

## **Validation of Powerflow application of GridPACK against commercial solvers like Powerworld and PSS/E**

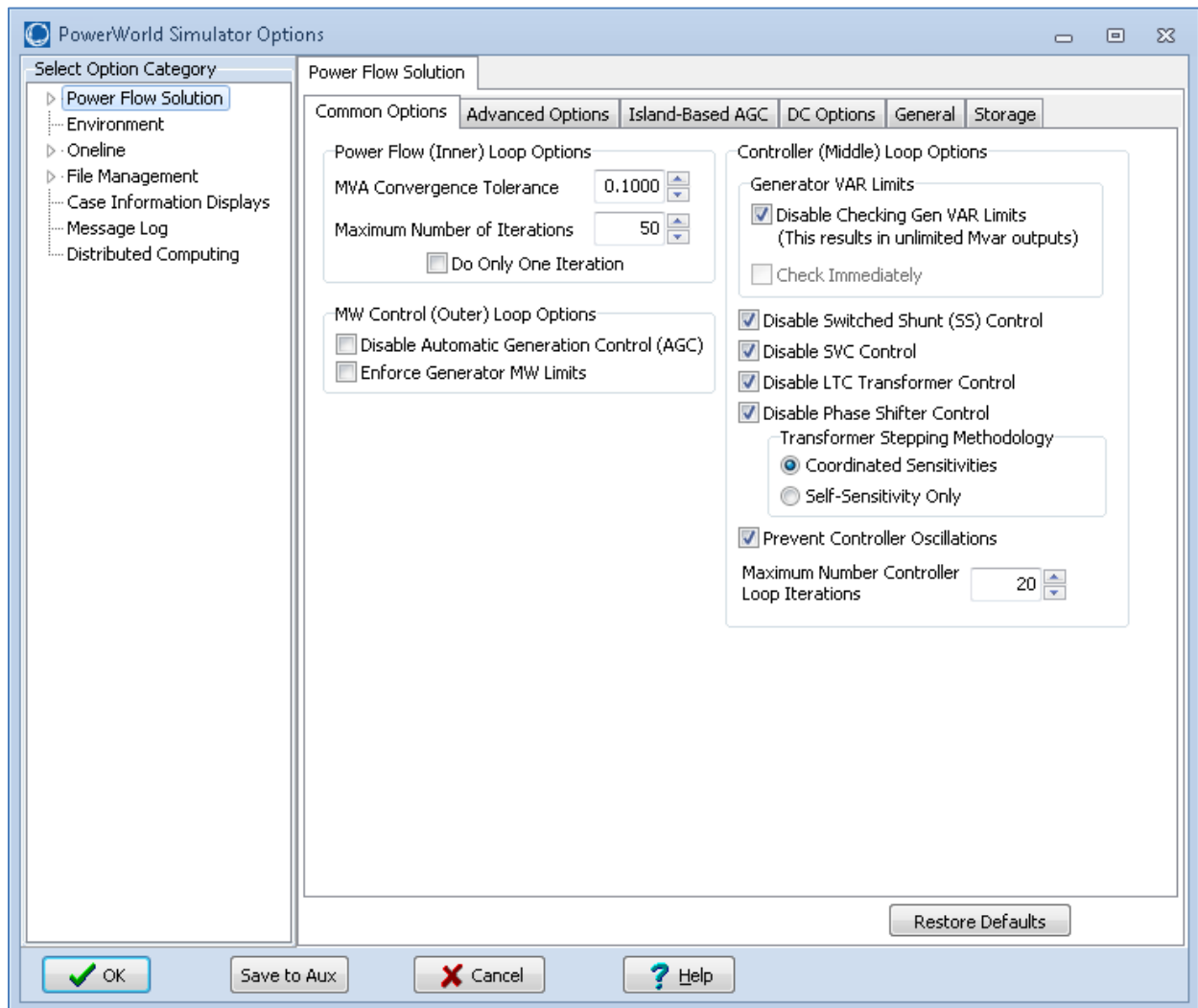
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This document provides validation results for the GridPACK™ powerflow application compared against commercial solvers like Powerworld and PSS/E. In this document, results from GridPACK™ are compared against two test systems, the IEEE 300 bus system and European 2736 bus system provided by MATPOWER.

