IEEE PES Task Force on Benchmark Systems for Stability Controls

Report on the Simplified 14-Generator Model of the Southeastern Australian Power System - CEPEL® Package

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The purpose of this document is to show the results of small-signal and transient analyses performed for the Simplified 14-Generator Model of the Southeastern Australian Power System using the software package of CEPEL®, as part of the work of the IEEE Task Force on Benchmark Systems for Stability Controls.

Among the software which constitute the CEPEL Package, three of them are relevant to the proposed study by this report: ANAREDE® [1], ANATEM® [2] and PACDYN® [3], which perform power-flow, small-signal and transient analyses, respectively. All the results are compared to the results provided by the original proponents of system [4], which are obtained from MUDPACK® (for small-signal analysis) and PSS/E® (for transient analysis).

This document is organized as follows: in Section 1 the general aspects of test system are briefly described; Section 2 shows the results of power flow; Section 3 shows the results of small-signal analysis and; Section 4 closes the document with the results of transient analysis.

1. System Description

The test system represents a simplified model of the eastern and southern 50 Hz Australian networks, shown in Figure 1 and originally proposed in [4]. In this system, there are 14 generators, 5 Static VAR Compensators (SVCs), 59 buses and 104 lines with voltage levels ranging from 15kV to 500kV.

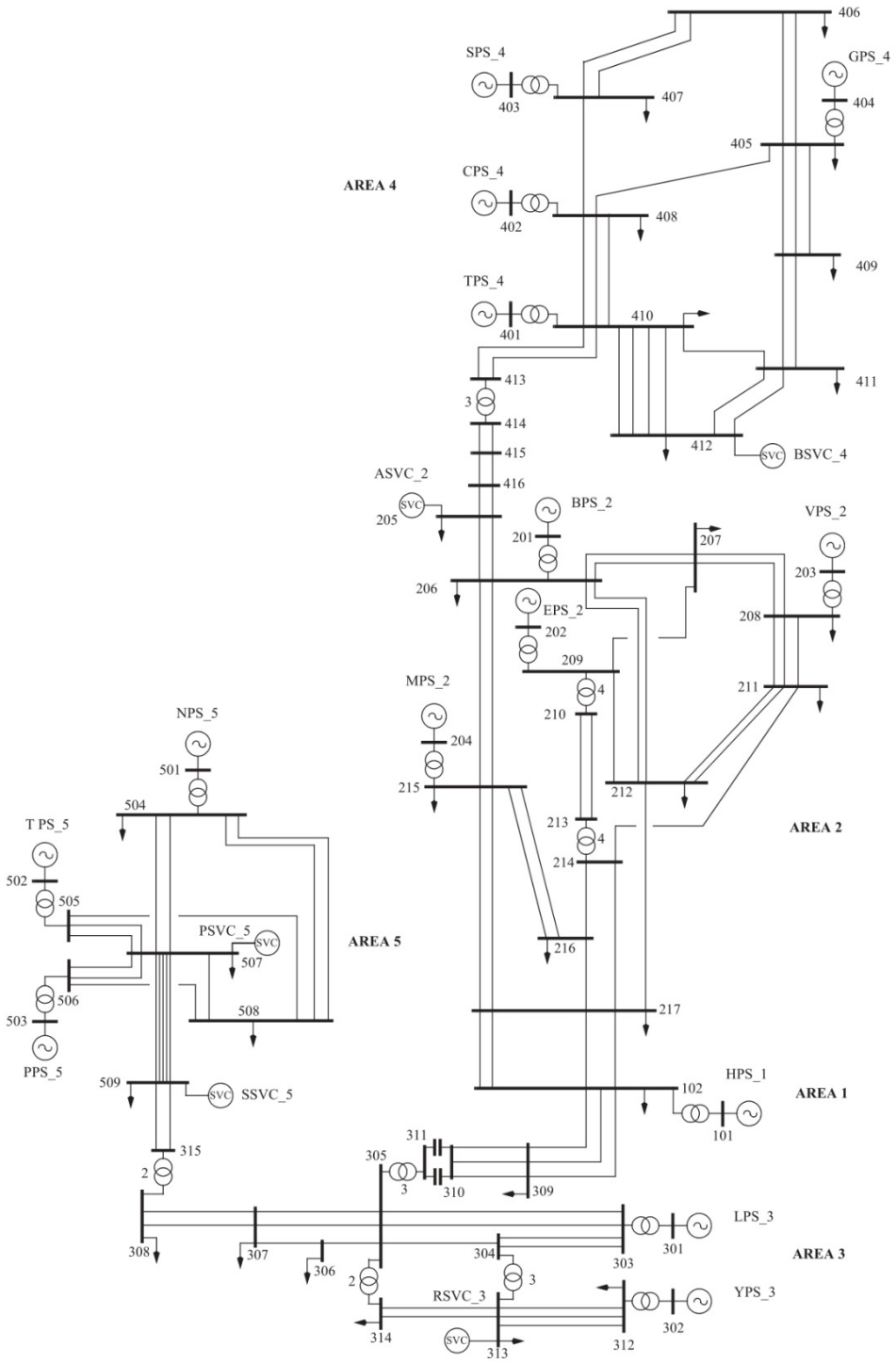

Figure 1 - Simplified 14-generator model of the southeastern Australian power system

To make the PSSs tuning assessment using both small-signal and transient approaches, six steady-state conditions – denoted as "Cases" - are considered. All Cases are summarized in Table 1, in terms of total MW values of load and generation.

Table 1- Six steady-state operating conditions

--	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Load Condition	Heavy	Medium-Heavy	Peak	Light	Medium	Light
Total Generation (MW)	23030	21590	25430	15050	19060	14840
Total Load (MW)	22300	21000	24800	14810	18600	14630

The system has been divided in 5 areas. There are 4 main areas and, hence, 3 inter-area modes, as well as 10 local-area modes. Without PSSs, most of the electromechanical modes are unstable. More details about the network and the dynamic models of the elements of the system are presented in [4].

2. Power Flow Analysis

All static analyses are performed in ANAREDE®**.** These results provide the equilibrium points for the simulations performed in both PACDYN® and ANATEM®.

From Table 2 to Table 7 the results obtained from ANAREDE® are compared with the results obtained from PSS/E® [4], for the six steady-state operating points. All results are provided in terms of injected active and reactive powers by the generators. In all cases, the terminal voltage magnitude of generators is equal to 1.0 p.u.

Table 2 - Power flow results of Case 1

GEN / Bus	Nº Units	Active Power [MW]		Reactive Power [MVAr]	
		PSS/E®	ANAREDE®	PSS/E®	ANAREDE®
HPS_1 / 101	4	75.2	74.57	77.9	78.2
BPS_2 / 201	6	600.0	600.0	95.6	96.3
EPS_2 / 202	5	500.00	500.00	132.7	132.4
VPS_2 / 203	4	375.0	375.0	132.8	132.6
MPS_2 / 204	6	491.7	491.7	122.4	122.4
LPS_3 / 301	7	600.0	600.0	142.3	142.8
YPS_3 / 302	3	313.3	313.3	51.5	52.2
TPS_4 / 401	4	350.0	350.0	128.7	128.9
CPS_4 / 402	3	279.0	279.0	59.3	59.5
SPS_4 / 403	4	350.0	350.0	52.3	52.3
GPS_4 / 404	6	258.3	258.3	54.5	54.6
NPS_5 / 501	2	300.0	300.0	25.3	25.9
TPS_5 / 502	4	200.0	200.0	40.1	40.3
PPS_5 /503	4	109.0	109.0	25.2	25.4

Table 3 - Power flow results of Case 2

GEN / Bus	Nº Units	Active Power [MW]		Reactive Power [MVAr]	
		PSS/E®	ANAREDE®	PSS/E®	ANAREDE®
HPS_1 / 101	3	159.6	158.4	54.4	54.6
BPS_2 / 201	5	560.0	560.0	38.9	38.9
EPS_2 / 202	4	480.0	480.0	60.5	60.6
VPS_2 / 203	3	450.0	450.0	82.4	82.5
MPS_2 / 204	4	396.0	396.0	17.8	17.8
LPS_3 / 301	8	585.0	585.0	141.1	141.3
YPS_3 / 302	4	383.0	383.0	63.3	63.9
TPS_4 / 401	4	350.0	350.0	116.5	116.4
CPS_4 / 402	3	290.0	290.0	31.4	31.5
SPS_4 / 403	4	350.0	350.0	47.2	47.1
GPS_4 / 404	6	244.0	244.0	39.8	39.8
NPS_5 / 501	2	300.0	300.0	-8.8	-8.3
TPS_5 / 502	4	200.0	200.0	53.0	53.1
PPS_5 /503	5	138.0	138.0	36.9	36.9

Table 4 - Power flow results of Case 3

GEN / Bus	Nº Units	Active Power [MW]		Reactive Power [MVAr]	
		PSS/E®	ANAREDE®	PSS/E®	ANAREDE®
HPS_1 / 101	12	248.3	248.4	21.8	21.9
BPS_2 / 201	6	550.0	550.0	109.1	109.2
EPS_2 / 202	5	470.0	470.0	127.6	127.5
VPS_2 / 203	2	225.0	225.0	157.0	157.2
MPS_2 / 204	6	536.0	536.0	96.5	96.7
LPS_3 / 301	8	580.0	580.0	157.6	157.8
YPS_3 / 302	4	318.0	318.0	49.6	50.3
TPS_4 / 401	4	350.0	350.0	123.2	123.2
CPS_4 / 402	3	290.0	290.0	32.0	32.1
SPS_4 / 403	4	350.0	350.0	47.3	47.3
GPS_4 / 404	6	244.0	244.0	40.0	40.0
NPS_5 / 501	2	300.0	300.0	6.5	7.1
TPS_5 / 502	4	180.0	180.0	48.8	48.8
PPS_5 /503	6	125.0	125.0	32.6	32.6

Table 5 - Power flow results of Case 4

GEN / Bus	Nº Units	Active Power [MW]		Reactive Power [MVAr]	
		PSS/E®	ANAREDE®	PSS/E®	ANAREDE®
HPS_1 / 101	2	0.0	1.2	-97.4	-97.5
BPS_2 / 201	4	540.0	540.0	-30.8	-30.8
EPS_2 / 202	3	460.0	460.0	-2.5	-2.6
VPS_2 / 203	3	470.0	470.0	9.4	9.4
MPS_2 / 204	4	399.3	399.3	-43.6	-43.5
LPS_3 / 301	6	555.0	555.0	16.6	17.0
YPS_3 / 302	2	380.0	380.0	-9.3	-9.1
TPS_4 / 401	3	320.0	320.0	-21.9	-19.4
CPS_4 / 402	2	290.0	290.0	-2.4	-2.0
SPS_4 / 403	3	320.0	320.0	14.2	14.3
GPS_4 / 404	3	217.0	217.0	-3.5	-3.4
NPS_5 / 501	2	280.0	280.0	-52.5	-52.5
TPS_5 / 502	3	180.0	180.0	-1.8	-1.8
PPS_5 /503	1	150.0	150.0	2.2	2.2

Table 6 - Power flow results of Case 5

GEN / Bus	Nº Units	Active Power [MW]		Reactive Power [MVAr]	
		PSS/E®	ANAREDE®	PSS/E®	ANAREDE®
HPS_1 / 101	3	-200.0	-199.3	-26.0	-26.2
BPS_2 / 201	5	560.0	560.0	38.7	38.6
EPS_2 / 202	4	480.0	480.0	67.2	67.1
VPS_2 / 203	2	460.0	460.0	83.1	83.1
MPS_2 / 204	4	534.4	534.4	55.2	55.3
LPS_3 / 301	8	550.0	550.0	88.1	88.7
YPS_3 / 302	3	342.0	342.0	43.8	44.6
TPS_4 / 401	4	346.0	346.0	84.9	85.3
CPS_4 / 402	3	280.0	280.0	45.4	45.3
SPS_4 / 403	4	340.0	340.0	46.3	46.3
GPS_4 / 404	5	272.0	272.0	50.4	50.3
NPS_5 / 501	2	280.0	280.0	-35.2	-35.0
TPS_5 / 502	4	190.0	190.0	0.1	0.1
PPS_5 /503	2	87.0	87.0	3.5	3.7

Table 7 - Power flow results of Case 6

GEN / Bus	Nº Units	Active Power [MW]		Reactive Power [MVAr]	
		PSS/E®	ANAREDE®	PSS/E®	ANAREDE®
HPS_1 / 101	2	0.0	-5.35	-102.2	-101.5
BPS_2 / 201	3	560.0	560.0	-53.5	-53.3
EPS_2 / 202	3	490.0	490.0	-7.3	-7.2
VPS_2 / 203	3	490.0	490.0	3.7	4.0
MPS_2 / 204	3	488.6	488.6	-61.2	-60.3
LPS_3 / 301	6	550.0	550.0	9.4	9.7
YPS_3 / 302	2	393.0	393.0	-6.9	-6.9
TPS_4 / 401	3	350.0	350.0	-32.6	-27.6
CPS_4 / 402	3	270.0	270.0	4.7	5.2
SPS_4 / 403	2	380.0	380.0	25.2	25.4
GPS_4 / 404	3	245.0	245.0	3.9	4.1
NPS_5 / 501	1	270.0	270.0	-42.2	-42.0
TPS_5 / 502	4	200.0	200.0	-9.7	-9.3
PPS_5 /503	2	120.0	120.0	-11.2	-10.9

3. Small-Signal Analysis

Small signal analysis is performed using PACDYN®. This software requires the dynamic data (in a formatted card file) and the network structure with the respective operating point, provided by ANAREDE®, as input data.

From Table 8 to Table 19, the eigenvalues obtained via MUDPACK® and PACDYN® are provided for the six operating points, with PSSs in- and out-of-service. The aim of showing the results of the two software is to establish a comparison and a cross-validation between them. It is important to remark that the presented eigenvalues are relative to electromechanical modes of oscillation, so the dominant state variables related to these eigenvalues are basically the rotor angles and rotor speeds of machines.

Table 8 - Rotor modes for Case 1: PSSs out of service

Real		Imaginary		Damping Ratio	
MUDPACK®	PACDYN®	MUDPACK®	PACDYN®	MUDPACK®	PACDYN®
-0.175	-0.174	10.442	10.442	0.017	0.017
0.109	0.109	9.583	9.585	-0.011	-0.011
0.041	0.039	8.959	8.960	-0.005	-0.004
-0.557	-0.558	8.634	8.635	0.064	0.065
-0.26	-0.261	8.368	8.370	0.031	0.031
-0.612	-0.612	8.047	8.047	0.076	0.076
-0.439	-0.440	7.965	7.966	0.055	0.055
0.014	0.014	7.812	7.813	-0.002	-0.002
-0.189	-0.188	7.724	7.721	0.024	0.024
-0.617	-0.618	7.425	7.425	0.083	0.083
0.115	0.115	3.970	3.970	-0.029	-0.029
0.088	0.088	2.601	2.601	-0.034	-0.034
-0.016	-0.016	2.028	2.028	0.008	0.008

Table 9 - Rotor modes for Case 1: PSSs in service

Real		Imaginary		Damping Ratio	
MUDPACK®	PACDYN®	MUDPACK®	PACDYN®	MUDPACK®	PACDYN®
-2.193	-2.193	10.386	10.387	0.207	0.207
-1.978	-1.979	9.742	9.745	0.199	0.199
-1.926	-1.928	9.293	9.293	0.203	0.203
-2.505	-2.506	8.858	8.859	0.272	0.272
-1.953	-1.954	8.261	8.263	0.230	0.230
-1.971	-1.971	8.490	8.490	0.226	0.226
-1.875	-1.877	7.756	7.756	0.235	0.235
-1.777	-1.780	7.643	7.643	0.226	0.227
-2.061	-2.055	7.872	7.871	0.253	0.253
-1.878	-1.879	7.588	7.588	0.240	0.240
-1.044	-1.047	3.640	3.636	0.276	0.277
-0.385	-0.385	2.402	2.402	0.158	0.158
-0.522	-0.524	1.798	1.796	0.279	0.280

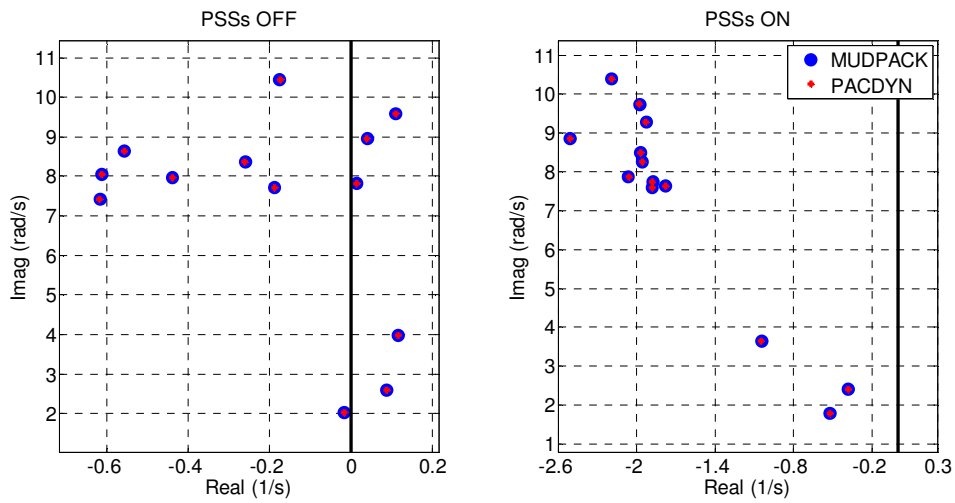

Figure 2 – Rotor modes of Case 1 in the complex plane

Table 10 - Rotor modes for Case 2: PSSs out of service

Real		Imaginary		Damping Ratio	
MUDPACK®	PACDYN®	MUDPACK®	PACDYN®	MUDPACK®	PACDYN®
0.066	0.066	10.743	10.743	-0.006	-0.006
0.101	0.101	9.563	9.566	-0.011	-0.011
-0.25	-0.250	9.261	9.261	0.027	0.027
-0.922	-0.922	8.613	8.613	0.106	0.106
-0.534	-0.535	8.669	8.670	0.062	0.062
-0.184	-0.185	8.482	8.484	0.022	0.022
-0.700	-0.701	8.293	8.292	0.084	0.084
-0.208	-0.208	7.929	7.930	0.026	0.026
-0.065	-0.064	7.385	7.382	0.009	0.009
-0.485	-0.486	7.570	7.570	0.064	0.064
0.193	0.194	3.772	3.770	-0.051	-0.051
0.054	0.054	2.863	2.863	-0.019	-0.019
0.081	0.081	1.915	1.914	-0.042	-0.042

Table 11 - Rotor modes for Case 2: PSSs in service

Real		Imaginary		Damping Ratio	
MUDPACK®	PACDYN®	MUDPACK®	PACDYN®	MUDPACK®	PACDYN®
-2.403	-2.403	10.964	10.964	0.214	0.214
-2.038	-2.039	9.725	9.728	0.205	0.205
-2.37	-2.369	9.644	9.643	0.239	0.239
-2.805	-2.804	8.962	8.962	0.299	0.299
-2.494	-2.495	8.936	8.937	0.269	0.269
-2.039	-2.040	8.379	8.381	0.236	0.237
-2.442	-2.439	8.370	8.369	0.280	0.280
-2.029	-2.032	7.739	7.739	0.254	0.254
-2.021	-2.017	7.490	7.487	0.261	0.260
-1.814	-1.815	7.772	7.771	0.227	0.227
-0.769	-0.769	3.537	3.535	0.212	0.213
-0.447	-0.446	2.542	2.541	0.173	0.173
-0.431	-0.431	1.759	1.759	0.238	0.238

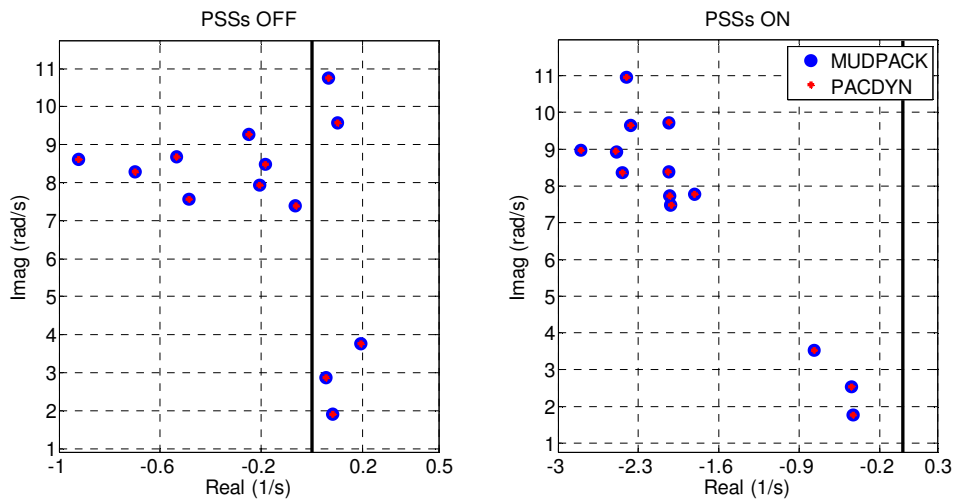

Figure 3 - Rotor modes of Case 2 in the complex plane

Table 12 - Rotor modes for Case 3: PSSs out of service

Real		Imaginary		Damping Ratio	
MUDPACK®	PACDYN®	MUDPACK®	PACDYN®	MUDPACK®	PACDYN®
-0.377	-0.377	11.109	11.109	0.034	0.034
0.101	0.101	9.563	9.565	-0.011	-0.011
-0.301	-0.301	9.019	9.019	0.033	0.033
-0.583	-0.584	8.660	8.661	0.067	0.067
-0.182	-0.183	8.476	8.477	0.021	0.022
-0.140	-0.140	8.256	8.256	0.017	0.017
-0.191	-0.192	7.909	7.910	0.024	0.024
-0.076	-0.075	7.381	7.378	0.010	0.010
-0.576	-0.577	7.625	7.625	0.075	0.075
-0.131	-0.131	6.314	6.313	0.021	0.021
0.011	0.011	4.076	4.076	-0.003	-0.003
0.020	0.020	2.670	2.670	-0.007	-0.007
-0.032	-0.032	2.050	2.050	0.015	0.016

Table 13 - Rotor modes for Case 3: PSSs in service

Real		Imaginary		Damping Ratio	
MUDPACK®	PACDYN®	MUDPACK®	PACDYN®	MUDPACK®	PACDYN®
-1.909	-1.909	11.244	11.244	0.167	0.167
-2.037	-2.038	9.724	9.727	0.205	0.205
-2.278	-2.278	9.100	9.100	0.243	0.243
-2.519	-2.520	8.914	8.915	0.272	0.272
-2.025	-2.026	8.376	8.378	0.235	0.235
-1.948	-1.948	8.492	8.491	0.224	0.224
-2.011	-2.013	7.727	7.727	0.252	0.252
-1.932	-1.928	7.535	7.533	0.248	0.248
-1.933	-1.935	7.800	7.800	0.241	0.241
-2.030	-2.029	5.909	5.907	0.325	0.325
-1.119	-1.120	3.707	3.704	0.289	0.290
-0.428	-0.428	2.418	2.417	0.174	0.175
-0.580	-0.581	1.860	1.860	0.298	0.298

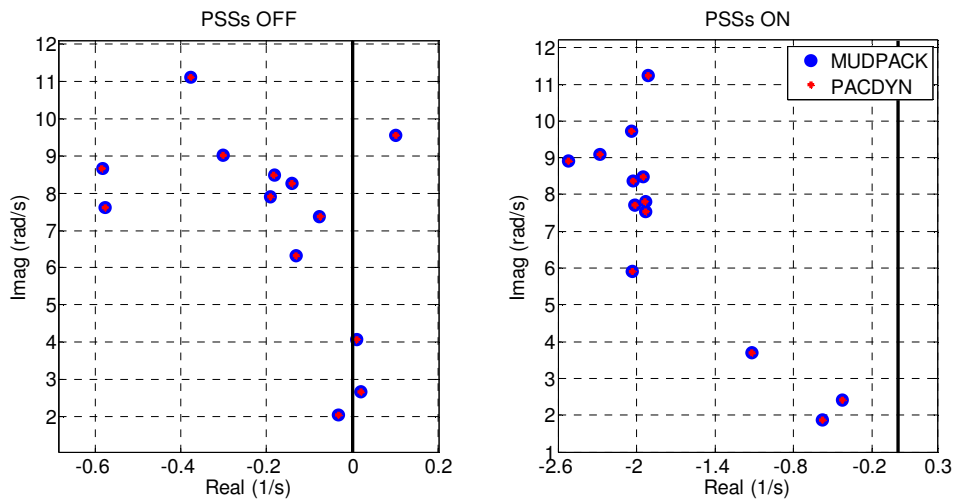

Figure 4 - Rotor modes of Case 3 in the complex plane

Table 14 - Rotor modes for Case 4: PSSs out of service

Real		Imaginary		Damping Ratio	
MUDPACK®	PACDYN®	MUDPACK®	PACDYN®	MUDPACK®	PACDYN®
0.197	0.197	10.484	10.485	-0.019	-0.019
0.030	0.030	9.665	9.664	-0.003	-0.003
-0.173	-0.173	9.369	9.369	0.018	0.018
-1.541	-1.541	8.276	8.272	0.183	0.183
-0.178	-0.178	8.779	8.781	0.020	0.020
-0.561	-0.559	8.581	8.582	0.065	0.065
-0.211	-0.211	8.278	8.275	0.025	0.026
-0.508	-0.508	8.522	8.521	0.06	0.060
-0.431	-0.432	8.211	8.212	0.052	0.053
-0.190	-0.190	7.200	7.200	0.026	0.026
0.165	0.164	4.743	4.746	-0.035	-0.035
0.023	0.020	3.573	3.570	-0.007	-0.006
-0.009	-0.008	2.678	2.682	0.003	0.003

Table 15 - Rotor modes for Case 4: PSSs in service

Real		Imaginary		Damping Ratio	
MUDPACK®	PACDYN®	MUDPACK®	PACDYN®	MUDPACK®	PACDYN®
-2.374	-2.374	10.774	10.773	0.215	0.215
-2.163	-2.163	9.951	9.951	0.212	0.212
-2.269	-2.269	9.813	9.814	0.225	0.225
-1.695	-1.693	8.169	8.165	0.203	0.203
-2.272	-2.271	8.793	8.793	0.250	0.250
-2.496	-2.496	9.064	9.064	0.266	0.266
-2.554	-2.550	8.445	8.444	0.289	0.289
-2.492	-2.492	8.826	8.826	0.272	0.272
-2.28	-2.279	8.279	8.279	0.265	0.265
-1.319	-1.321	7.494	7.493	0.173	0.174
-1.08	-1.081	4.581	4.581	0.229	0.230
-0.563	-0.573	3.322	3.318	0.167	0.170
-0.589	-0.590	2.513	2.519	0.228	0.228

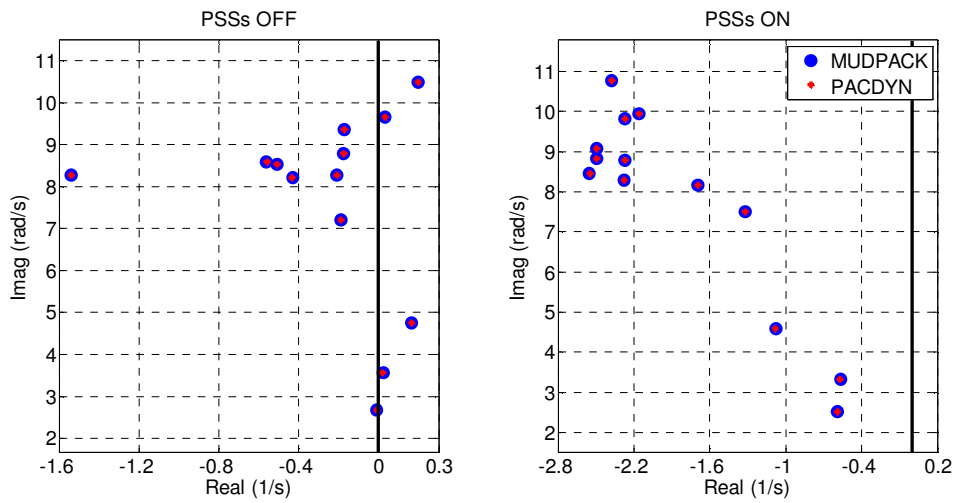

Figure 5 - Rotor modes of Case 4 in the complex plane

Table 16 - Rotor modes for Case 5: PSSs out of service

Real		Imaginary		Damping Ratio	
MUDPACK®	PACDYN®	MUDPACK®	PACDYN®	MUDPACK®	PACDYN®
0.181	0.181	10.940	10.940	-0.017	-0.017
0.086	0.086	9.57	9.572	-0.009	-0.009
-0.163	-0.163	9.171	9.171	0.018	0.018
-0.182	-0.182	8.696	8.695	0.021	0.021
-0.496	-0.496	8.554	8.555	0.058	0.058
-0.263	-0.264	8.452	8.454	0.031	0.031
-0.524	-0.527	7.975	7.975	0.066	0.066
0.008	0.007	7.896	7.899	0.001	-0.001
-0.157	-0.158	7.736	7.734	0.020	0.020
-0.765	-0.766	7.241	7.241	0.105	0.105
0.191	0.192	4.152	4.152	-0.046	-0.046
0.006	0.006	3.122	3.122	-0.002	-0.002
0.059	0.059	2.154	2.155	-0.027	-0.027

Table 17 - Rotor modes for Case 5: PSSs in service

Real		Imaginary		Damping Ratio	
MUDPACK®	PACDYN®	MUDPACK®	PACDYN®	MUDPACK®	PACDYN®
-2.409	-2.409	11.257	11.256	0.209	0.209
-1.988	-1.989	9.762	9.765	0.200	0.200
-2.093	-2.093	9.395	9.394	0.217	0.218
-2.187	-2.187	9.119	9.119	0.233	0.233
-2.471	-2.471	8.828	8.828	0.270	0.270
-2.024	-2.025	8.382	8.385	0.235	0.235
-2.382	-2.380	7.969	7.969	0.286	0.286
-1.853	-1.856	7.809	7.811	0.231	0.231
-2.116	-2.113	7.865	7.864	0.260	0.260
-1.858	-1.860	7.449	7.448	0.242	0.242
-0.884	-0.886	3.902	3.900	0.221	0.221
-0.457	-0.457	2.889	2.890	0.156	0.156
-0.497	-0.498	1.957	1.956	0.246	0.247

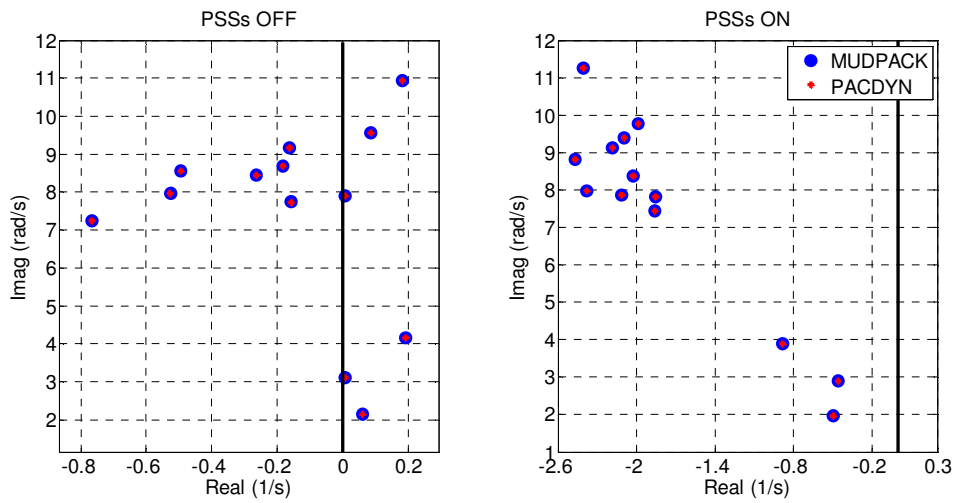

Figure 6 - Rotor modes of Case 5 in the complex plane

Table 18 - Rotor modes for Case 6: PSSs out of service

Real		Imaginary		Damping Ratio	
MUDPACK®	PACDYN®	MUDPACK®	PACDYN®	MUDPACK®	PACDYN®
0.276	0.274	10.390	10.391	-0.027	-0.026
0.318	0.317	10.138	10.138	-0.031	-0.031
-0.129	-0.129	9.423	9.425	0.014	0.014
-0.233	-0.219	8.920	8.921	0.026	0.025
-0.455	-0.455	8.738	8.739	0.052	0.052
-0.136	-0.135	8.578	8.581	0.016	0.016
-0.213	-0.213	8.285	8.283	0.026	0.026
-1.507	-1.501	8.237	8.235	0.180	0.179
-0.301	-0.301	8.128	8.129	0.037	0.037
-0.359	-0.361	7.250	7.251	0.049	0.050
0.200	0.201	4.810	4.810	-0.041	-0.042
0.054	0.054	3.552	3.554	-0.015	-0.015
0.036	0.036	2.597	2.601	-0.014	-0.014

Table 19 - Rotor modes for Case 6: PSSs in service

Real		Imaginary		Damping Ratio	
MUDPACK®	PACDYN®	MUDPACK®	PACDYN®	MUDPACK®	PACDYN®
-2.217	-2.217	10.708	10.705	0.203	0.203
-2.142	-2.141	10.652	10.652	0.197	0.197
-2.069	-2.065	10.017	10.012	0.202	0.202
-2.522	-2.515	9.541	9.551	0.256	0.255
-2.381	-2.382	9.023	9.023	0.255	0.255
-2.320	-2.315	8.506	8.507	0.263	0.263
-2.579	-2.575	8.453	8.481	0.292	0.292
-1.701	-1.694	8.168	8.166	0.204	0.203
-2.076	-2.076	8.242	8.241	0.244	0.244
-1.598	-1.601	7.553	7.553	0.207	0.207
-1.078	-1.078	4.644	4.642	0.226	0.226
-0.565	-0.576	3.298	3.298	0.169	0.172
-0.520	-0.520	2.451	2.456	0.207	0.207

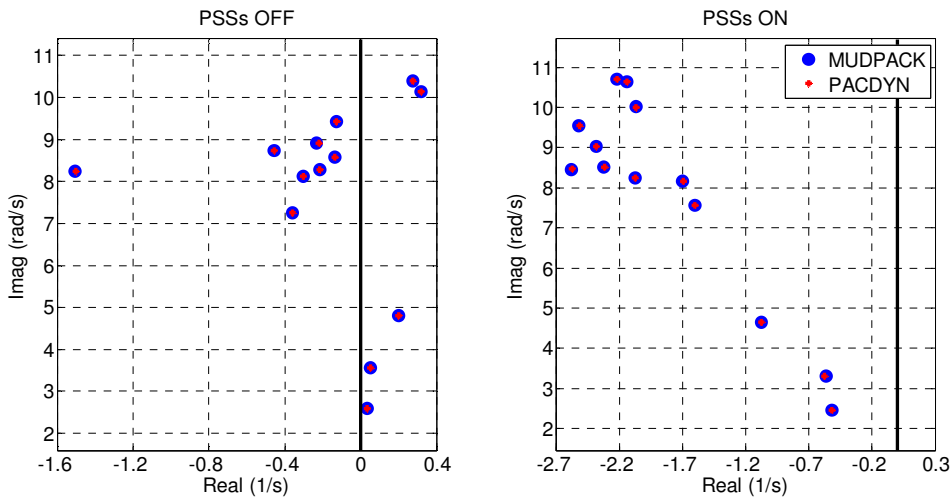

Figure 7 - Rotor modes of Case 6 in the complex plane

4. Transient Analysis

All the transient analyses performed in this report uses ANATEM®. This software also requires the dynamic data (in a formatted card file) and the network structure with the respective operating point, provided by ANAREDE®, as input data.

Three disturbances are simulated in this study and described as follows:

A. Two-phase-to-ground fault at Bus 209 at t = 0.5 s, and cleared in 100 ms without disconnecting any circuit elements;
B. Two-phase-to-ground fault at Bus 303 at t = 0.5 s, and cleared in 80 ms without disconnecting any circuit elements;
C. Two-phase-to-ground fault at Bus 506 at t = 0.5 s, and cleared in 100 ms without disconnecting any circuit elements.

The operating point of Case 2 is used for the simulations, with all generators stabilizers in service.

Rotor speed deviation, terminal voltage, active power and stabilizer output of all synchronous machines are shown in the plots contained in Appendix A of this document. For comparison purposes, in all plots the results of ANATEM® and PSS/E®[4] are superimposed. Analogously,terminal voltage and equivalent susceptance are also provided for all SVCs. It can be seen that the results exhibit a very satisfactory visual match, and the whole set of results shown in this reports contributes to the validation of the corresponding benchmark system.

5. References

[1] DRE - Departamento de Redes Elétricas, *Manual do Usuário: Programa de Análise de Redes V09.07*.05, CEPEL, 2011.

[2] DRE - Departamento de Redes Elétricas, *Manual do Usuário: Análise de Transitórios Eletromecânicos V10.04.06*, CEPEL, 2012.

[3] S. GOMES Jr, T. S. AMARAL, F. L. LÍRIO, *User's Manual: PacDyn Version 9.4*, CEPEL, 2012.

[4] Michael Gibbard and David Vowles, *"Simplified 14-generator model of the SE Australian power system,"* IEEE Task Force on Benchmark Systems for Stability Controls, June 2014.

