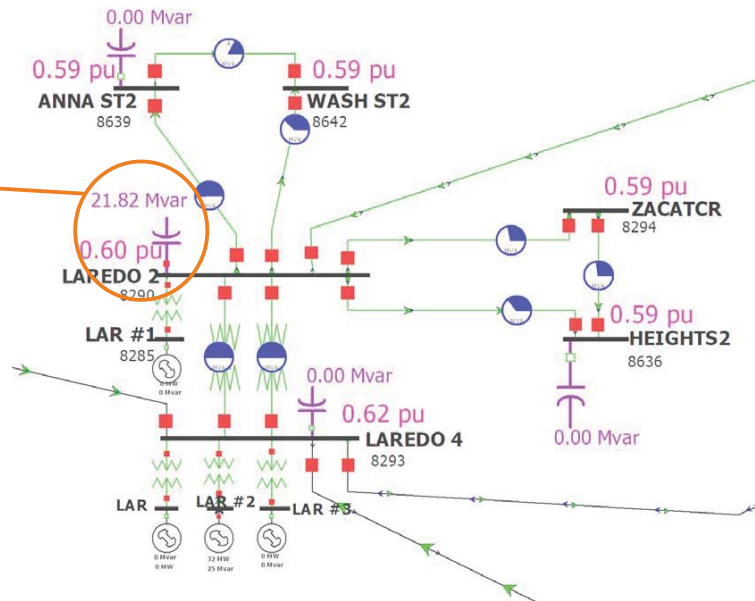


- Close the Switched Shunt at Laredo 2 (8290)



Hit **Single Solution**

- Solution Successful
 - Bus voltages are at 0.60 per unit!
 - This is a “low voltage” solution



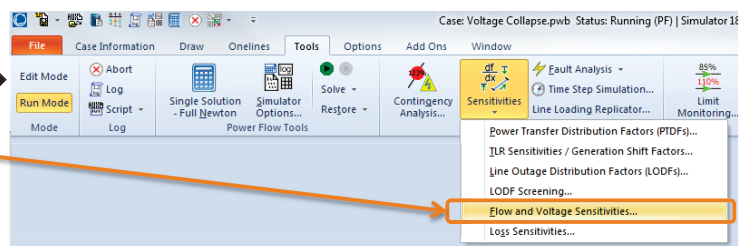
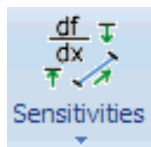
Verify Low Voltage Solution



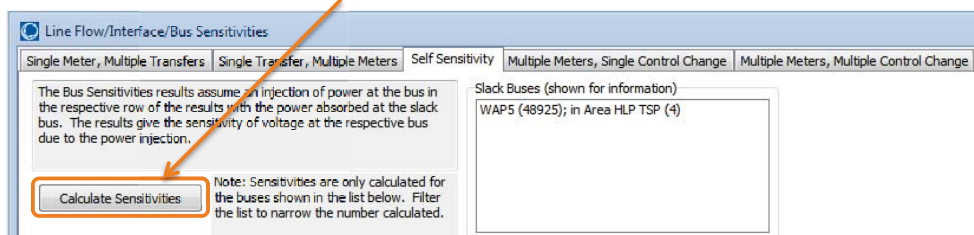
- Calculate the voltage sensitivity with respect to a change in reactive power