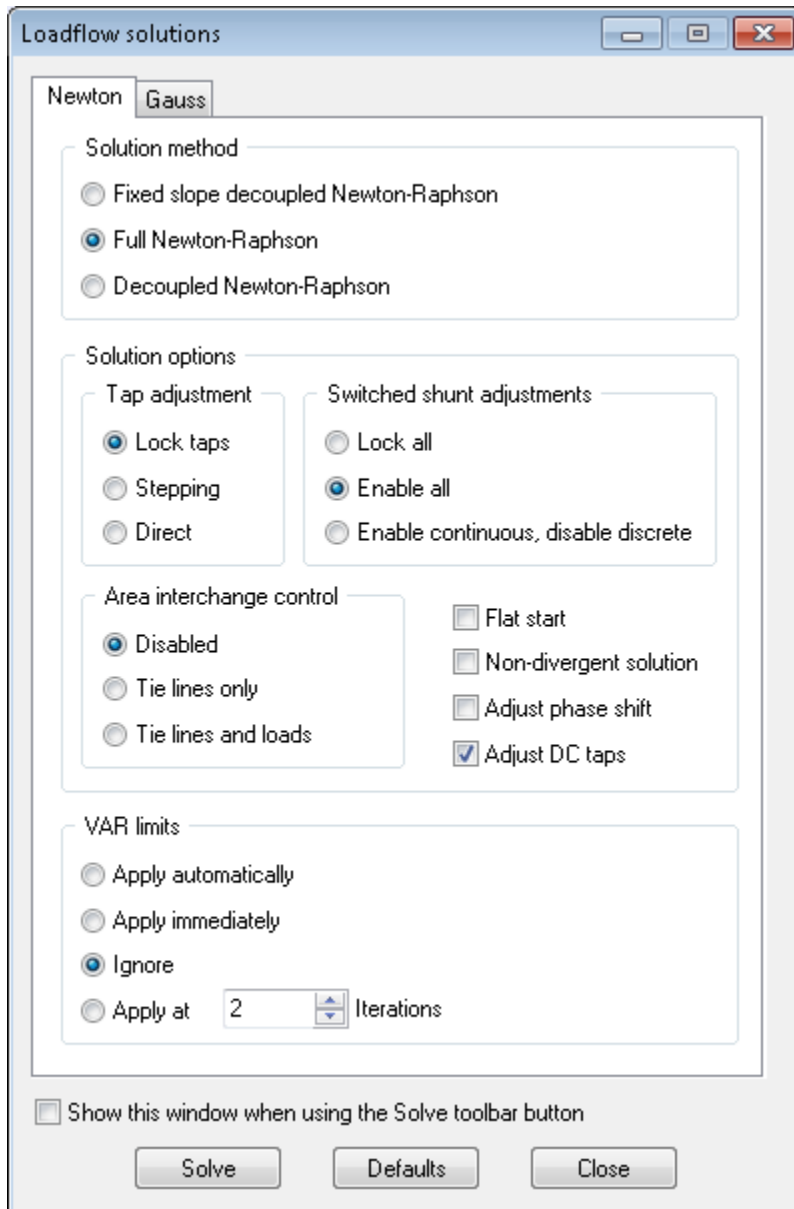
GridPACK™ uses a Newton Raphson algorithm on a parallel processing platform to solve the power flow equations. GridPACK™ has a relatively fixed procedure for solving the power flow equations, whereas commercial solvers provide more options.

## Choice of settings:

The Powerworld settings for power flow:



The PSS/E settings for power flow:



Both Powerworld and PSS/E softwares have a default tolerance of 0.1 MVA. It is often difficult to converge these commercial solvers' power flows if the tolerance is reduced by an order of magnitude magnitude or so (for example  $1e-6$  MVA)

Based on the analysis of the results, which will be explained in the next section, it seems that GridPACK™ has these particular settings:

Generator VAR limits – No limit

Transformer tap control – No control

Switched shunt control – No control

Further analysis of the settings and GridPACK™ solution strategy will be explained in the next section:

**Validation results and analysis:**

IEEE 300 bus system:

The first two graphs show the largest bus mismatches compared between GridPACK™, Powerworld, and PSS/E. For the same parameters, the results for the GridPACK™ powerflow calculations are in good agreement with Powerworld and PSS/E. The mismatch in bus voltage, angle and branch flows between GridPACK and commercial solvers is within the mismatch that is observed between commercial solvers. Figures 1-3 show the 20 maximum mismatches between different solvers.