Appendix A

A.1 Fault A

A.1.1 Generator HPS_1 – Bus 101

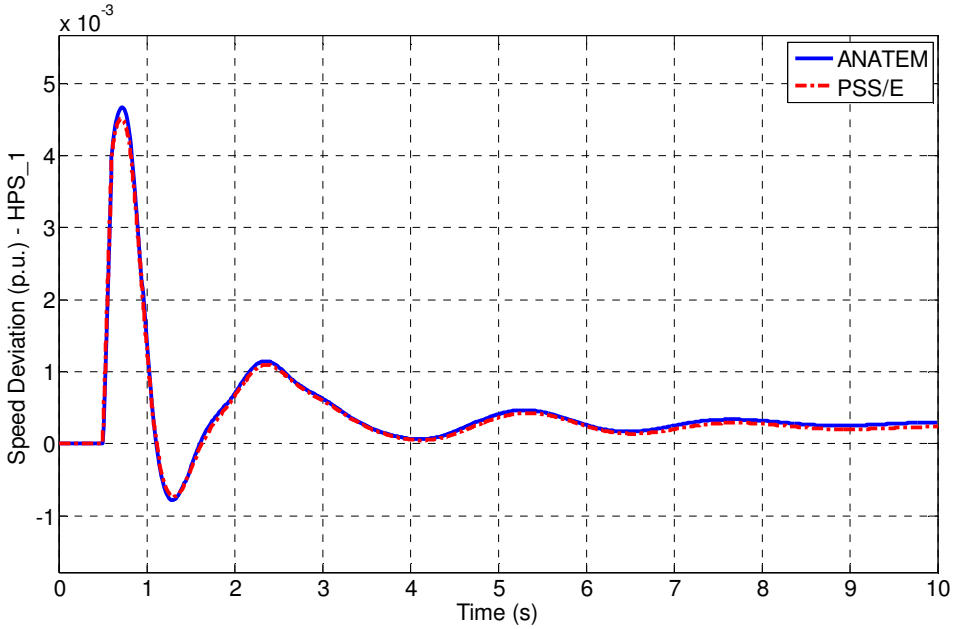

Figure 8 - Speed deviation of generator HPS_1 for Fault A

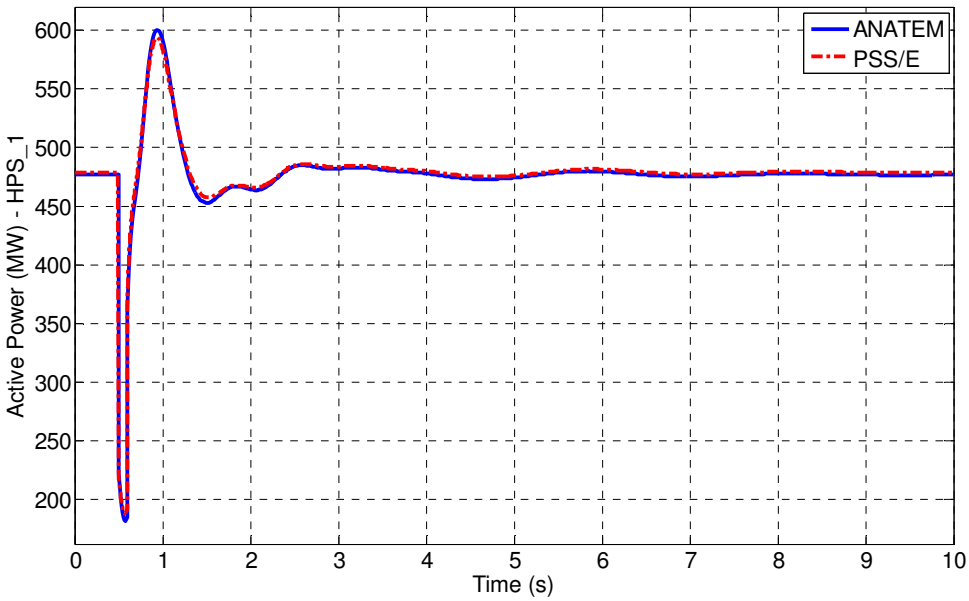

Figure 9 - Active power output of generator HPS_1 for Fault A

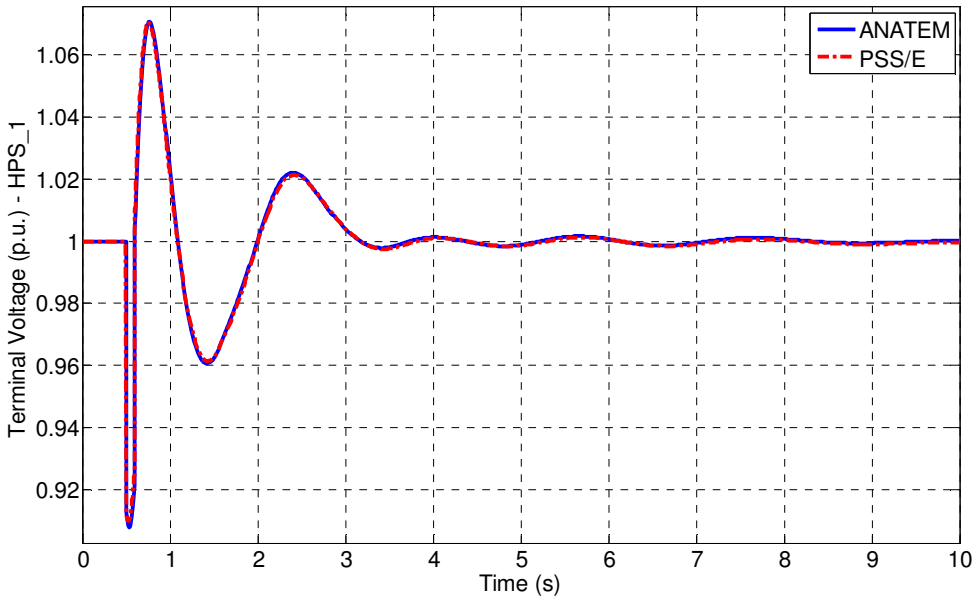

Figure 10 - Terminal voltage of generator HPS_1 for Fault A

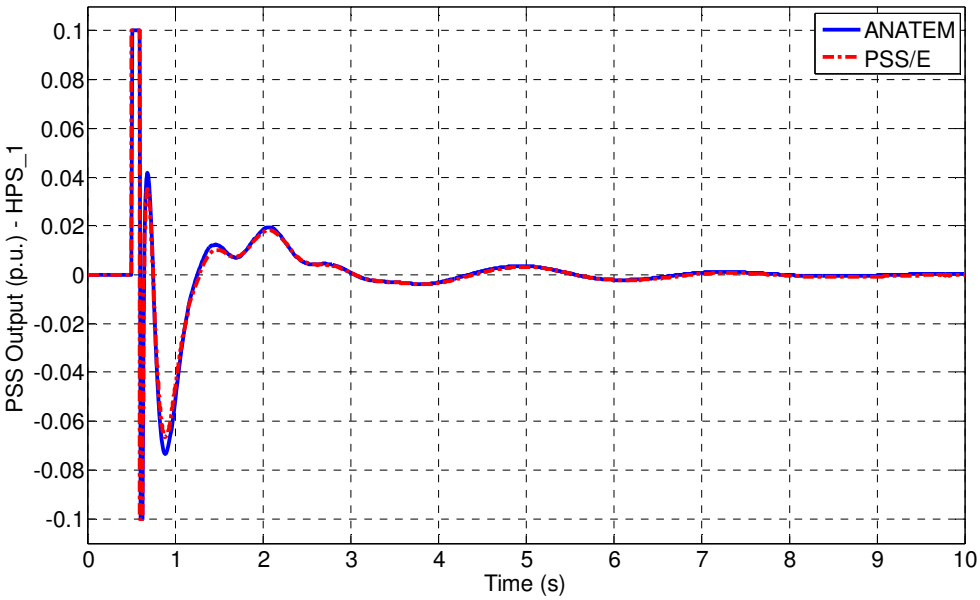

Figure 11 - PSS output of generator HPS_1 for Fault A

A.1.2 Generator BPS_2 – Bus 201

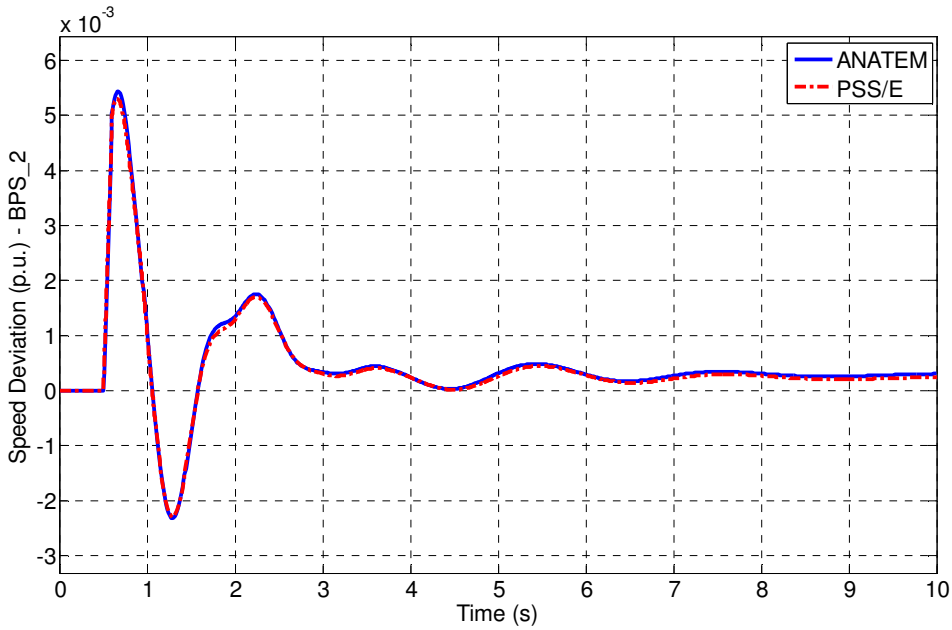

Figure 12 - Speed deviation of generator BPS_2 for Fault A

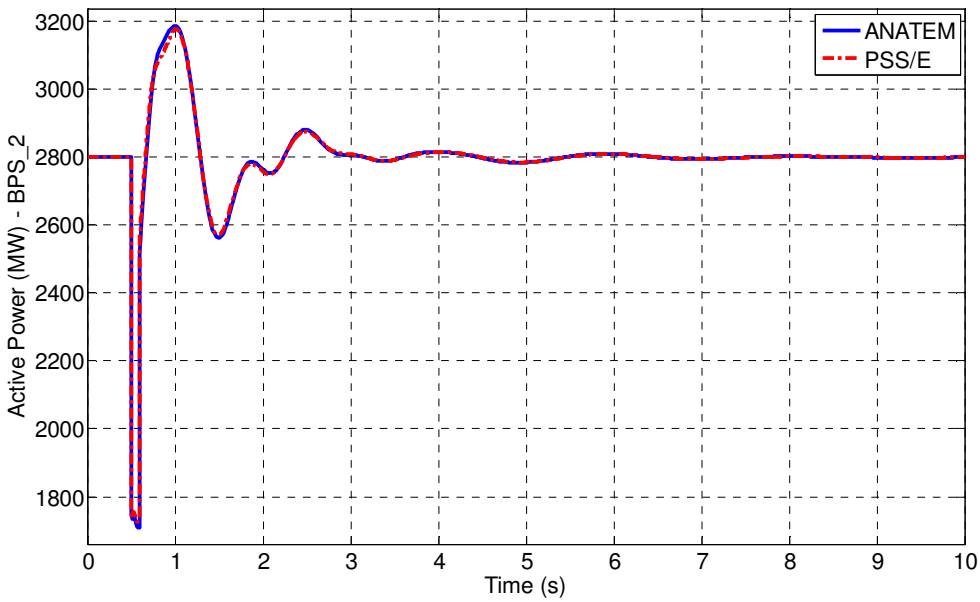

Figure 13 - Active power output of generator BPS_2 for Fault A

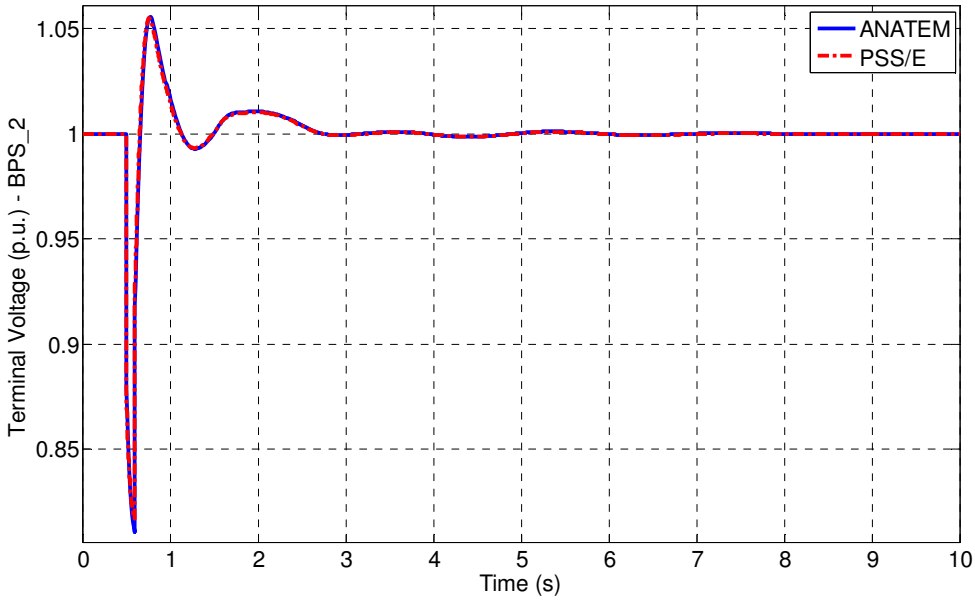

Figure 14 - Terminal voltage of generator BPS_2 for Fault A

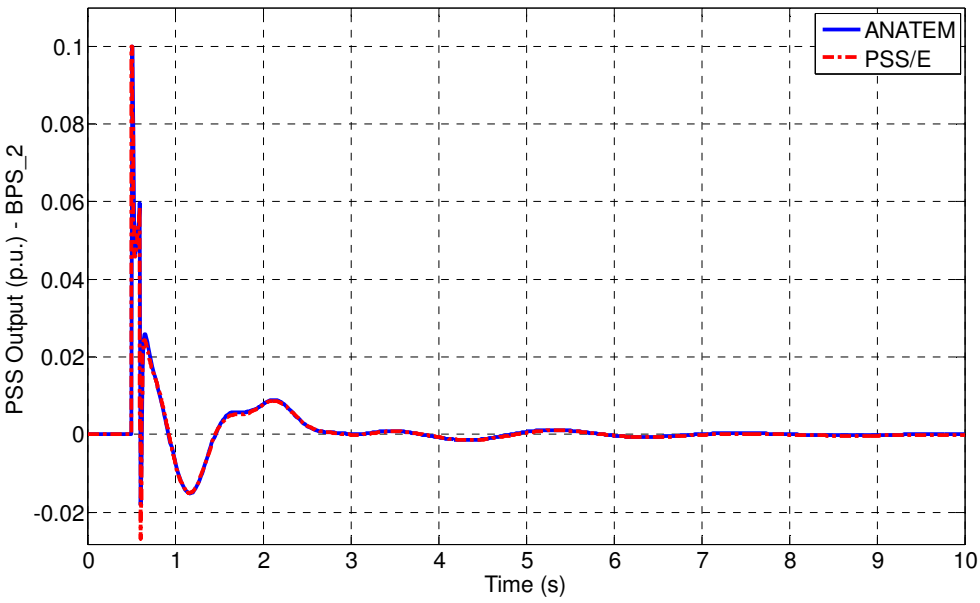

Figure 15 - PSS output of generator BPS_2 for Fault A

A.1.3 Generator EPS_2 – Bus 202

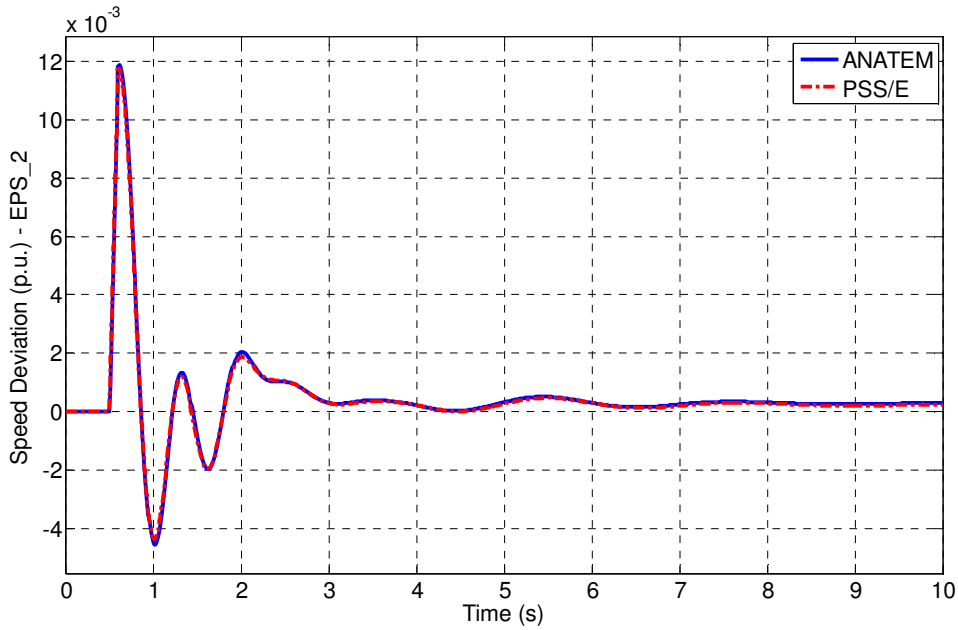

Figure 16 - Speed deviation of generator EPS_2 for Fault A

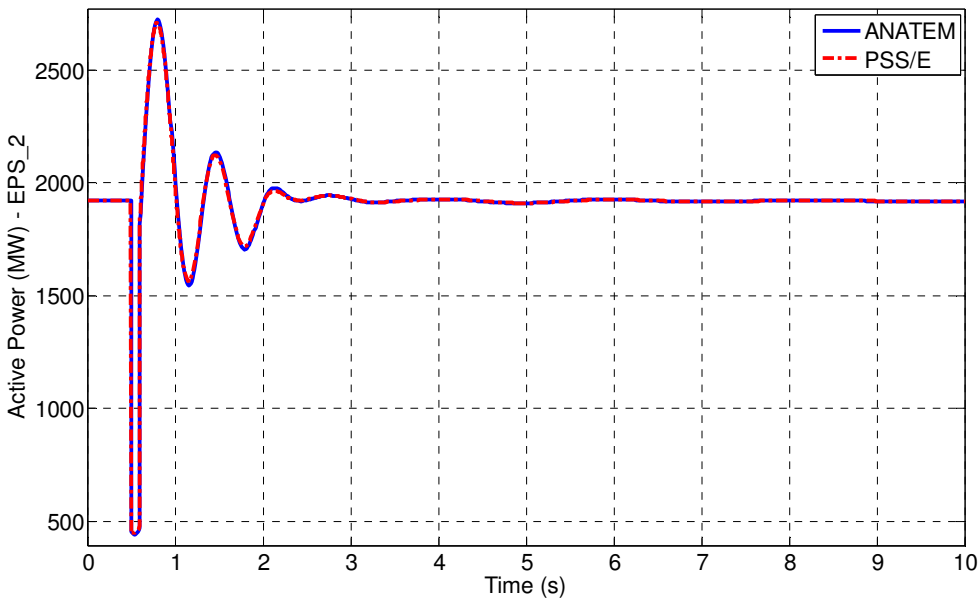

Figure 17 - Active power output of generator EPS_2 for Fault A

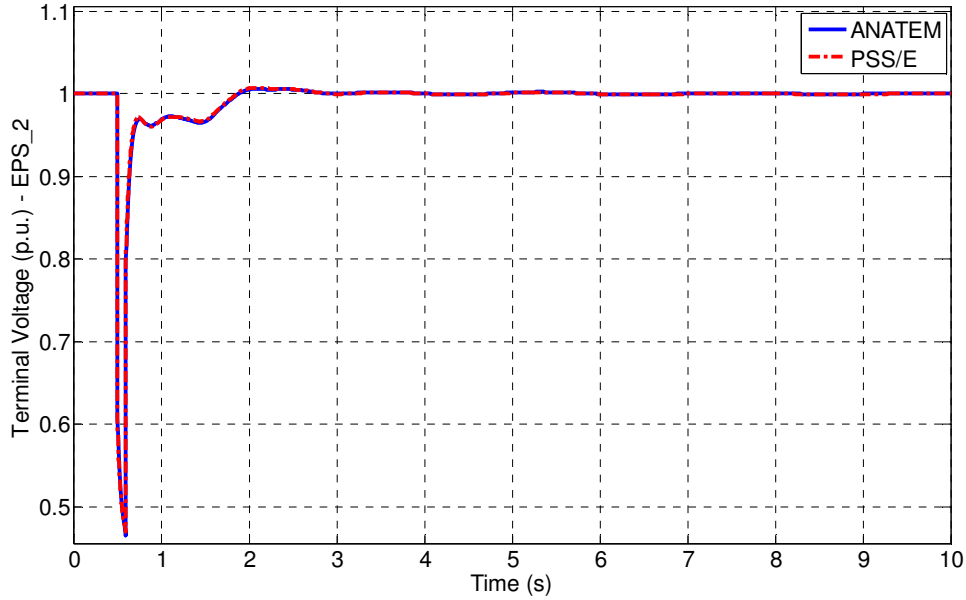

Figure 18 - Terminal voltage of generator EPS_2 for Fault A

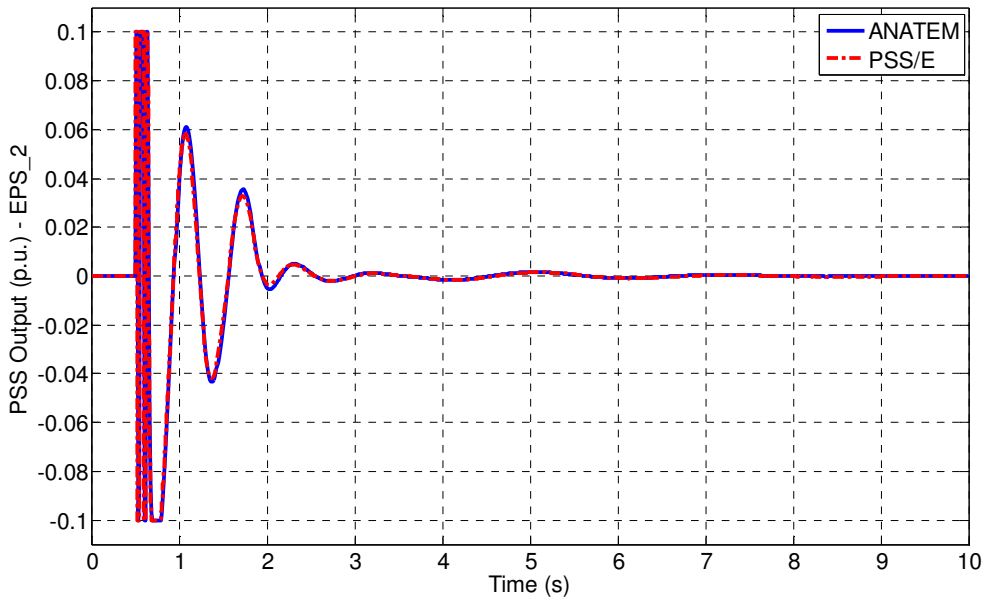

Figure 19 - PSS output of generator EPS_2 for Fault A

A.1.4 Generator VPS_2 – Bus 203

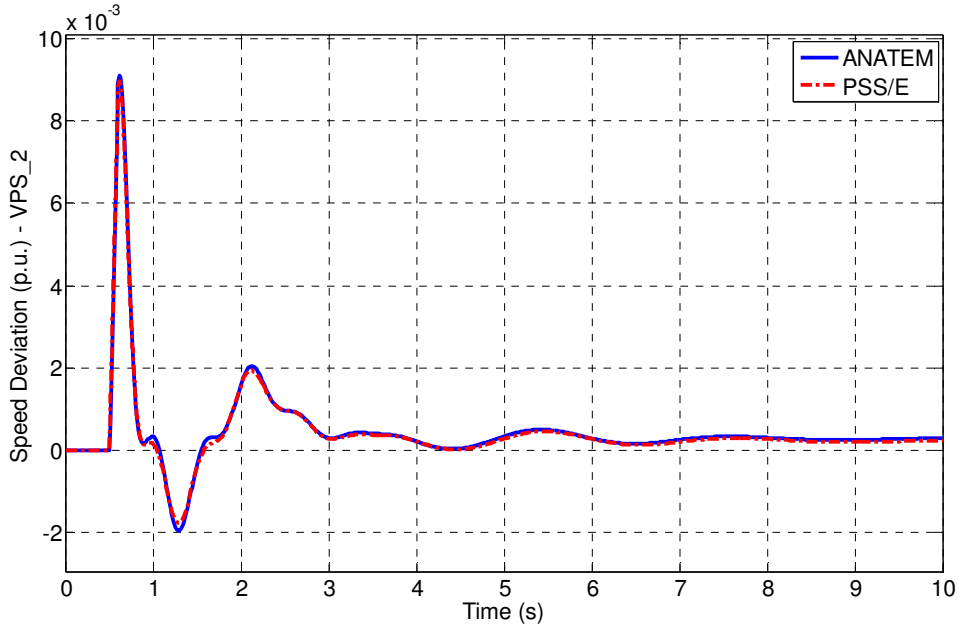

Figure 20 - Speed deviation of generator VPS_2 for Fault A

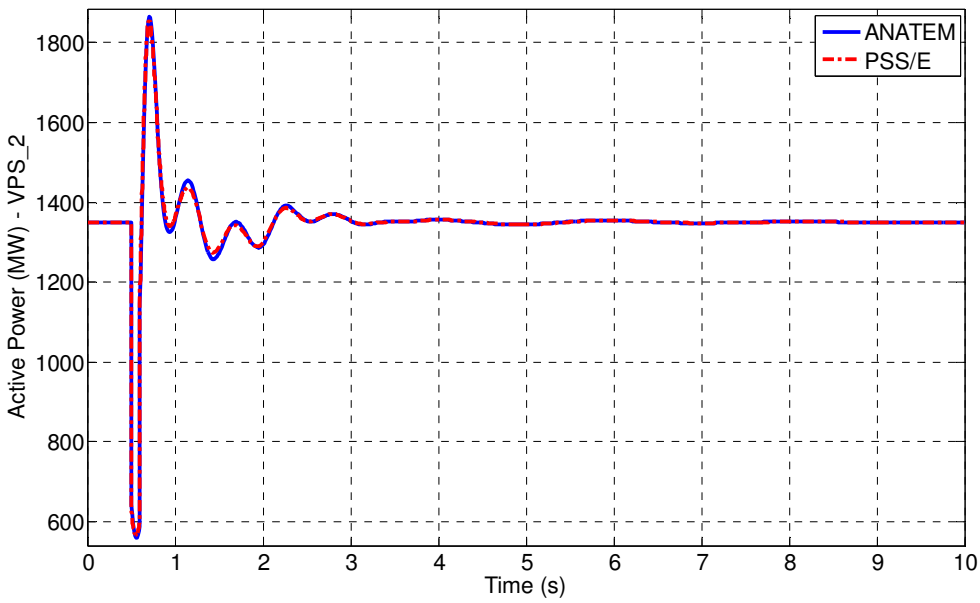

Figure 21 - Active power output of generator VPS_2 for Fault A

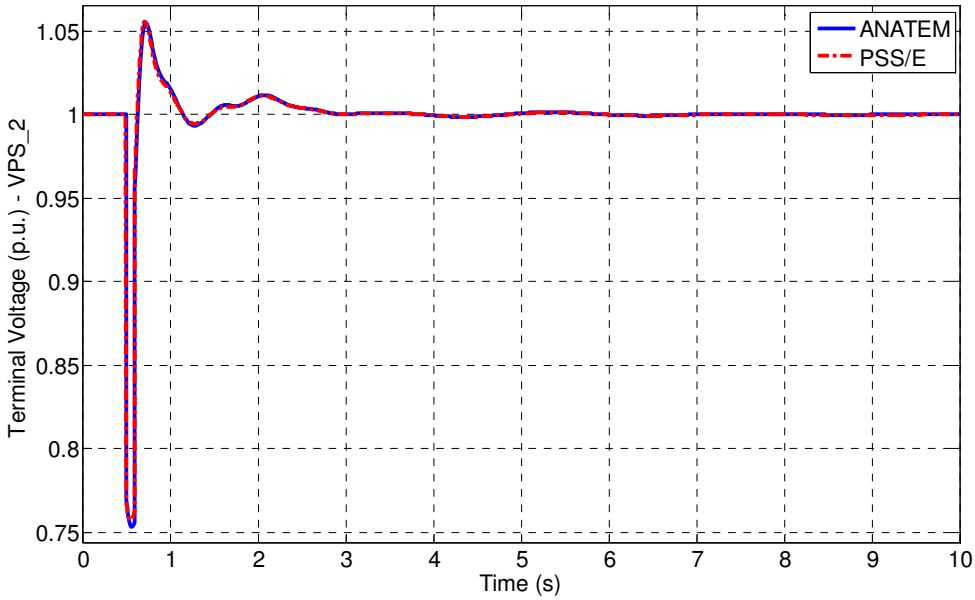

Figure 22 - Terminal voltage of generator VPS_2 for Fault A

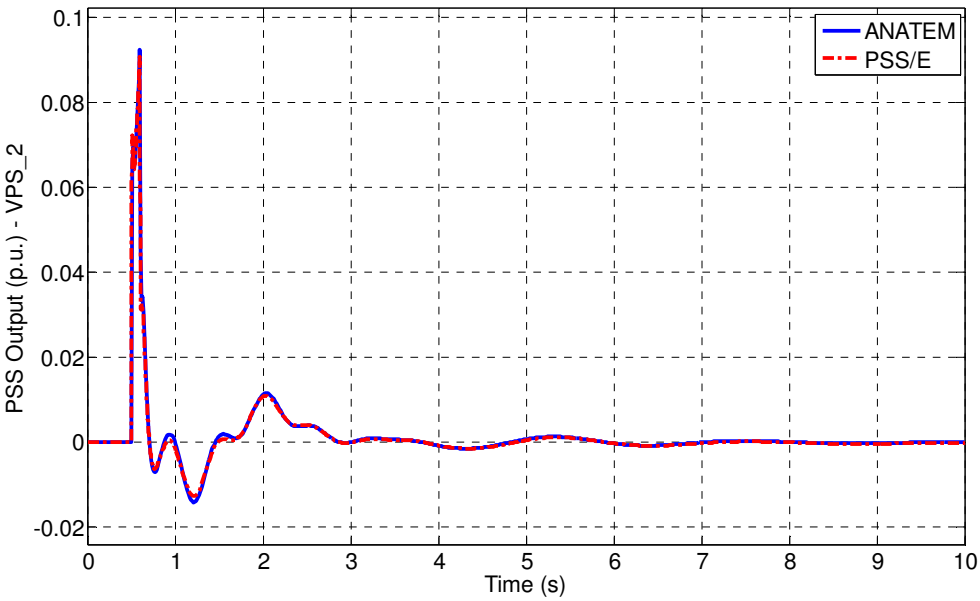

Figure 23 - PSS output of generator VPS_2 for Fault A

A.1.5 Generator MPS_2 – Bus 204

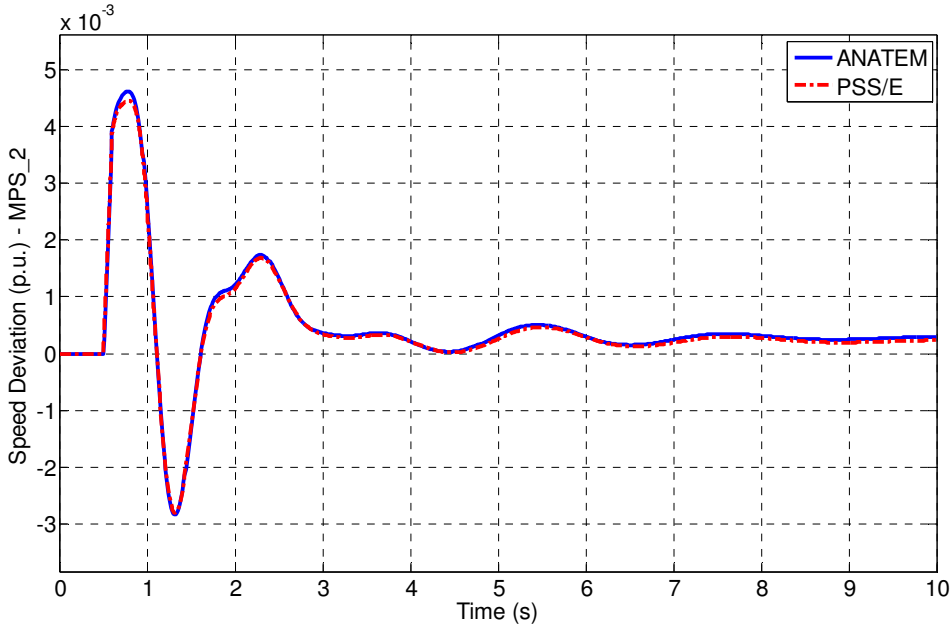

Figure 24 - Speed deviation of generator MPS_2 for Fault A

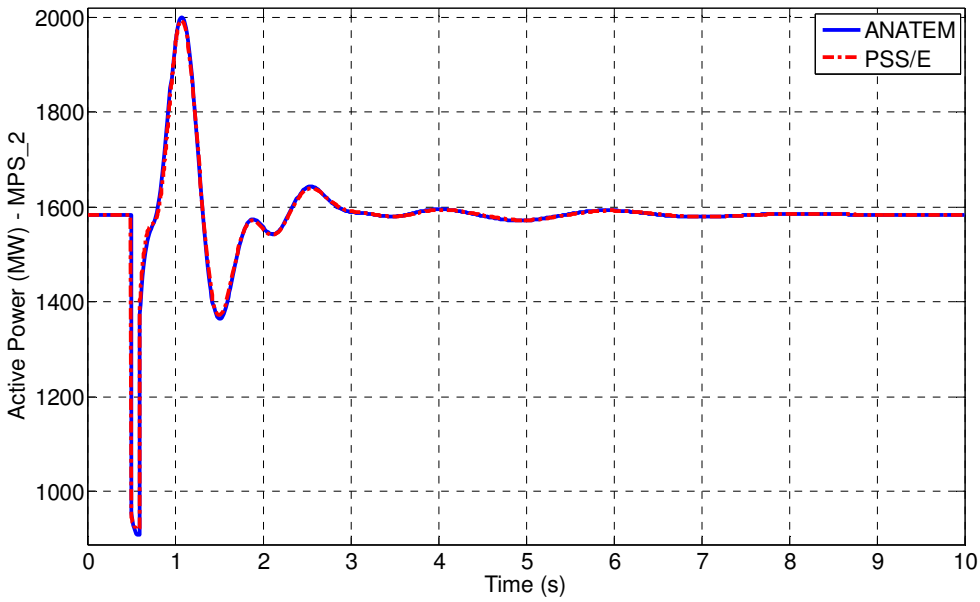

Figure 25 - Active power output of generator MPS_2 for Fault A

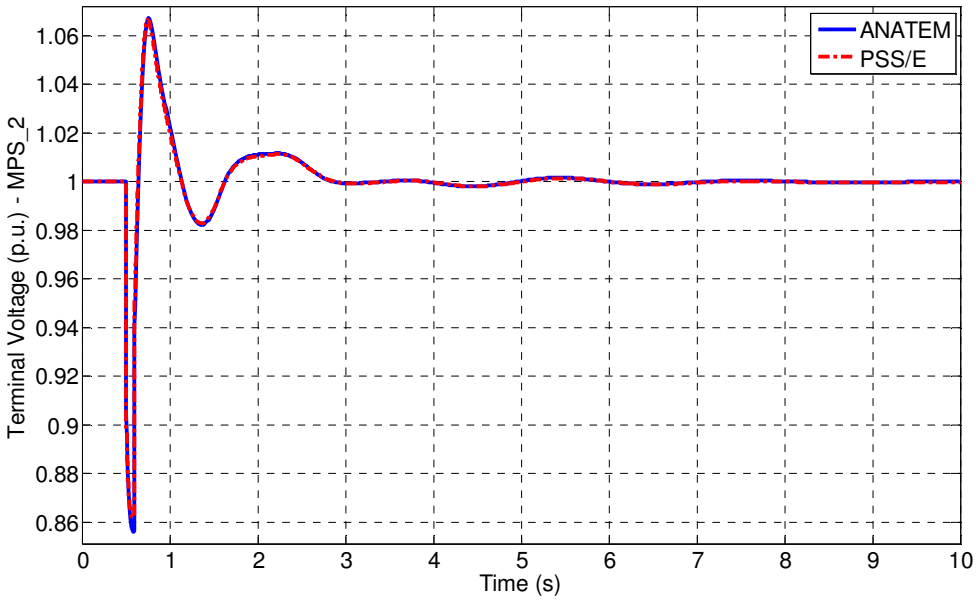

Figure 26 - Terminal voltage of generator MPS_2 for Fault A

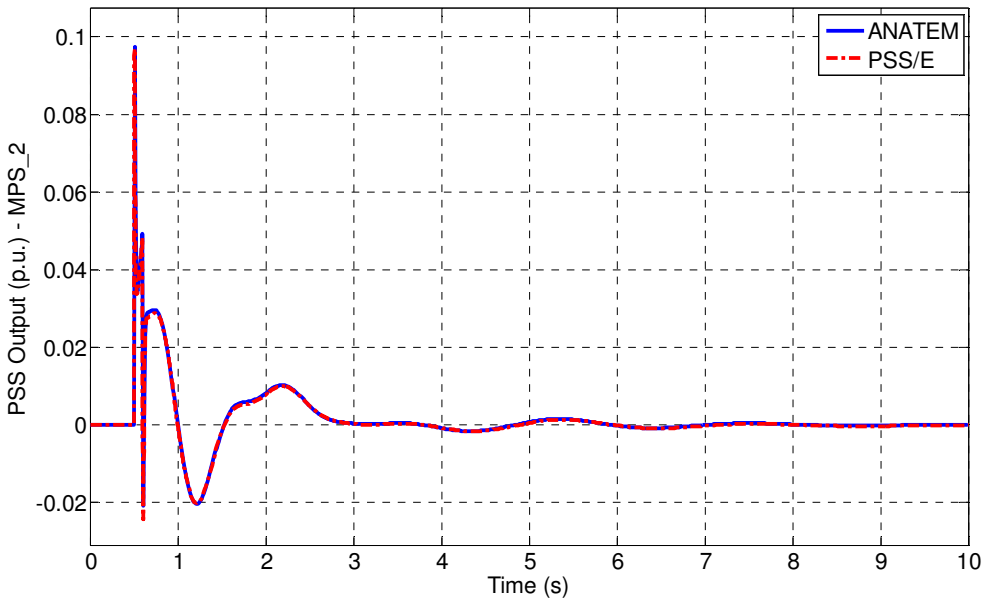

Figure 27 - PSS output of generator MPS_2 for Fault A

A.1.6 Generator LPS_3 – Bus 301

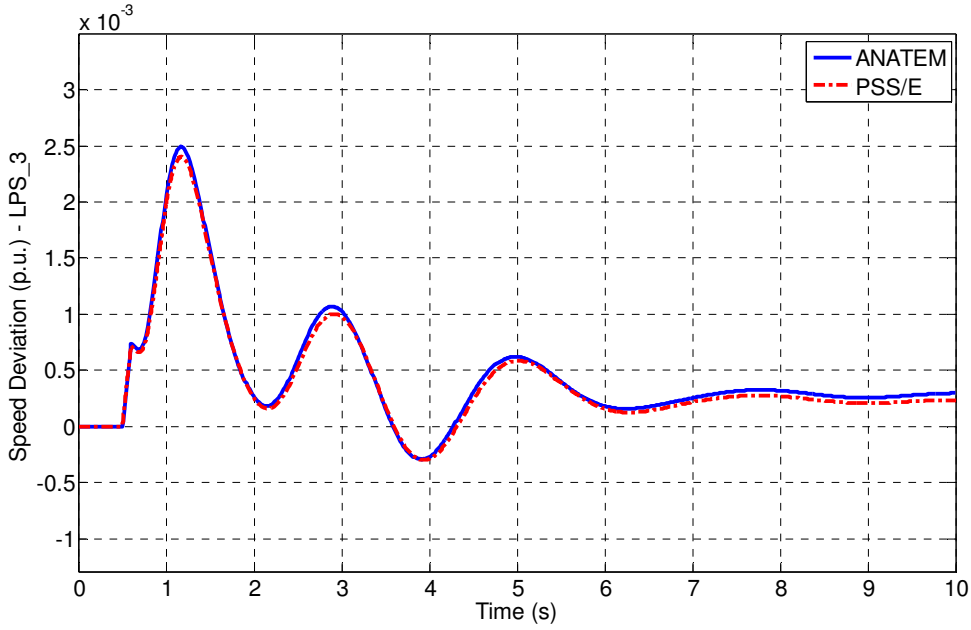

Figure 28 - Speed deviation of generator LPS_3 for Fault A

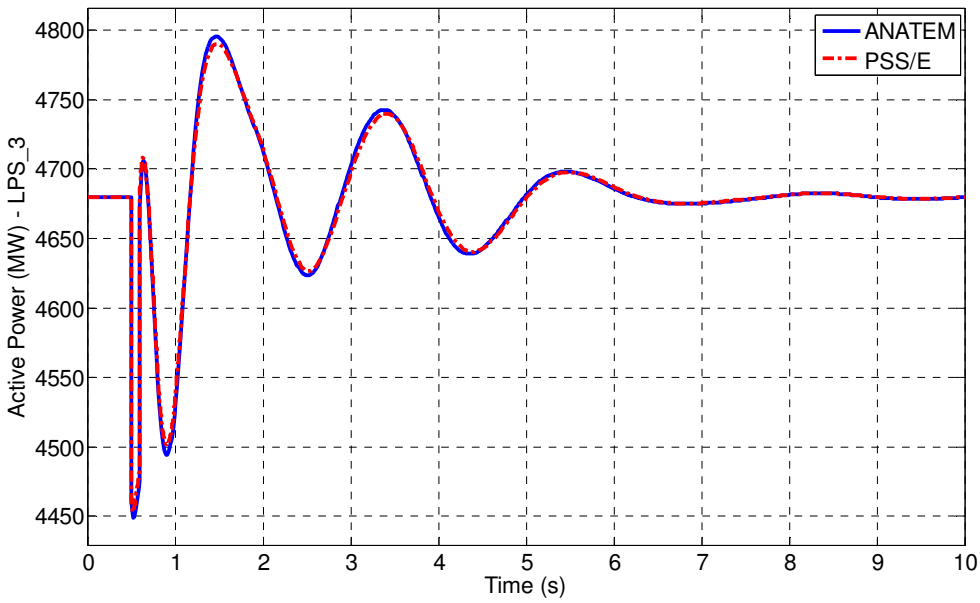

Figure 29 - Active power output of generator LPS_3 for Fault A

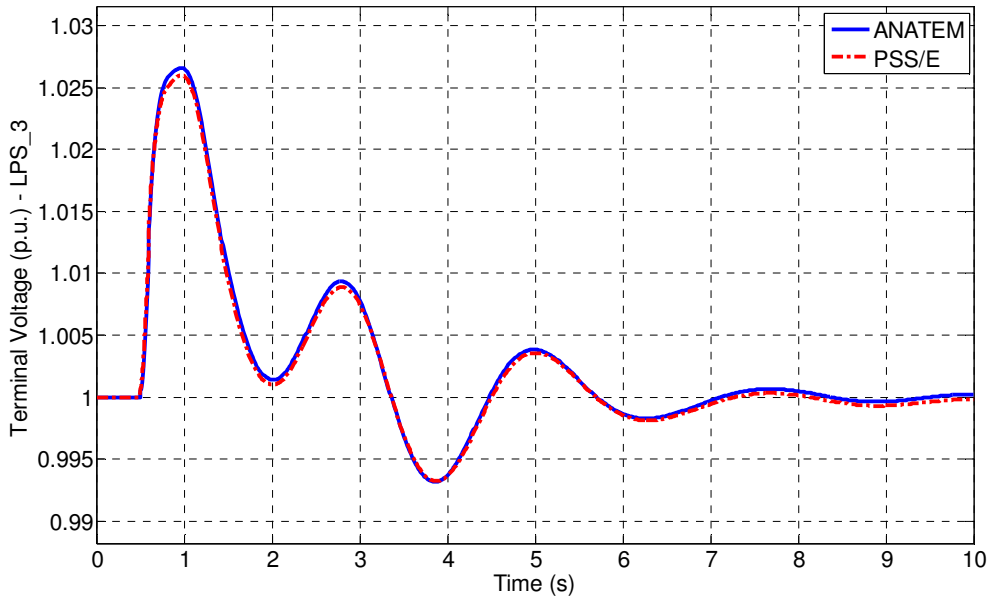

Figure 30 - Terminal voltage of generator LPS_3 for Fault A

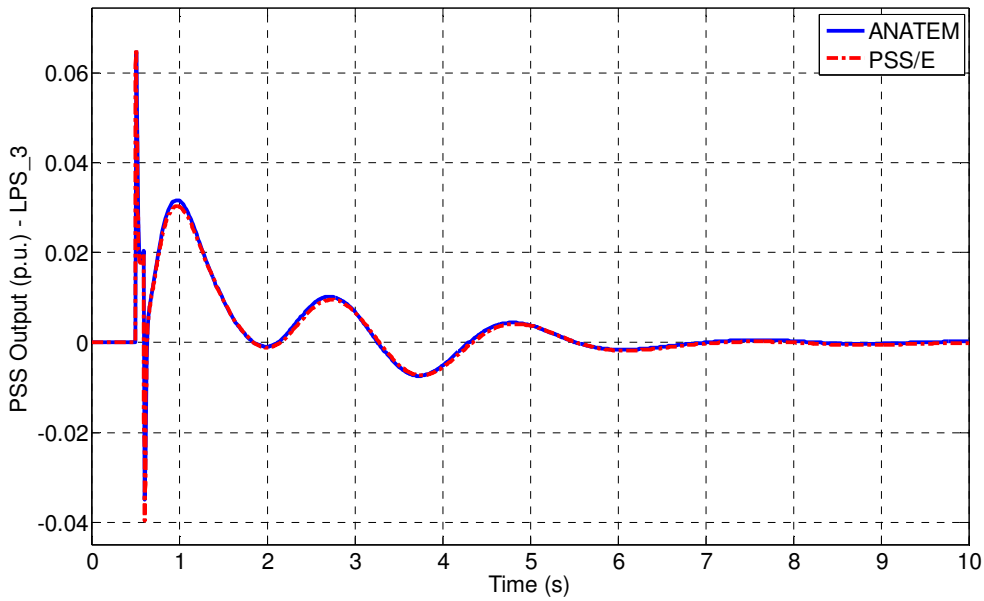

Figure 31 - PSS output of generator LPS_3 for Fault A

A.1.7 Generator YPS_3 – Bus 302

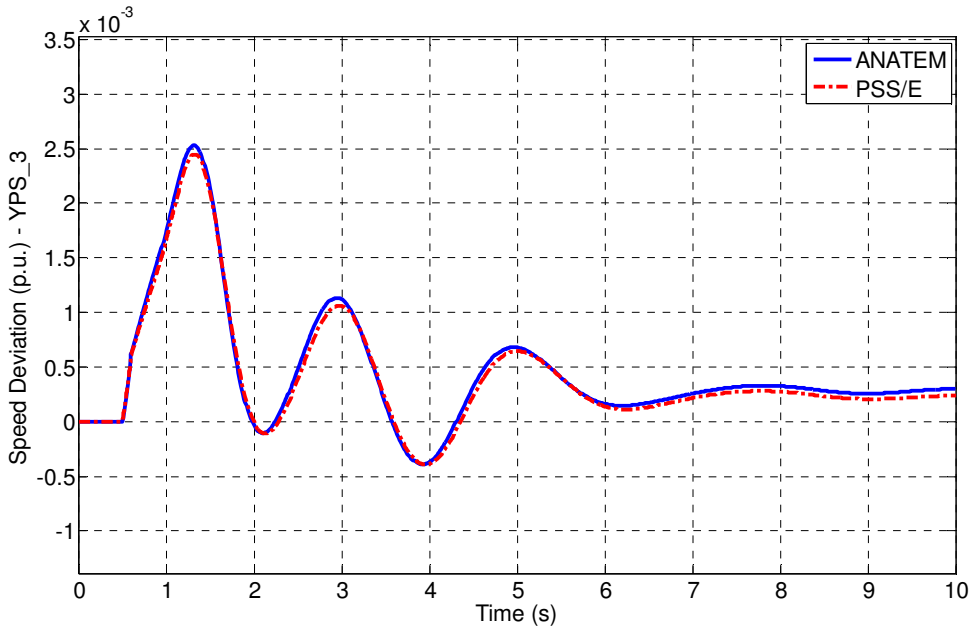