$$\left(\frac{dV}{dQ} \right)$$

- 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	Area Num	Area Name	dV/dP	dV/dQ ▲
1	8293	LAREDO 4	8	AEP TSP	-0.00289623	-0.00179957
2	8645	DEL MAR 4	8	AEP TSP	-0.00288083	-0.00170152
3	8290	LAREDO 2	8	AEP TSP	-0.00384095	-0.00169288
4	8918	MILO 4	8	AEP TSP	-0.00269957	-0.00167136
5	8647	UNIVERS4	8	AEP TSP	-0.00279659	-0.00161705
6	8643	MINESRD4	8	AEP TSP	-0.00249009	-0.00156981
7	8649	GATETPE4	8	AEP TSP	-0.00267809	-0.00152733
8	8648	GATEWAY4	8	AEP TSP	-0.00261444	-0.00146456
9	8650	GATETPW4	8	AEP TSP	-0.00252324	-0.00144244
10	8296	WORMCP 4	8	AEP TSP	-0.00261839	-0.00140832
11	8909	NLARSWW4	8	AEP TSP	-0.00205367	-0.00140637
12	8295	WORMSR 4	8	AEP TSP	-0.00247487	-0.00138204
13	8655	SIRVIST	8	AEP TSP	-0.00258155	-0.00137348
14	8654	SIRVIST	8	AEP TSP	-0.00254468	-0.00136706
15	8653	S.NINO 4	8	AEP TSP	-0.00257097	-0.00136276
16	8641	SIEVISTA	8	AEP TSP	-0.00254819	-0.00129175
17	8294	ZACACR	8	AEP TSP	-0.00398982	-0.00122976
18	8636	HEIGHTS2	8	AEP TSP	-0.00411332	-0.00121342
19	8639	ANNA ST2	8	AEP TSP	-0.00415424	-0.00119949
20	8642	WASH ST2	8	AEP TSP	-0.00421556	-0.00109894
21	8646	RIOBRAV4	8	AEP TSP	-0.00196807	-0.00090851
22	8288	LAR #3	8	AEP TSP	-0.00278332	-0.00037728
23	80012	LAR	8	AEP TSP	-0.00284695	-0.00028247
24	99993	STAR BUS	8	AEP TSP	0.00002389	-0.00028201
25	9885	YGNACIO	8	AEP TSP	-0.00116852	-0.00017545
26	8901	LHEDM	8	AEP TSP	-0.00000683	-0.00015584
27	8905	LHEDL	8	AEP TSP	-0.00000674	-0.00015441
28	8619	ENCINL 4	8	AEP TSP	-0.00076043	-0.00013283
29	8903	LHRHM	8	AEP TSP	0.00000141	-0.00012416
30	8902	LHRHL	8	AEP TSP	0.00000151	-0.00012282
31	99996	STAR BUS	8	AEP TSP	0.00000062	-0.00007489

Negative values including at bus 8290

$$\left(\frac{dV}{dQ} \right)$$

Determine location of negative dV/dQ buses



- Determine Path Distances to Buses

Laredo 8290

Determine Path Distances to Buses

Start Element Type: Bus (selected)

Sort: By Name (selected)

Bus List:

- 8285 (LAR #1) [138 kV]
- 8287 (LAR #2) [138 kV]
- 8290 (LAREDO 2) [69 kV]
- 8293 (LAREDO 4) [138 kV]
- 8294 (ZACACR) [69 kV]
- 8295 (WORMSR 4) [138 kV]
- 8296 (WORMCP 4) [138 kV]

Distance Measure: **|Z|** (selected)

Lines to Process: **Only closed** (selected)

Bus Field to Populate: Custom\Floating Point 1

Calculate

Results Table:

Number	Name	Area Name	Zone Name	Nom kV	Cust Float 1
1	ROANSRA	BEPC TSP	BEPC	138.00	0.375790
2	4 IOLA	BEPC TSP	BEPC	138.00	0.924262
3	5 IOLA	BEPC TSP	BEPC	69.00	1.066128
4	9 BEDIAS	BEPC TSP	BEPC	69.00	1.182593
5	13 KEITH	BEPC TSP	BEPC	69.00	1.249730
6	17 CARLOSSW	BEPC TSP	BEPC	69.00	1.347146
7	21 CARLOS	BEPC TSP	BEPC	69.00	1.473489
8	25 NTHZULCH	BEPC TSP	BEPC	69.00	1.369260
9	29 BROWN	BEPC TSP	BEPC	69.00	1.066128

Connections Other

Determine Path Distances to Buses...

Determine Shortest Path Between...