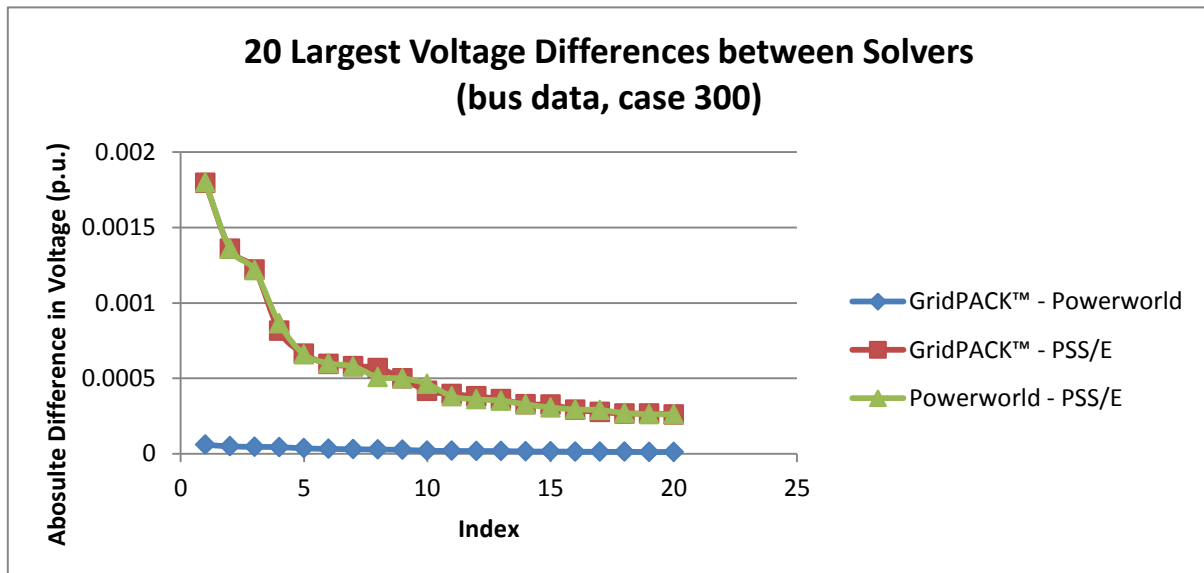


Figure 1: Comparison of calculated voltage magnitudes from GridPACK, Powerworld and PSS/E for 300 bus test case.

Powerworld			PSSE		Powerworld - PSSE	
Bus	Voltage (pu)	Angle (deg)	Voltage (pu)	Angle (deg)	$\Delta V$	$\Delta Ang$
224	1.00025	-21.35	1.00205	-21.35	0.0018	0
175	0.97308	-7.18	0.974439	-7.18	0.001359	0
226	1.01801	-21.41	1.019227	-21.4	0.001217	0.01
163	1.04106	2.93	1.040196	2.94	0.000864	0.01
225	0.94528	-11.14	0.945939	-11.16	0.000659	0.02
Gridpack™			PSSE		Gridpack™ - PSSE	
Bus	Voltage (pu)	Angle (deg)	Voltage (pu)	Angle (deg)	$\Delta V$	$\Delta Ang$
224	1.000254	-21.349743	1.00205	-21.35	0.001796	0.000257
175	0.973081	-7.180312	0.974439	-7.18	0.001358	0.000312
226	1.018005	-21.405482	1.019227	-21.4	0.001222	0.005482
163	1.041011	2.929255	1.040196	2.94	0.000815	0.010745
225	0.945276	-11.141547	0.945939	-11.16	0.000663	0.018453
Gridpack™			Powerworld		Gridpack™ - Powerworld	
Bus	Voltage (pu)	Angle (deg)	Voltage (pu)	Angle (Deg)	$\Delta V$	$\Delta Ang$
204	0.96671	-29.548667	0.96665	-29.55	6E-05	0.001333
163	1.041011	2.929255	1.04106	2.93	4.9E-05	0.000745
164	0.983914	9.684465	0.98396	9.68	4.6E-05	0.004465
205	0.985554	-28.515769	0.98551	-28.52	4.4E-05	0.004231
193	0.998236	-27.470335	0.9982	-27.47	3.6E-05	0.000335