Figure 32 - Speed deviation of generator YPS_3 for Fault A

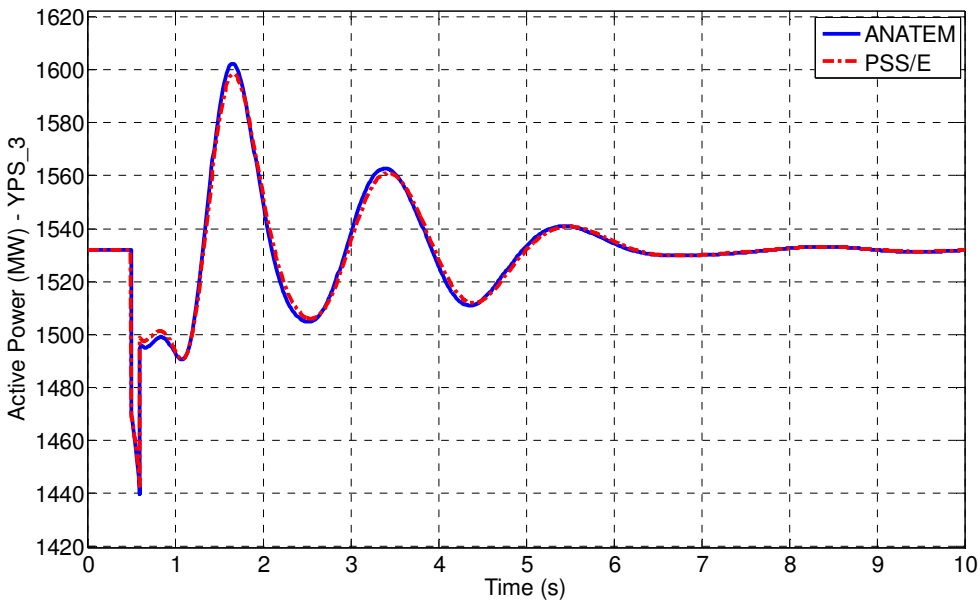

Figure 33 - Active power output of generator YPS_3 for Fault A

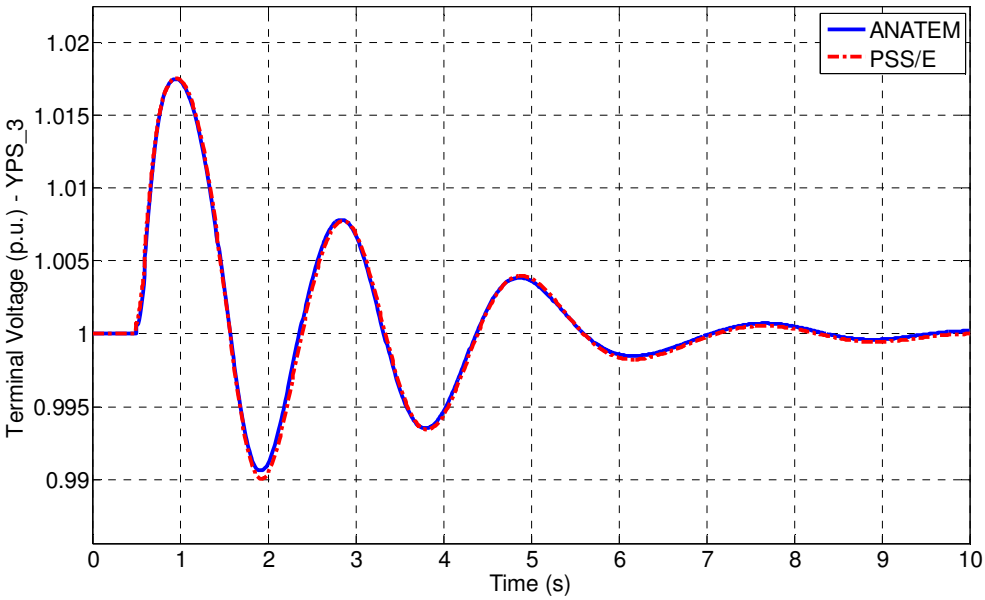

Figure 34 - Terminal voltage of generator YPS_3 for Fault A

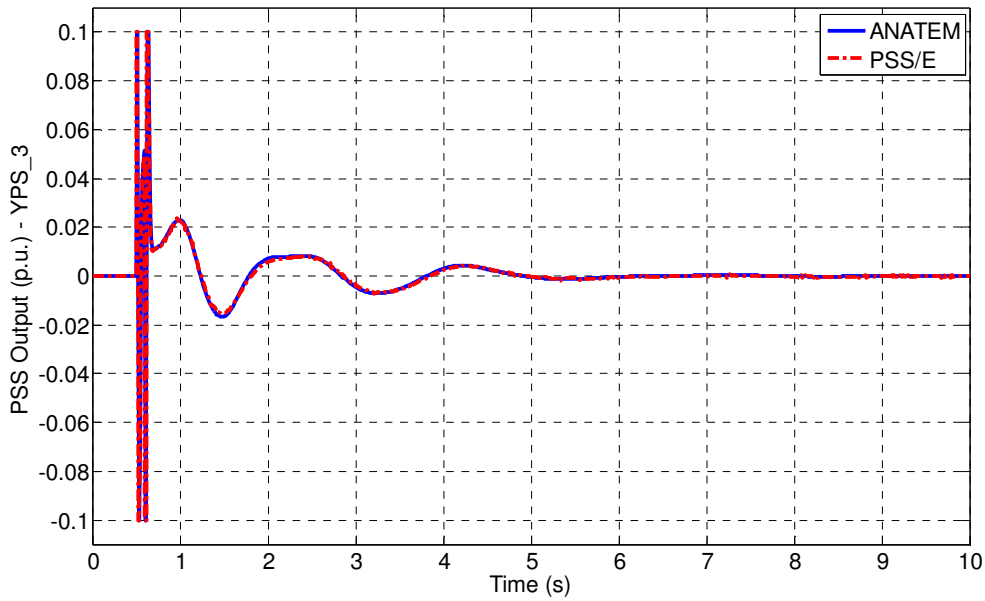

Figure 35 - PSS output of generator YPS_3 for Fault A

A.1.8 Generator TPS_4 – Bus 401

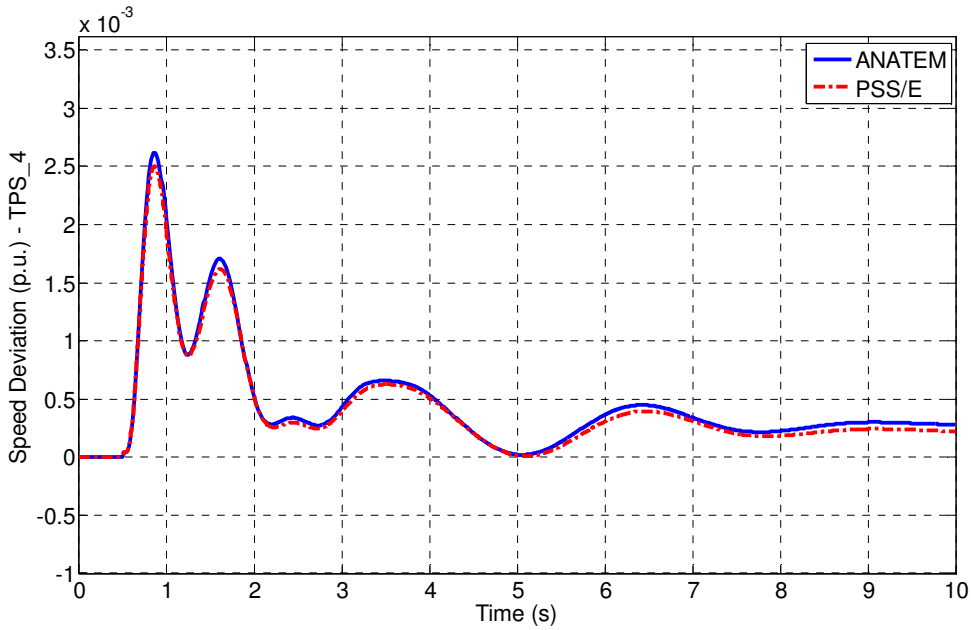

Figure 36 - Speed deviation of generator TPS_4 for Fault A

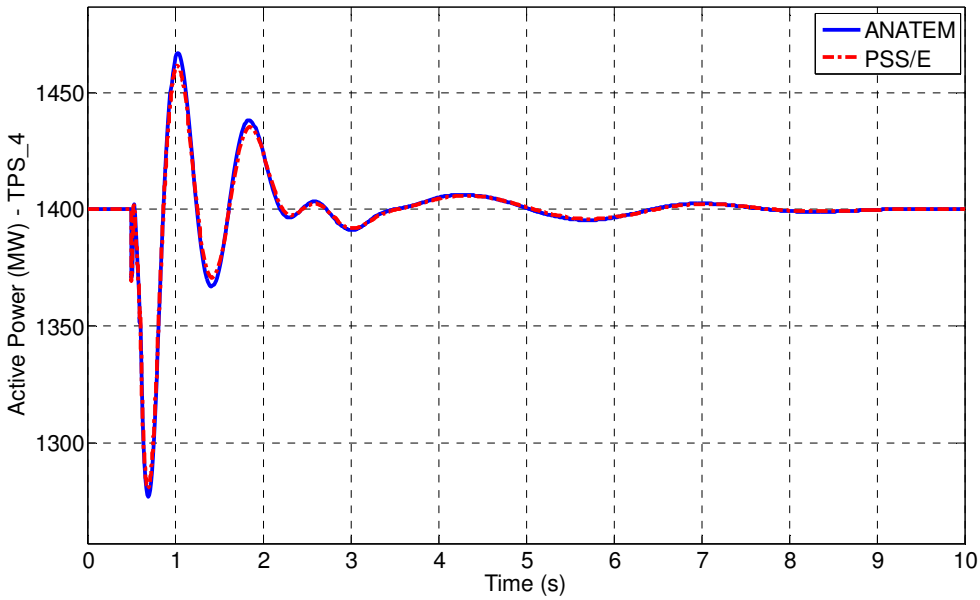

Figure 37 - Active power output of generator TPS_4 for Fault A

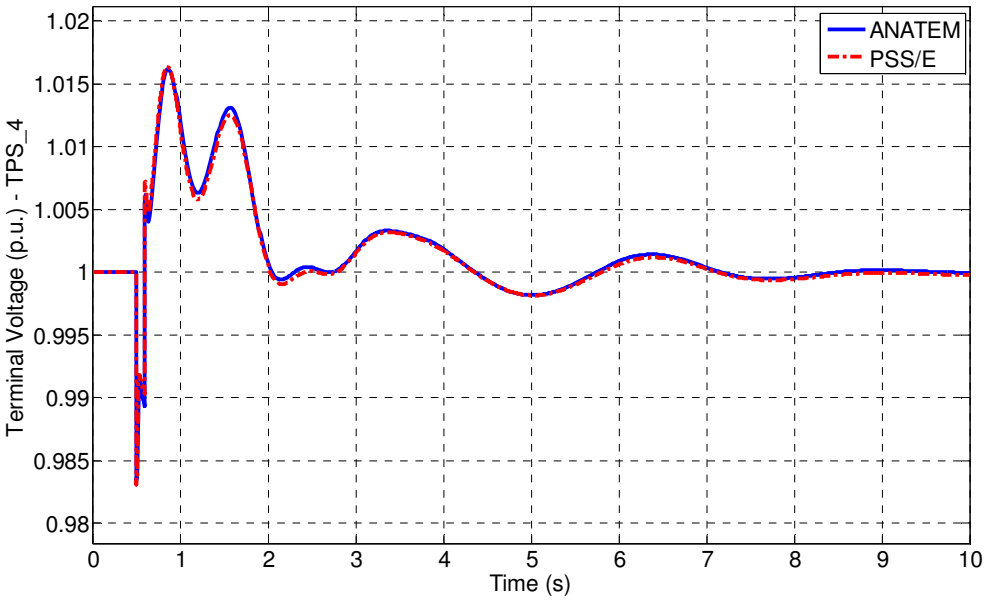

Figure 38 - Terminal voltage of generator TPS_4 for Fault A

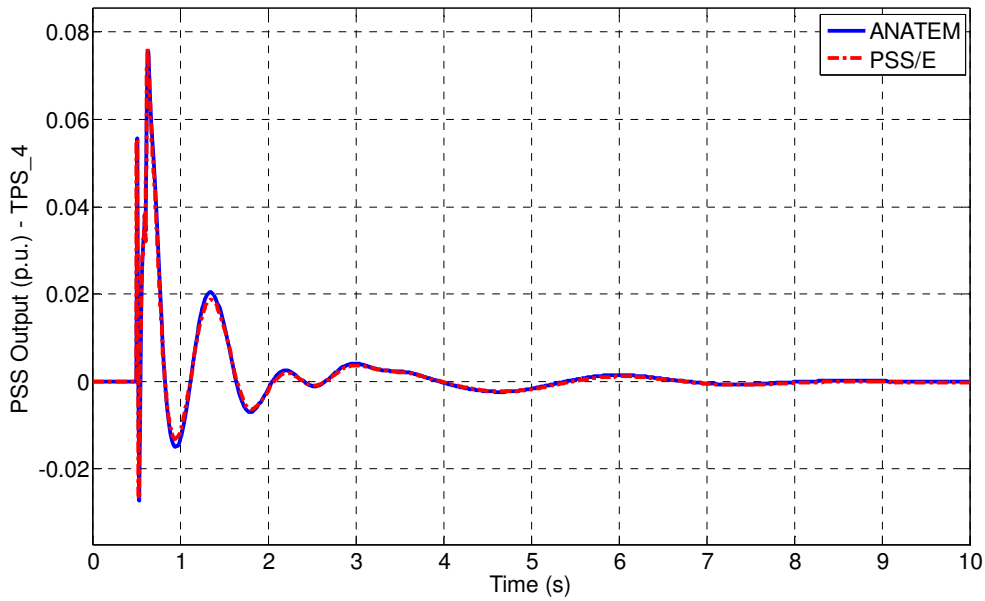

Figure 39 - PSS output of generator TPS_4 for Fault A

A.1.9 Generator CPS_4 – Bus 402

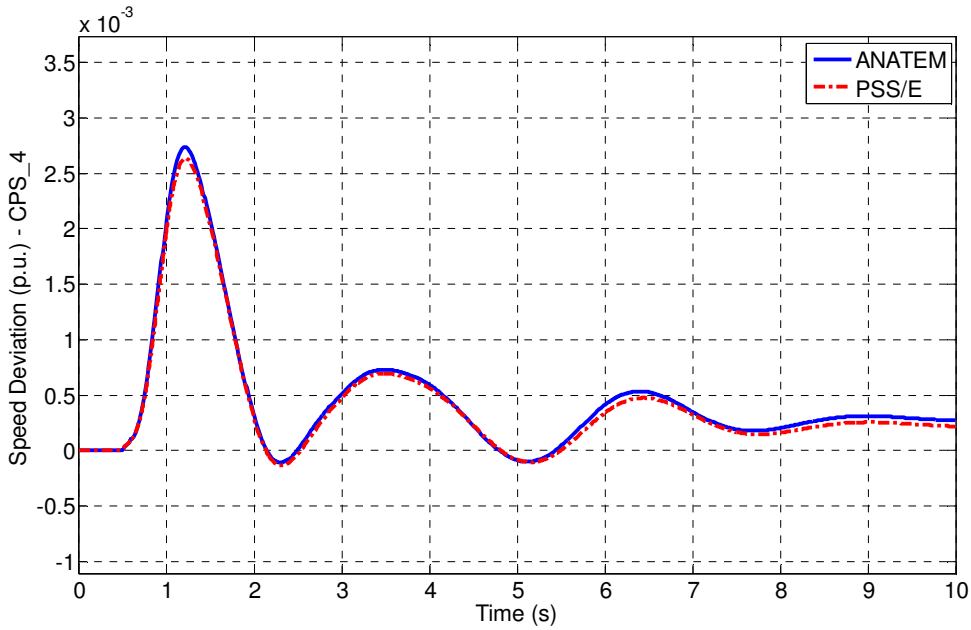

Figure 40 - Speed deviation of generator CPS_4 for Fault A

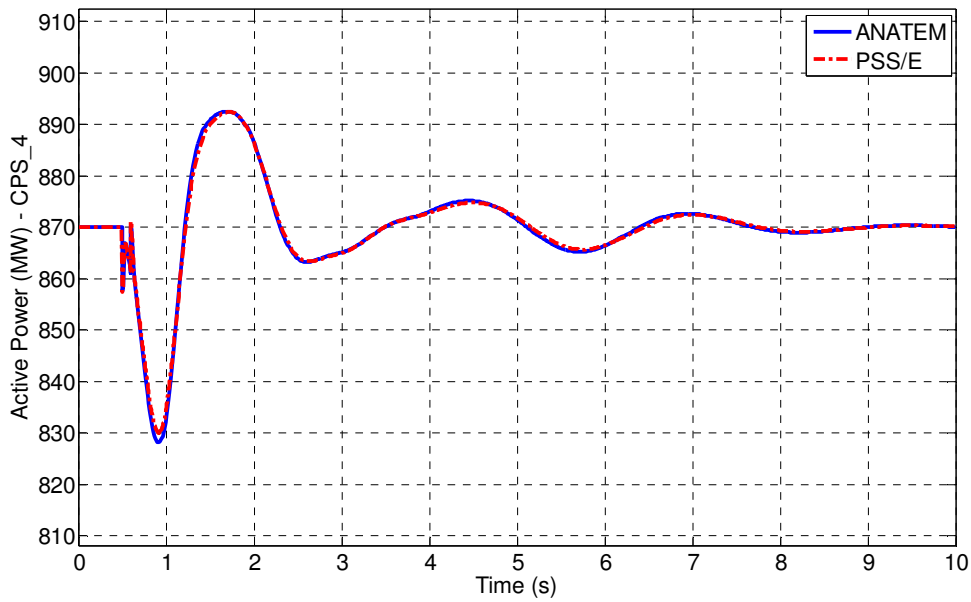

Figure 41 - Active power output of generator CPS_4 for Fault A

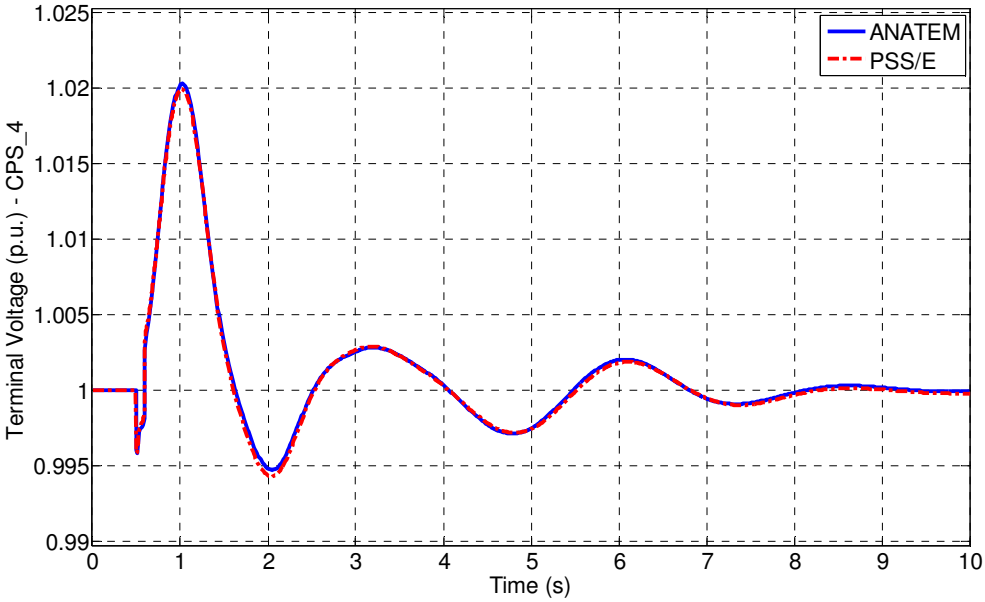

Figure 42 - Terminal voltage of generator CPS_4 for Fault A

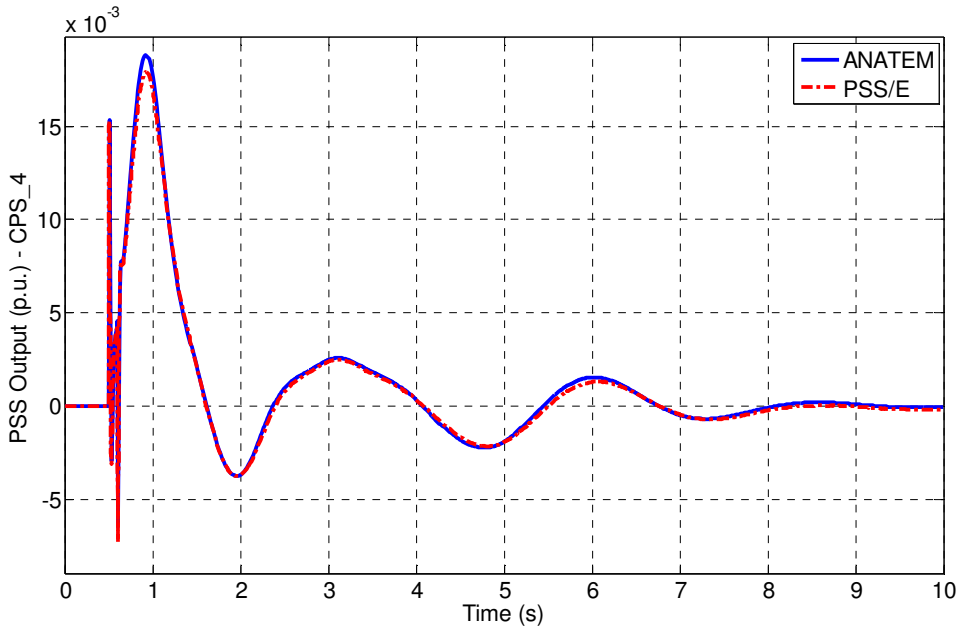

Figure 43 - PSS output of generator CPS_4 for Fault A

A.1.10 Generator SPS_4 – Bus 403

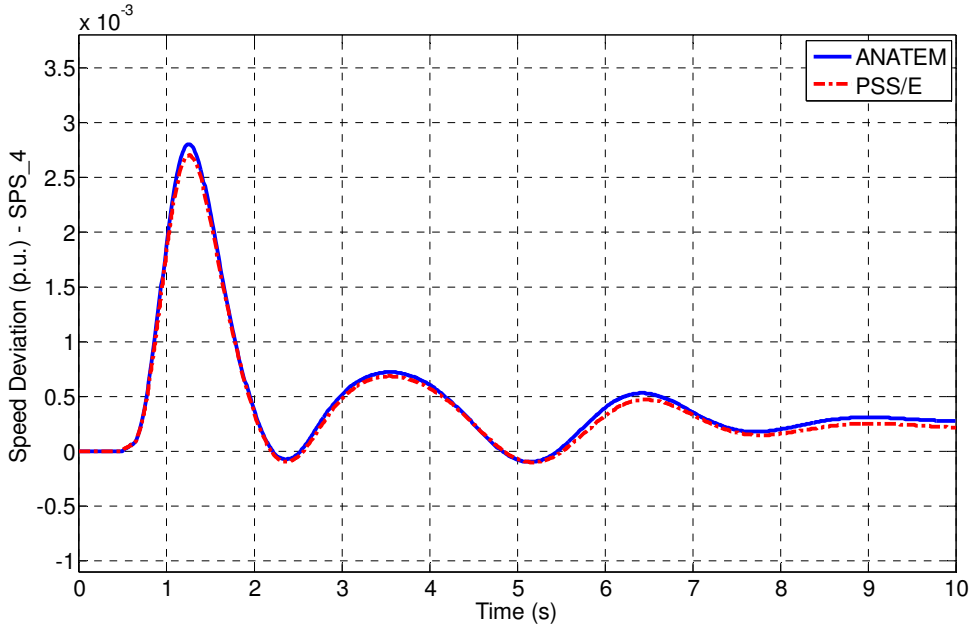

Figure 44 - Speed deviation of generator SPS_4 for Fault A

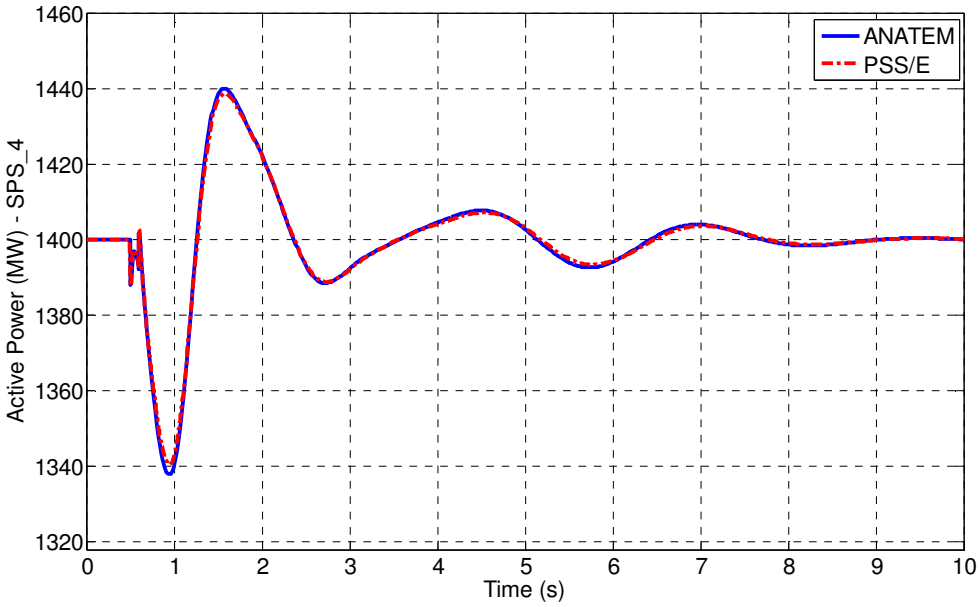

Figure 45 - Active power output of generator SPS_4 for Fault A

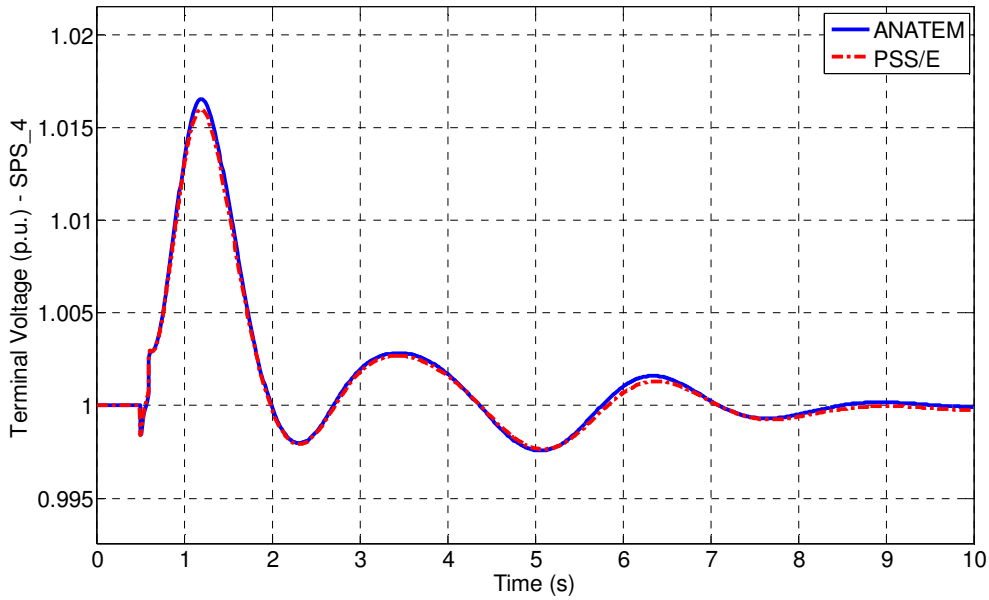

Figure 46 - Terminal voltage of generator SPS_4 for Fault A

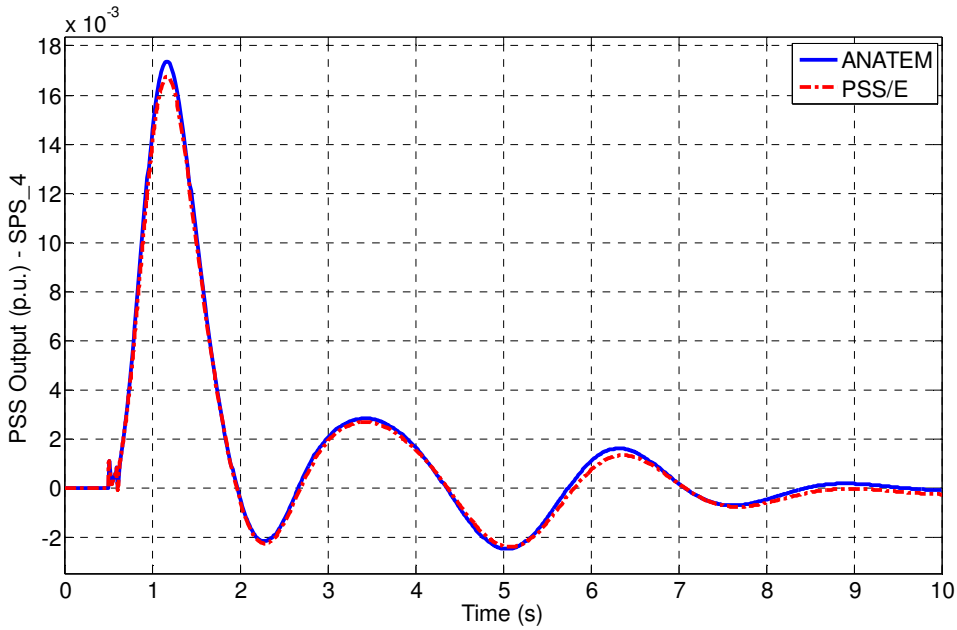

Figure 47 - PSS output of generator SPS_4 for Fault A

A.1.11 Generator GPS_4 – Bus 404

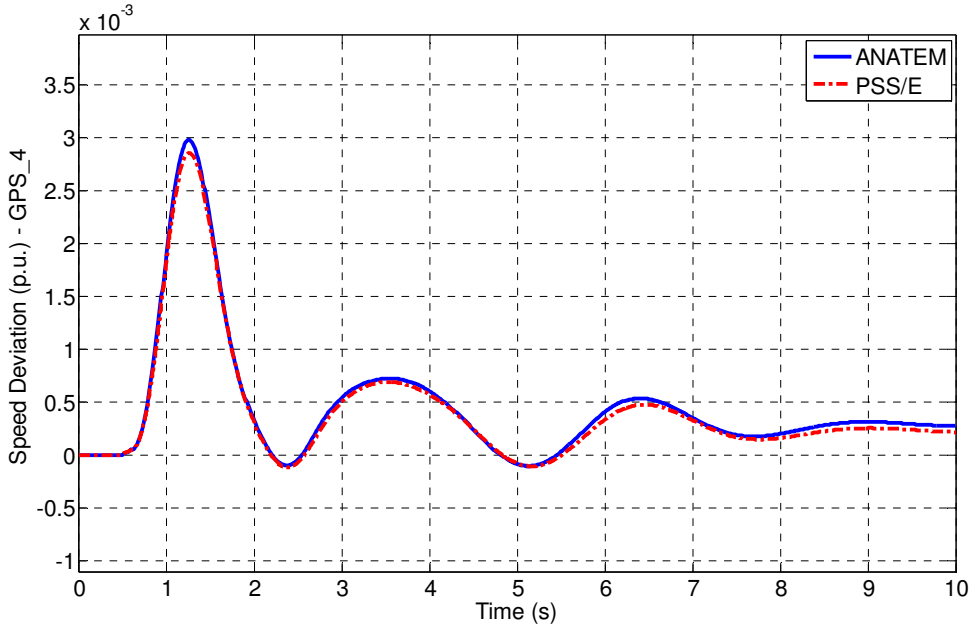

Figure 48 - Speed deviation of generator GPS_4 for Fault A

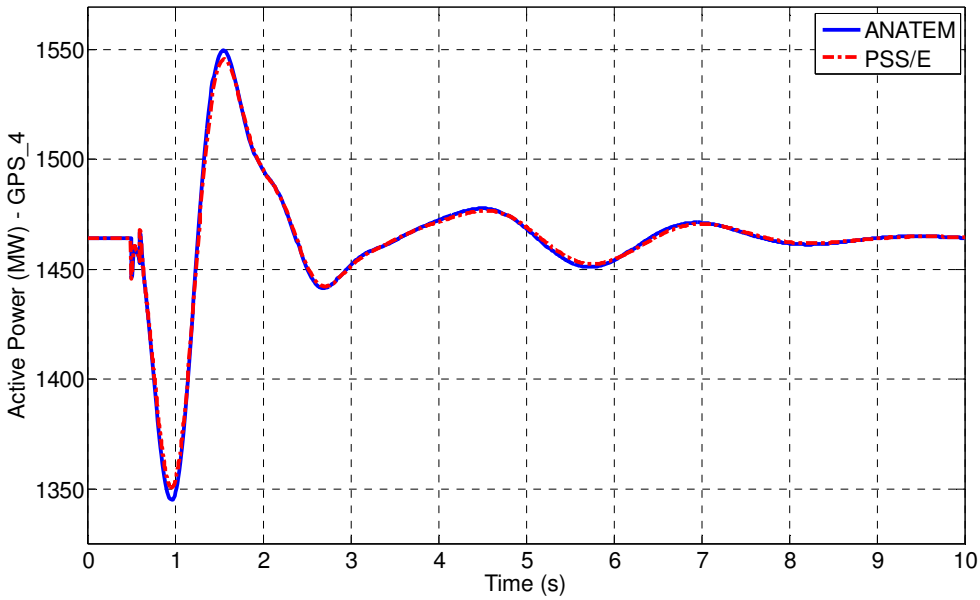

Figure 49 - Active power output of generator GPS_4 for Fault A

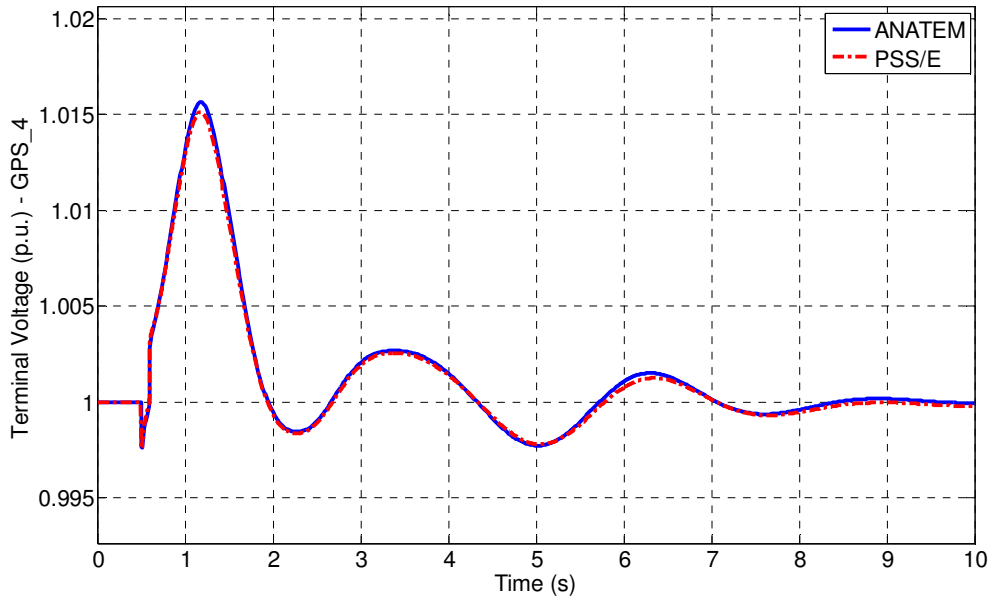

Figure 50 - Terminal voltage of generator GPS_4 for Fault A

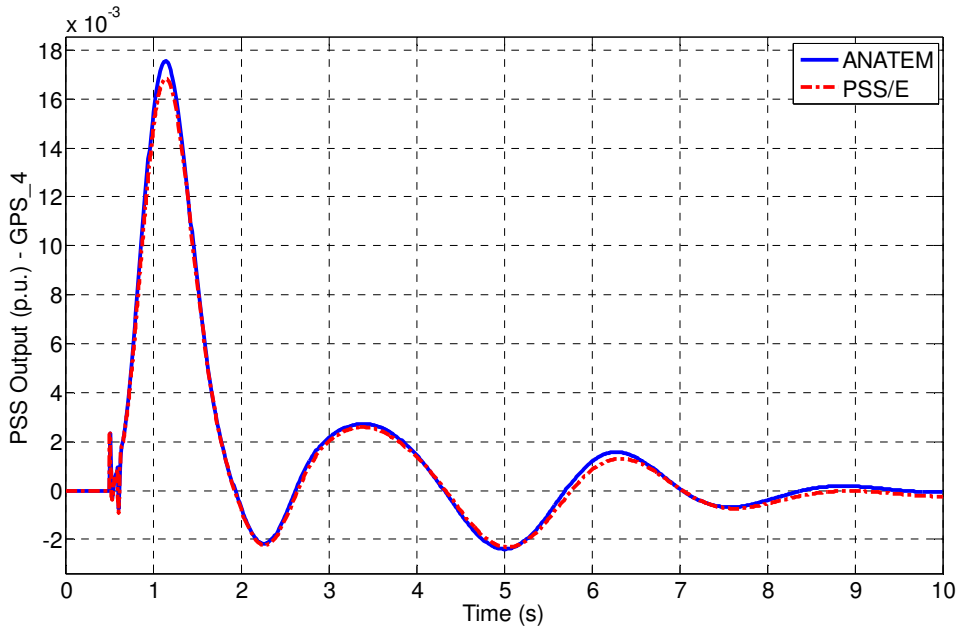

Figure 51 - PSS output of generator GPS_4 for Fault A

A.1.12 Generator NPS_5 – Bus 501

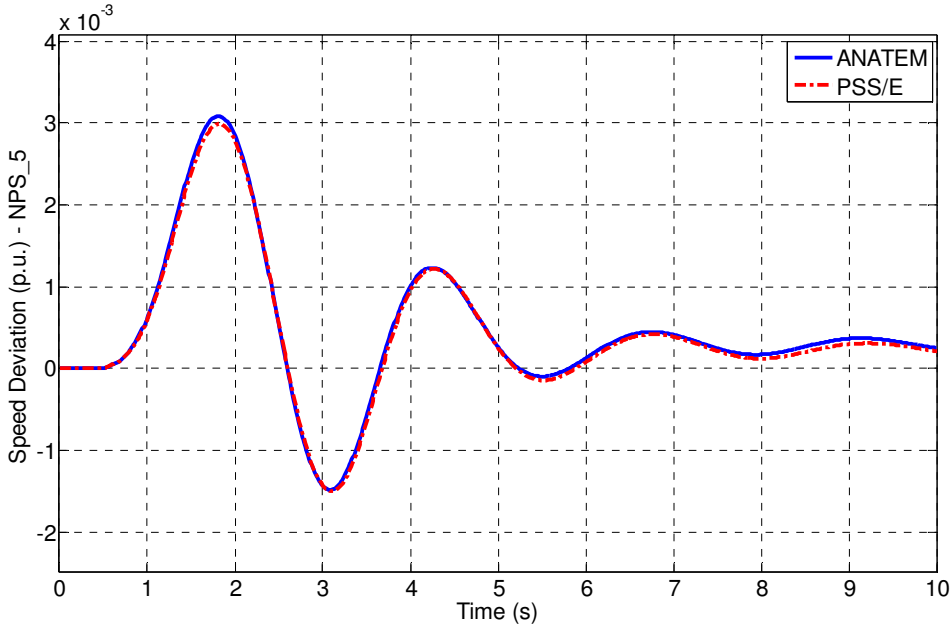

Figure 52 - Speed deviation of generator NPS_5 for Fault A

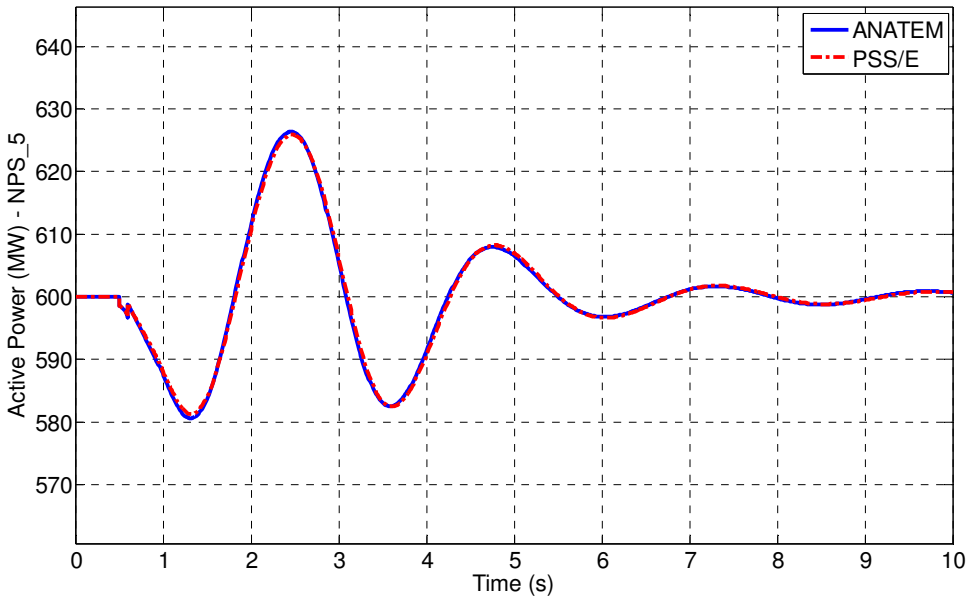

Figure 53 - Active power output of generator NPS_5 for Fault A

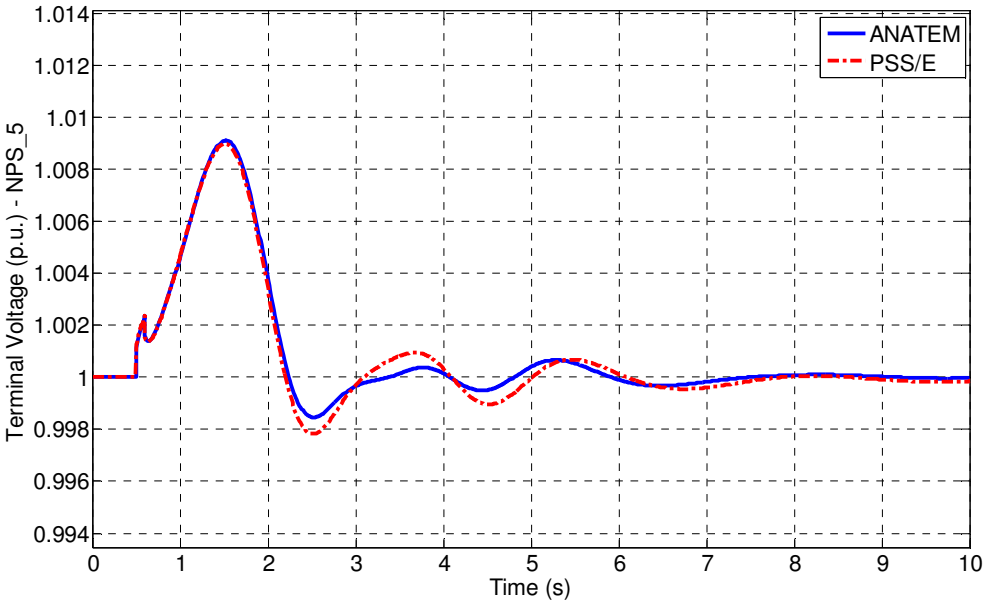

Figure 54 - Terminal voltage of generator NPS_5 for Fault A

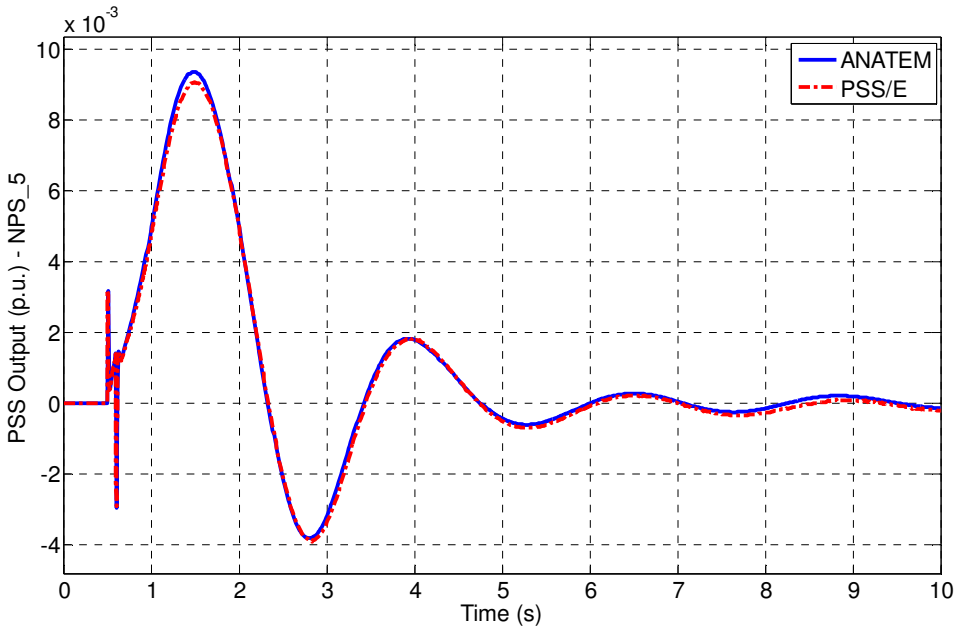

Figure 55 - PSS output of generator NPS_5 for Fault A

A.1.13 Generator TPS_5 – Bus 502

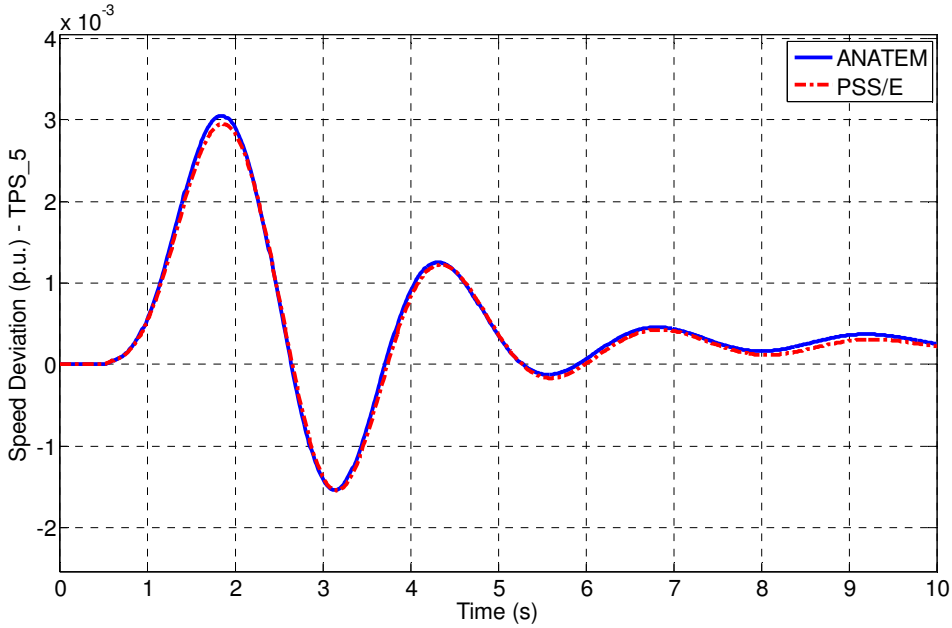

Figure 56 - Speed deviation of generator TPS_5 for Fault A

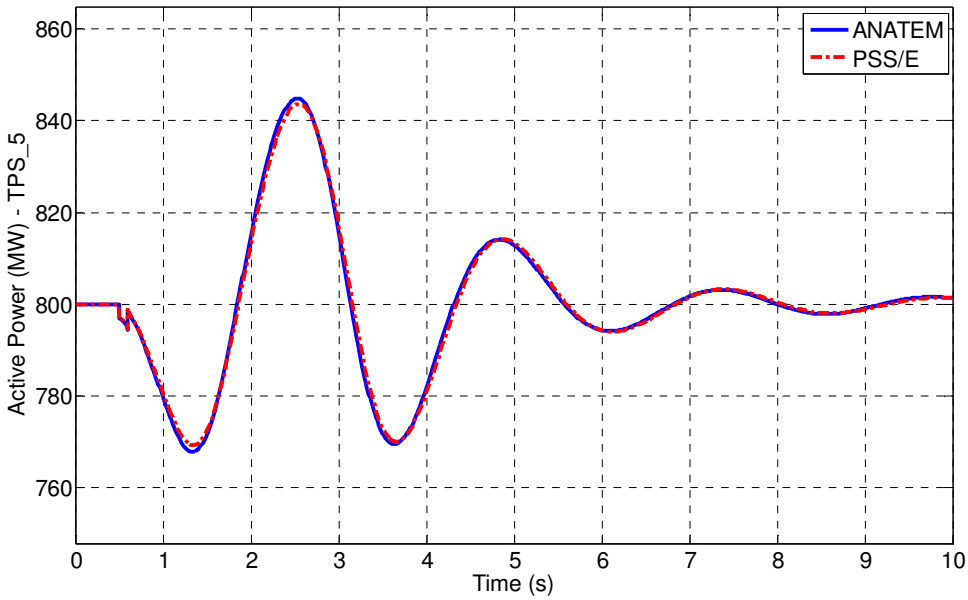