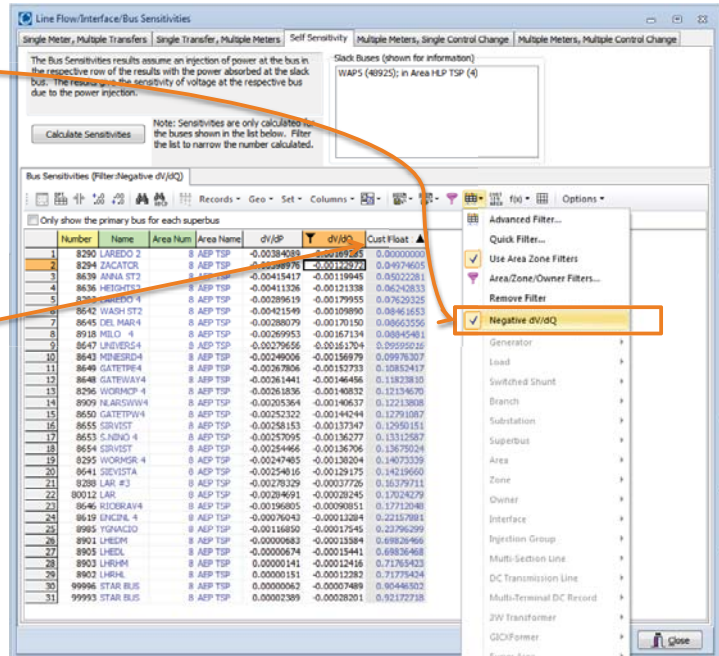
Facility Analysis ...

Branches that Create Islands...

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

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 Laredo
- What about the last 6?



Other Negative dV/dQ values

	Number	Name	Area Num	Area Name	dV/dP	dV/dQ	Cust Float 1 ▲
26	8901	LHEDM	8	AEP TSP	-0.00000683	-0.00015584	0.69826466
27	8905	LHEDL	8	AEP TSP	-0.00000674	-0.00015441	0.69836468
28	8903	LHRHM	8	AEP TSP	0.00000141	-0.00012416	0.71765423
29	8902	LHRHL	8	AEP TSP	0.00000151	-0.00012282	0.71775424
30	99996	STAR BUS	8	AEP TSP	0.00000062	-0.00007489	0.90446502
31	99993	STAR BUS	8	AEP TSP	0.00002389	-0.00028201	0.92172718

- Buses next to the branches with negative series reactances can result in negative dV/dQ
 - This is normal behavior for these buses
- 8901, 8902, 8903, and 8905 are all next to Series Capacitors
 - Bus View of 8901 and 8903
- 99993 and 99996 are both fictitious “star” of a three-winding transformer
 - Bus View of 99993 and 99996

Robust Solution Process



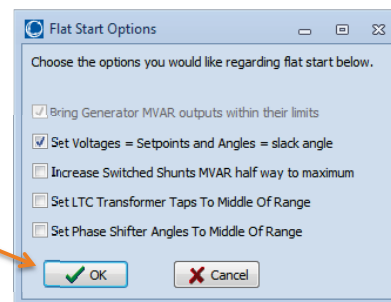
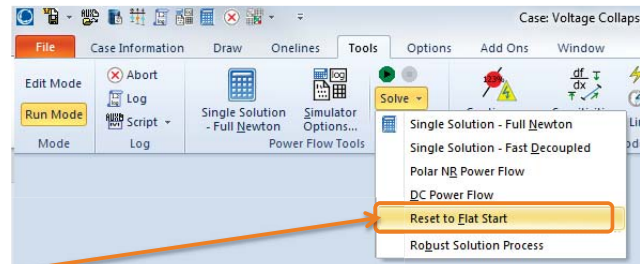
- Sometimes a Flat Start followed by the Robust Solution Process can achieve a successful solution

- 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

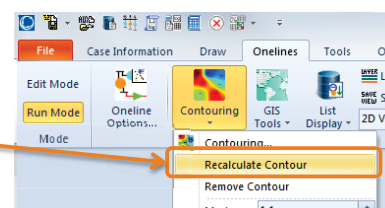
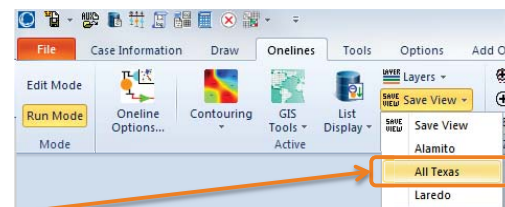
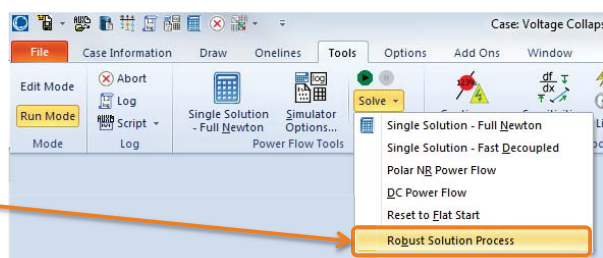
– Go to **Tools** Ribbon Tab