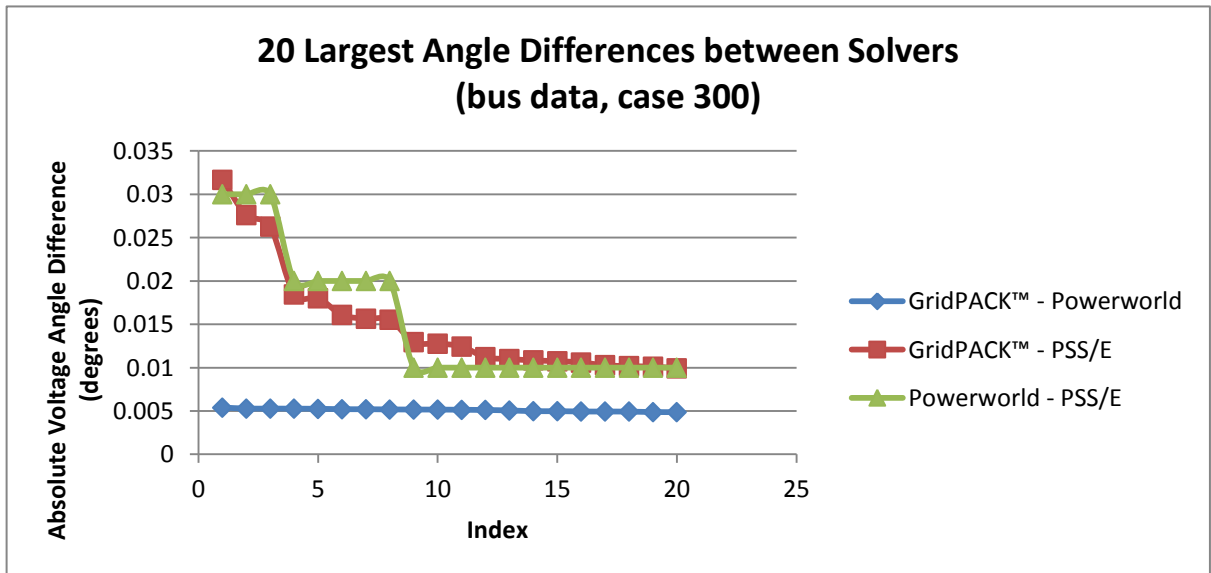


Figure 2: Comparison of calculated voltage angles from GridPACK, Powerworld and PSS/E for 300 bus test case.

Bus	Voltage (pu)	Angle (deg)	Voltage (pu)	Angle (deg)	$\Delta V$	$\Delta Ang$
166	0.99726	30.24	0.99717	30.27	9E-05	0.03
7166	1.0145	35.07	1.0145	35.1	0	0.03
191	1.0435	12.45	1.0435	12.42	0	0.03
165	1.00023	26.33	1.00006	26.35	0.00017	0.02
155	1.01775	6.77	1.017701	6.79	4.9E-05	0.02
Gridpack™			PSSE		Gridpack™ - PSSE	
Bus	Voltage (pu)	Angle (deg)	Voltage (pu)	Angle (deg)	$\Delta V$	$\Delta Ang$
191	1.0435	12.451664	1.0435	12.42	0	0.031664
7166	1.0145	35.072373	1.0145	35.1	0	0.027627
166	0.997254	30.243735	0.99717	30.27	8.4E-05	0.026265
225	0.945276	-11.141547	0.945939	-11.16	0.000663	0.018453
165	1.000211	26.331975	1.00006	26.35	0.000151	0.018025
Gridpack™			Powerworld		Gridpack™ - Powerworld	
Bus	Voltage (pu)	Angle (deg)	Voltage (pu)	Angle (deg)	$\Delta V$	$\Delta Ang$
78	0.990023	-24.034599	0.99002	-24.04	3E-06	0.005401
9025	0.964756	-20.434718	0.96476	-20.44	4E-06	0.005282
8	1.0153	2.415278	1.0153	2.41	0	0.005278
139	1.011709	-3.544731	1.01171	-3.55	1E-06	0.005269
17	1.064906	-13.084747	1.06491	-13.09	4E-06	0.005253