Figure 57 - Active power output of generator TPS_5 for Fault A

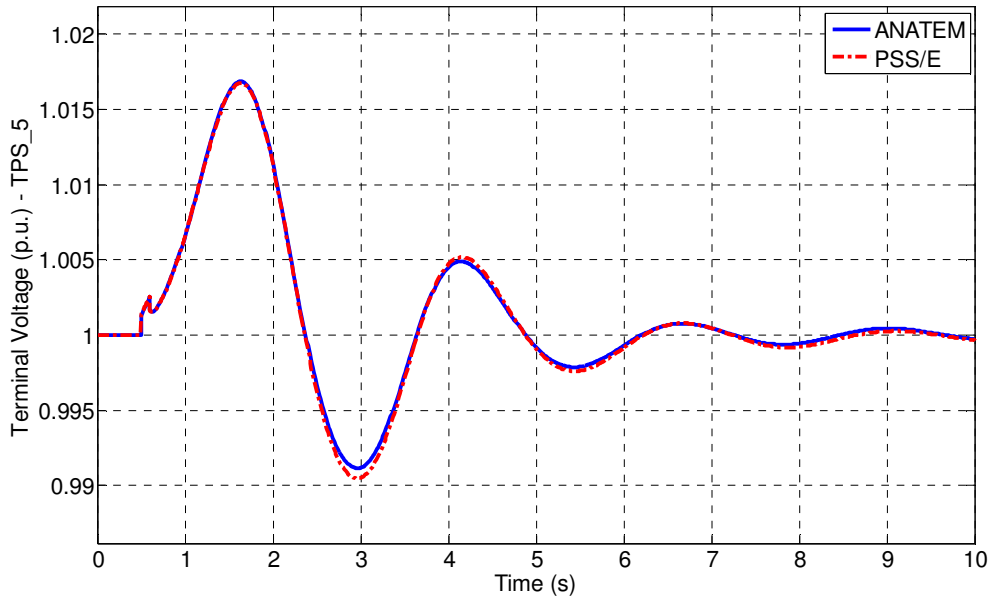

Figure 58 - Terminal voltage of generator TPS_5 for Fault A

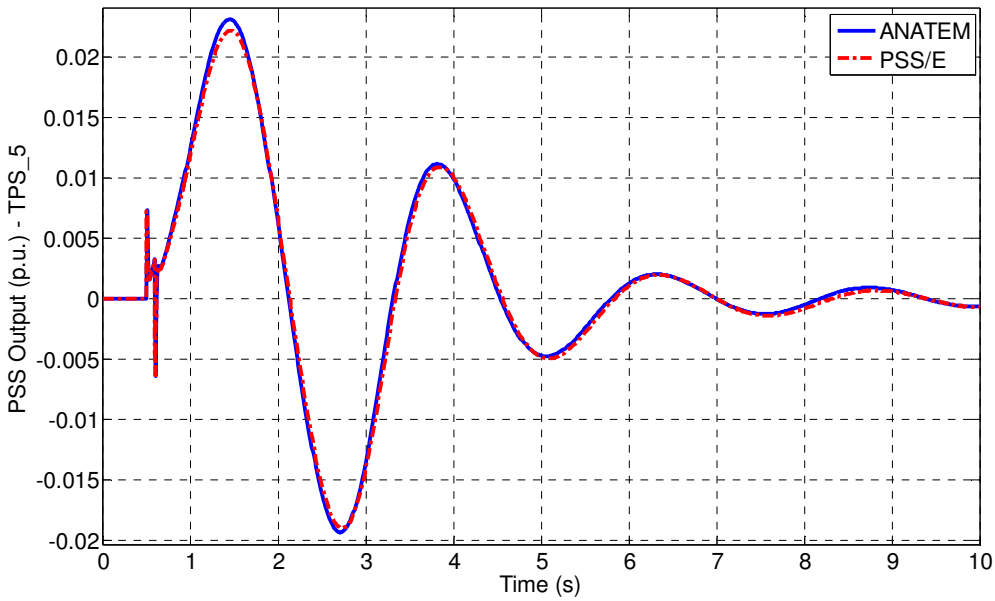

Figure 59 - PSS output of generator TPS_5 for Fault A

A.1.14 Generator PPS_5 – Bus 503

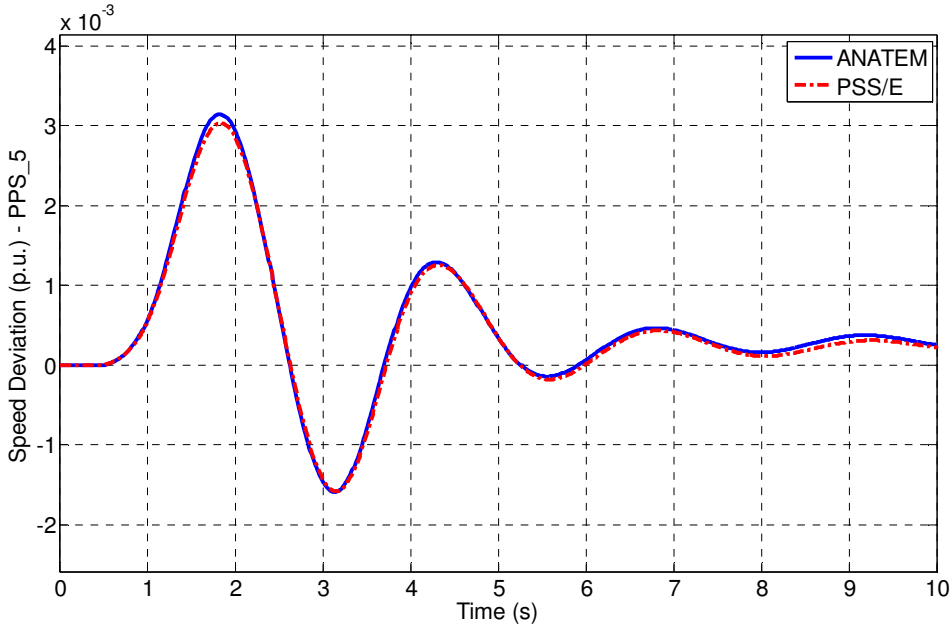

Figure 60 - Speed deviation of generator PPS_5 for Fault A

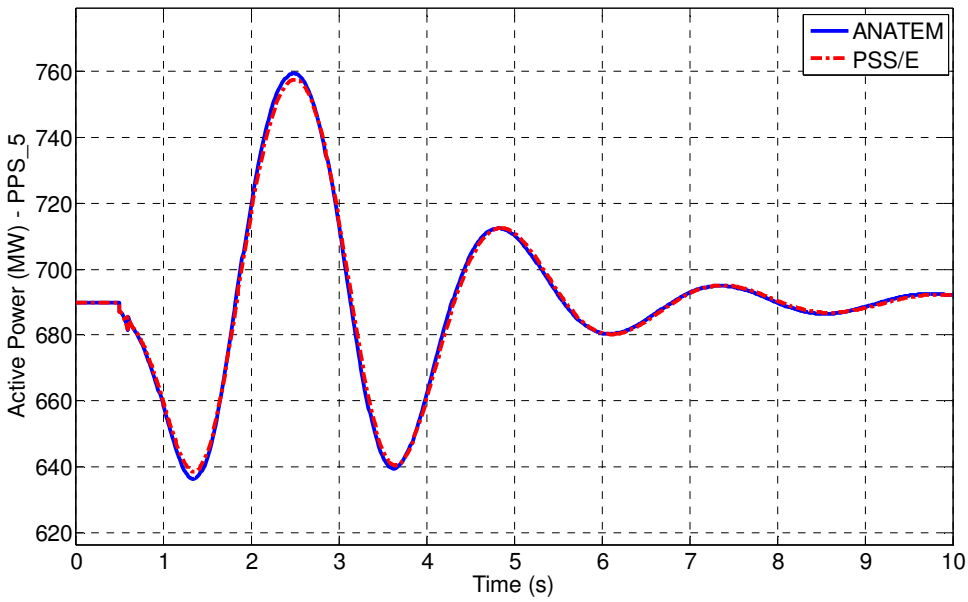

Figure 61 - Active power output of generator PPS_5 for Fault A

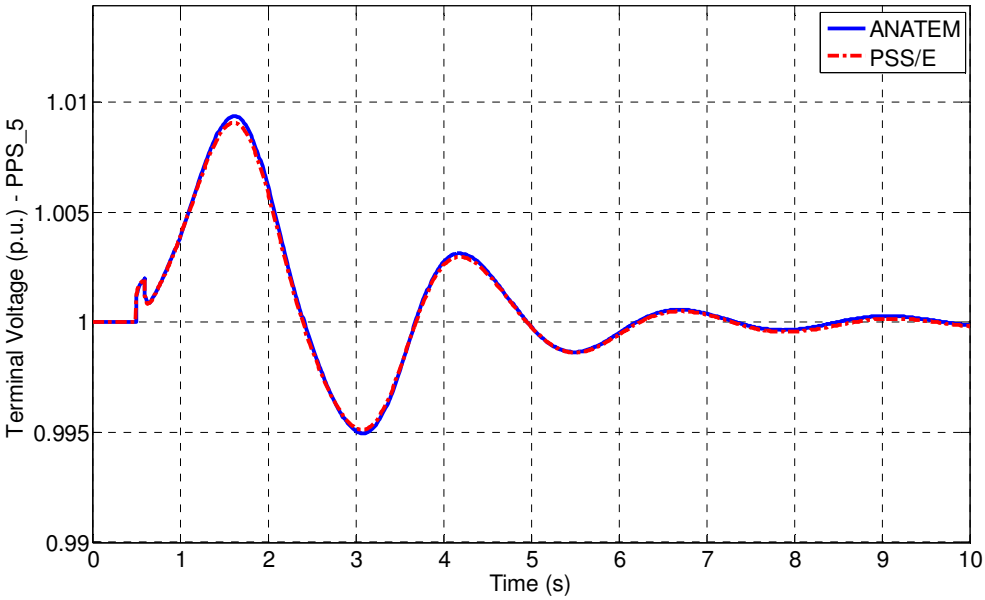

Figure 62 - Terminal voltage of generator PPS_5 for Fault A

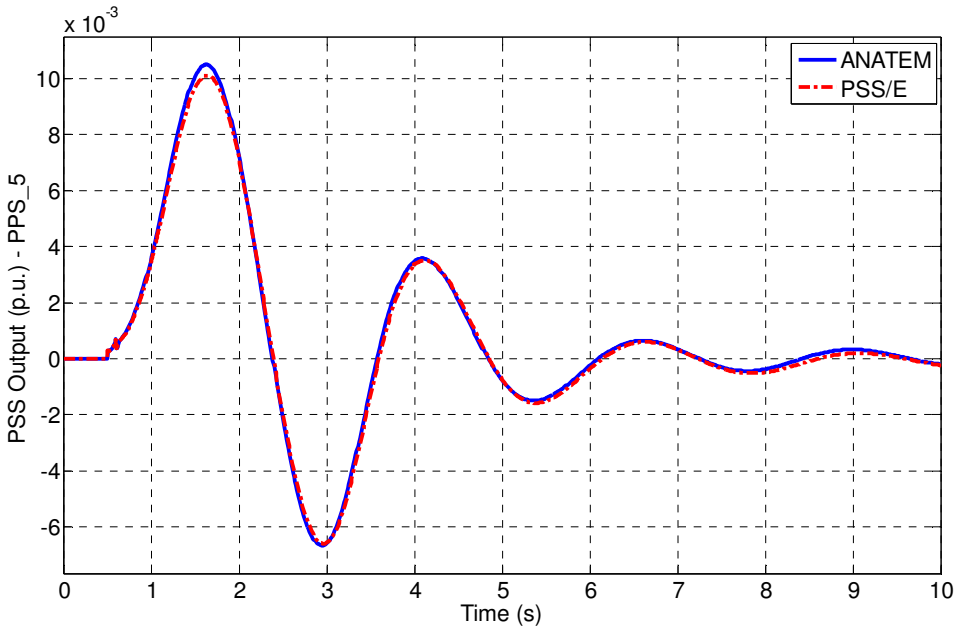

Figure 63 - PSS output of generator PPS_5 for Fault A

A.1.15 SVC ASVC_2 – Bus 205

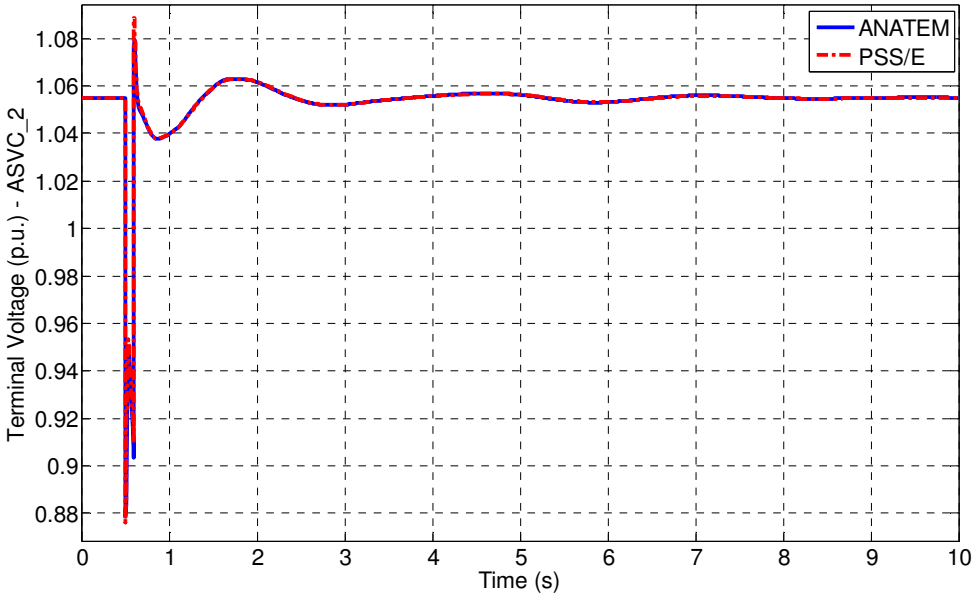

Figure 64 - Terminal voltage of SVC ASVC_2 for Fault A

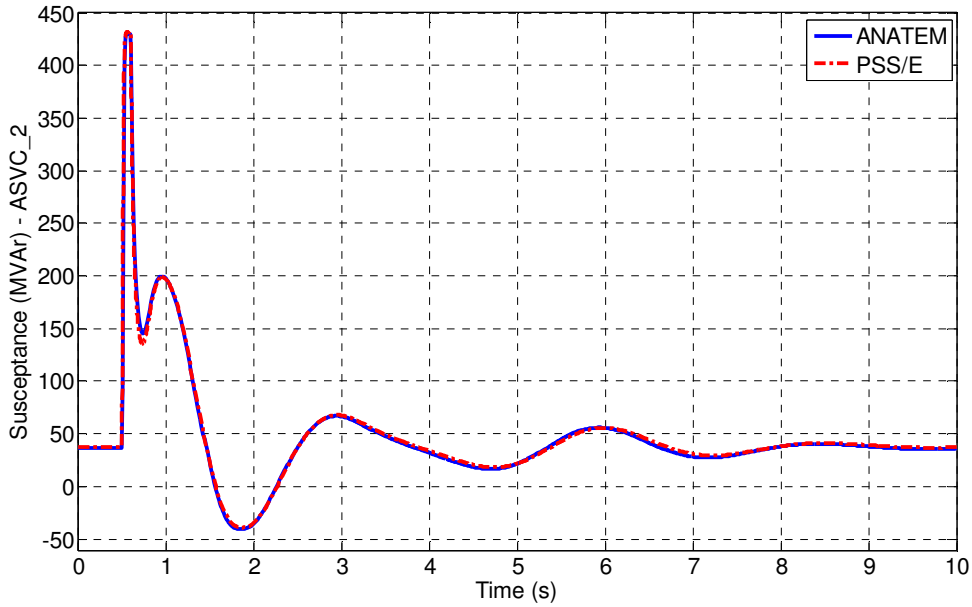

Figure 65 - Susceptance of SVC ASVC_2 for Fault A

A.1.16 SVC RSVC_3 – Bus 313

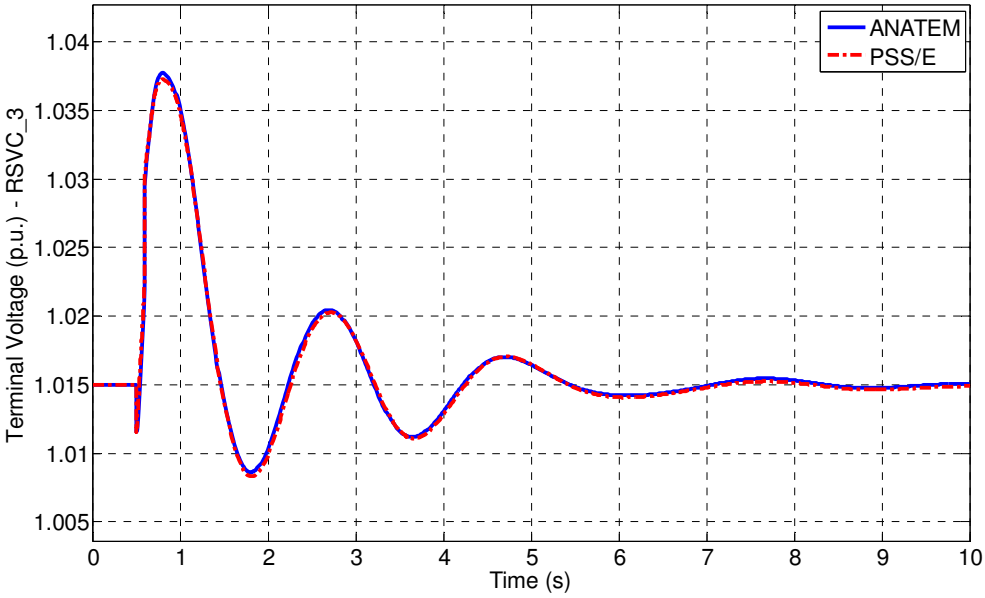

Figure 66 - Terminal voltage of SVC RSVC_3 for Fault A

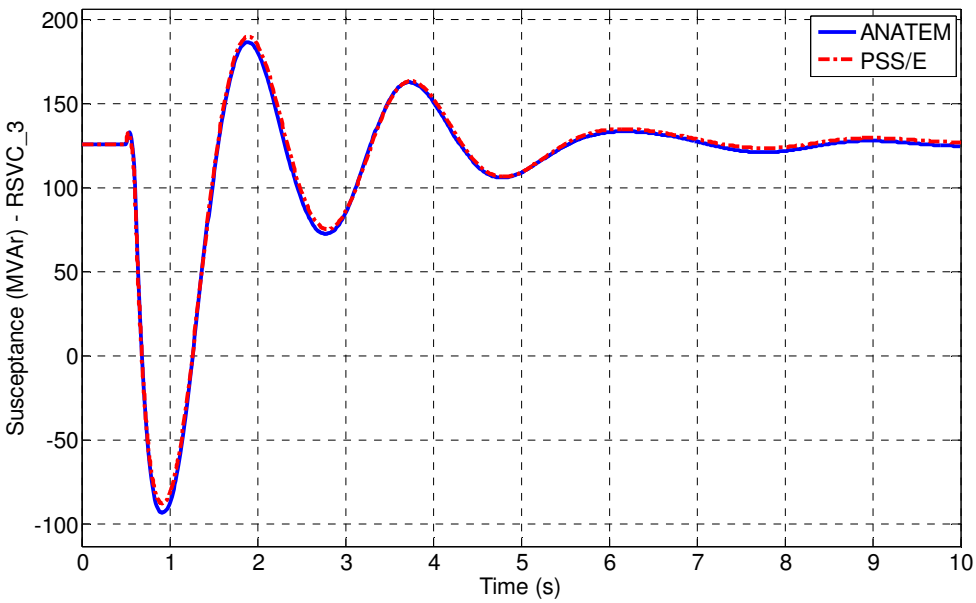

Figure 67 - Susceptance of SVC RSVC_3 for Fault A

A.1.17 SVC BSVC_4 – Bus 412

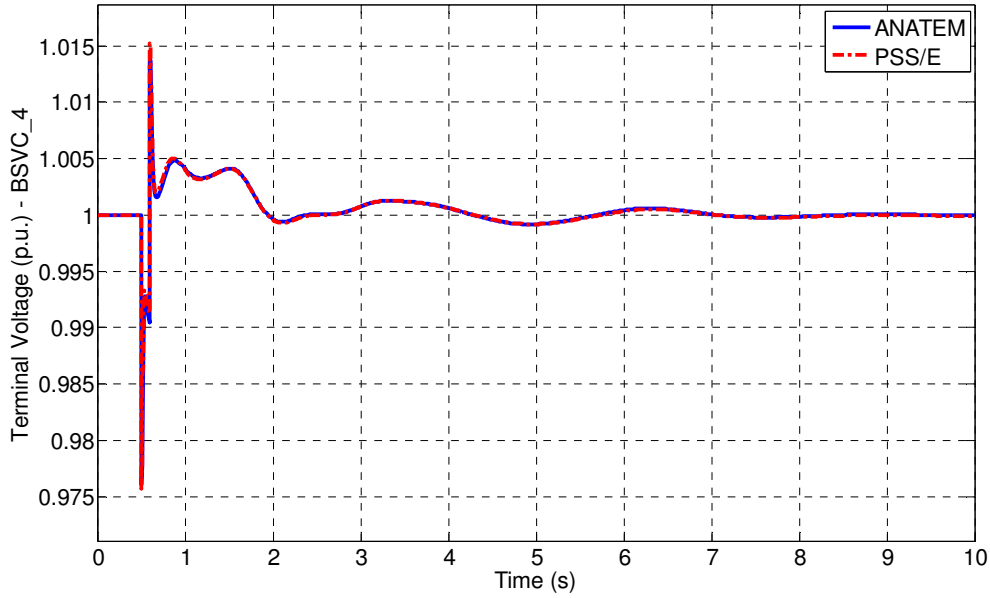

Figure 68 - Terminal voltage of SVC BSVC_4 for Fault A

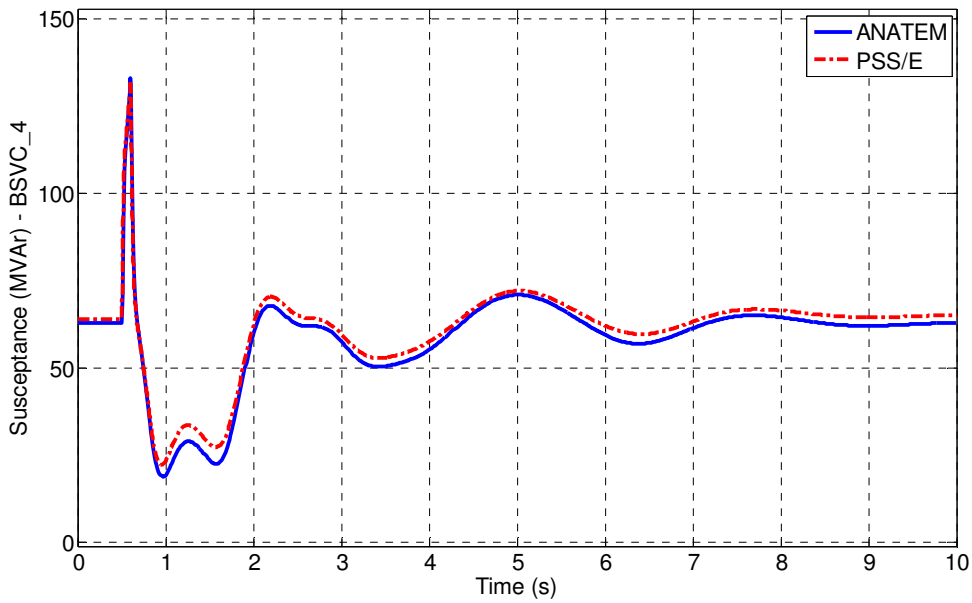

Figure 69 - Susceptance of SVC BSVC_4 for Fault A

A.1.18 SVC PSVC_5 – Bus 507

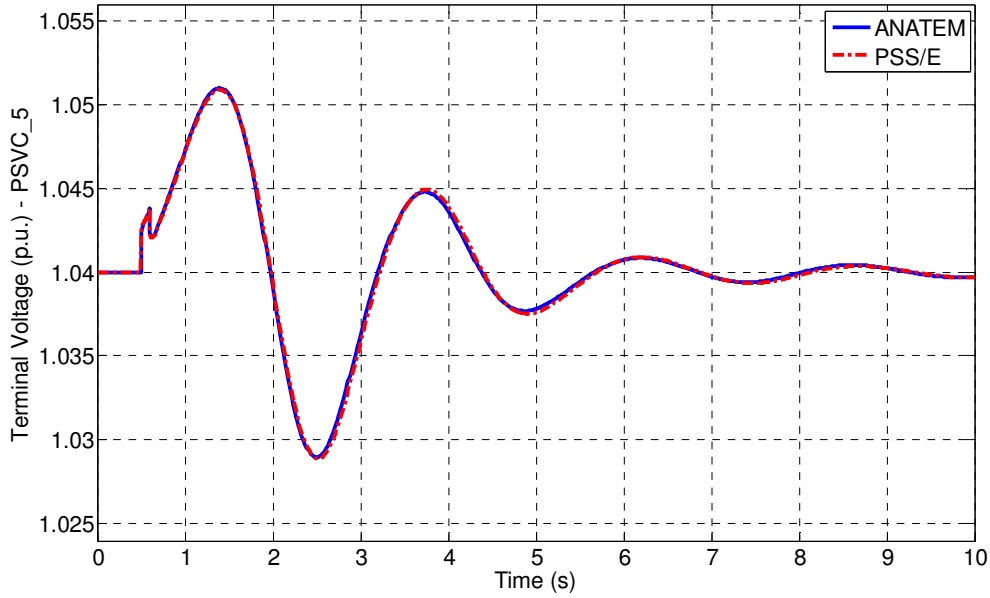

Figure 70 - Terminal voltage of SVC PSVC_5 for Fault A

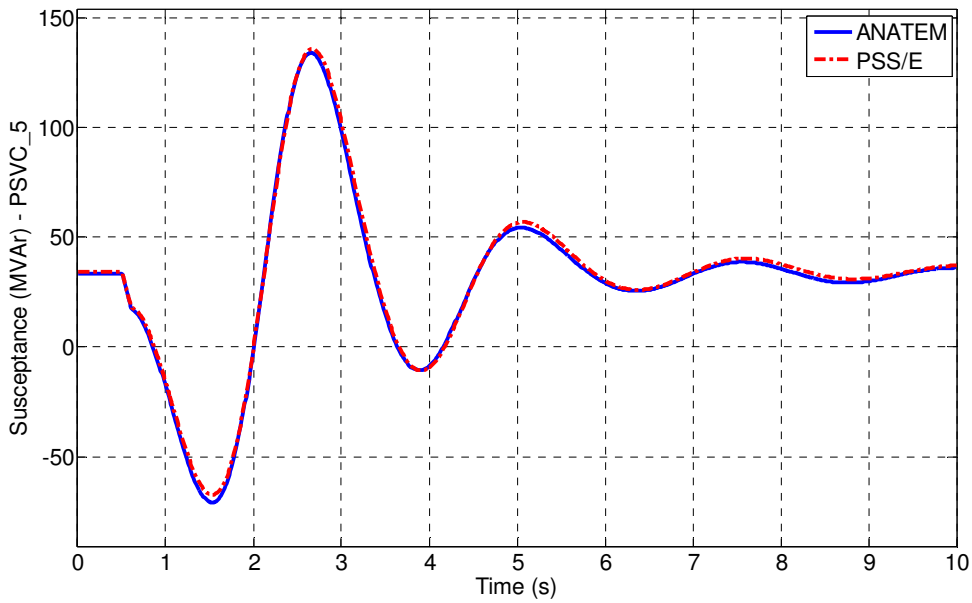

Figure 71 - Susceptance of SVC PSVC_5 for Fault A

A.1.19 SVC SSVC_5 – Bus 509

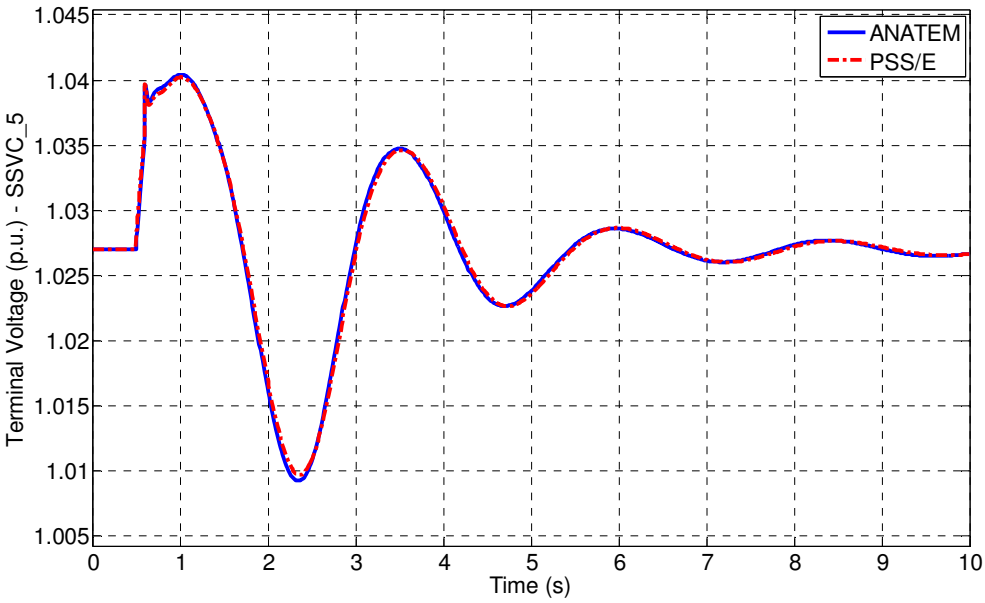

Figure 72 - Terminal voltage of SVC SSVC_5 for Fault A

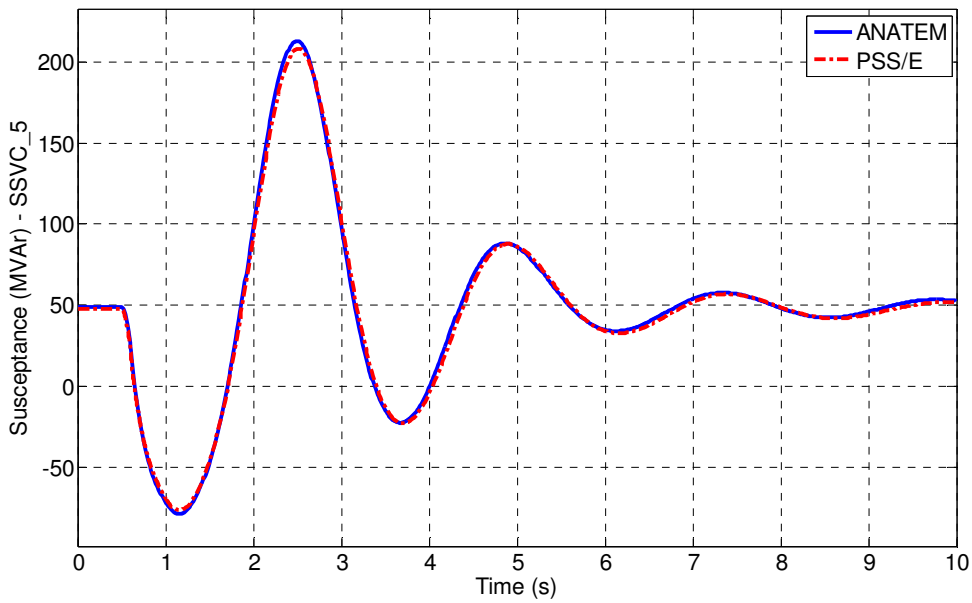

Figure 73 - Susceptance of SVC SSVC_5 for Fault A

A.2 Fault B

A.2.1 Generator HPS_1 – Bus 101

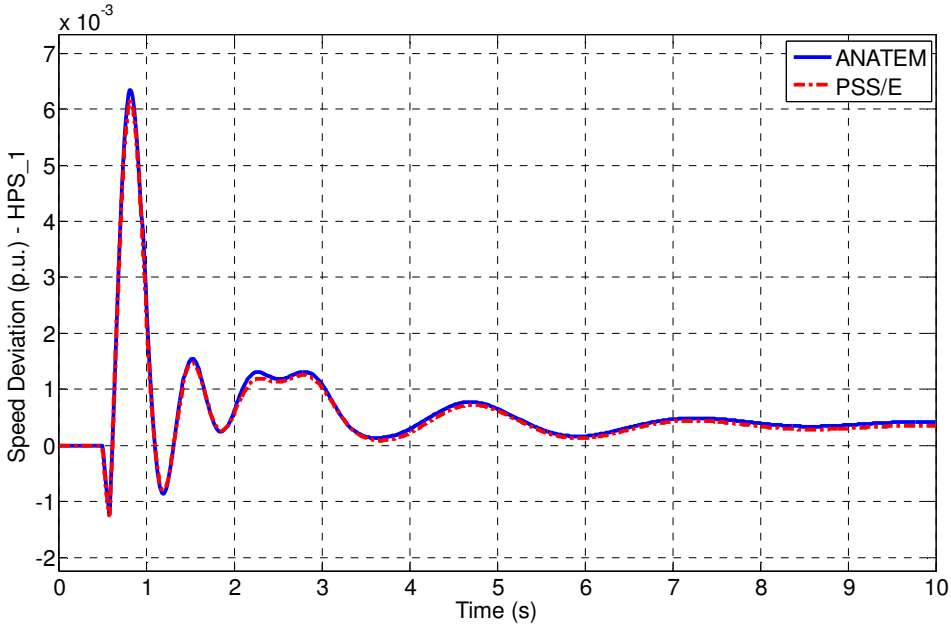

Figure 74 - Speed deviation of generator HPS_1 for Fault B

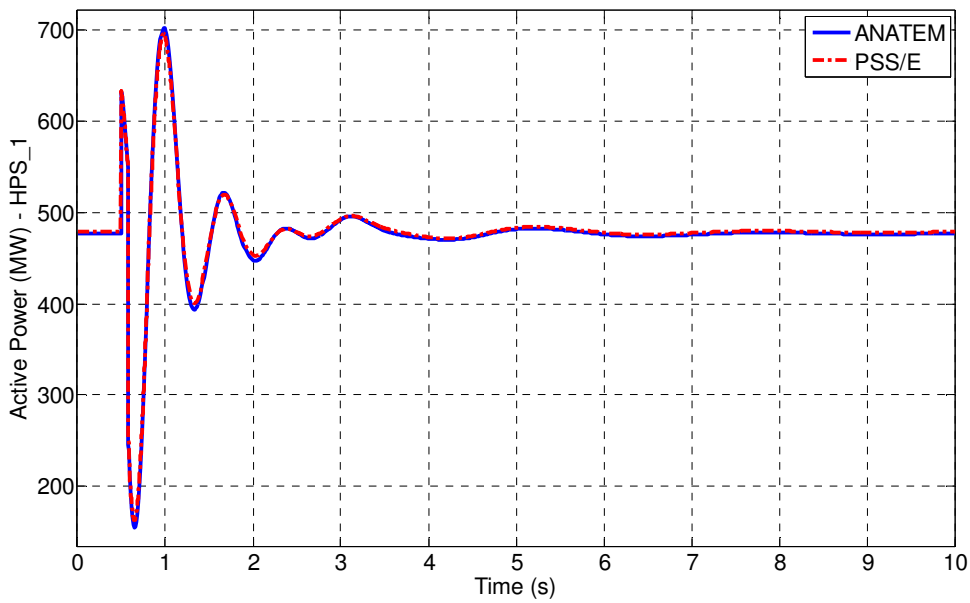

Figure 75 - Active power output of generator HPS_1 for Fault B

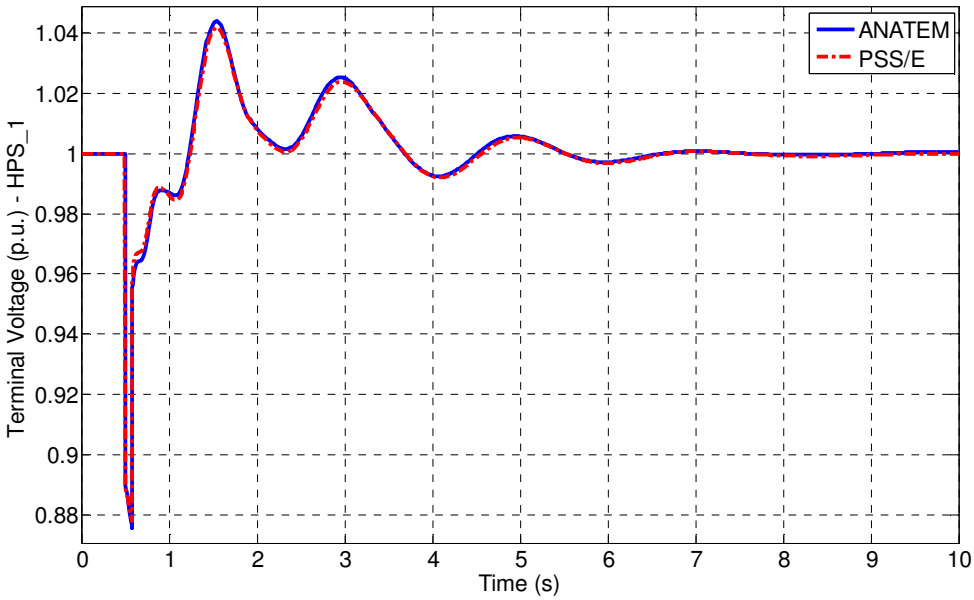

Figure 76 - Terminal voltage of generator HPS_1 for Fault B

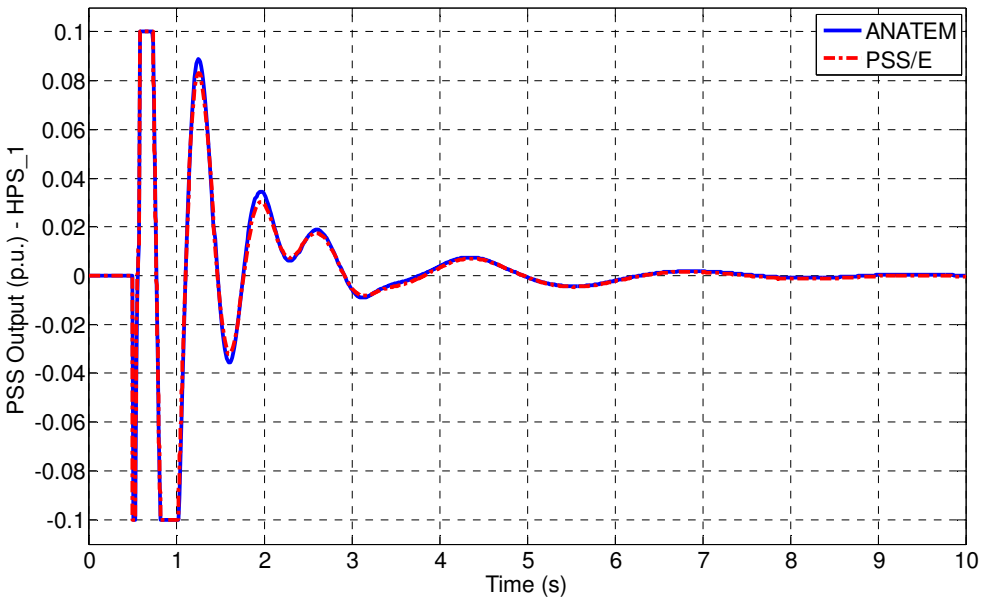

Figure 77 - PSS output of generator HPS_1 for Fault B

A.2.2 Generator BPS_2 – Bus 201

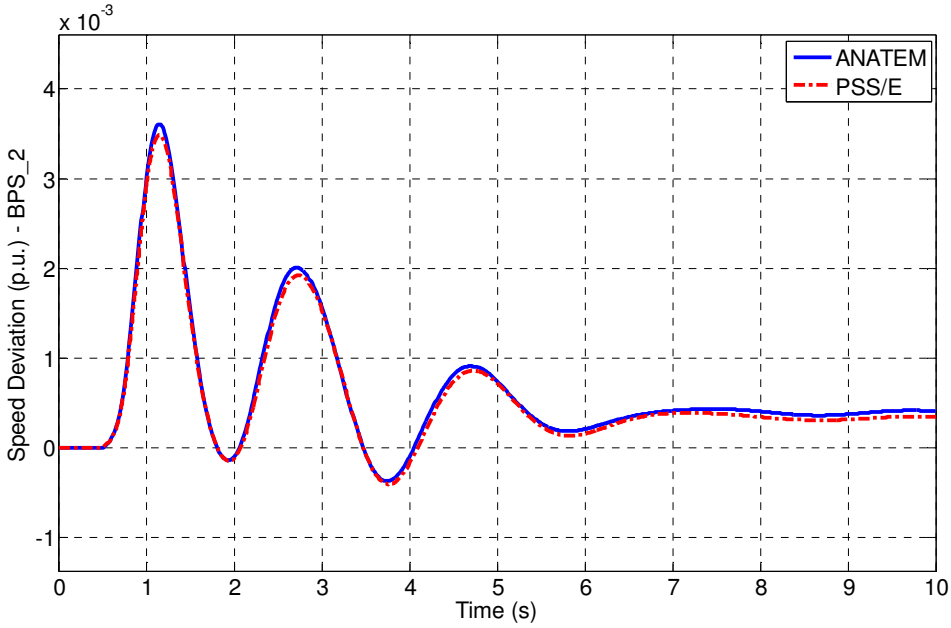

Figure 78 - Speed deviation of generator BPS_2 for Fault B

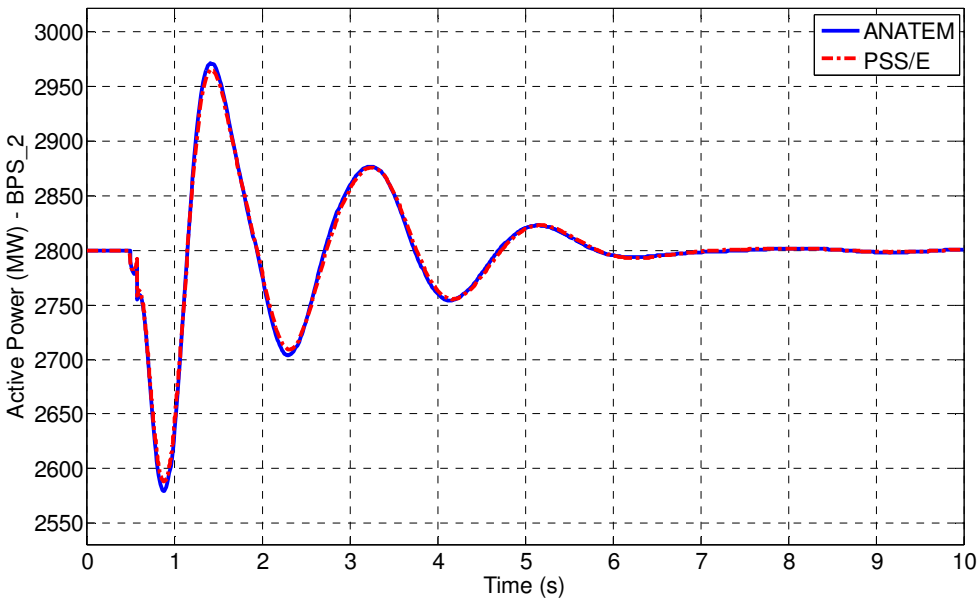

Figure 79 - Active power output of generator BPS_2 for Fault B

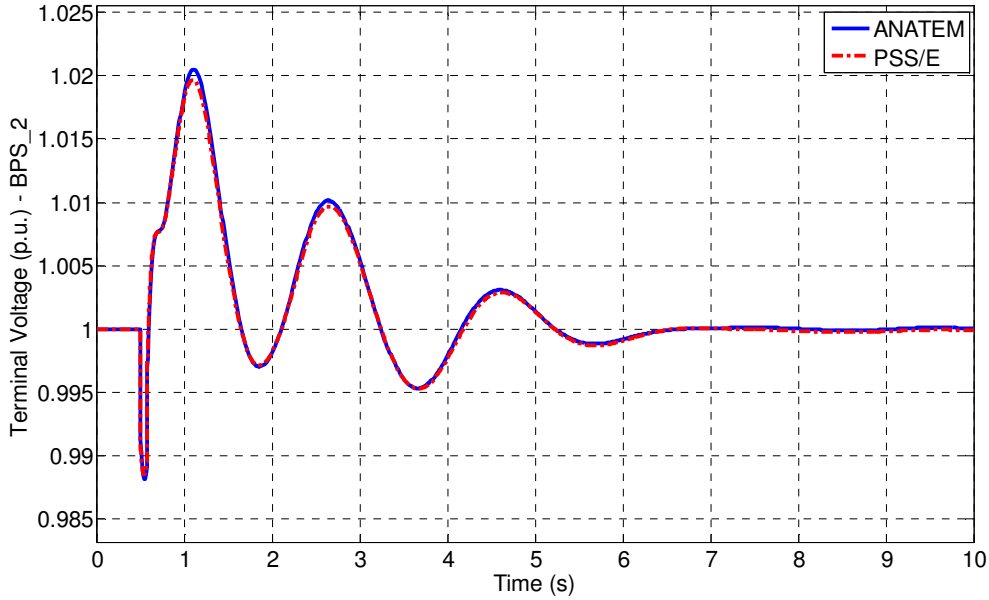

Figure 80 - Terminal voltage of generator BPS_2 for Fault B

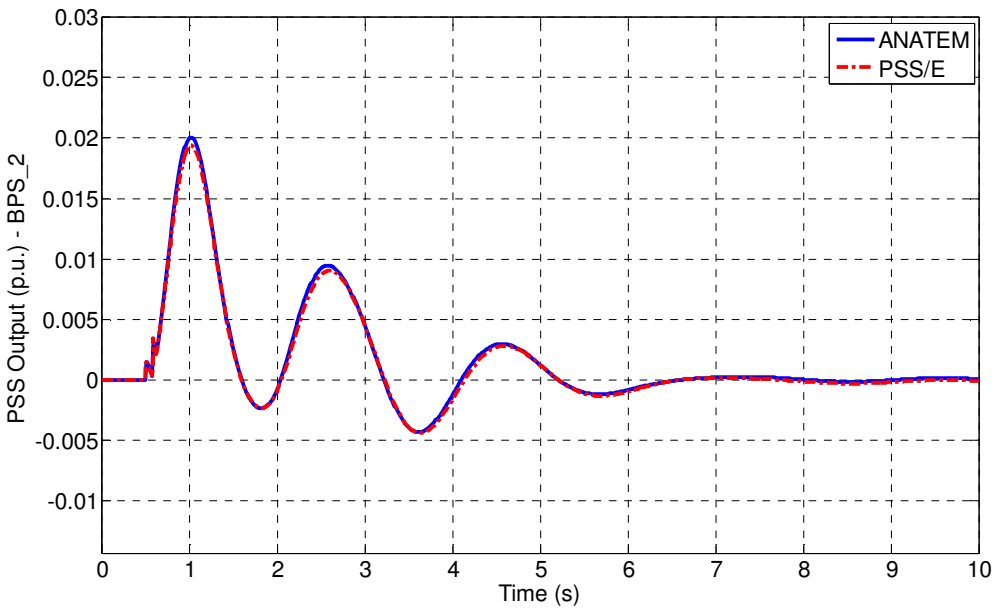

Figure 81 - PSS output of generator BPS_2 for Fault B

A.2.3 Generator EPS_2 – Bus 202

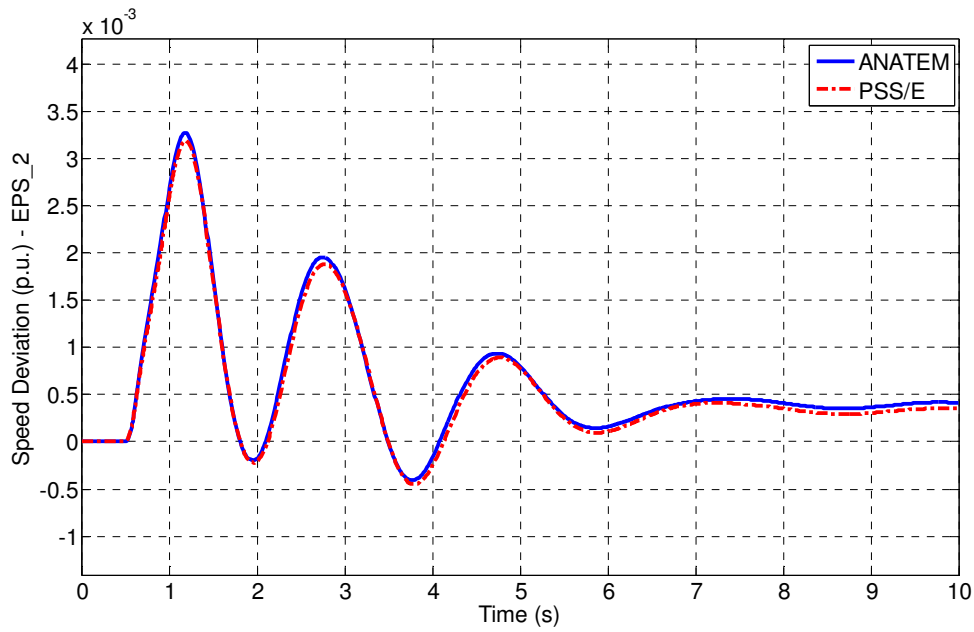