- 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** → **All Texas**

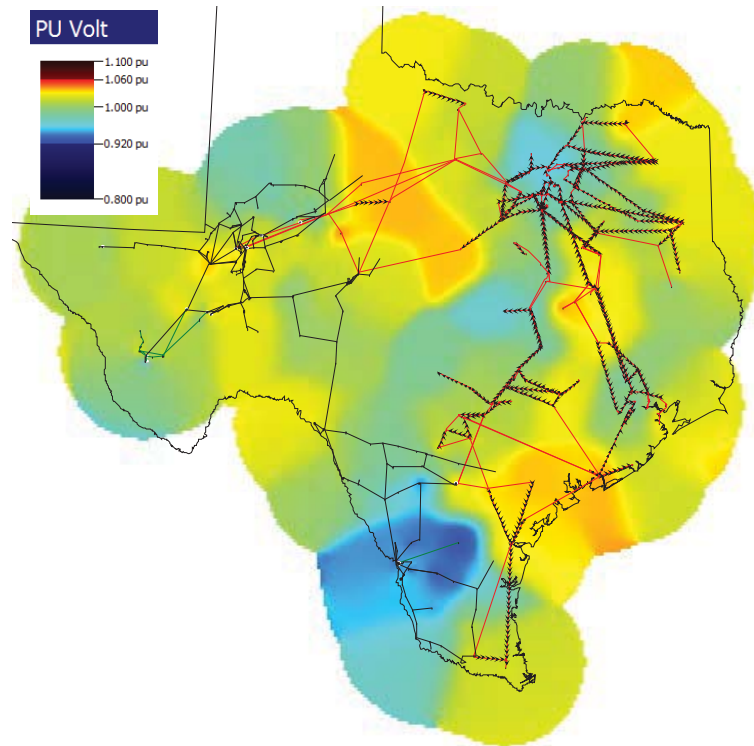
- On **Onelines** Ribbon Tab, choose **Contouring** → **Recalculate Contour**



Result after: Robust Solution Process



- Solution is achieved!



S3: Conditioning Hard-to-Solve Cases

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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

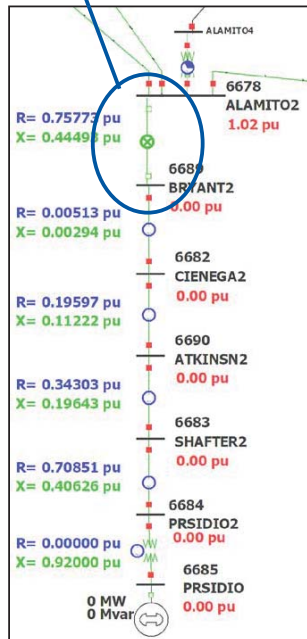
Problems with Decoupled Power Flow Solution



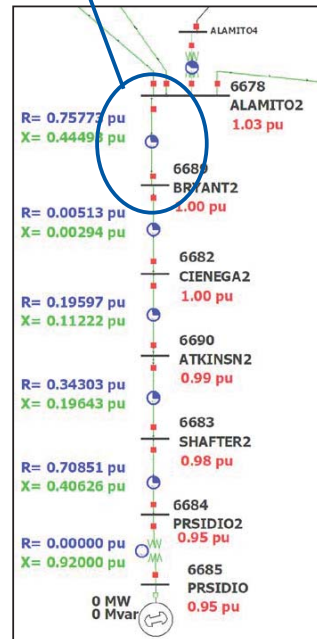
- Decoupled Solution has trouble with transmission lines with high R/X ratios
- For the Alamito Region
 - R/X values are very large!
 - Normal Value about 0.2
 - These are 1.5 and higher.
- This can be resolved
 - Opening the Line
 - Single Solution
 - Closing the line
 - Single Solution



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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