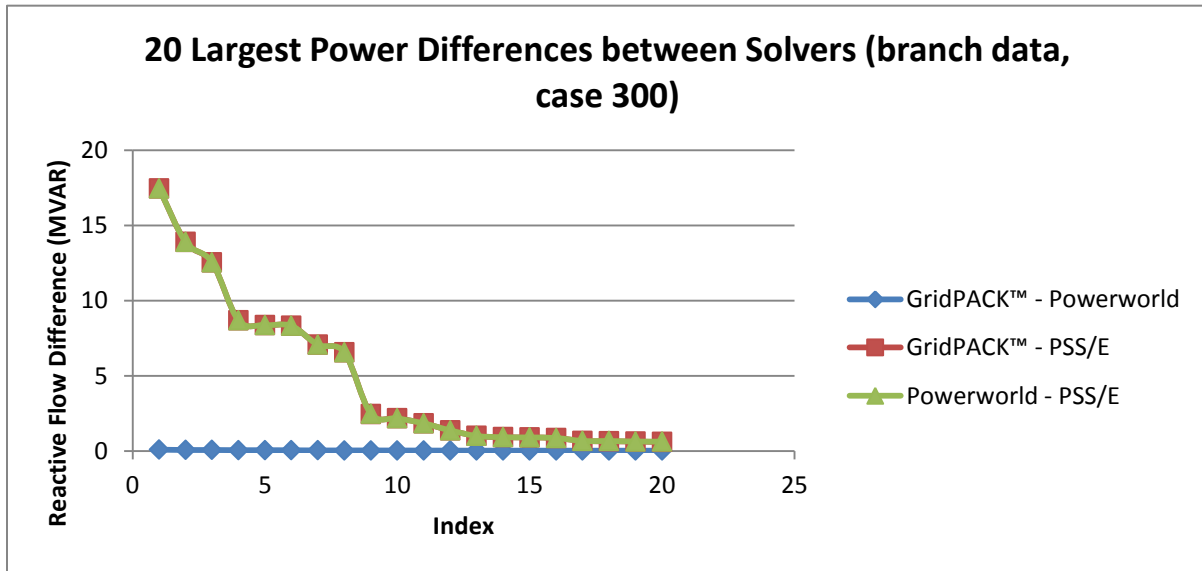


Figure 3: Comparison of calculated reactive power between GridPACK, Powerworld and PSS/E for 300 bus test case.

Bus 1	Bus 2	CKT	MW	Mvar	P	Q	$\Delta P$	$\Delta Q$
222	237	1	-78	-26.6152	-78	-44.0679	0	17.45267
190	231	BL	528.9429	-363.699	528.986	-349.793	0.04312	13.90623
231	237	BL	-452.149	-527.838	-452.052	-515.289	0.09718	12.54888

227	231	1	-235	-106.043	-235	-114.722	1.53E-05	8.679546
221	223	BL	325.4972	140.7018	325.5046	149.0766	0.00738	8.374769
			<b>GridPACK™</b>		<b>PSSE</b>		<b>GridPACK™ - PSSE</b>	
<b>Bus 1</b>	<b>Bus 2</b>	<b>CKT</b>	<b>P</b>	<b>Q</b>	<b>P</b>	<b>Q</b>	<b>ΔP</b>	<b>ΔQ</b>
222	237	1	-78	-26.6147	-78	-44.0679	0	17.45322
190	231	BL	528.9429	-363.69	528.986	-349.793	0.04316	13.89749
231	237	BL	-452.149	-527.828	-452.052	-515.289	0.09719	12.53894
227	231	1	-235	-106.042	-235	-114.722	1.53E-05	8.679884
221	223	BL	325.4972	140.7021	325.5046	149.0766	0.00743	8.374499
			<b>Gridpack™</b>		<b>Powerworld</b>		<b>Gridpack™ - Powerworld</b>	
<b>Bus 1</b>	<b>Bus 2</b>	<b>CKT</b>	<b>P</b>	<b>Q</b>	<b>MW</b>	<b>Mvar</b>	<b>ΔP</b>	<b>ΔQ</b>
155	156	1	102.8437	21.9238	102.8433	22.0108	0.00036	0.086997
7166	166	1	553	136.924	553	136.8603	0	0.063729
165	166	BL	-552.385	51.92083	-552.384	51.9833	0.00031	0.062472
162	165	BL	-546.877	-37.9969	-546.877	-37.9458	8.5E-05	0.051064
162	164	BL	461.8771	13.99686	461.877	13.9458	8.5E-05	0.051064

European 2736 bus system (MATPOWER library):

Figures 4-6 show the largest bus mismatches in bus voltage and phase angle and branch flow compared among Powerworld, PSSE, and GridPACK™. The maximum mismatch in bus voltage between GridPACK and commercial solvers is about 0.0032 and about 0.035 degrees in the bus angles. Such a mismatch is acceptable based on similar differences between commercial solvers with other cases.