Figure 82 - Speed deviation of generator EPS_2 for Fault B

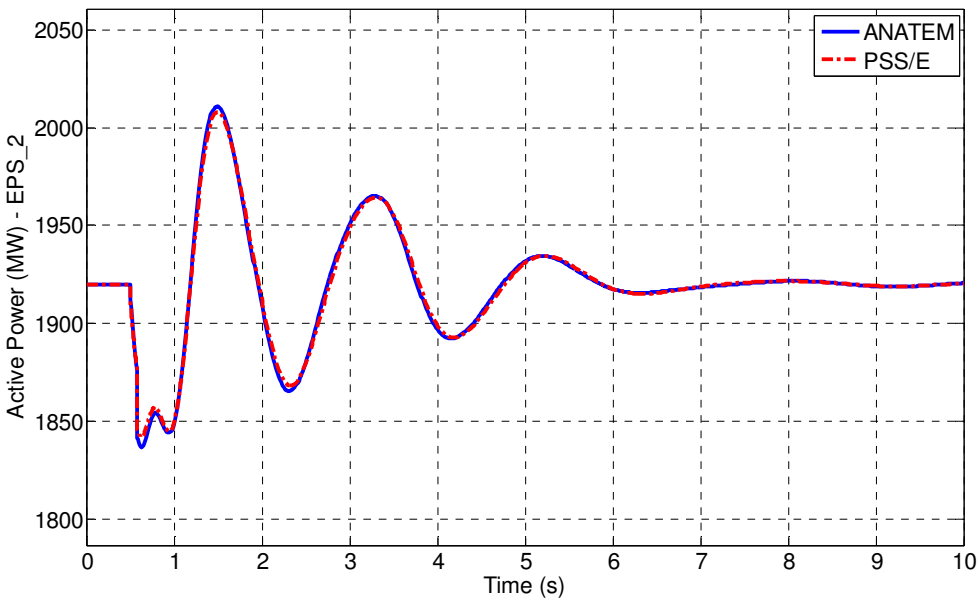

Figure 83 - Active power output of generator EPS_2 for Fault B

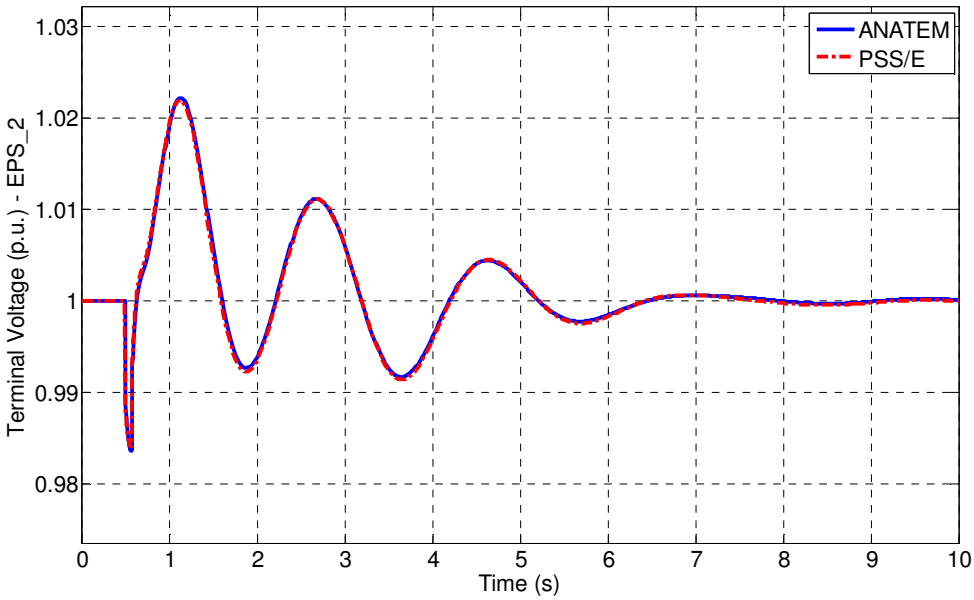

Figure 84 - Terminal voltage of generator EPS_2 for Fault B

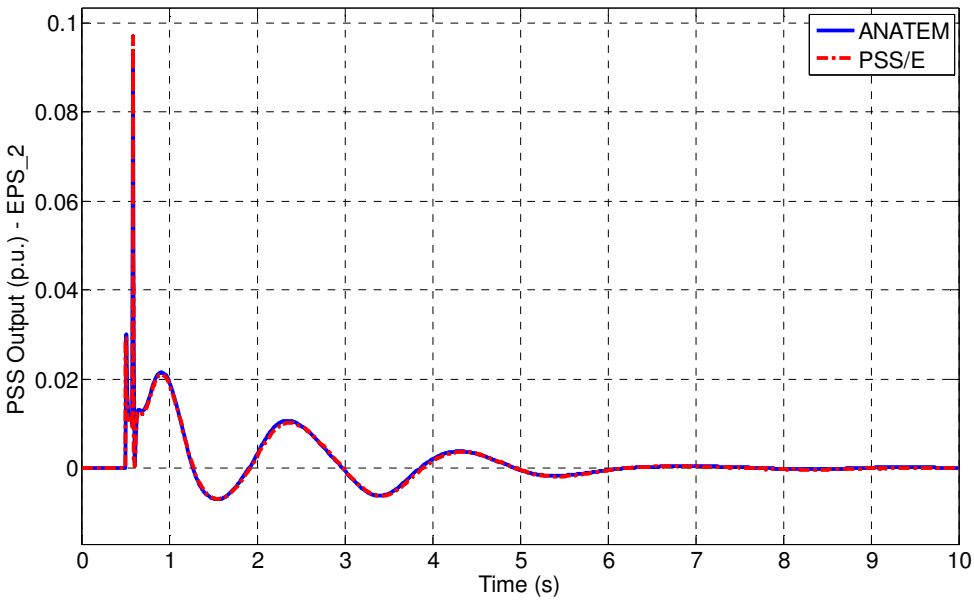

Figure 85 - PSS output of generator EPS_2 for Fault B

A.2.4 Generator VPS_2 – Bus 203

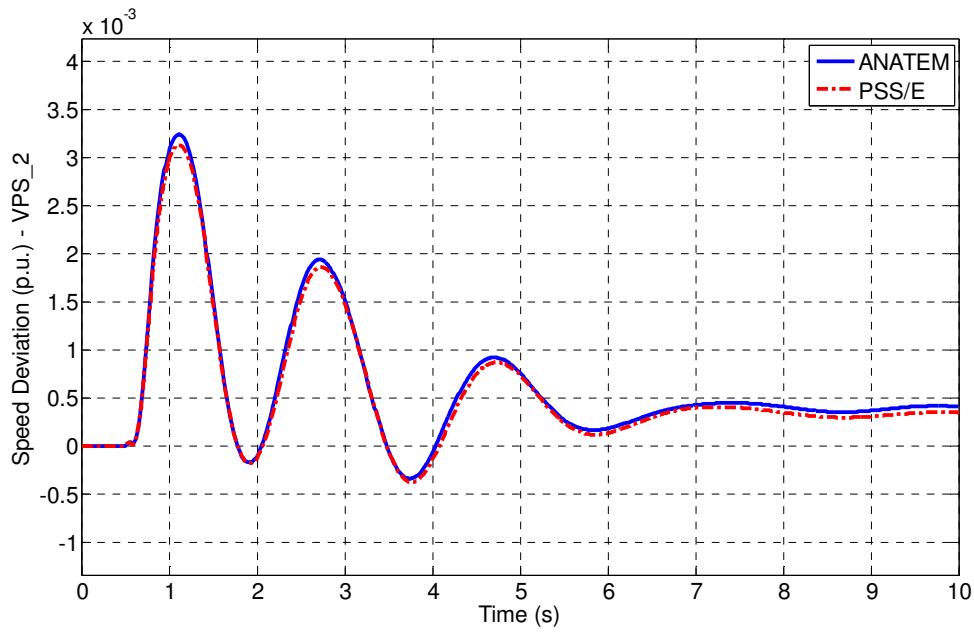

Figure 86 - Speed deviation of generator VPS_2 for Fault B

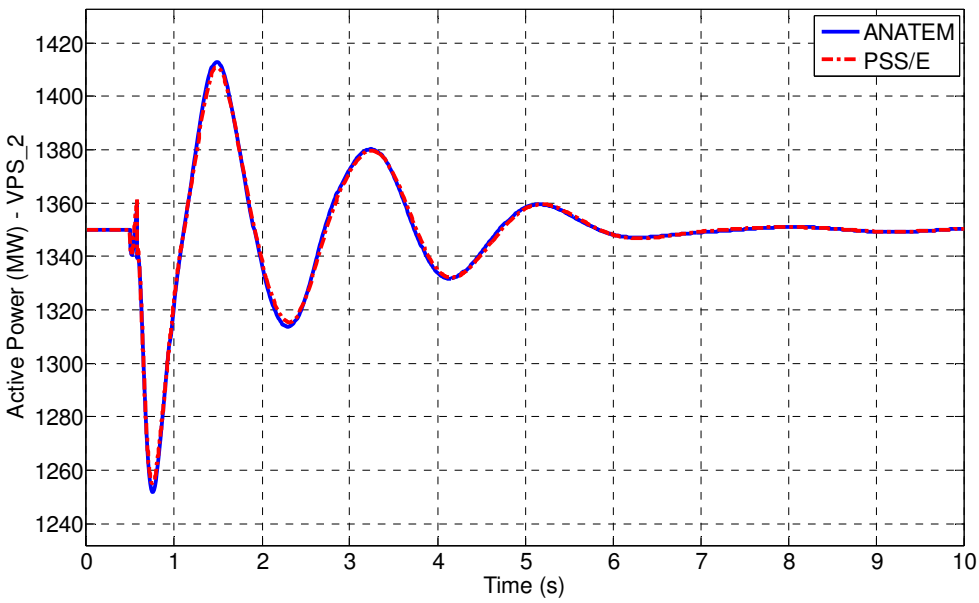

Figure 87 - Active power output of generator VPS_2 for Fault B

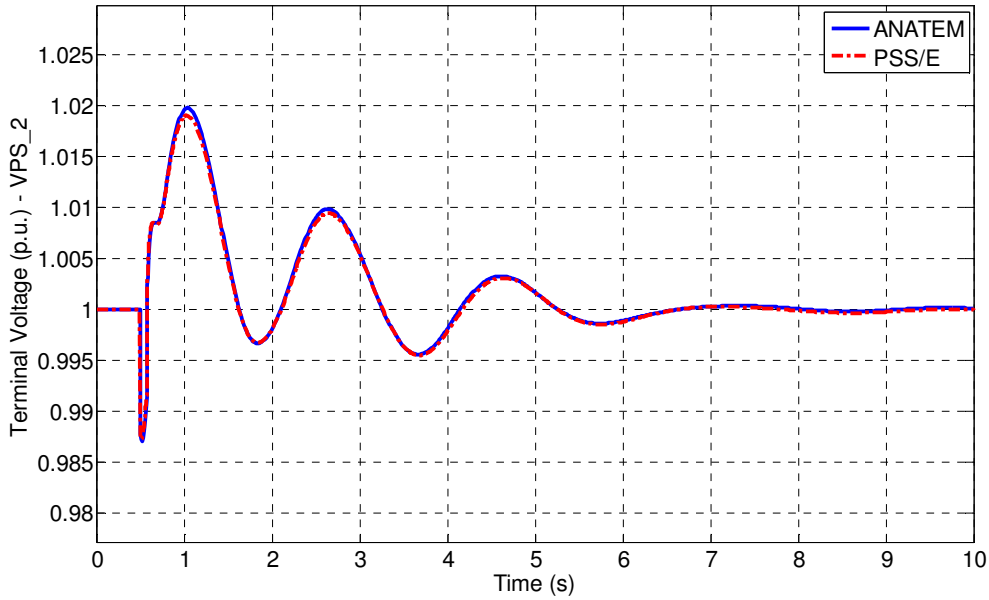

Figure 88 - Terminal voltage of generator VPS_2 for Fault B

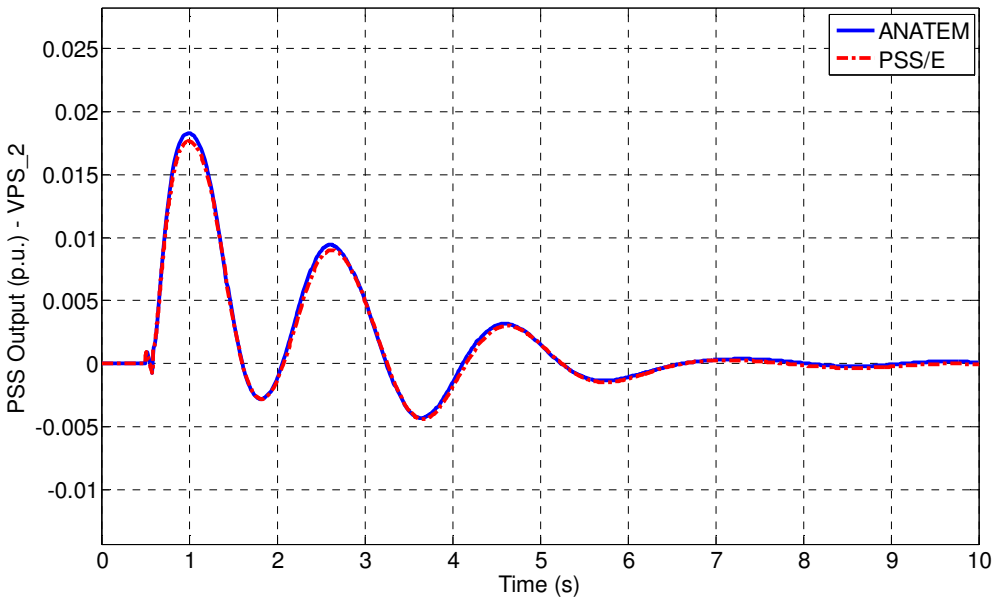

Figure 89 - PSS output of generator VPS_2 for Fault B

A.2.5 Generator MPS_2 – Bus 204

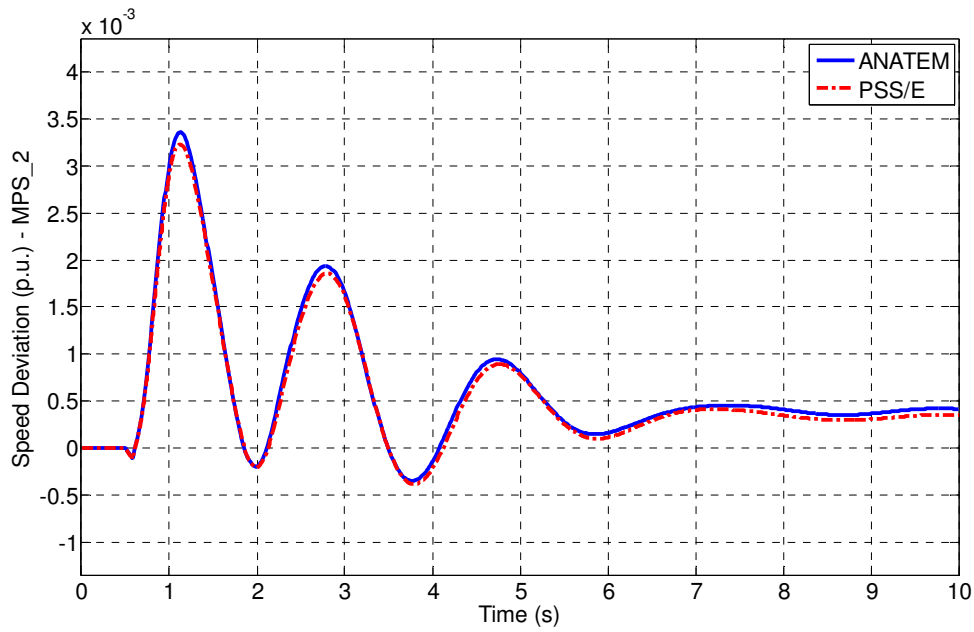

Figure 90 - Speed deviation of generator MPS_2 for Fault B

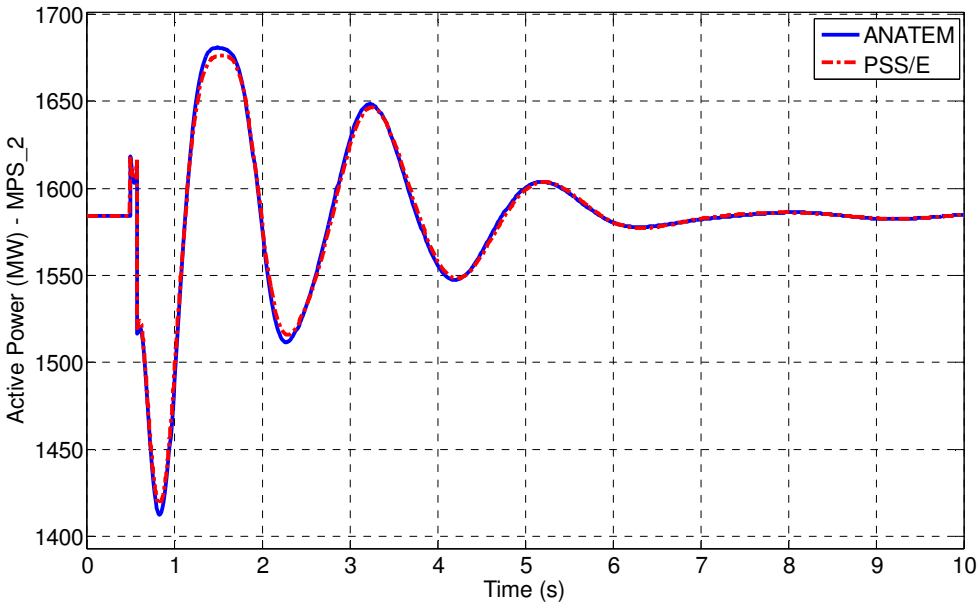

Figure 91 - Active power output of generator MPS_2 for Fault B

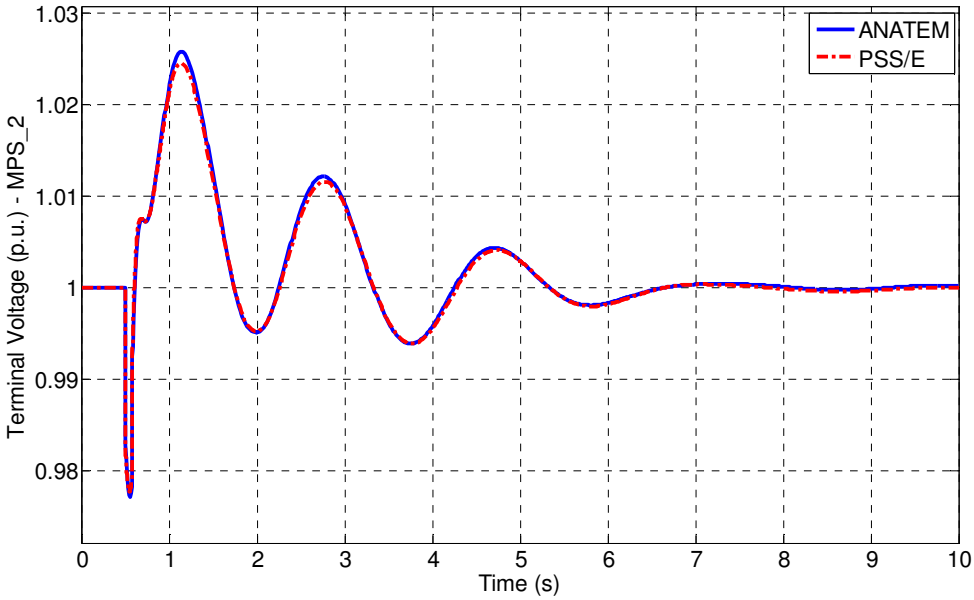

Figure 92 - Terminal voltage of generator MPS_2 for Fault B

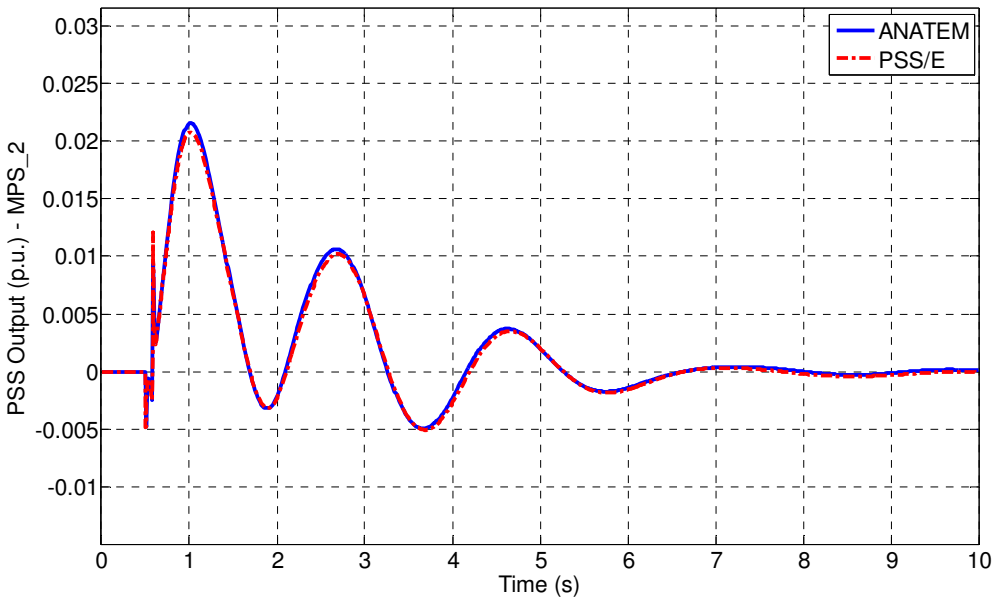

Figure 93 - PSS output of generator MPS_2 for Fault B

A.2.6 Generator LPS_3 – Bus 301

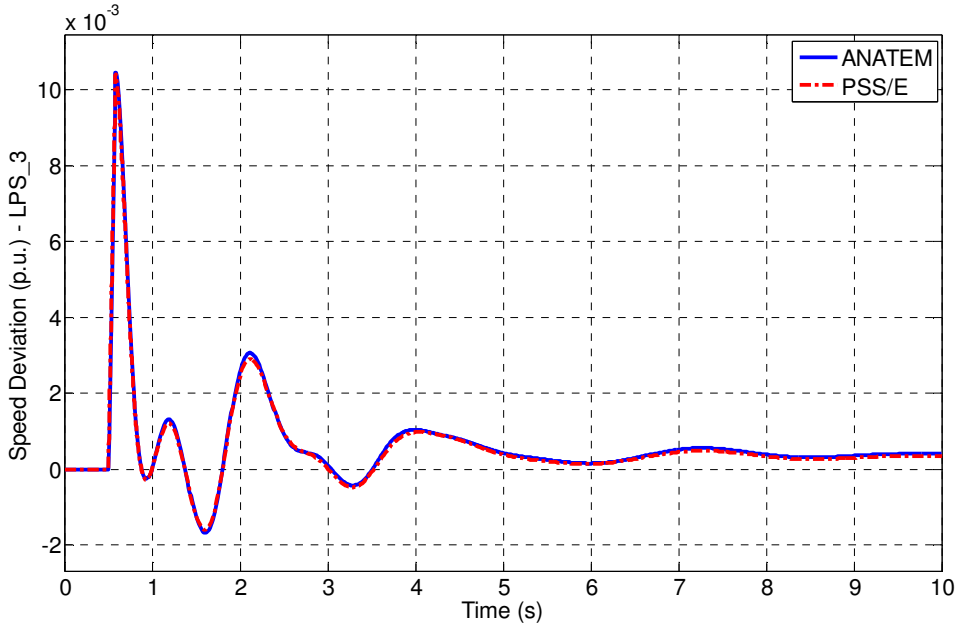

Figure 94 - Speed deviation of generator LPS_3 for Fault B

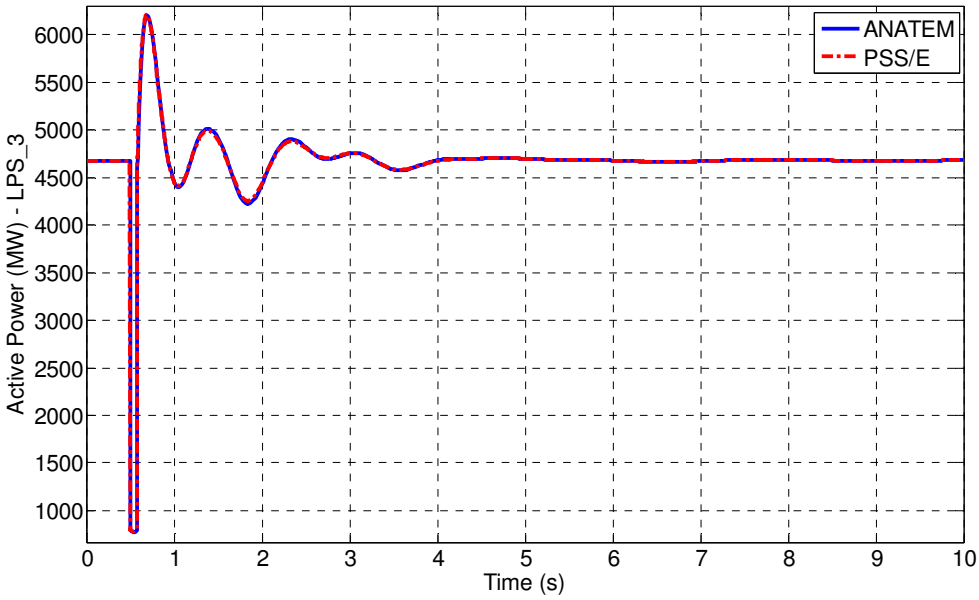

Figure 95 - Active power output of generator LPS_3 for Fault B

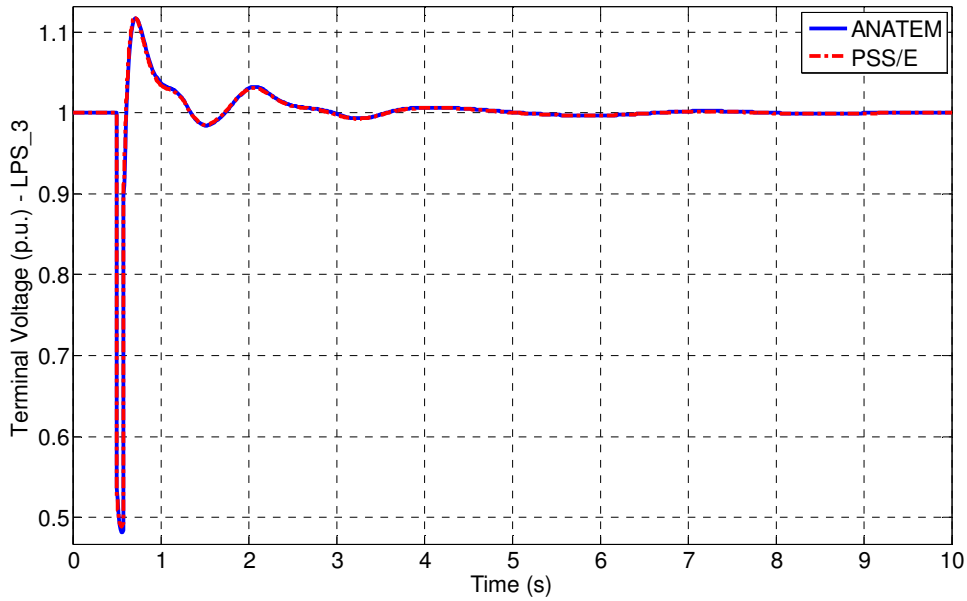

Figure 96 - Terminal voltage of generator LPS_3 for Fault B

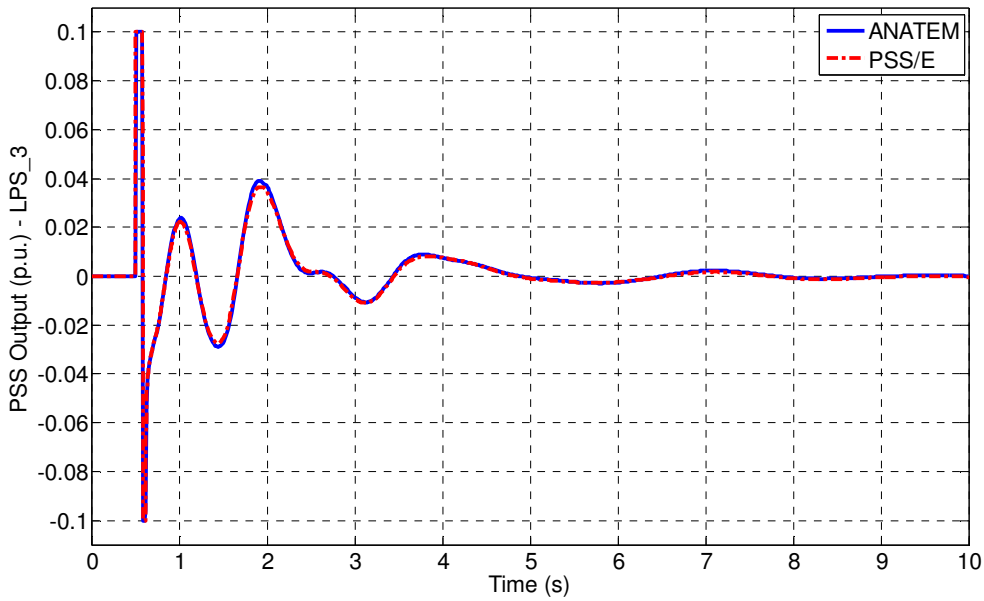

Figure 97 - PSS output of generator LPS_3 for Fault B

A.2.7 Generator YPS_3 – Bus 302

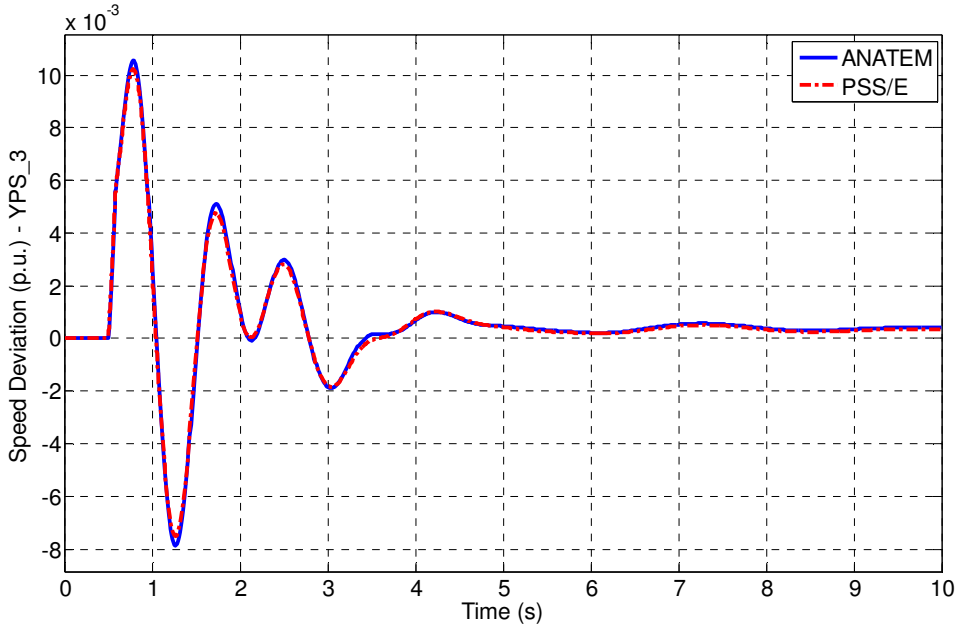

Figure 98 - Speed deviation of generator YPS_3 for Fault B

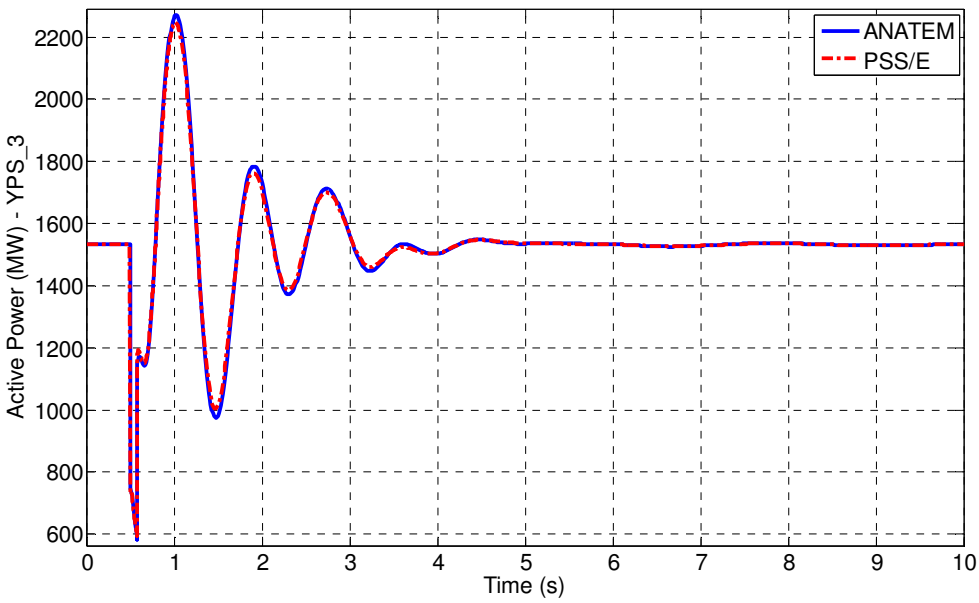

Figure 99 - Active power output of generator YPS_3 for Fault B

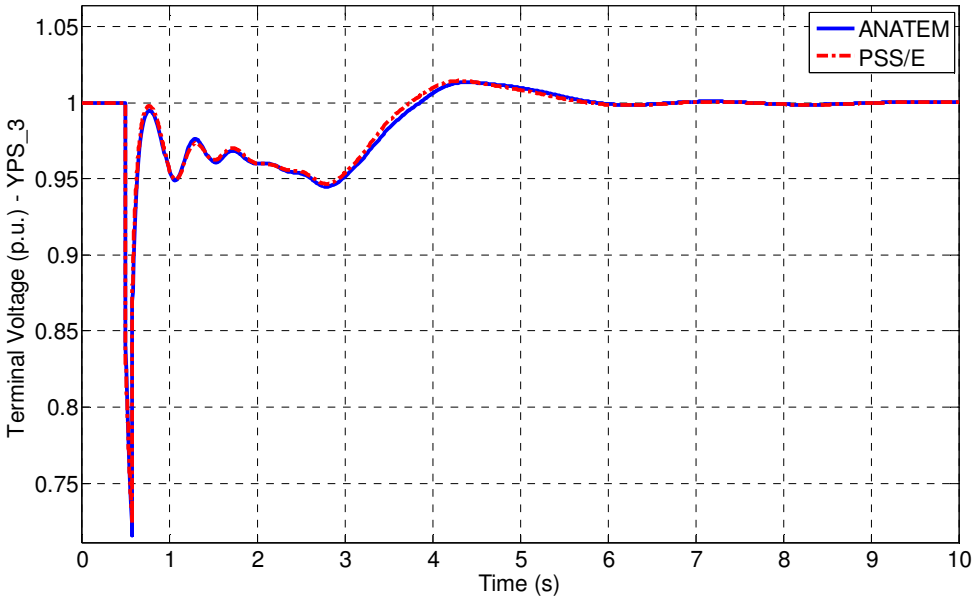

Figure 100 - Terminal voltage of generator YPS_3 for Fault B

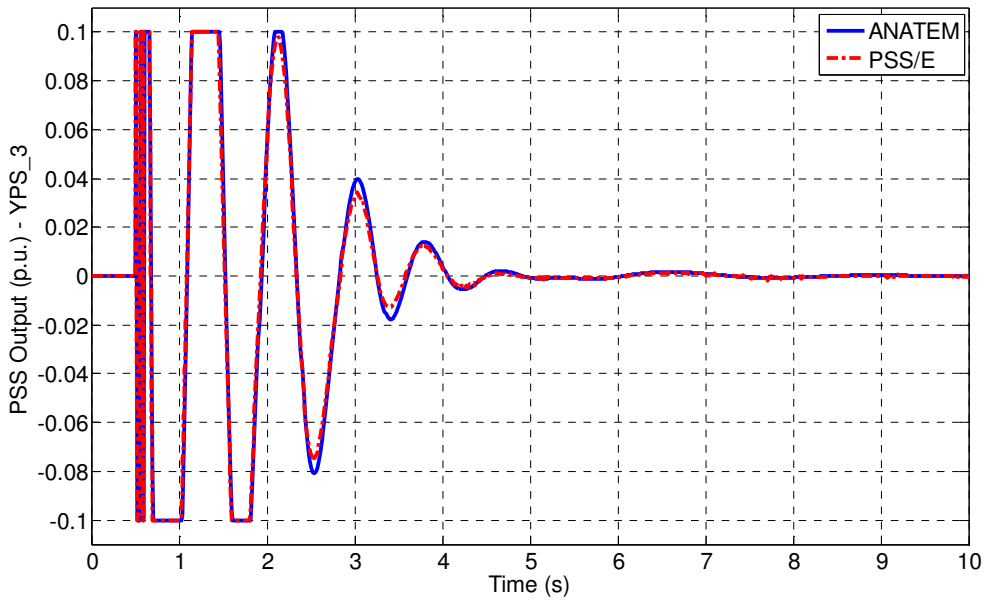

Figure 101 - PSS output of generator YPS_3 for Fault B

A.2.8 Generator TPS_4 – Bus 401

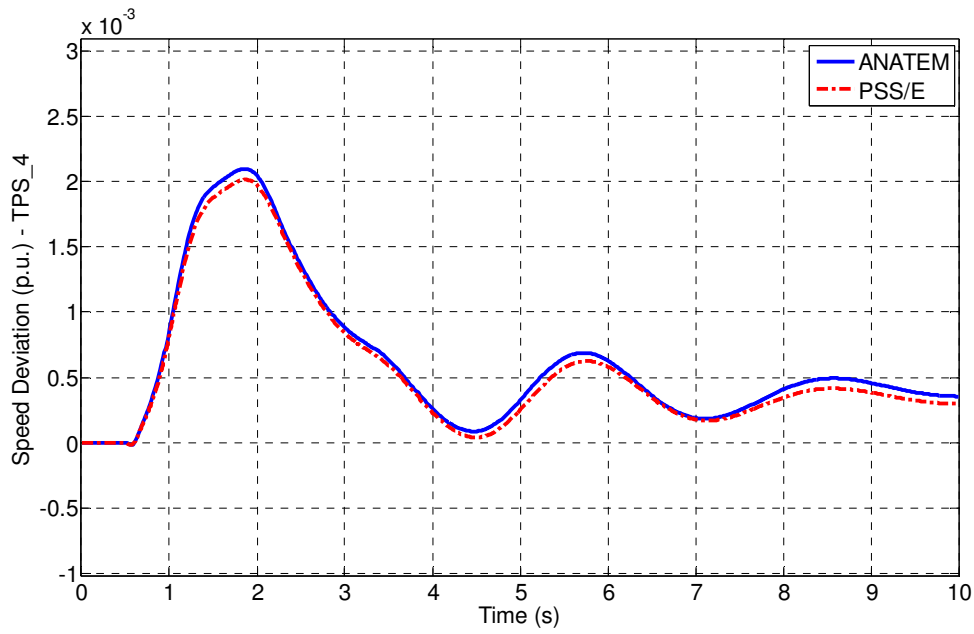

Figure 102 - Speed deviation of generator TPS_4 for Fault B

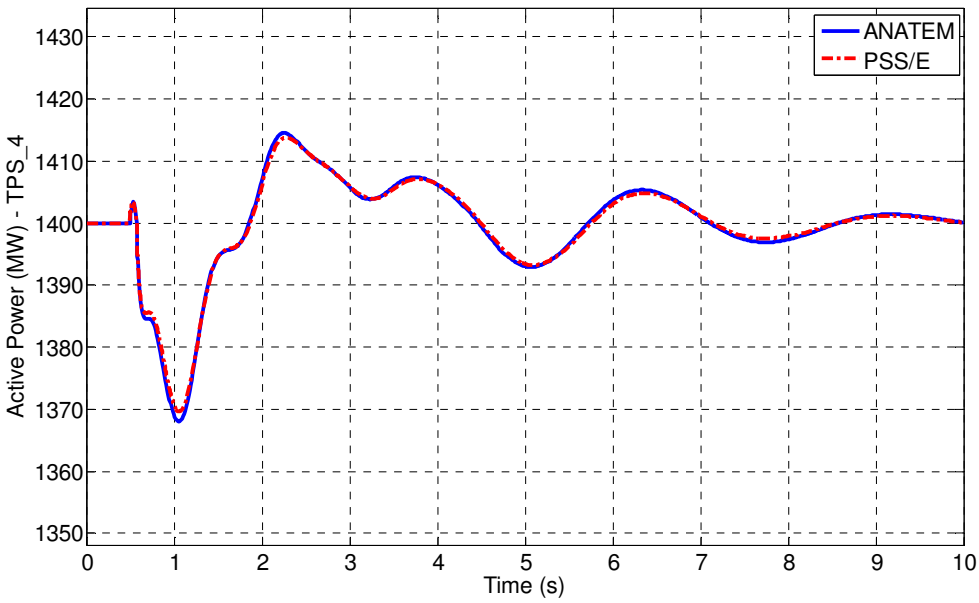

Figure 103 - Active power output of generator TPS_4 for Fault B

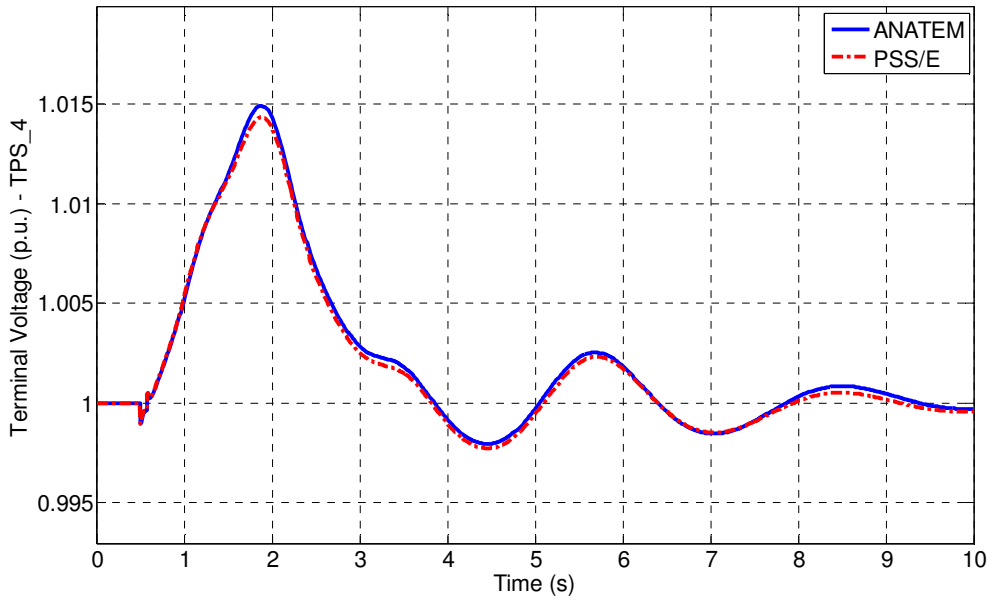

Figure 104 - Terminal voltage of generator TPS_4 for Fault B

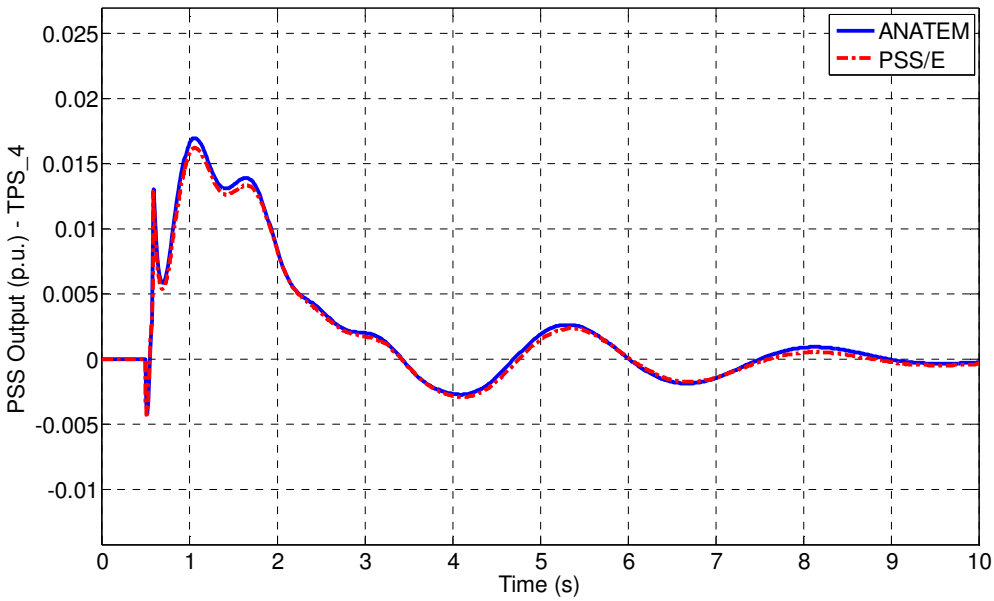

Figure 105 - PSS output of generator TPS_4 for Fault B

A.2.9 Generator CPS_4 – Bus 402

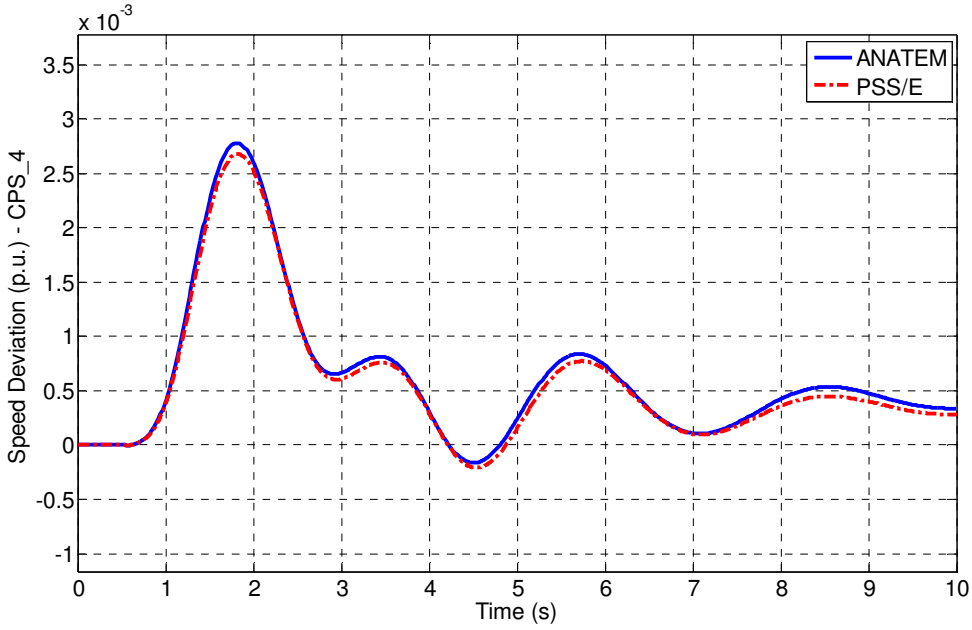

Figure 106 - Speed deviation of generator CPS_4 for Fault B

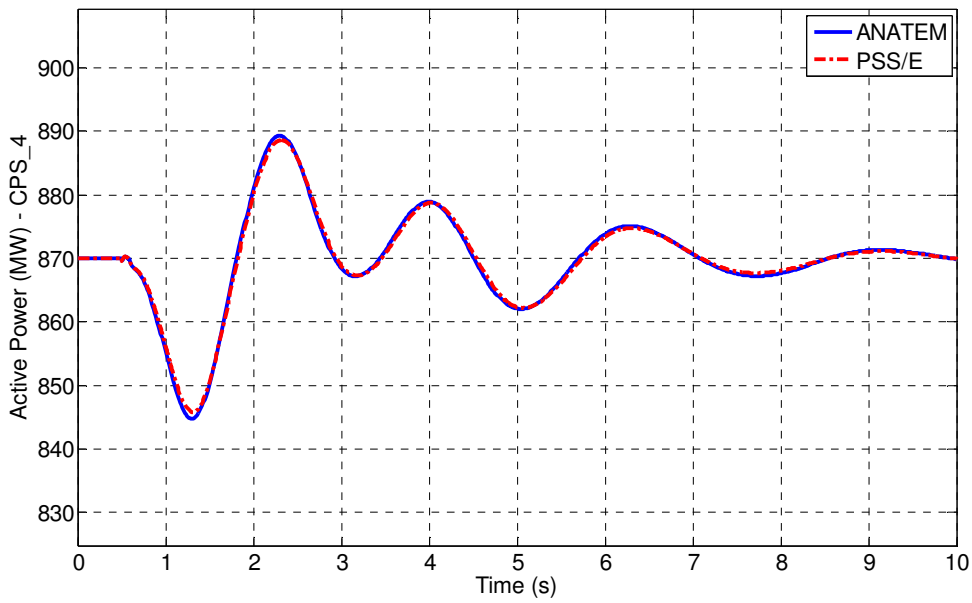

Figure 107 - Active power output of generator CPS_4 for Fault B

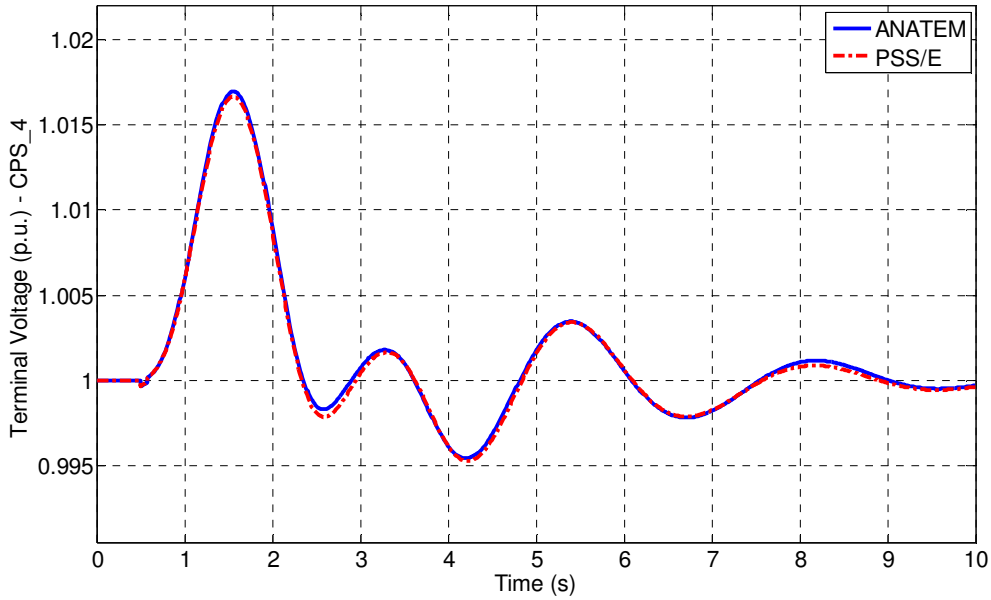

Figure 108 - Terminal voltage of generator CPS_4 for Fault B

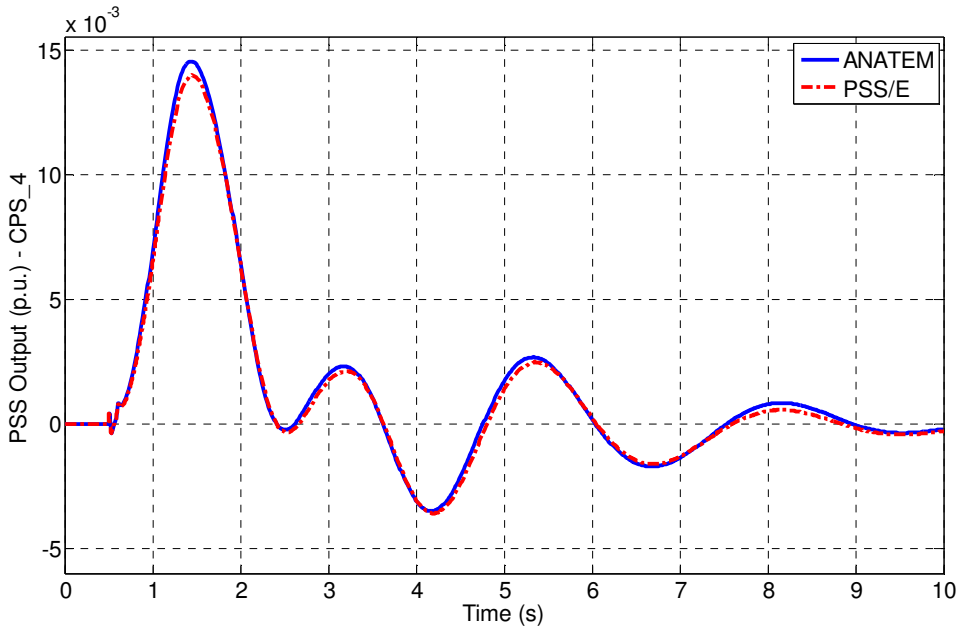

Figure 109 - PSS output of generator CPS_4 for Fault B

A.2.10 Generator SPS_4 – Bus 403

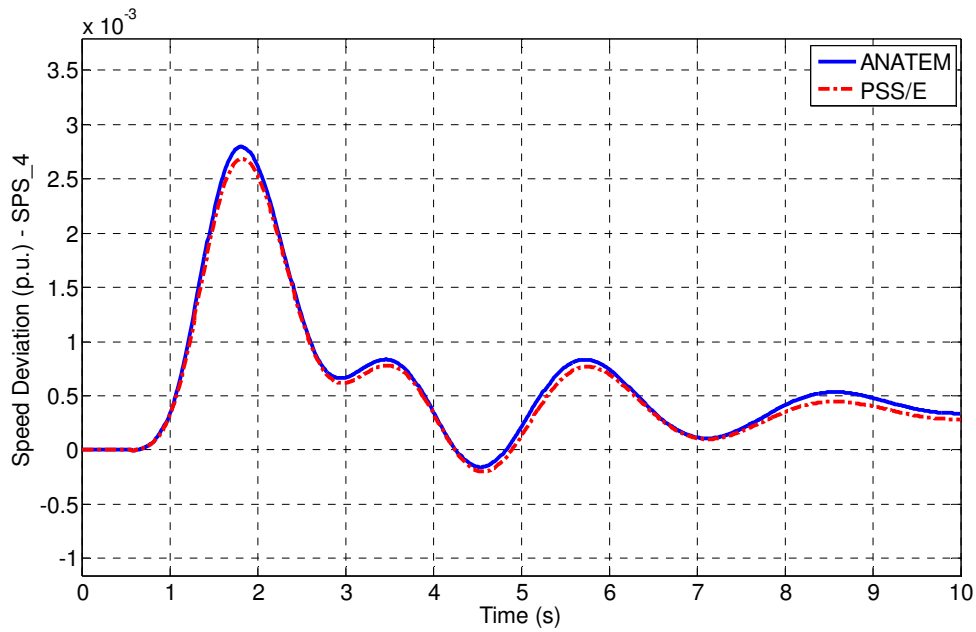

Figure 110 - Speed deviation of generator SPS_4 for Fault B

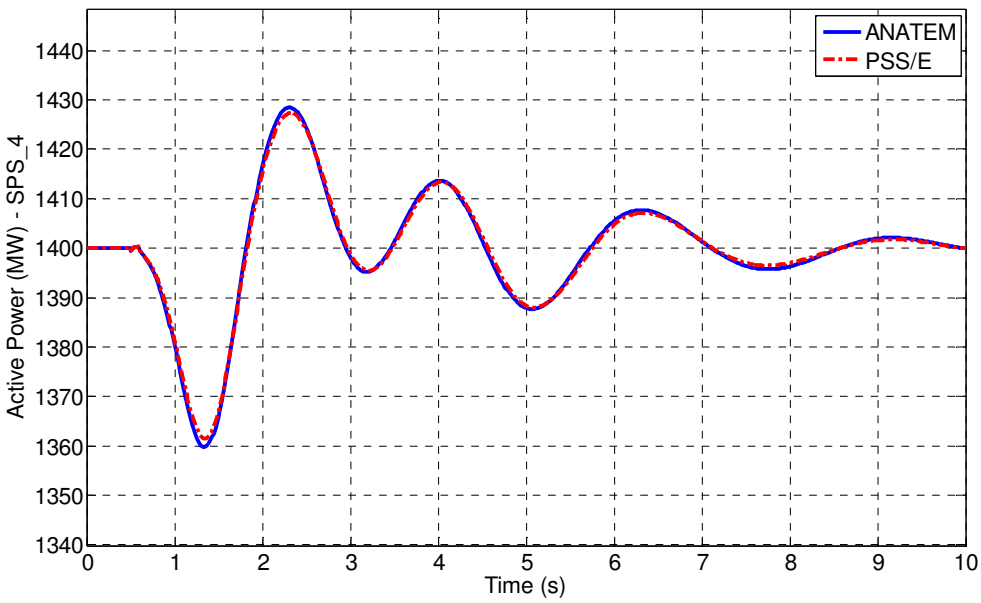

Figure 111 - Active power output of generator SPS_4 for Fault B

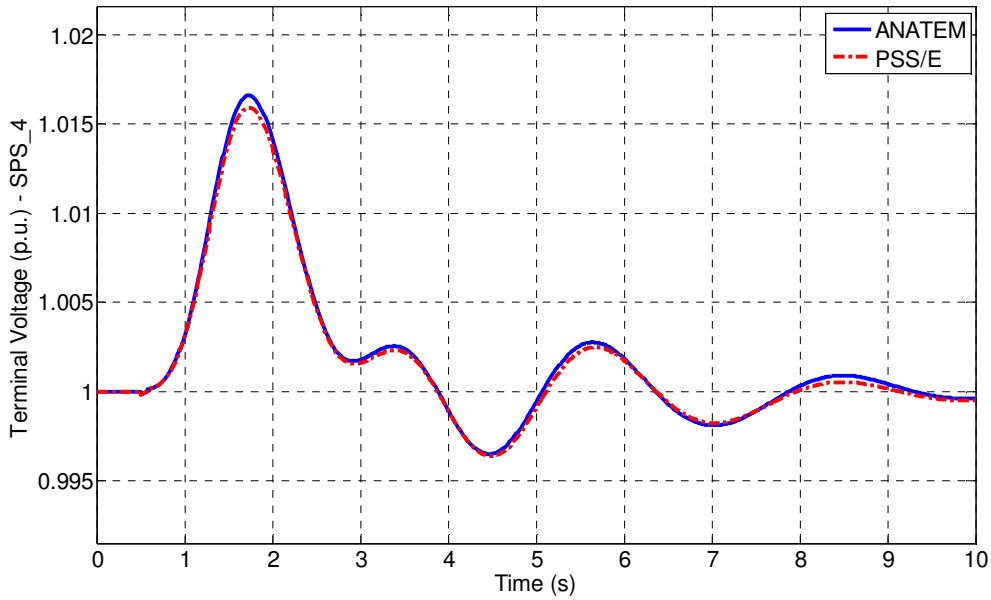

Figure 112 - Terminal voltage of generator SPS_4 for Fault B

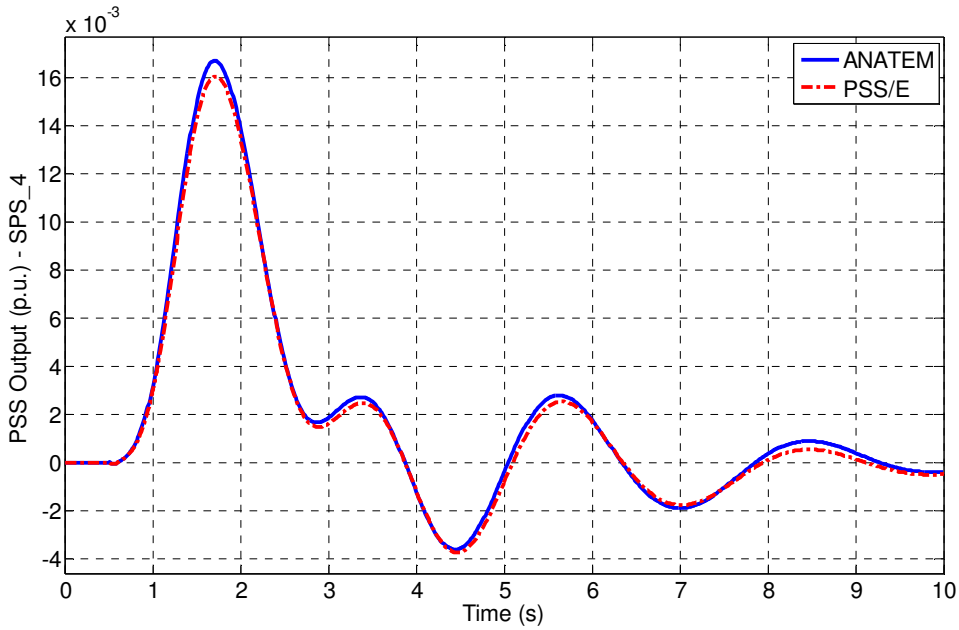

Figure 113 - PSS output of generator SPS_4 for Fault B

A.2.11 Generator GPS_4 – Bus 404

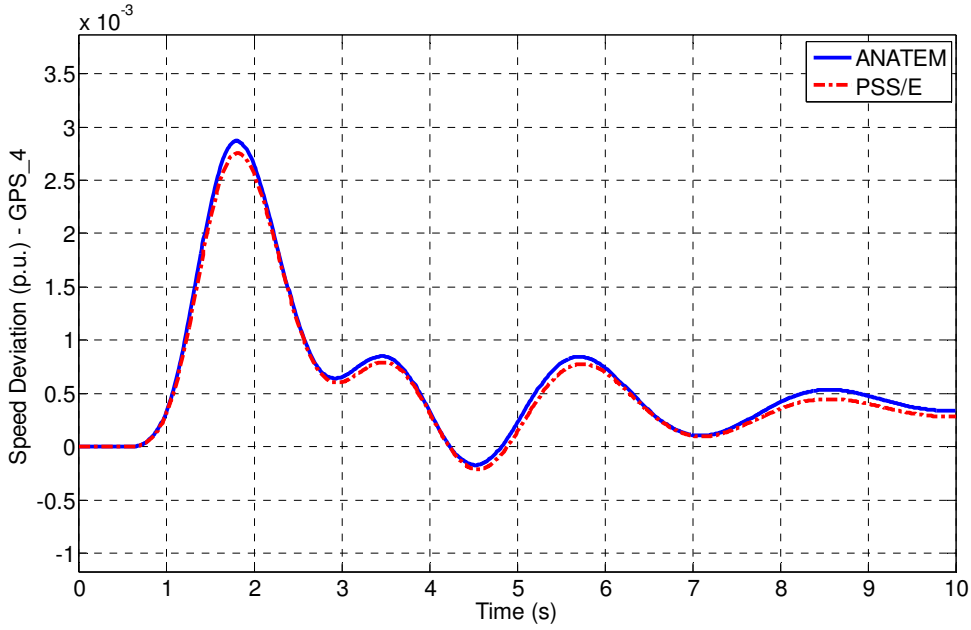

Figure 114 - Speed deviation of generator GPS_4 for Fault B

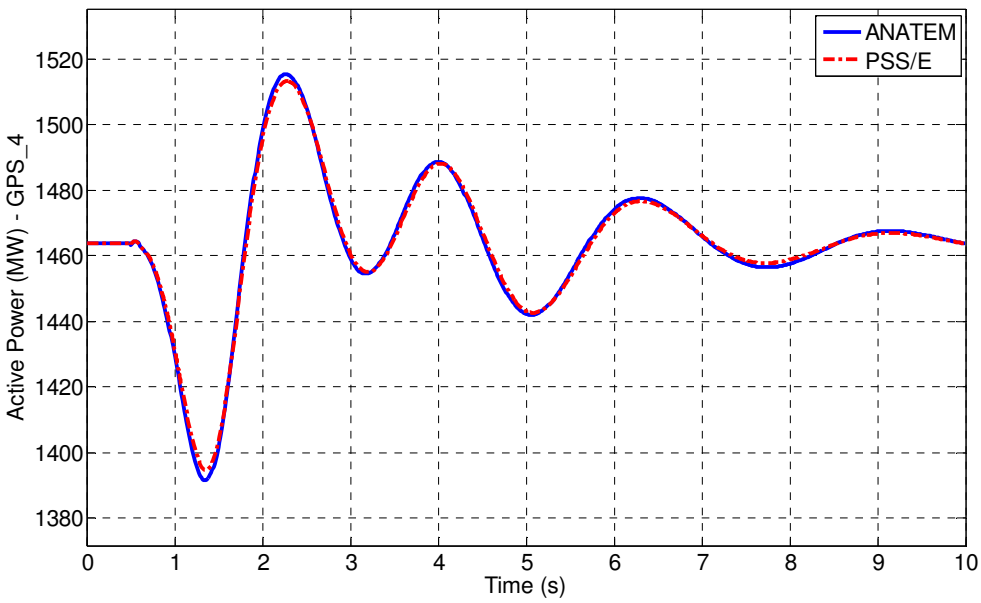

Figure 115 - Active power output of generator GPS_4 for Fault B

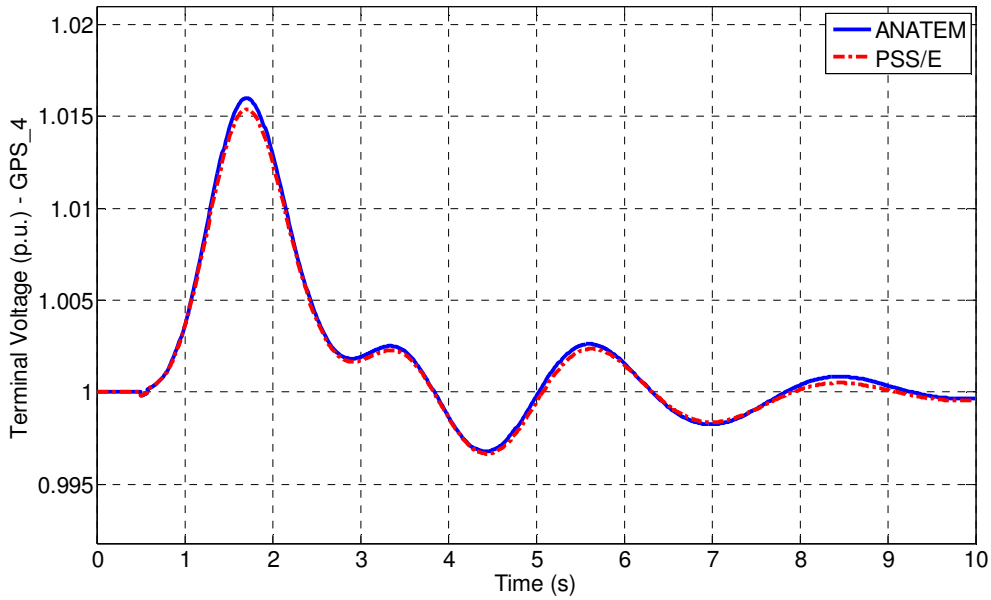

Figure 116 - Terminal voltage of generator GPS_4 for Fault B

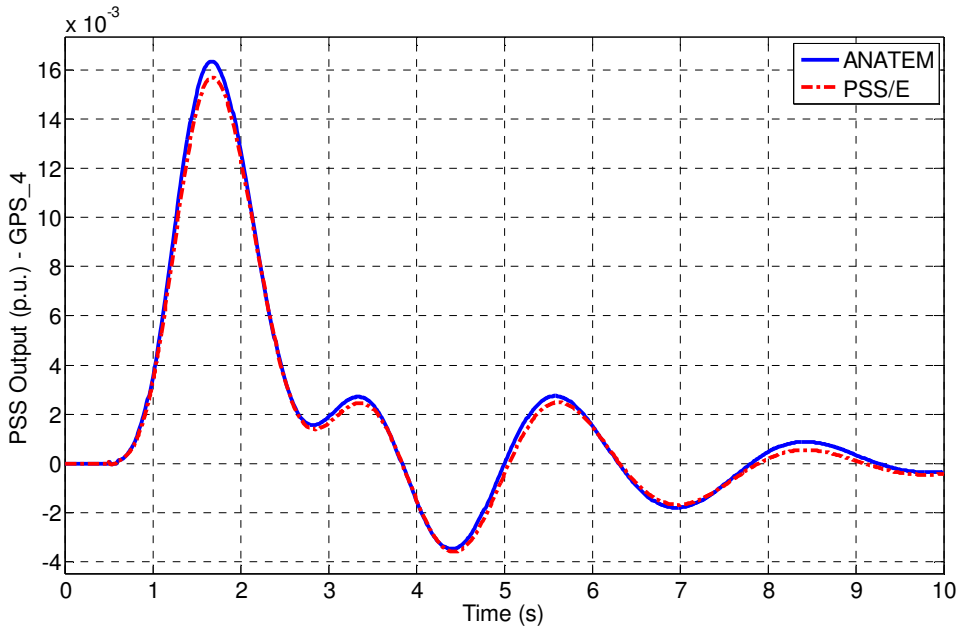

Figure 117 - PSS output of generator GPS_4 for Fault B

A.2.12 Generator NPS_5 – Bus 501

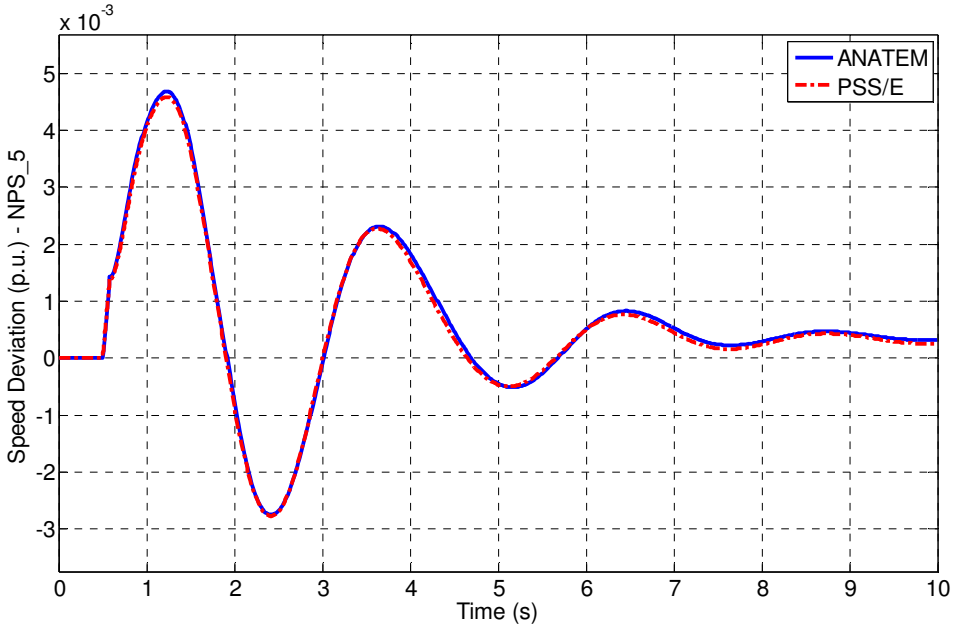

Figure 118 - Speed deviation of generator NPS_5 for Fault B

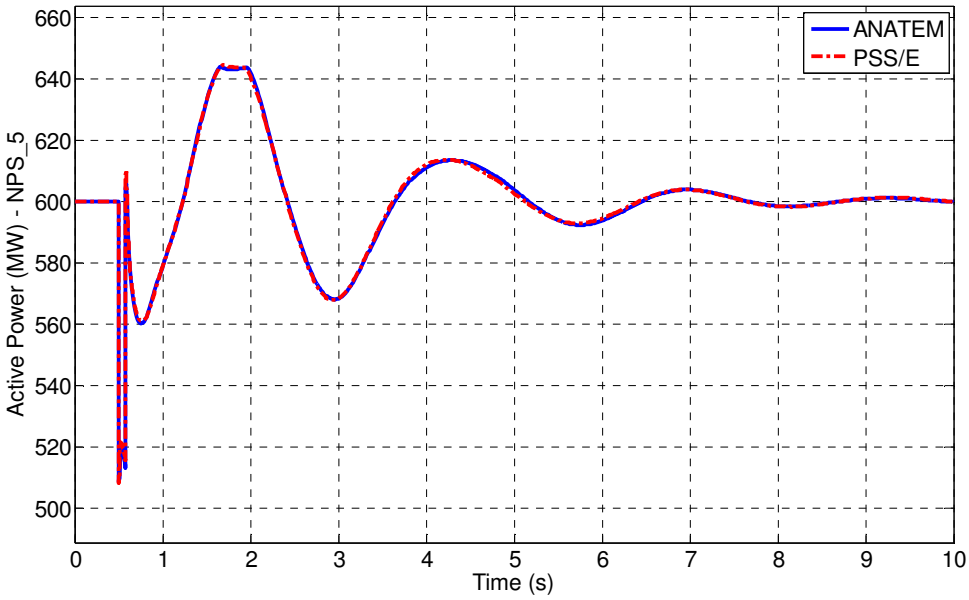

Figure 119 - Active power output of generator NPS_5 for Fault B

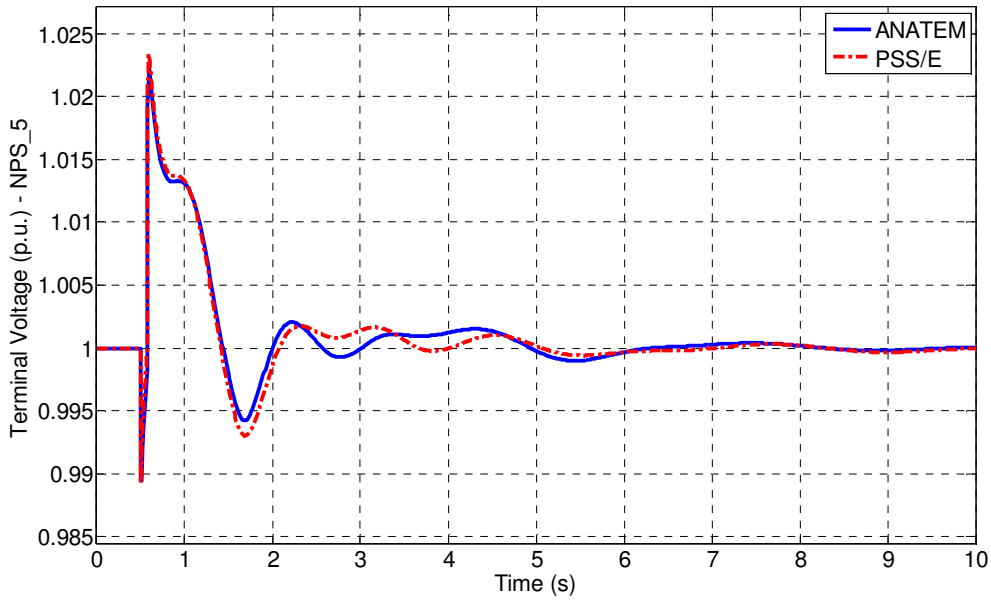

Figure 120 - Terminal voltage of generator NPS_5 for Fault B

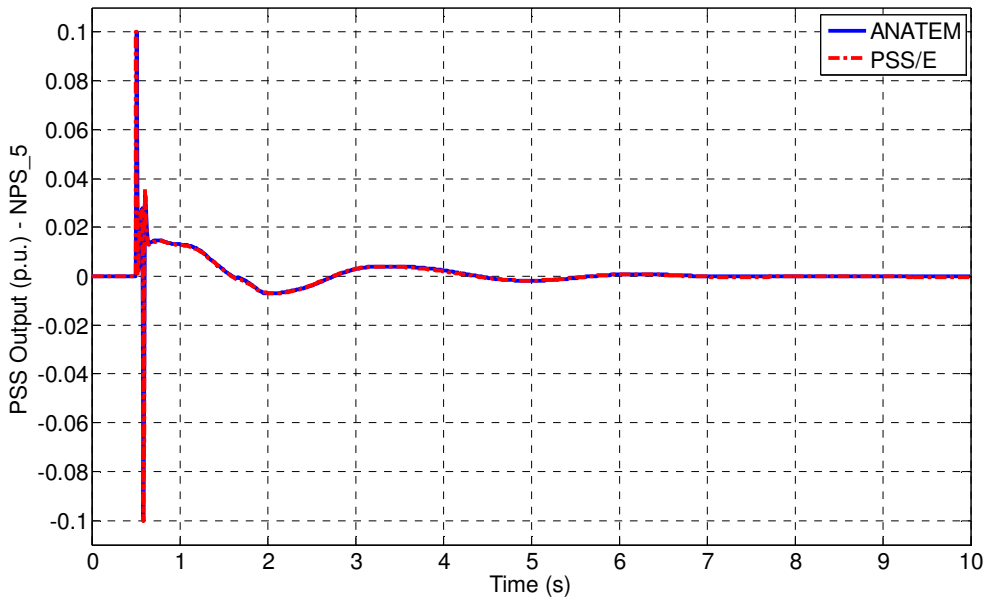

Figure 121 - PSS output of generator NPS_5 for Fault B

A.2.13 Generator TPS_5 – Bus 502

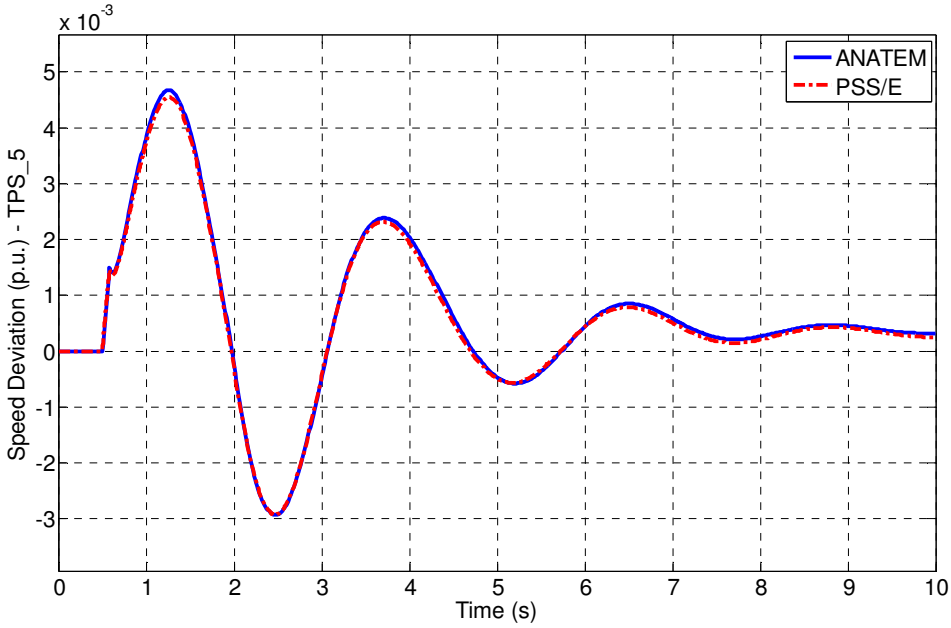

Figure 122 - Speed deviation of generator TPS_5 for Fault B

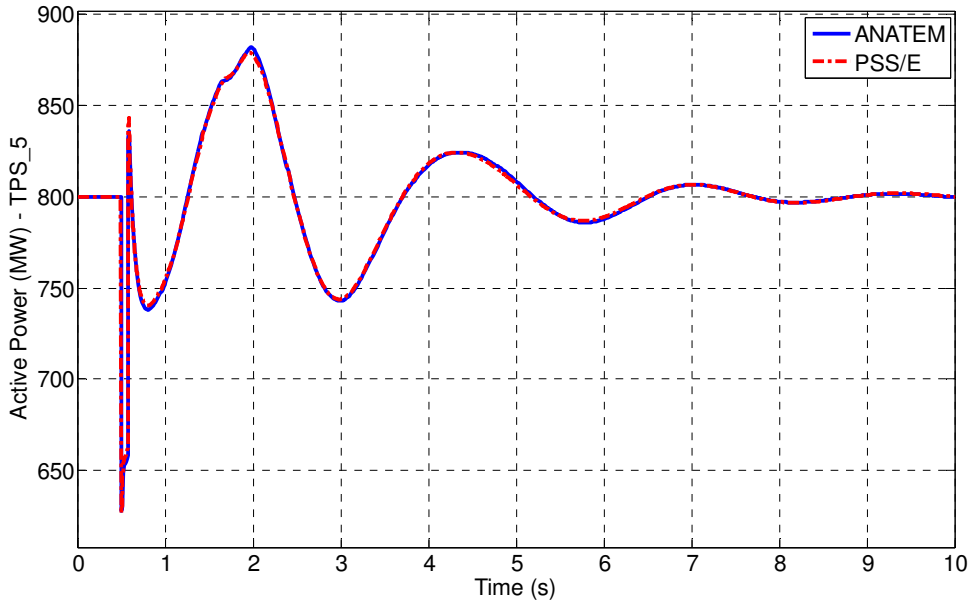

Figure 123 - Active power output of generator TPS_5 for Fault B

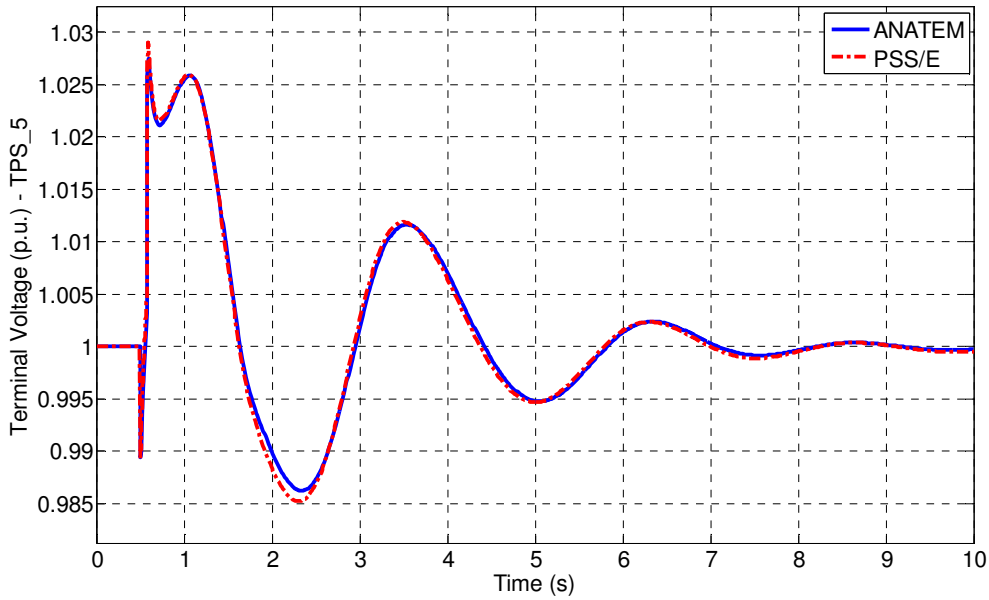

Figure 124 - Terminal voltage of generator TPS_5 for Fault B

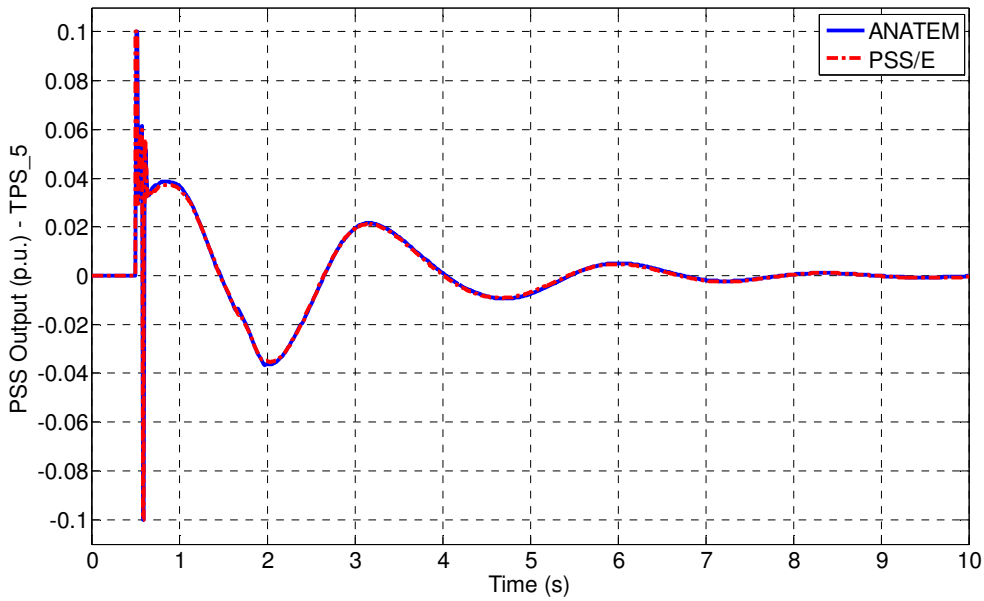

Figure 125 - PSS output of generator TPS_5 for Fault B

A.2.14 Generator PPS_5 – Bus 503

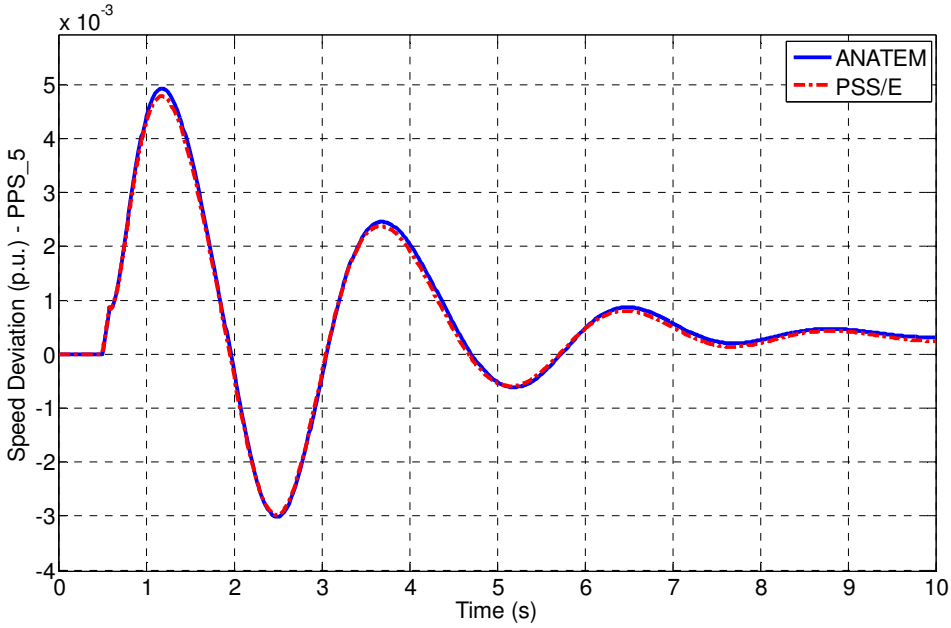

Figure 126 - Speed deviation of generator PPS_5 for Fault B

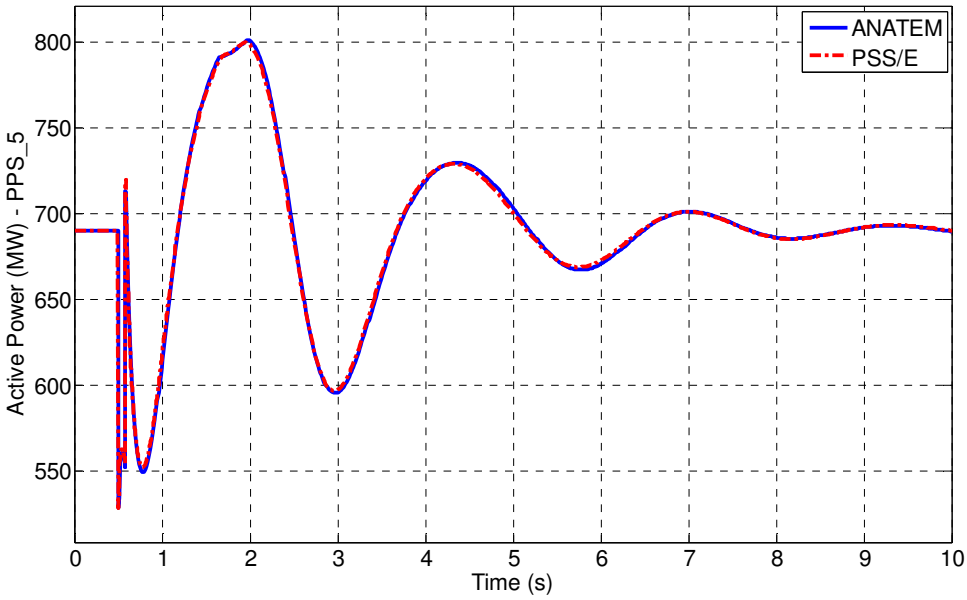

Figure 127 - Active power output of generator PPS_5 for Fault B

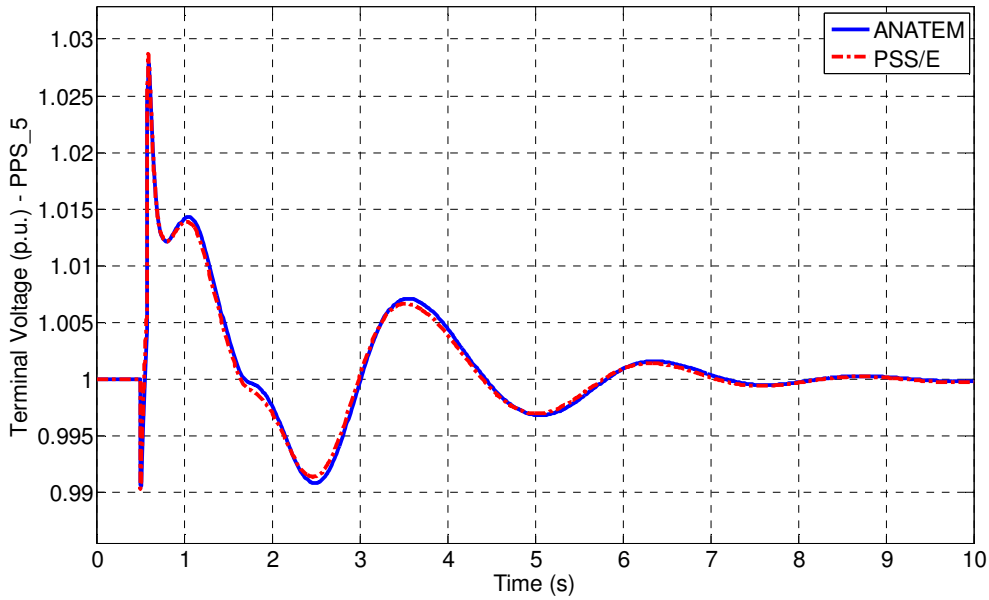

Figure 128 - Terminal voltage of generator PPS_5 for Fault B

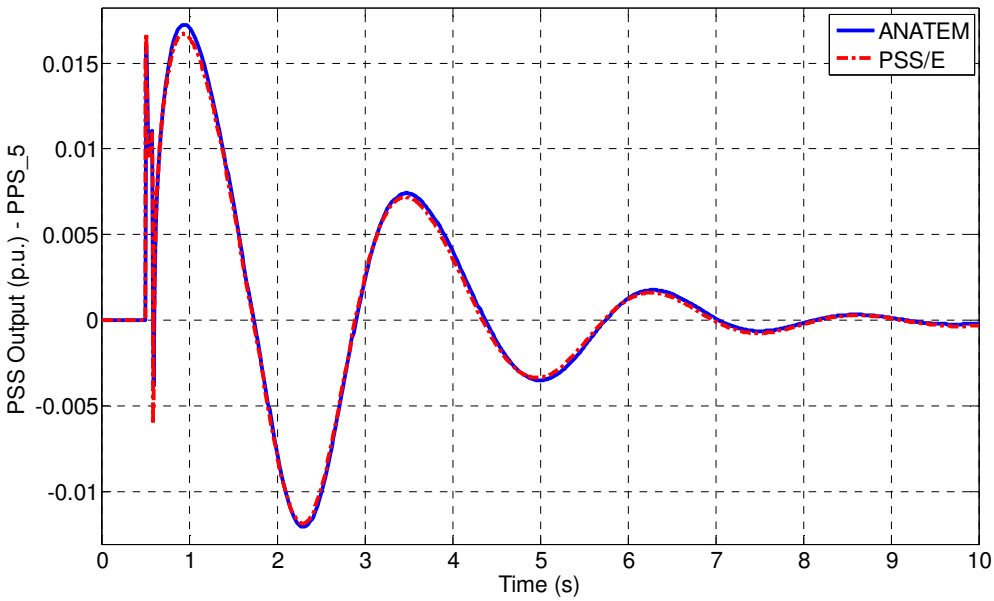

Figure 129 - PSS output of generator PPS_5 for Fault B

A.2.15 SVC ASVC_2 – Bus 205

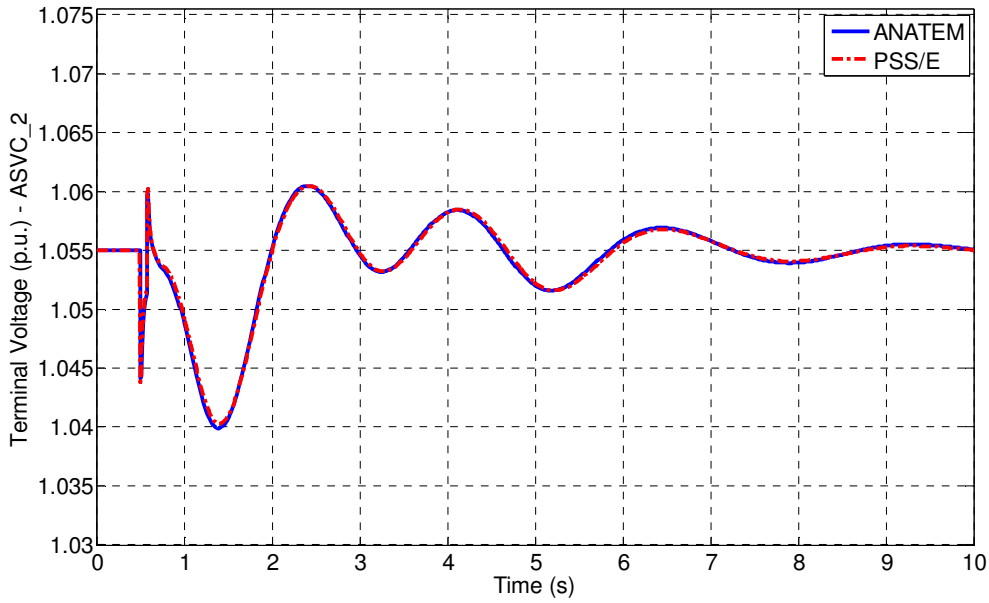

Figure 130 - Terminal voltage of SVC ASVC_2 for Fault B

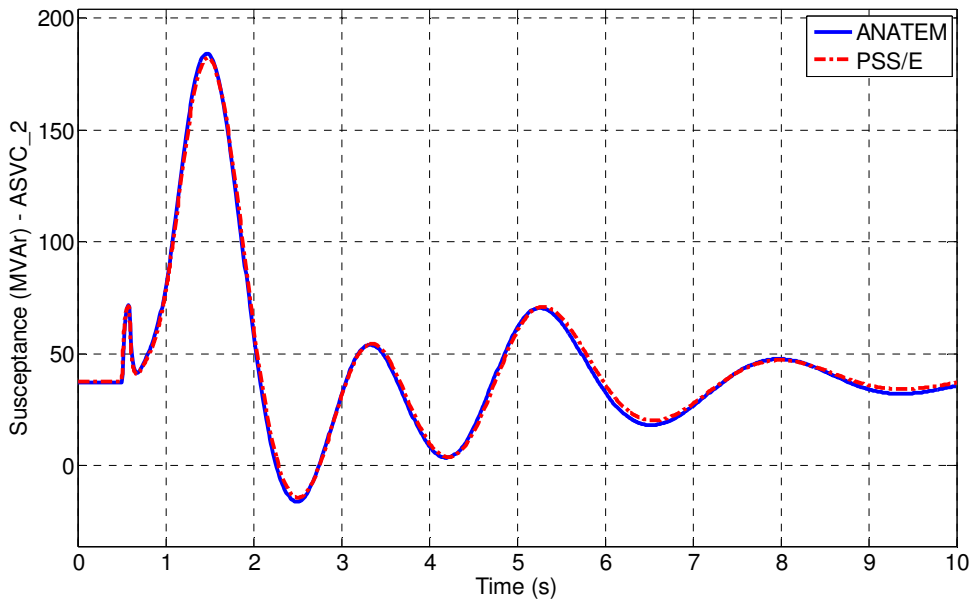

Figure 131 - Susceptance of SVC ASVC_2 for Fault B

A.2.16 SVC RSVC_3 – Bus 313

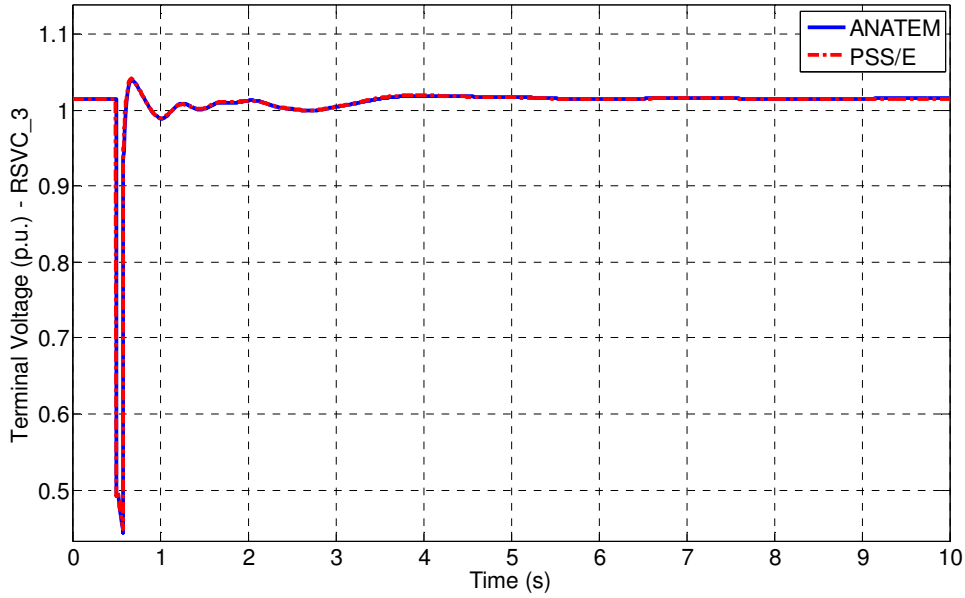