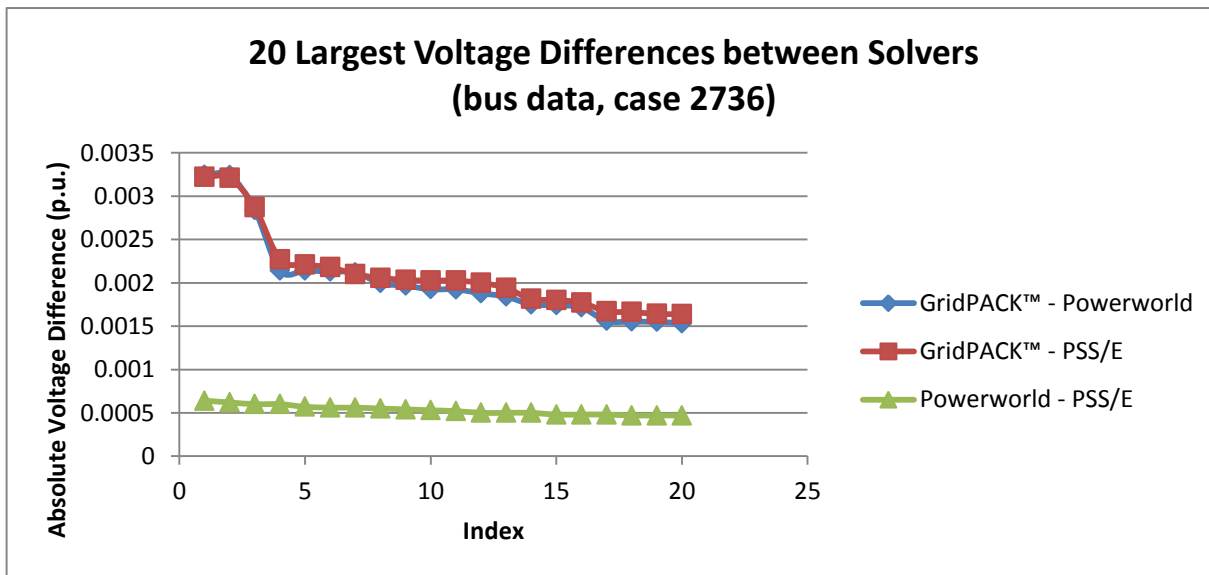


Figure 4: Comparison of calculated voltage magnitudes from GridPACK, Powerworld and PSS/E for European 2736 bus test case.

		Powerworld		PSSE		Powerworld - PSSE	
Bus	Voltage (pu)	Angle (deg)	Voltage (pu)	Angle (deg)	$\Delta V$	$\Delta Ang$	
2209	1.09076	20.628	1.0914	20.6263	0.00064	0.0017	
2206	1.09038	20.5864	1.091	20.5846	0.00062	0.0018	
2210	1.0906	20.6	1.0912	20.5982	0.0006	0.0018	
2208	1.0891	20.4003	1.0897	20.3988	0.0006	0.0015	
2201	1.08713	20.3729	1.0877	20.3719	0.00057	0.001	
		GridPACK™		PSSE		GridPACK™ - PSSE	
Bus	Voltage (pu)	Angle (deg)	Voltage (pu)	Angle (deg)	$\Delta V$	$\Delta Ang$	
2516	1.055277	10.969782	1.0585	10.9352	0.003223	0.034582	
2568	1.05599	11.030275	1.0592	10.9953	0.00321	0.034975	
2449	1.04973	10.336278	1.0526	10.3167	0.00287	0.019578	
2202	1.04443	11.25968	1.0467	11.2423	0.00227	0.01738	
2228	1.04849	11.673873	1.0507	11.6571	0.00221	0.016773	
		GridPACK™		Powerworld		GridPACK™ - Powerworld	
Bus	Voltage (pu)	Angle (deg)	Voltage (pu)	Angle (deg)	$\Delta V$	$\Delta Ang$	
2516	1.055277	10.969782	1.05852	10.9315	0.003243	0.038282	
2568	1.05599	11.030275	1.05923	10.9917	0.00324	0.038575	
2449	1.04973	10.336278	1.05257	10.3129	0.00284	0.023378	
2056	1.04402	11.316453	1.04616	11.2957	0.00214	0.020753	
2228	1.04849	11.673873	1.05063	11.6541	0.00214	0.019773	

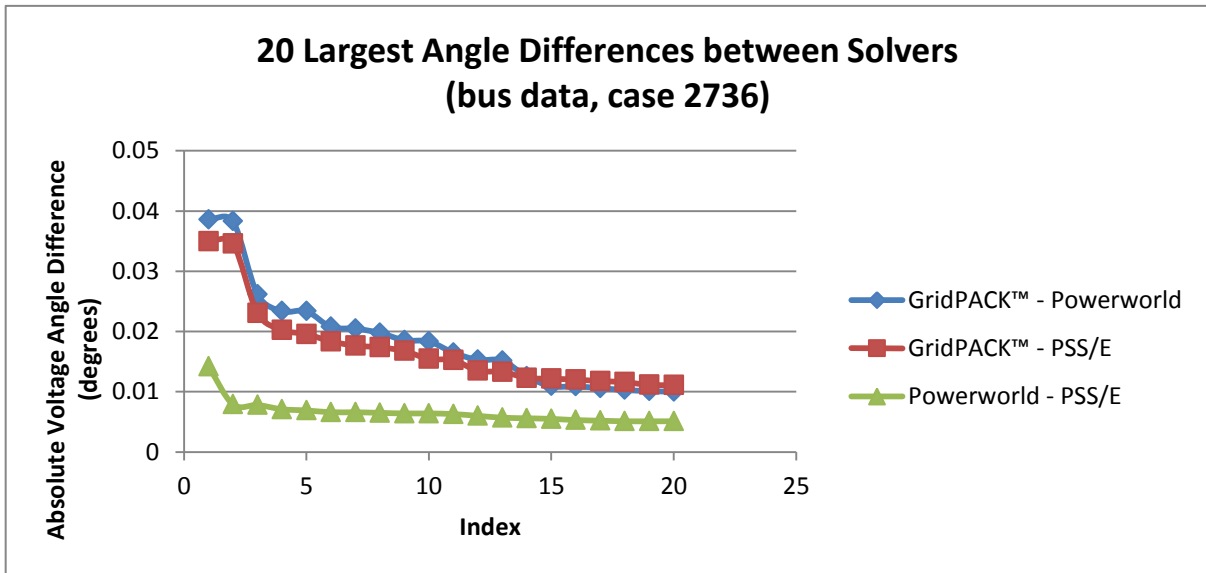


Figure 5: Comparison of calculated voltage angles from GridPACK, Powerworld and PSS/E for European 2736 bus test case.



	Powerworld		PSSE		Powerworld - PSSE	
Bus	Voltage (pu)	Angle (deg)	Voltage (pu)	Angle (deg)	$\Delta V$	$\Delta Ang$
220	1.08853	20.3348	1.0885	20.349	3E-05	0.0142
214	1.09209	16.9099	1.0921	16.9178	1E-05	0.0079
493	1.09185	16.8637	1.0919	16.8715	5E-05	0.0078
217	1.09161	16.7837	1.0916	16.7908	1E-05	0.0071
341	1.08719	16.63	1.0873	16.6369	0.00011	0.0069
	GridPACK™		PSSE		GridPACK™ - PSSE	
Bus	Voltage (pu)	Angle (deg)	Voltage (pu)	Angle (deg)	$\Delta V$	$\Delta Ang$
2568	1.05599	11.030275	1.0592	10.9953	0.00321	0.034975
2516	1.055277	10.969782	1.0585	10.9352	0.003223	0.034582
2438	1.0503	10.95865	1.0523	10.9356	0.002	0.02305
1984	1.049959	10.987469	1.0519	10.9672	0.001941	0.020269
2449	1.04973	10.336278	1.0526	10.3167	0.00287	0.019578
	GridPACK™		Powerworld		GridPACK™ - Powerworld	
Bus	Voltage (pu)	Angle (deg)	Voltage (pu)	Angle (deg)	$\Delta V$	$\Delta Ang$
2568	1.05599	11.030275	1.05923	10.9917	0.00324	0.038575
2516	1.055277	10.969782	1.05852	10.9315	0.003243	0.038282
2438	1.0503	10.95865	1.05218	10.9325	0.00188	0.02615
2449	1.04973	10.336278	1.05257	10.3129	0.00284	0.023378
1984	1.049959	10.987469	1.0518	10.9641	0.001841	0.023369

The maximum mismatch in the branch reactive power flow for GridPACK – PSS/E is 12.67 Mvar which is the same as that between Powerworld – PSS/E. These larger mismatches is among branches that have lower impedance. The mismatches are comparable between different solvers and can be accepted as has been seen between commercial solvers.