Figure 132 - Terminal voltage of SVC RSVC_3 for Fault B

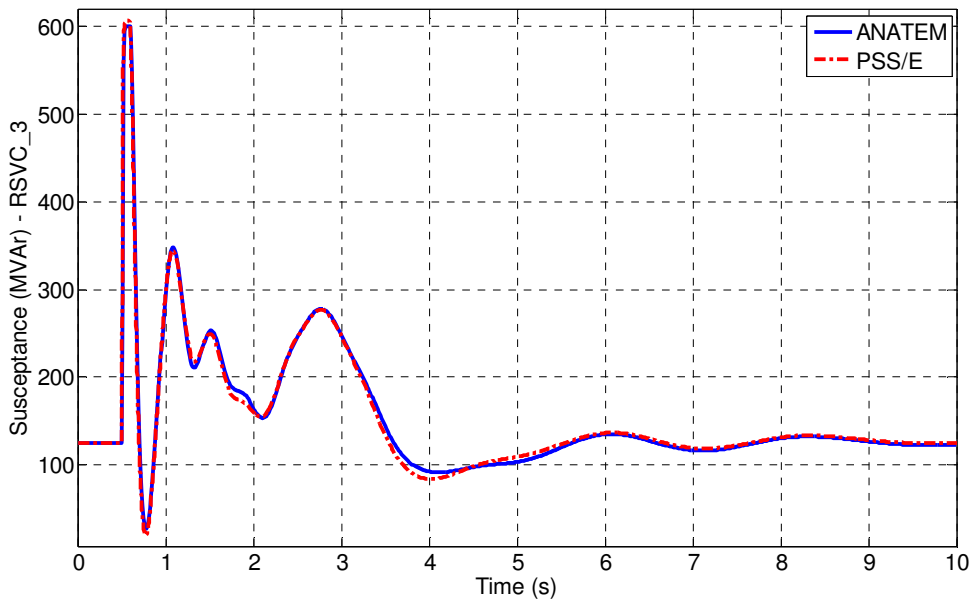

Figure 133 – Susceptance of SVC RSVC_3 for Fault B

A.2.17 SVC BSVC_4 – Bus 412

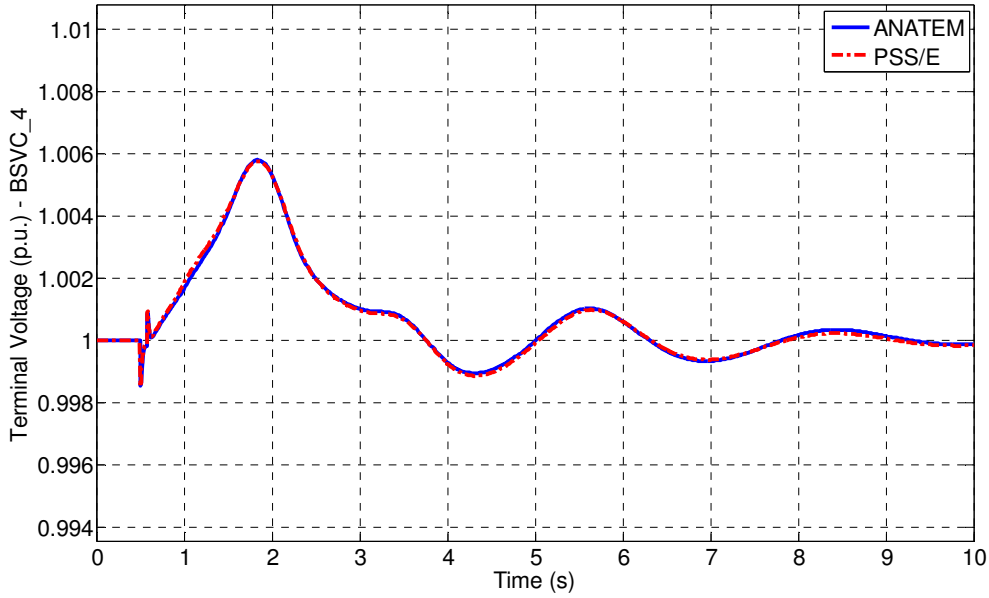

Figure 134 - Terminal voltage of SVC BSVC_4 for Fault B

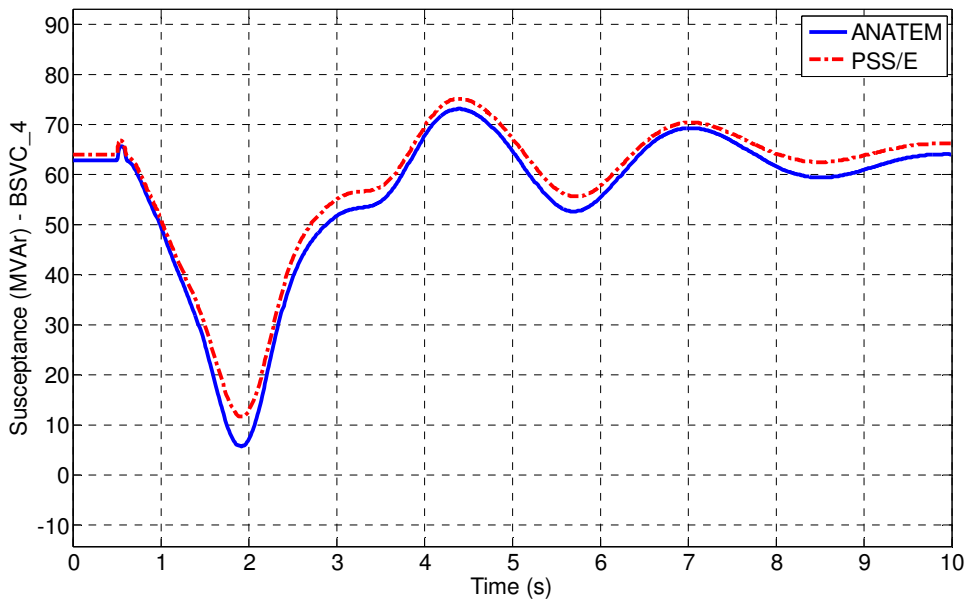

Figure 135 - Susceptance of SVC BSVC_4 for Fault B

A.2.18 SVC PSVC_5 – Bus 507

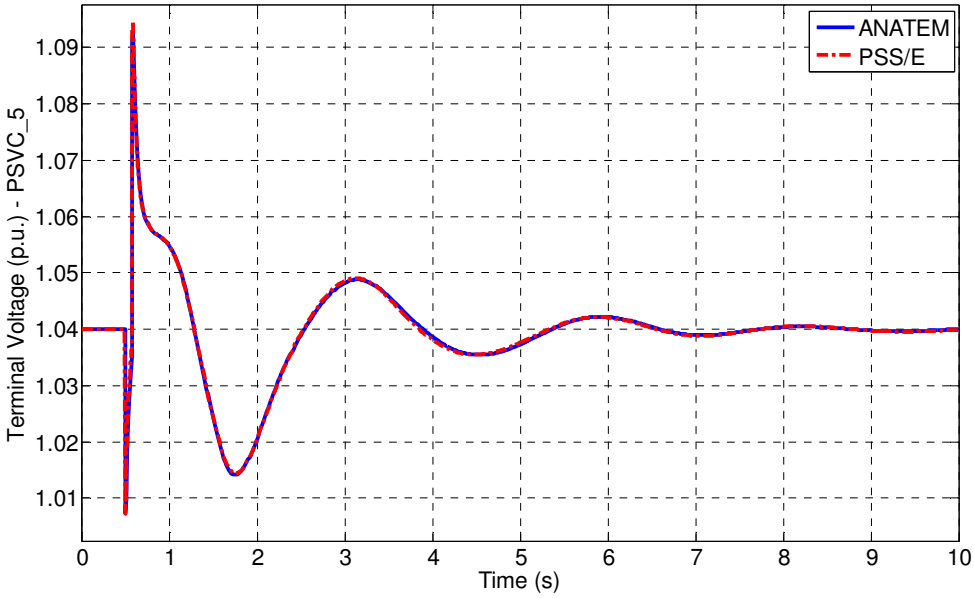

Figure 136 - Terminal voltage of SVC PSVC_5 for Fault B

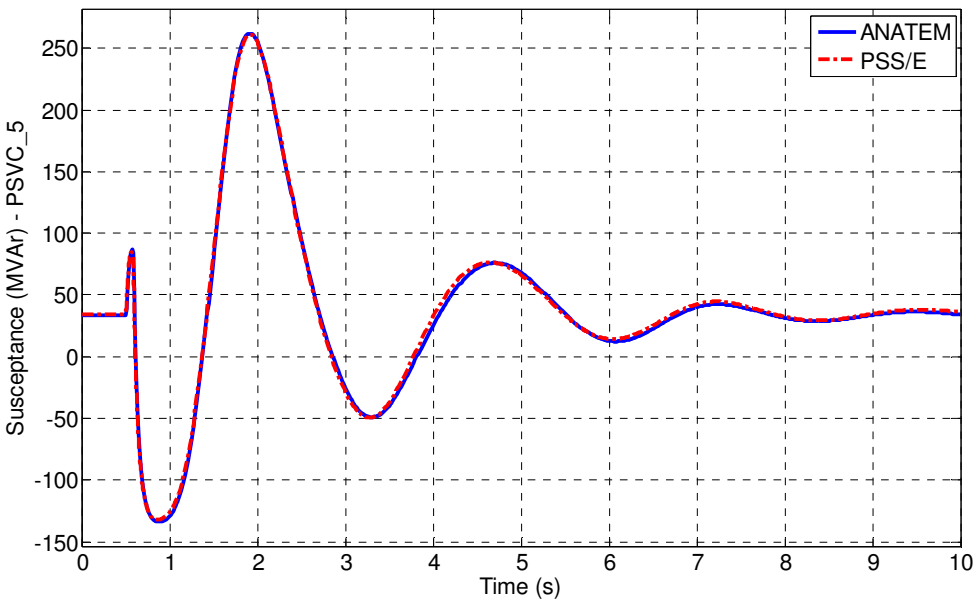

Figure 137 - Susceptance of SVC PSVC_5 for Fault B

A.2.19 SVC SSVC_5 – Bus 509

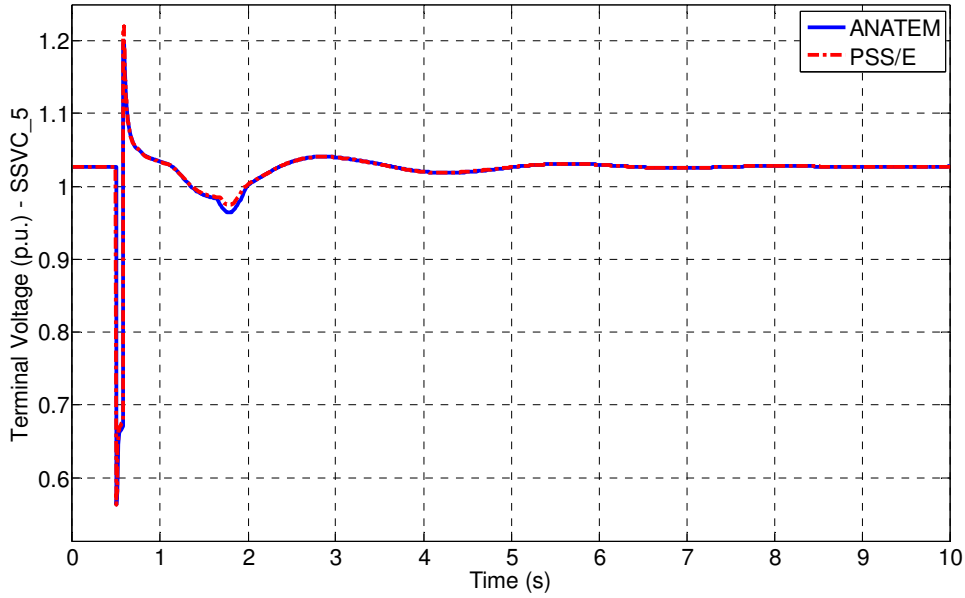

Figure 138 - Terminal voltage of SVC SSVC_5 for Fault B

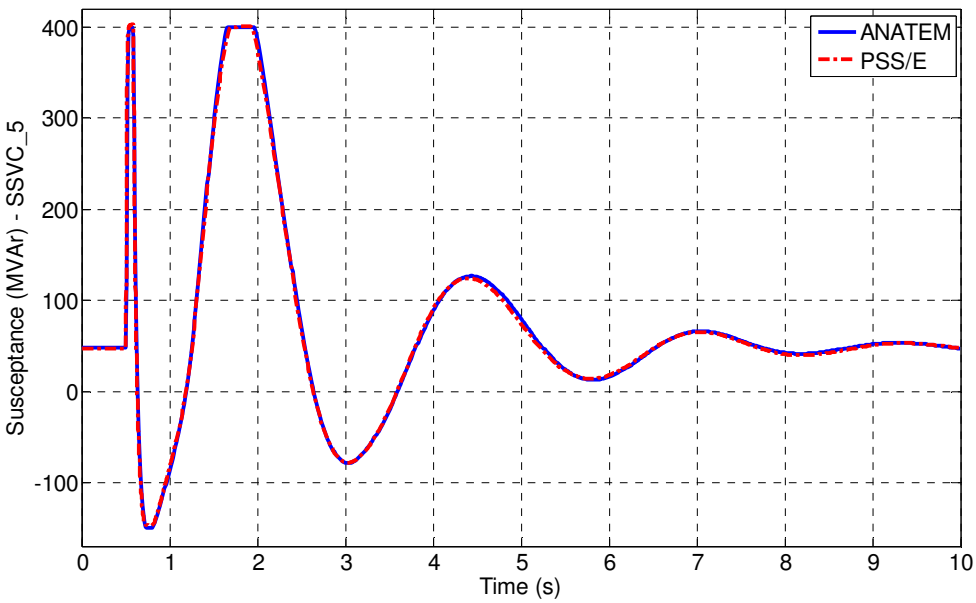

Figure 139 - Susceptance of SVC SSVC_5 for Fault B

A.3 Fault C

A.3.1 Generator HPS_1 – Bus 101

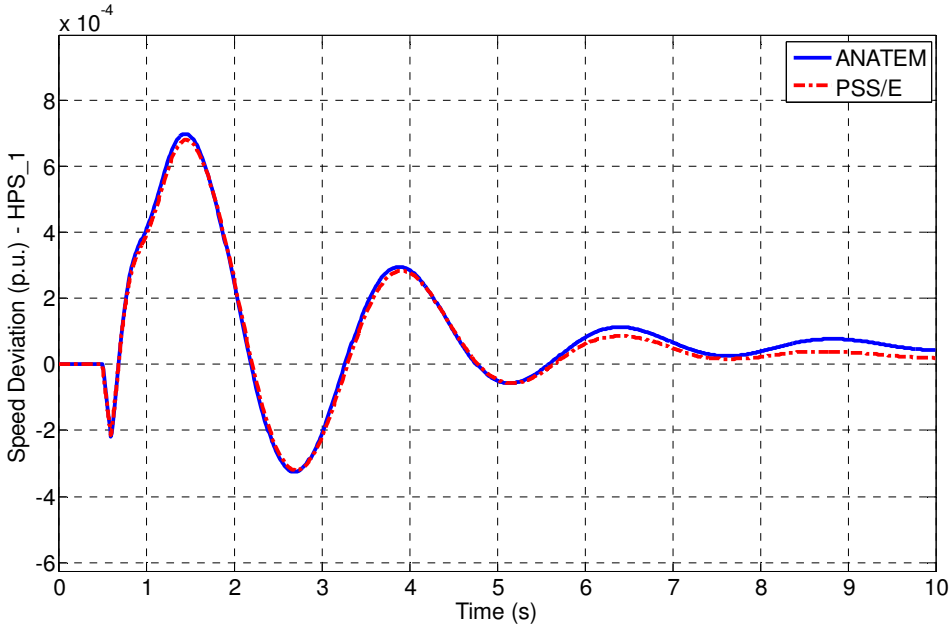

Figure 140 - Speed deviation of generator HPS_1 for Fault C

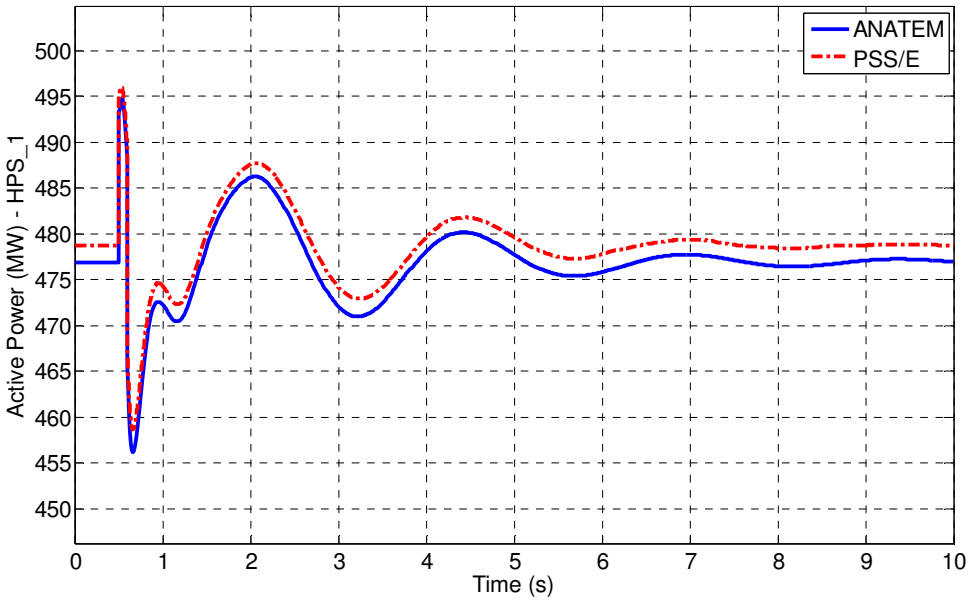

Figure 141 - Active power output of generator HPS_1 for Fault C

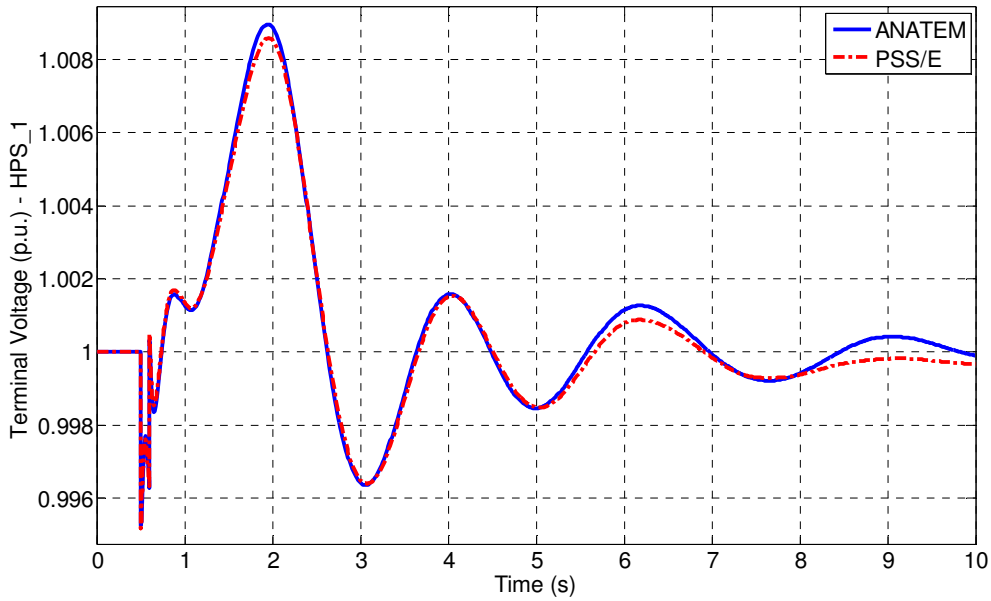

Figure 142 - Terminal voltage of generator HPS_1 for Fault C

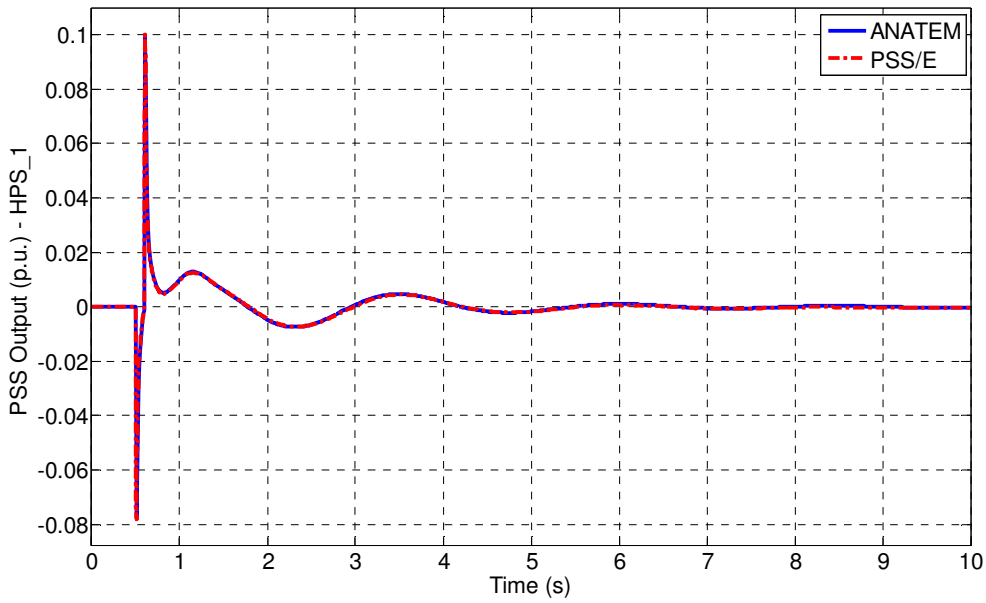

Figure 143 - PSS output of generator HPS_1 for Fault C

A.3.2 Generator BPS_2 – Bus 201

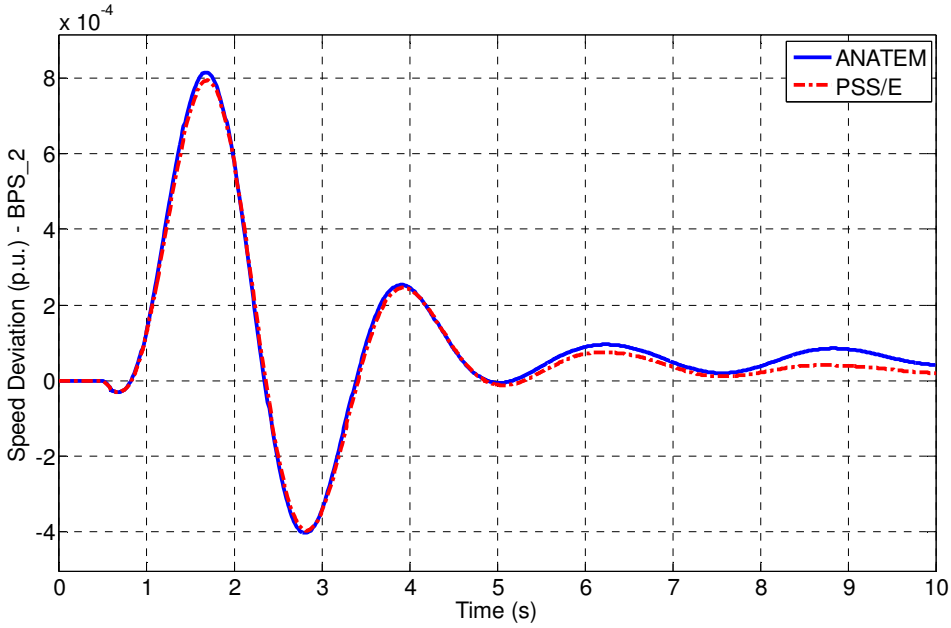

Figure 144 - Speed deviation of generator BPS_2 for Fault C

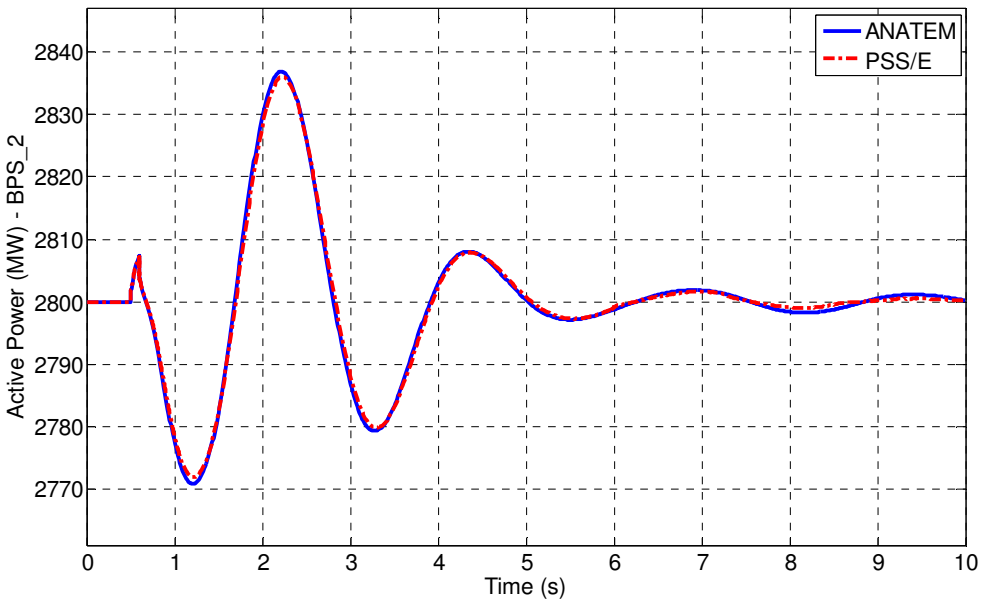

Figure 145 - Active power output of generator BPS_2 for Fault C

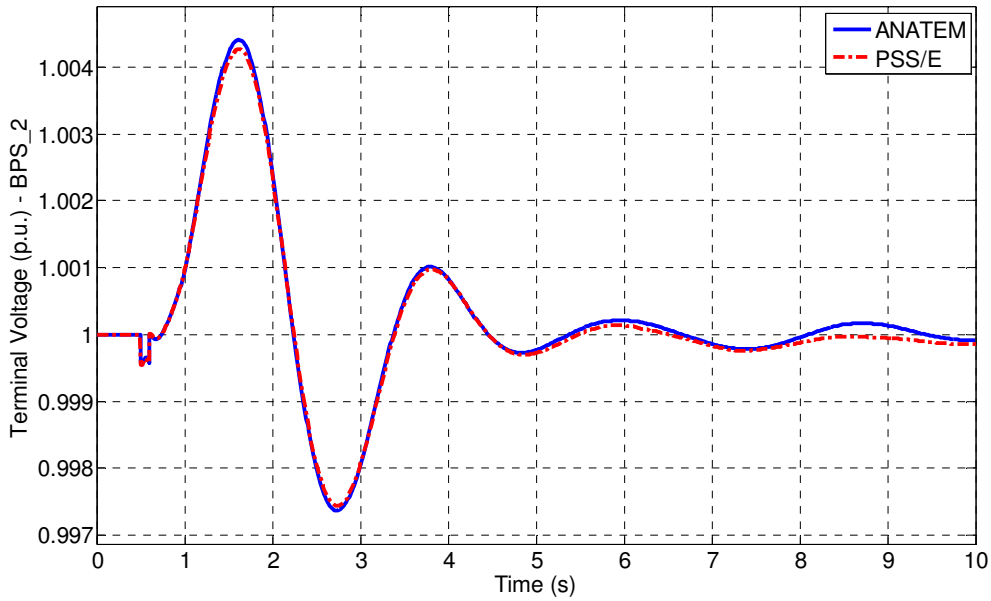

Figure 146 - Terminal voltage of generator BPS_2 for Fault C

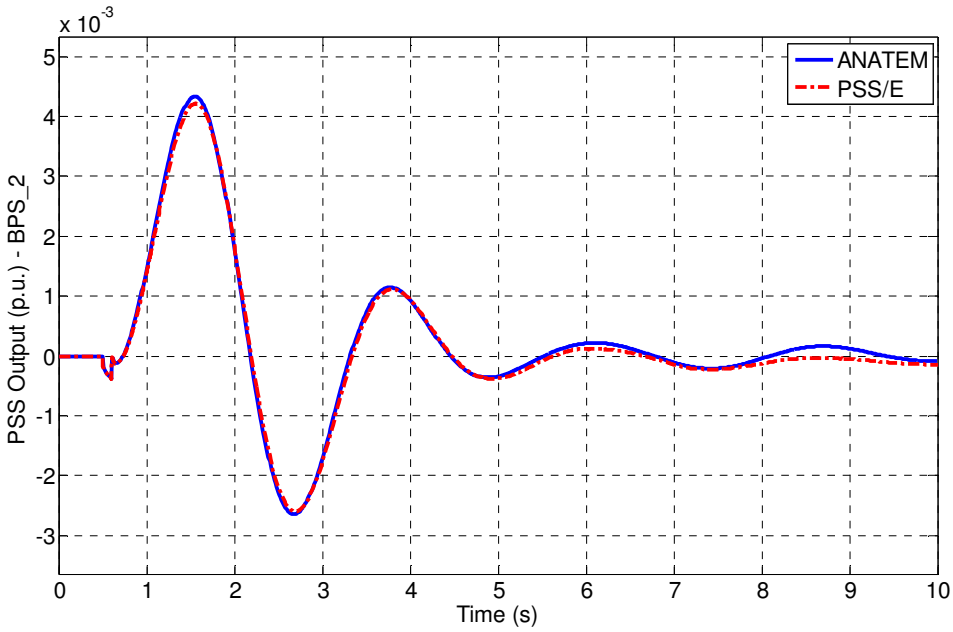

Figure 147 - PSS output of generator BPS_2 for Fault C

A.3.3 Generator EPS_2 – Bus 202

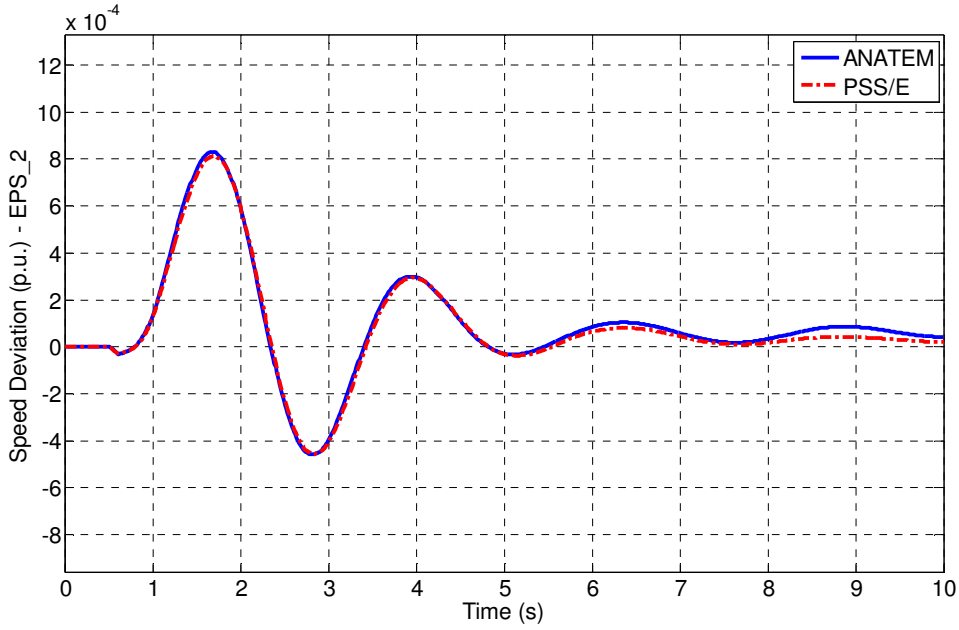

Figure 148 - Speed deviation of generator EPS_2 for Fault C

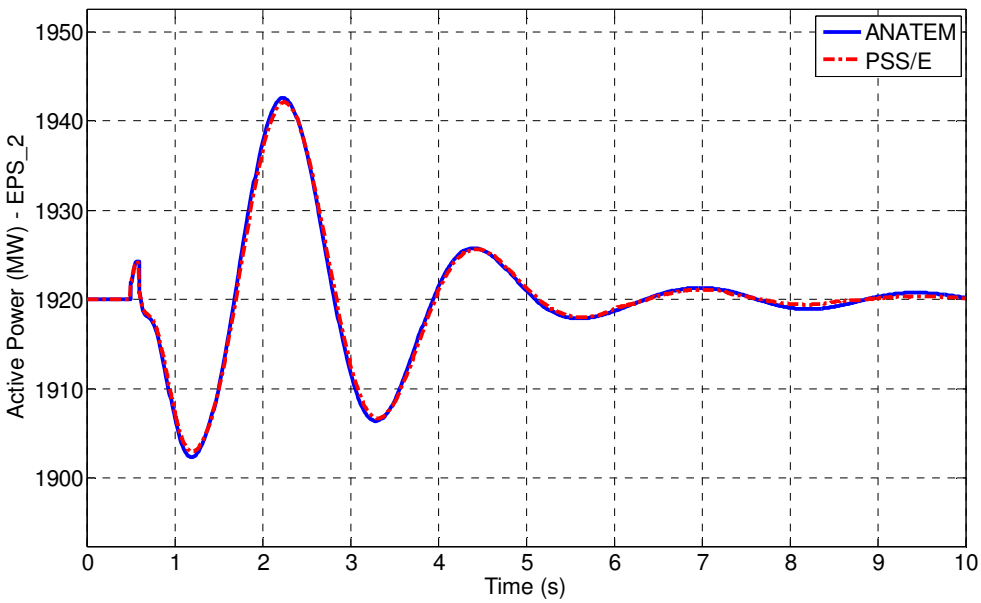

Figure 149 - Active power output of generator EPS_2 for Fault C

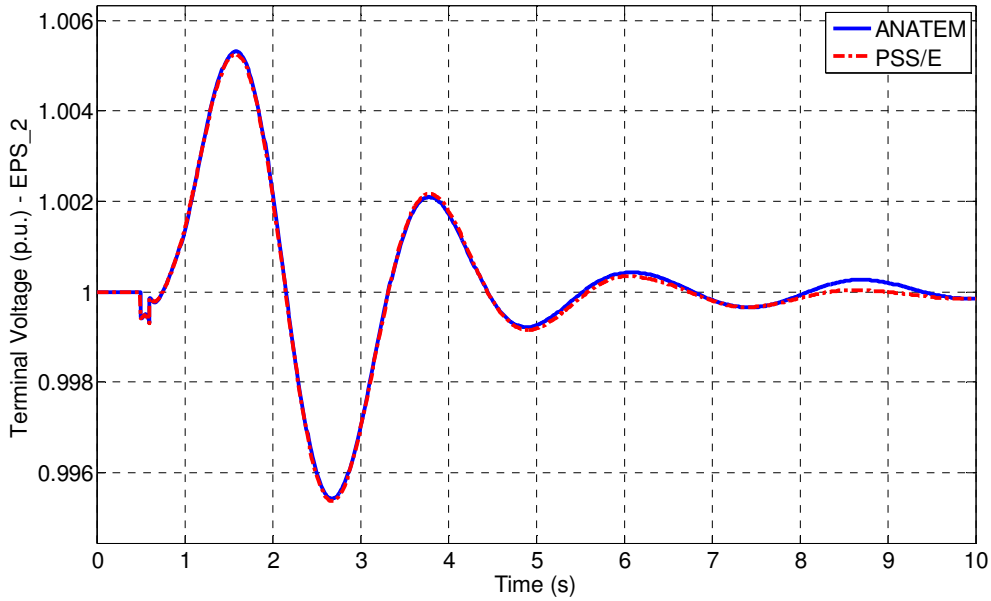

Figure 150 - Terminal voltage of generator EPS_2 for Fault C

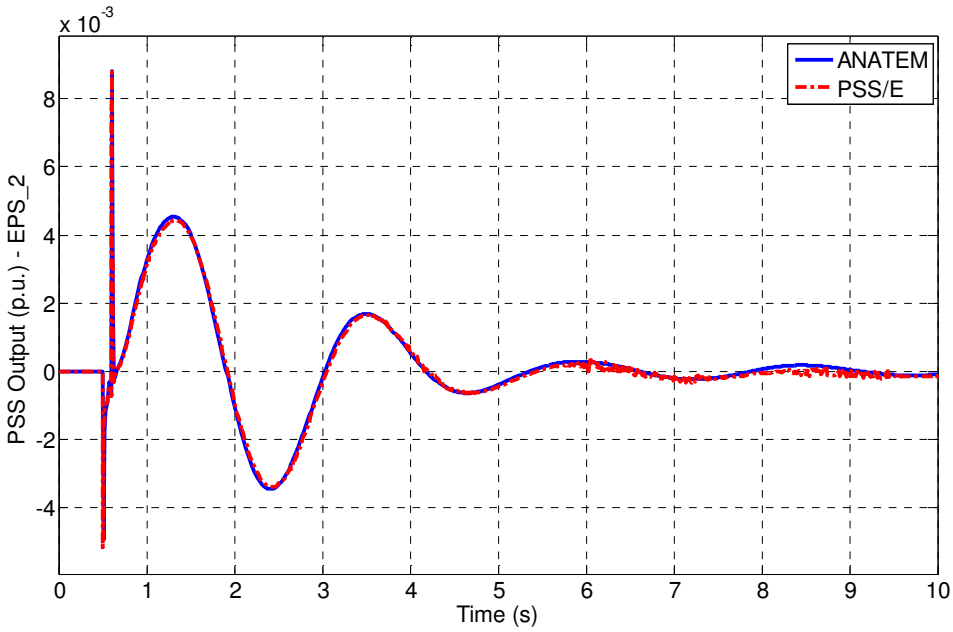

Figure 151 - PSS output of generator EPS_2 for Fault C

A.3.4 Generator VPS_2 – Bus 203

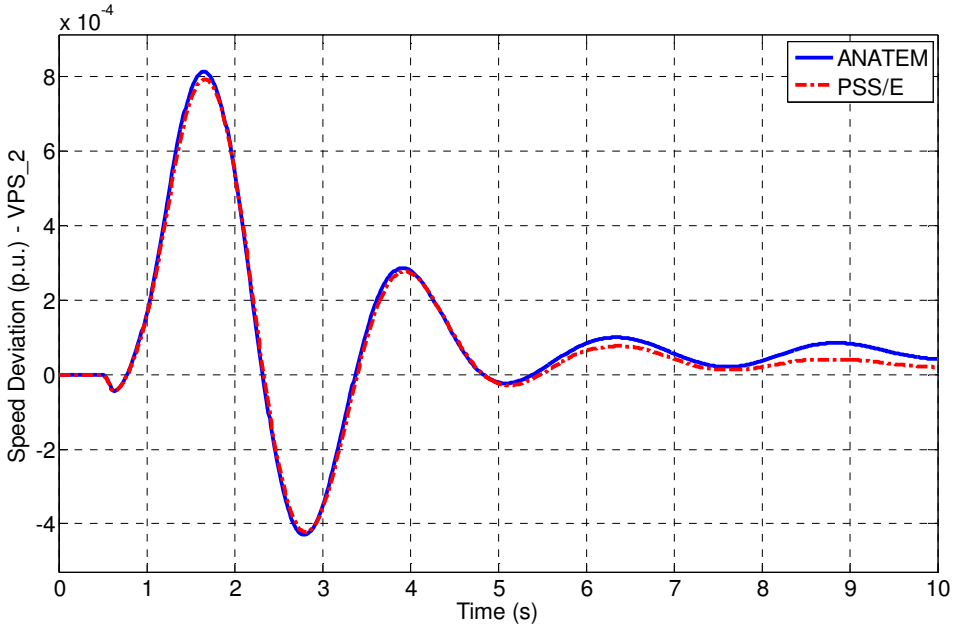

Figure 152 - Speed deviation of generator VPS_2 for Fault C

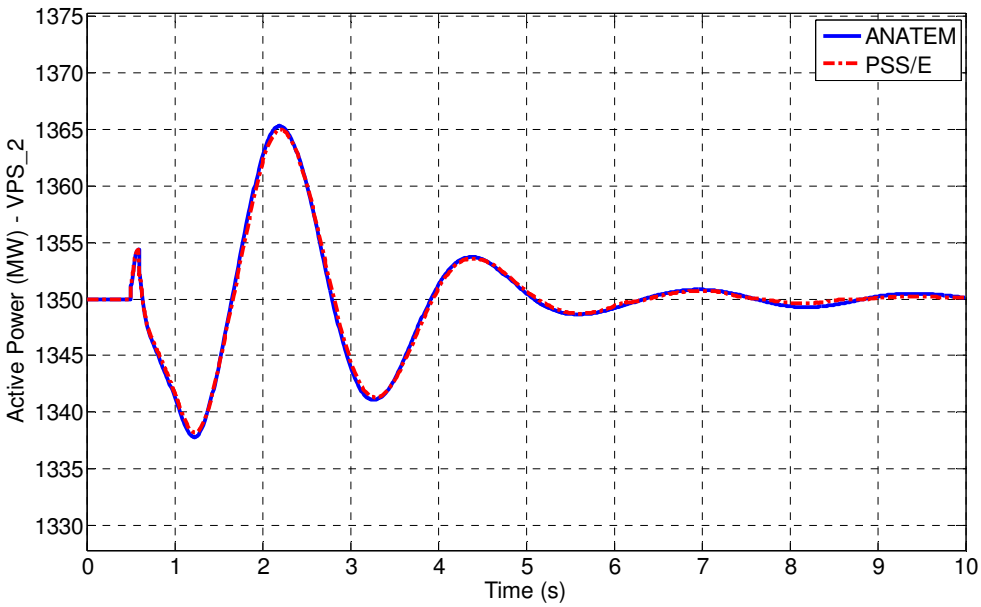

Figure 153 - Active power output of generator VPS_2 for Fault C

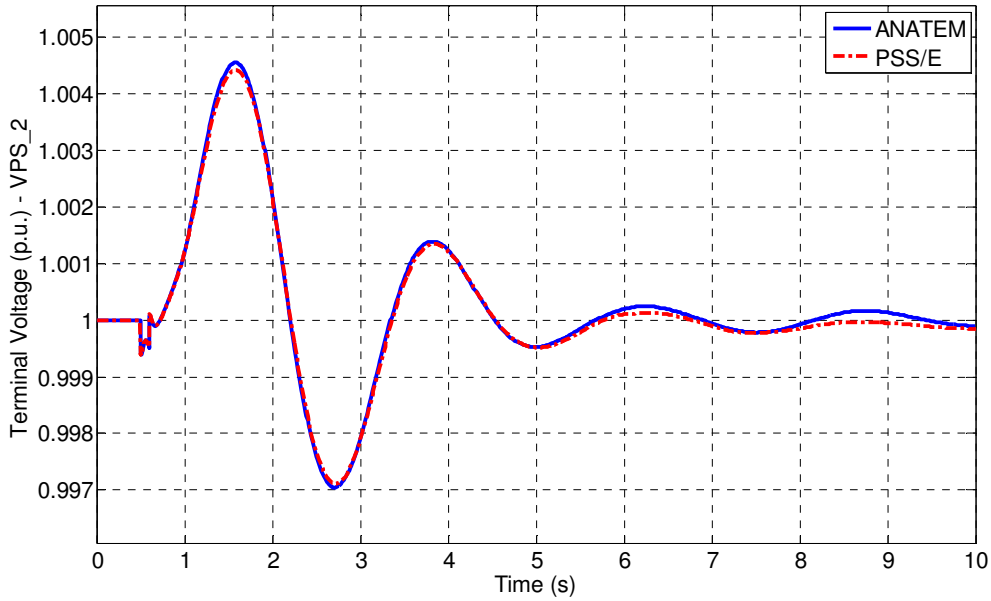

Figure 154 - Terminal voltage of generator VPS_2 for Fault C

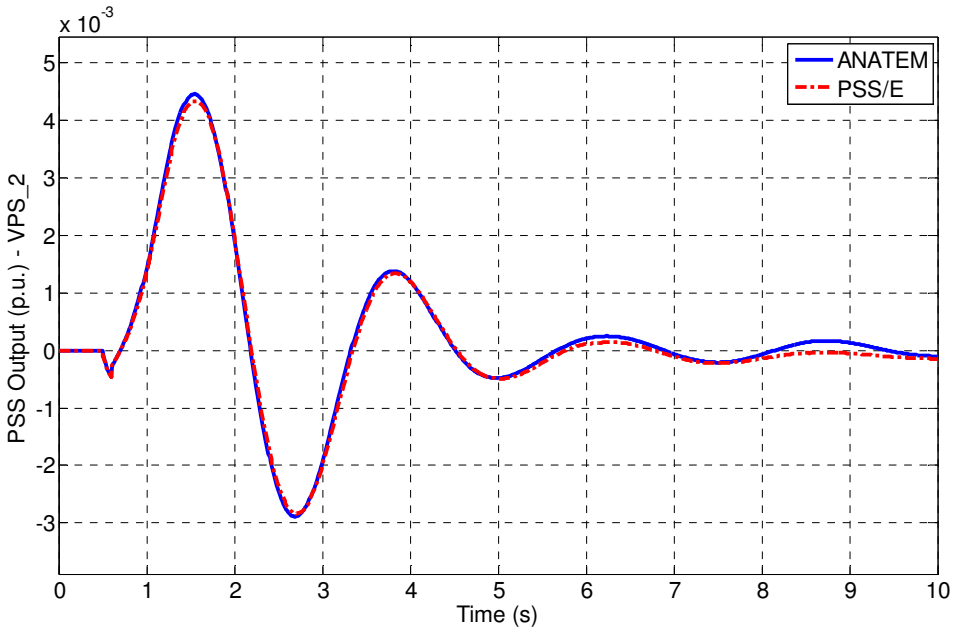

Figure 155 - PSS output of generator VPS_2 for Fault C

A.3.5 Generator MPS_2 – Bus 204

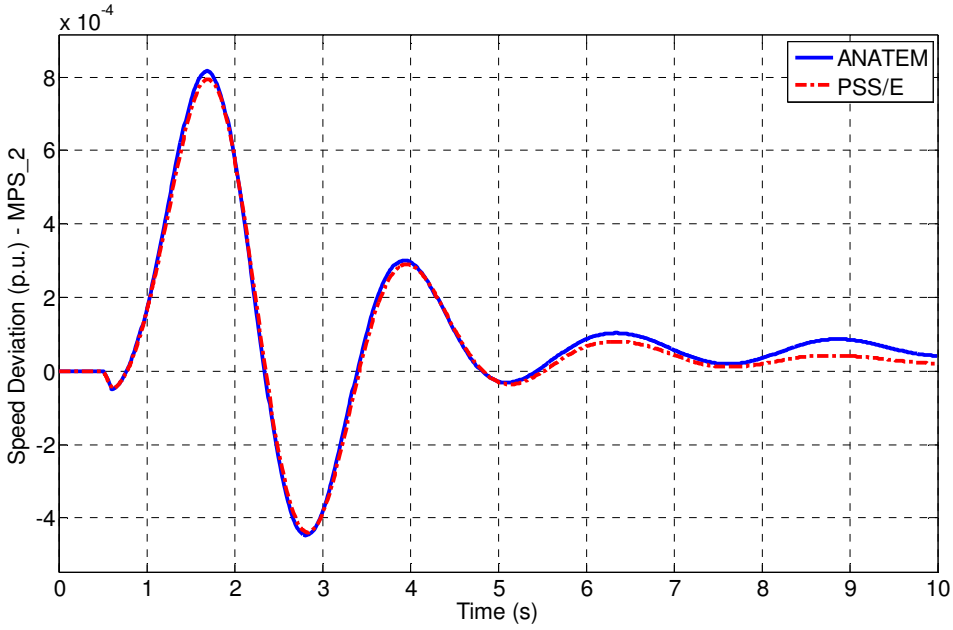

Figure 156 - Speed deviation of generator MPS_2 for Fault C