The next graph shows the largest branch data mismatch between solvers for case 2736:

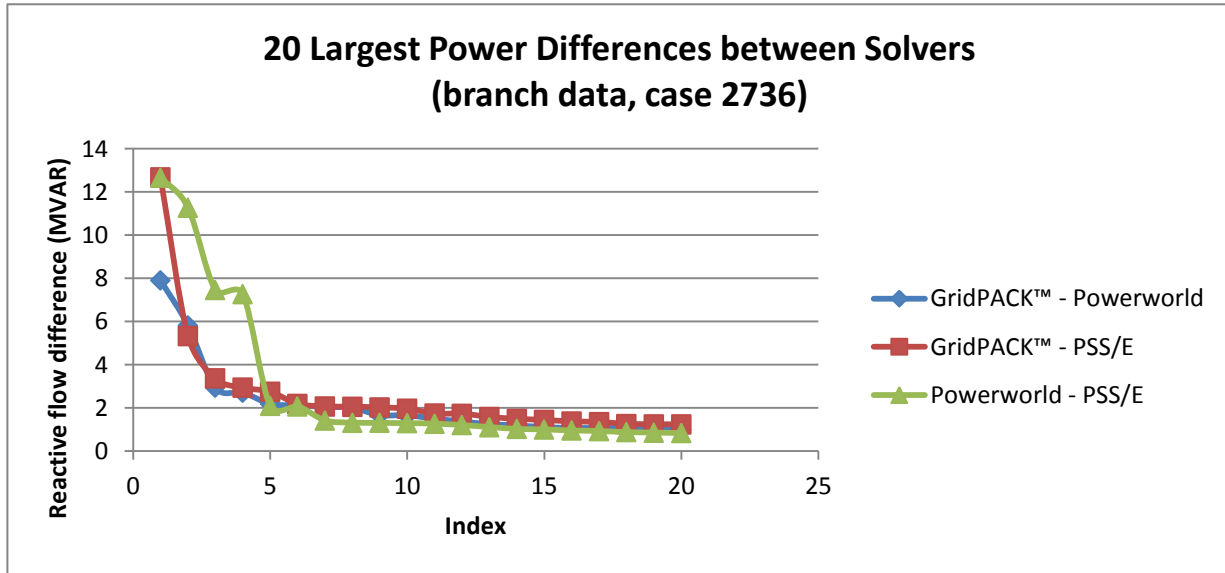


Figure 6: Comparison of calculated reactive power between GridPACK, Powerworld and PSS/E for European 2736 bus test case.

			Powerworld		PSSE		Powerworld - PSSE	
Bus 1	Bus 2	CKT	MW	Mvar	P	Q	$\Delta P$	$\Delta Q$
29	28	BL	177.5750	-16.9023	177.4978	-29.5735	0.0772	12.6712
150	149	BL	35.5833	-11.7545	35.5575	-23.0323	0.0258	11.2778
57	56	BL	-110.3671	-41.1480	-110.3752	-33.6897	0.0081	7.4583
205	204	BL	20.2708	3.8959	20.2716	-3.3785	0.0008	7.2744
127	126	BL	13.0317	-5.3736	13.0487	-3.2760	0.0170	2.0976
			GridPACK™		PSSE		GridPACK™ - PSSE	
Bus 1	Bus 2	CKT	P	Q	P	Q	$\Delta P$	$\Delta Q$
29	28	BL	177.5549	-16.9004	177.4978	-29.5735	0.0571	12.6731
57	56	BL	-110.3676	-39.0264	-110.3752	-33.6897	0.0076	5.3367
150	149	BL	35.5949	-19.6594	35.5575	-23.0323	0.0374	3.3729
2471	2470	BL	-2.7882	-3.6311	-2.7212	-6.5719	0.0670	2.9409
18	17	BL	2.1158	34.0131	2.1258	31.2614	0.0100	2.7517
			GridPACK™		Powerworld		GridPACK™ - Powerworld	
Bus 1	Bus 2	CKT	P	Q	MW	Mvar	$\Delta P$	$\Delta Q$
150	149	BL	35.5949	-19.6594	35.5833	-11.7545	0.0116	7.9049
205	204	BL	20.2820	-1.9315	20.2708	3.8959	0.0111	5.8274
2471	2470	BL	-2.7882	-3.6311	-2.7243	-6.5730	0.0639	2.9419
18	17	BL	2.1158	34.0131	2.1270	31.2984	0.0112	2.7147
2568	2592	BL	-26.8160	-2.2879	-26.8607	-0.0954	0.0447	2.1925

**Conclusions:**

The results shown verify that when similar choice of power flow options are chosen, GridPACK™ results are very close to the results produced from the commercial grade solvers Powerworld and PSS/E.