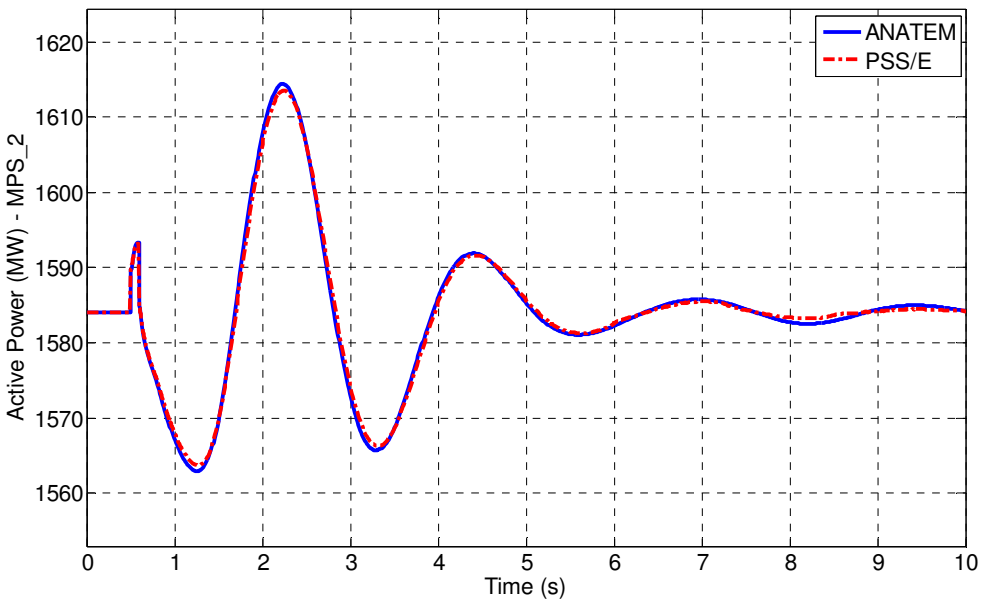

Figure 157 - Active power output of generator MPS_2 for Fault C

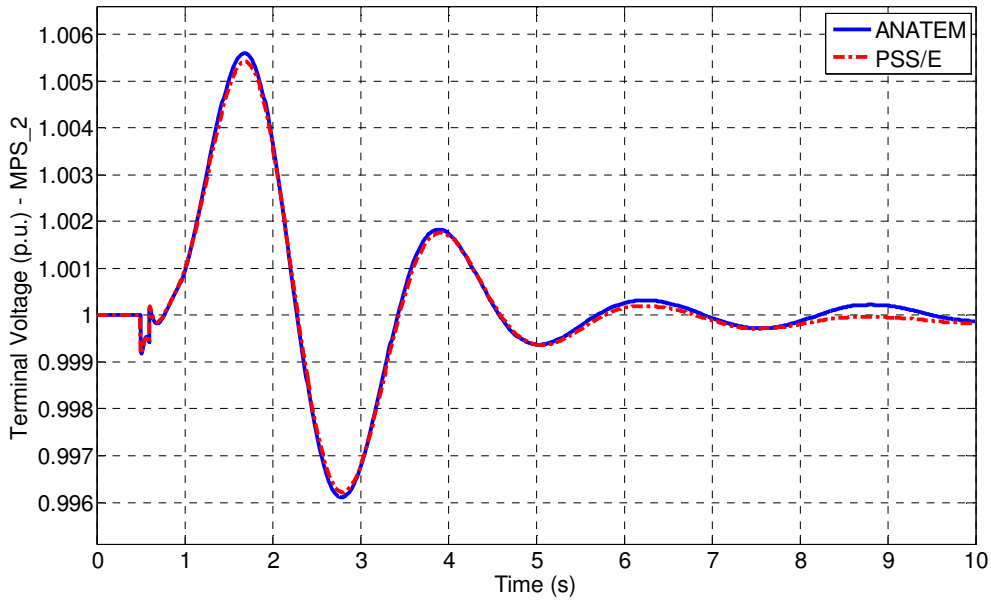

Figure 158 - Terminal voltage of generator MPS_2 for Fault C

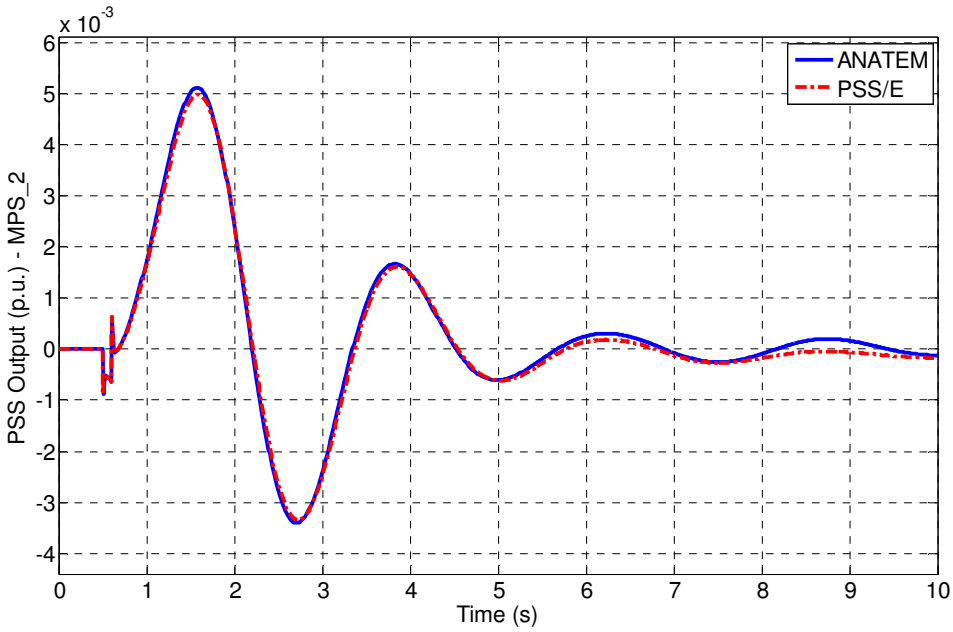

Figure 159 - PSS output of generator MPS_2 for Fault C

A.3.6 Generator LPS_3 – Bus 301

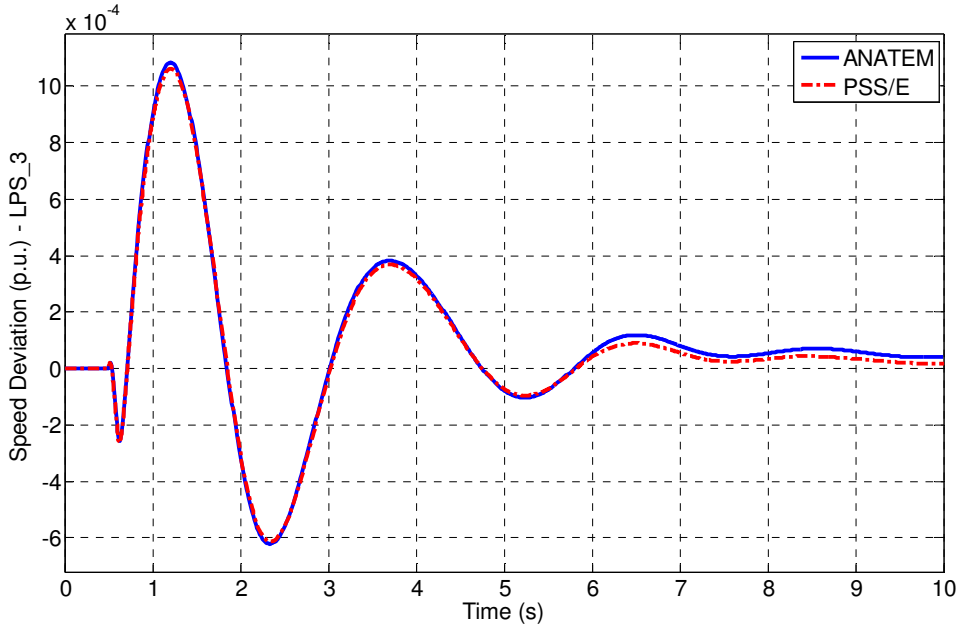

Figure 160 - Speed deviation of generator LPS_3 for Fault C

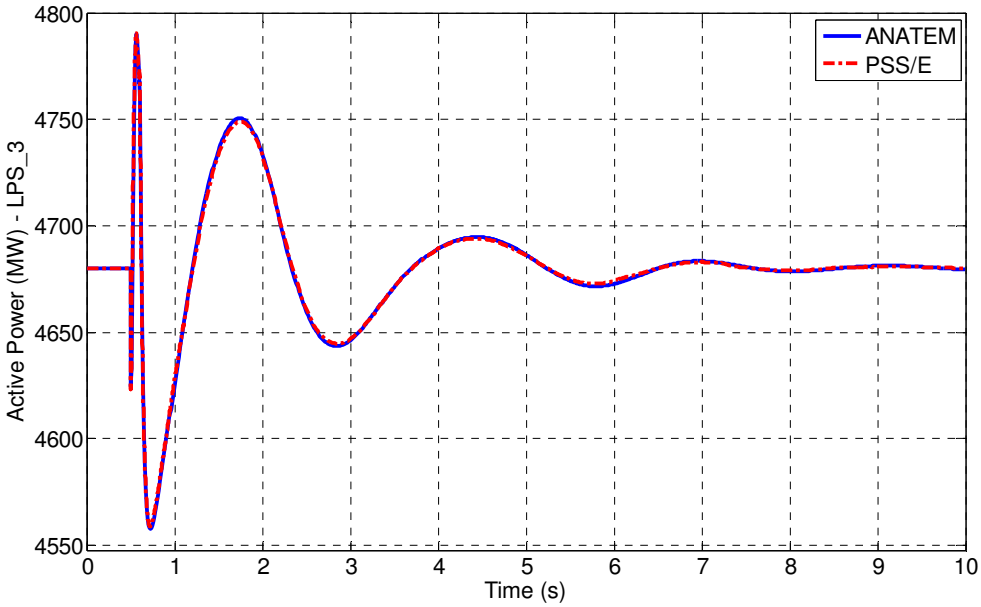

Figure 161 - Active power output of generator LPS_3 for Fault C

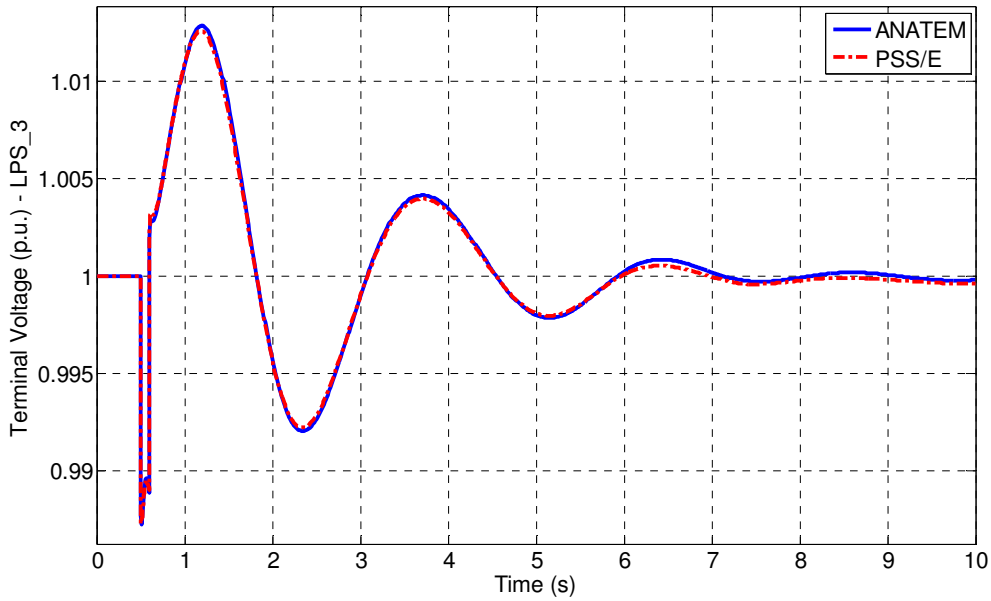

Figure 162 - Terminal voltage of generator LPS_3 for Fault C

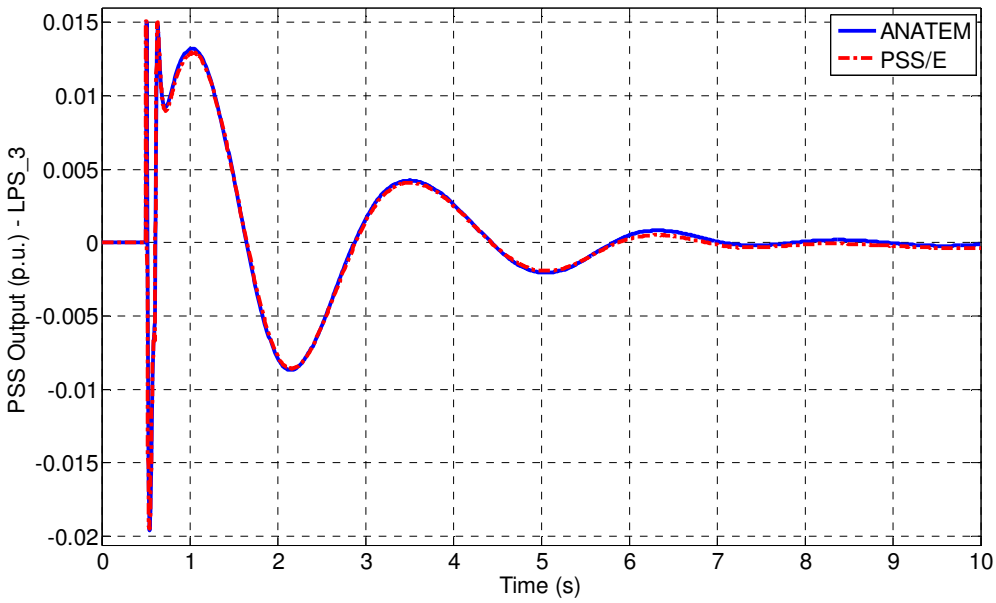

Figure 163 - PSS output of generator LPS_3 for Fault C

A.3.7 Generator YPS_3 – Bus 302

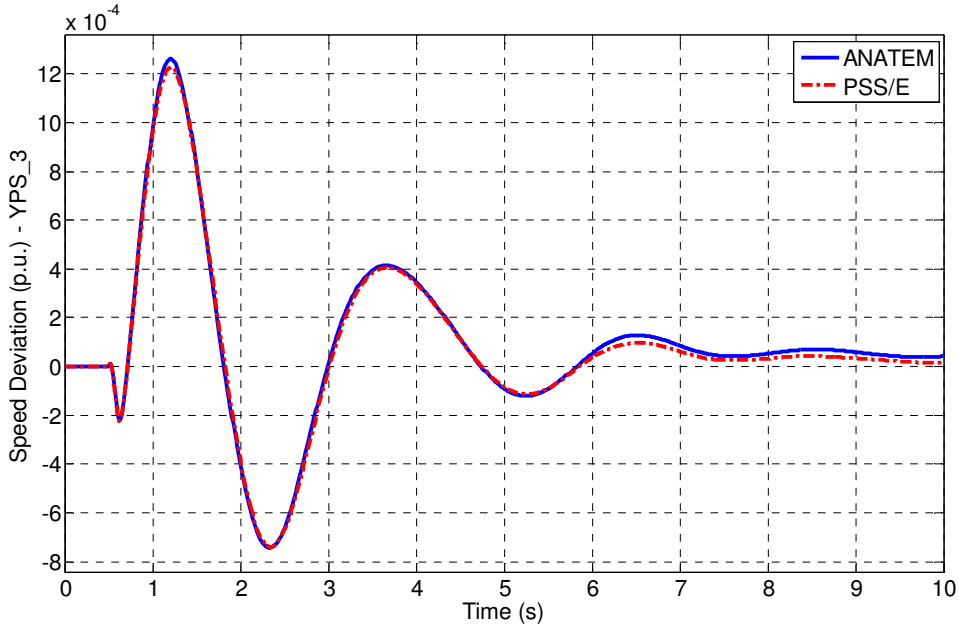

Figure 164 - Speed deviation of generator YPS_3 for Fault C

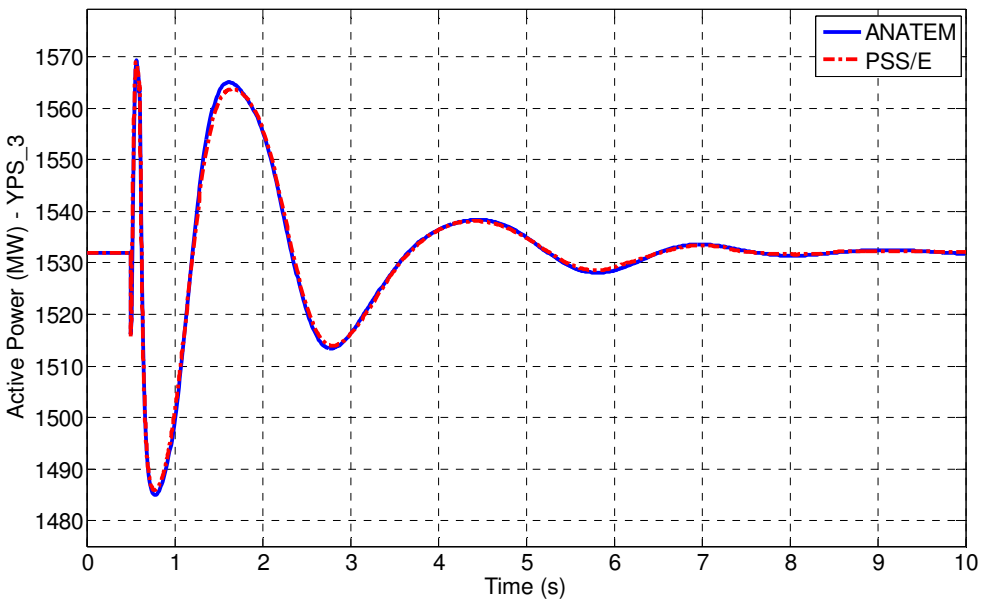

Figure 165 - Active power output of generator YPS_3 for Fault C

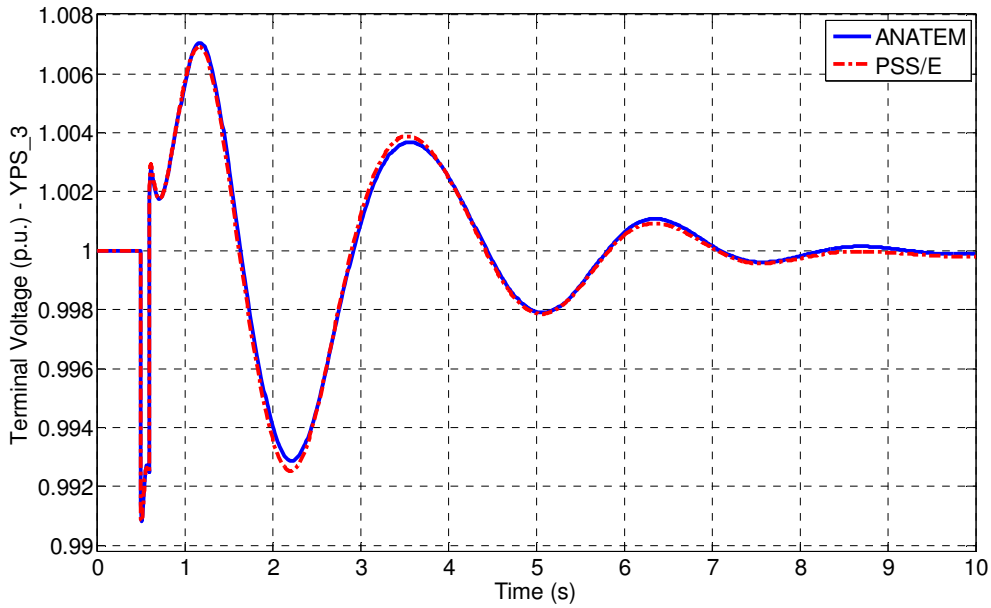

Figure 166 - Terminal voltage of generator YPS_3 for Fault C

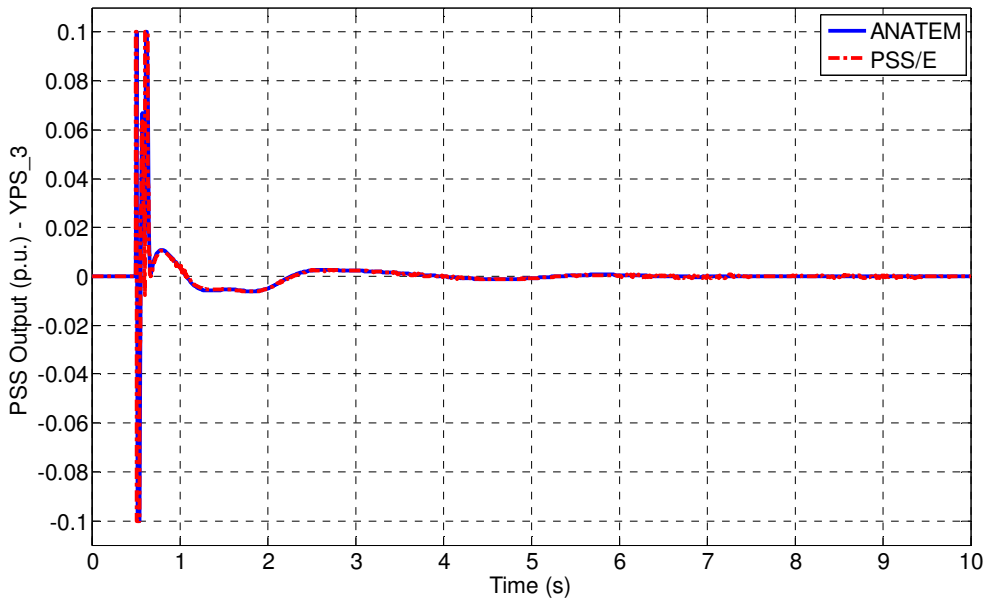

Figure 167 - PSS output of generator YPS_3 for Fault C

A.3.8 Generator TPS_4 – Bus 401

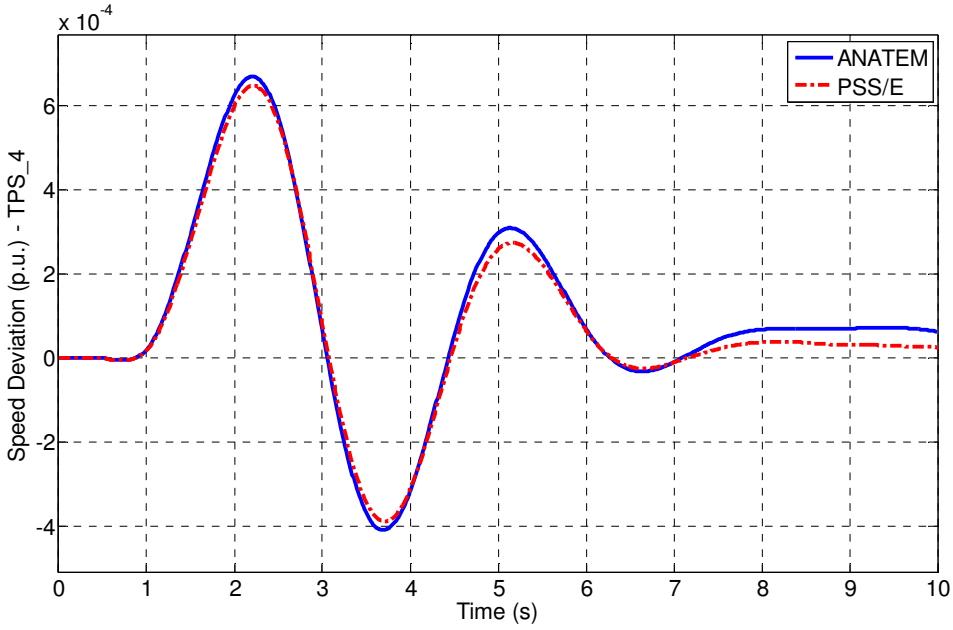

Figure 168 - Speed deviation of generator TPS_4 for Fault C

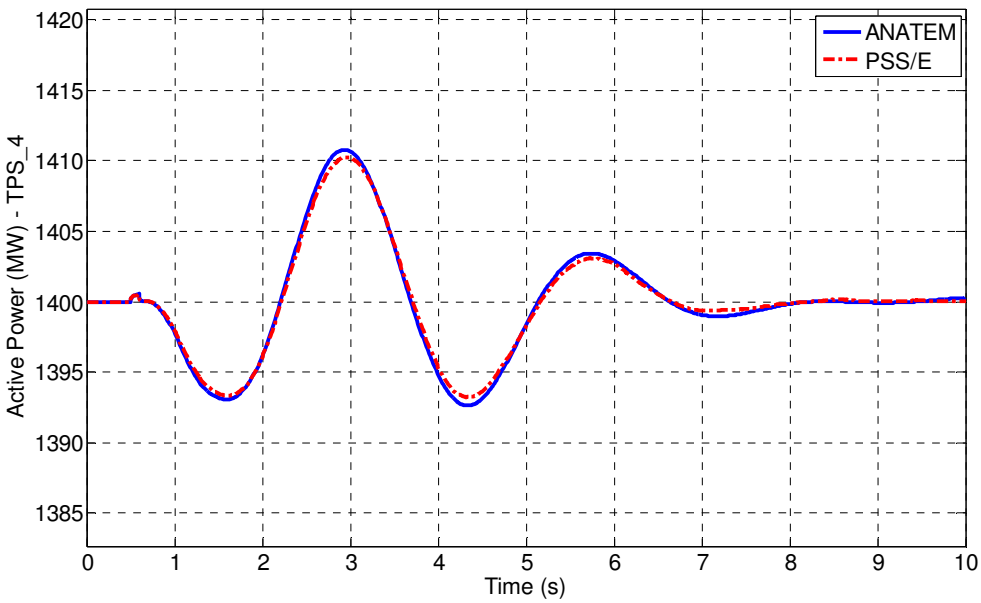

Figure 169 - Active power output of generator TPS_4 for Fault C

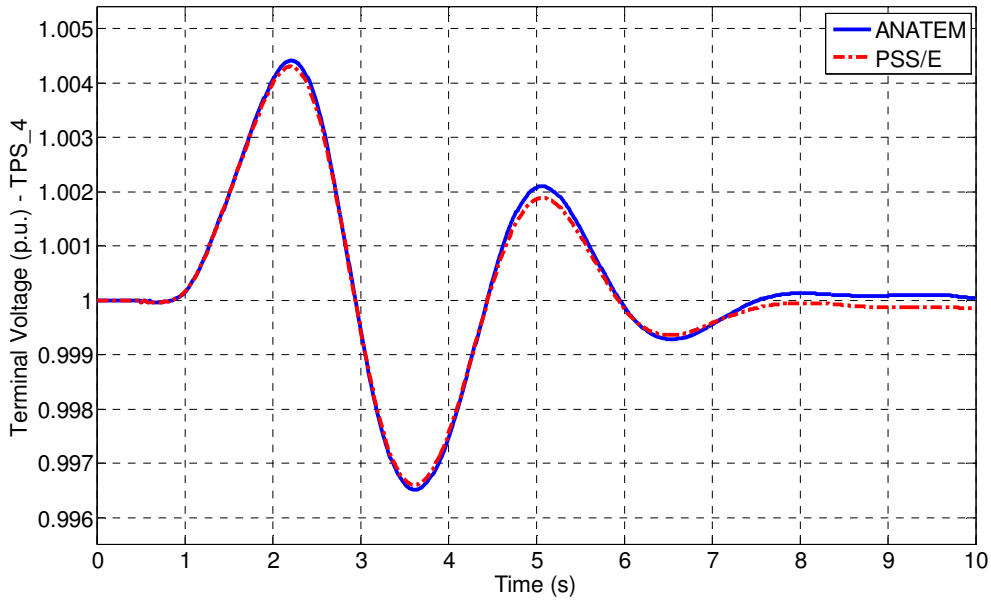

Figure 170 - Terminal voltage of generator TPS_4 for Fault C

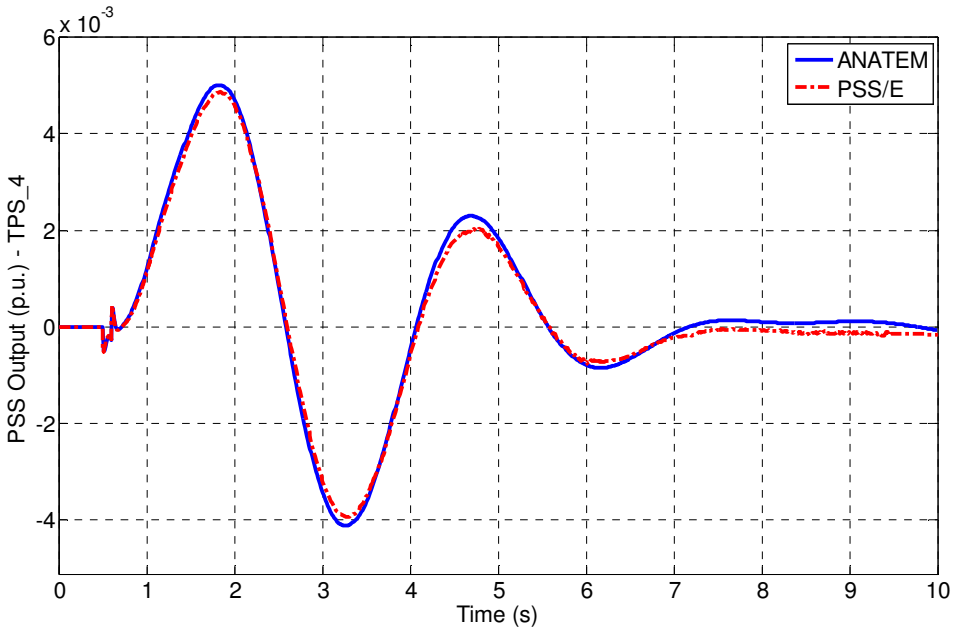

Figure 171 - PSS output of generator TPS_4 for Fault C

A.3.9 Generator CPS_4 – Bus 402

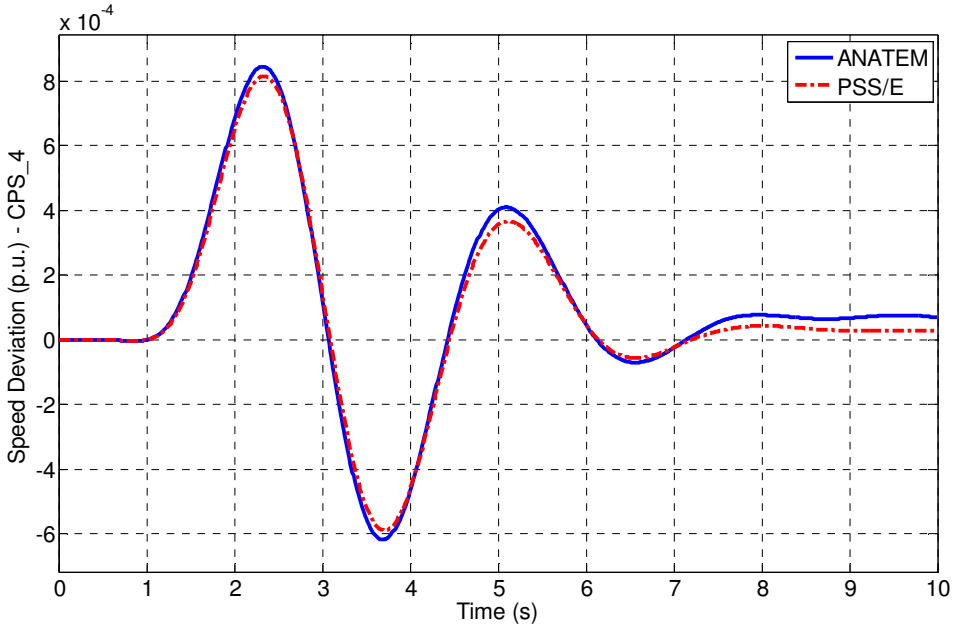

Figure 172 - Speed deviation of generator CPS_4 for Fault C

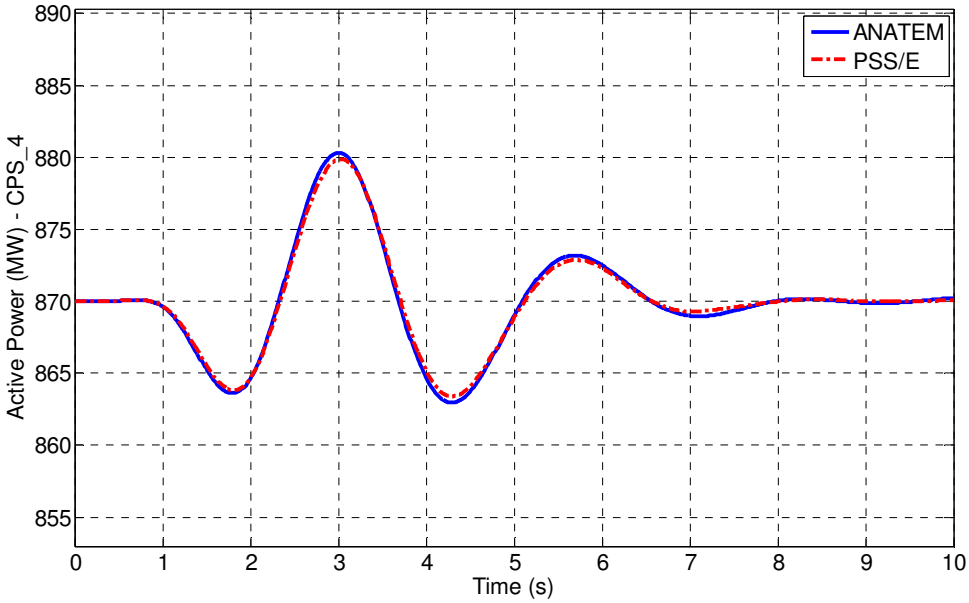

Figure 173 - Active power output of generator CPS_4 for Fault C

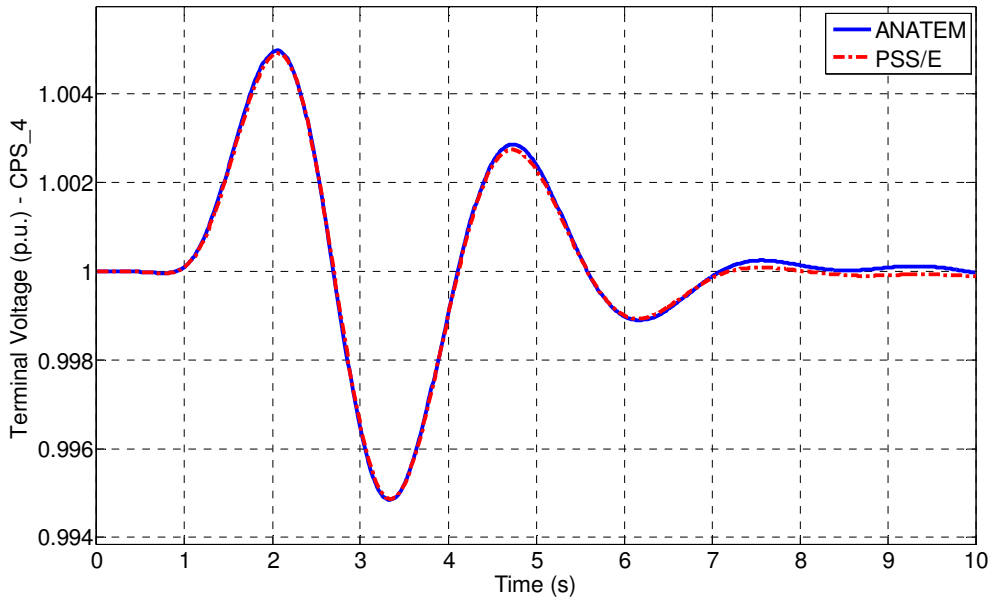

Figure 174 - Terminal voltage of generator CPS_4 for Fault C

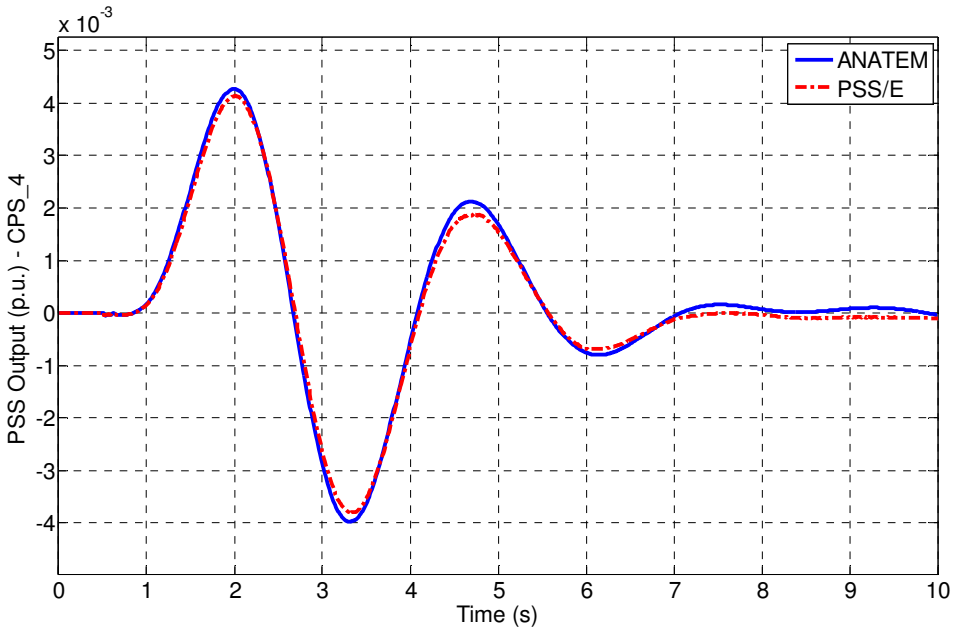

Figure 175 - PSS output of generator CPS_4 for Fault C

A.3.10 Generator SPS_4 – Bus 403

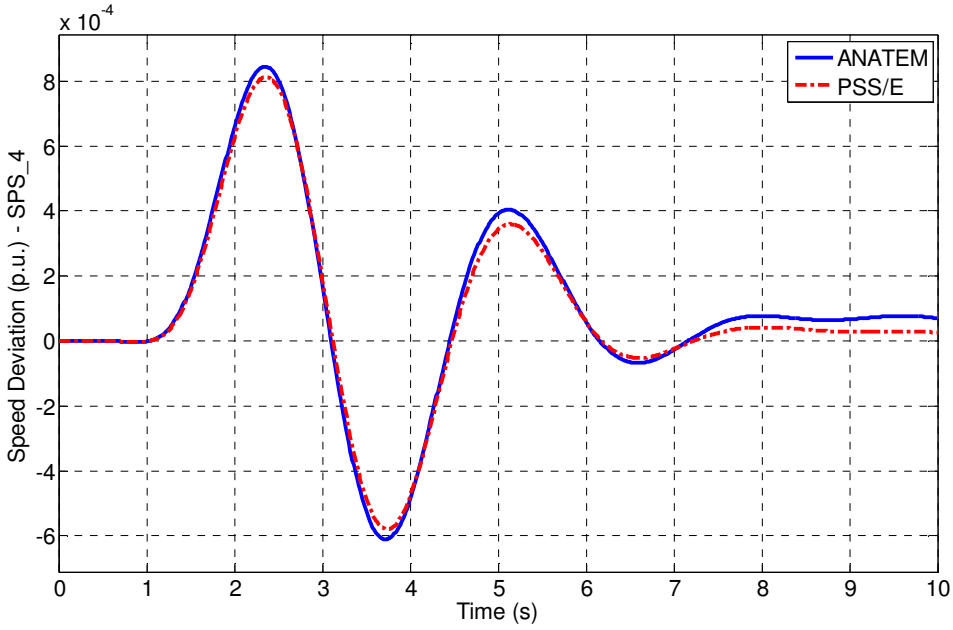

Figure 176 - Speed deviation of generator SPS_4 for Fault C

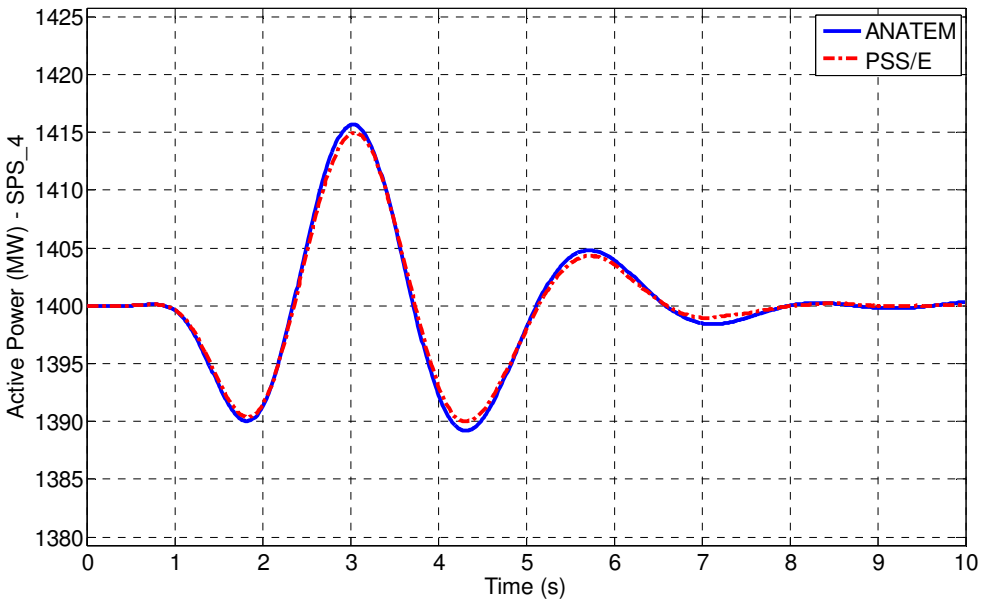

Figure 177 - Active power output of generator SPS_4 for Fault C

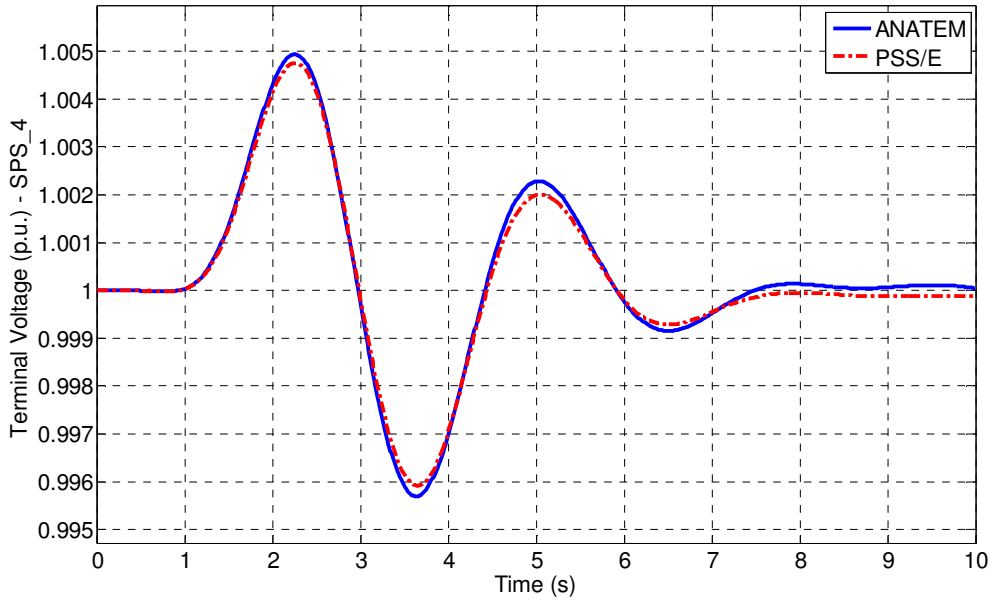

Figure 178 - Terminal voltage of generator SPS_4 for Fault C

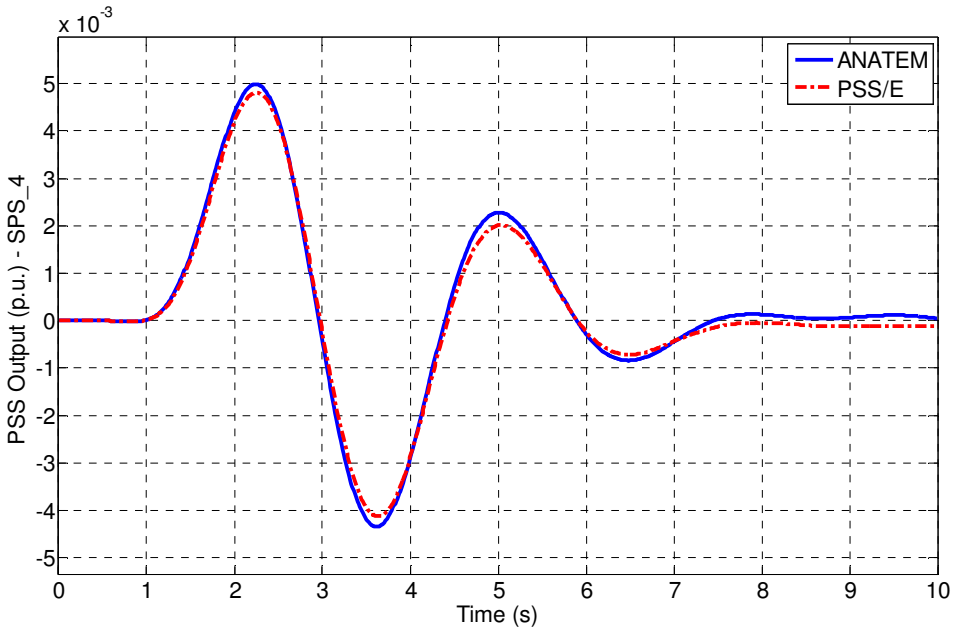

Figure 179 - PSS output of generator SPS_4 for Fault C

A.3.11 Generator GPS_4 – Bus 404

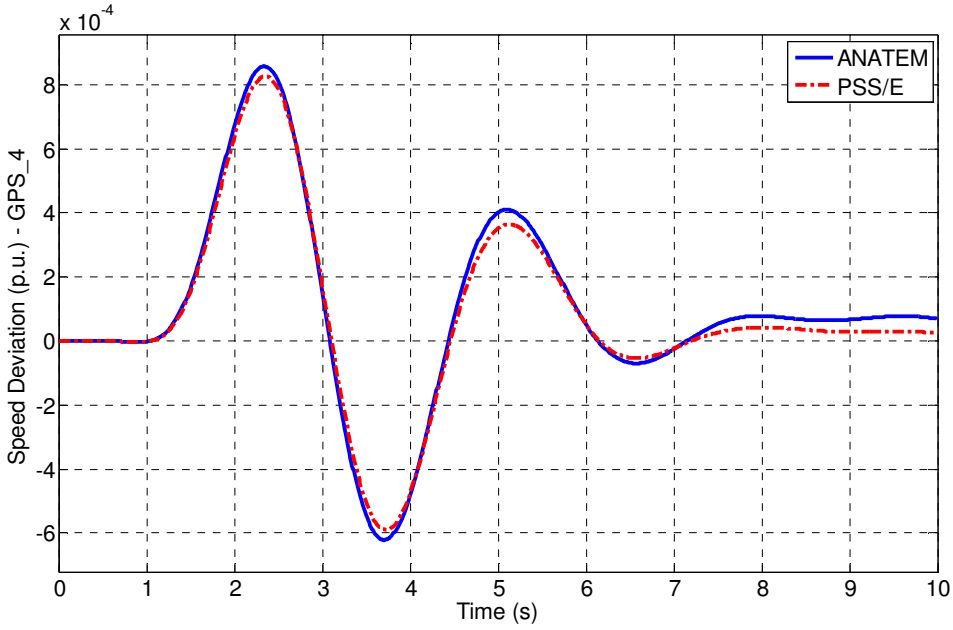

Figure 180 - Speed deviation of generator GPS_4 for Fault C

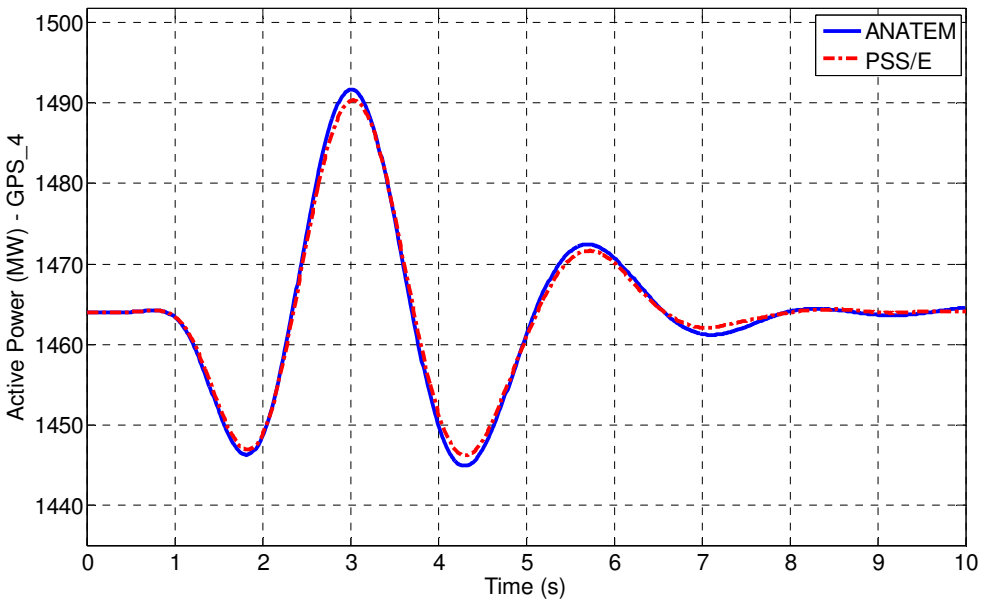

Figure 181 - Active power output of generator GPS_4 for Fault C

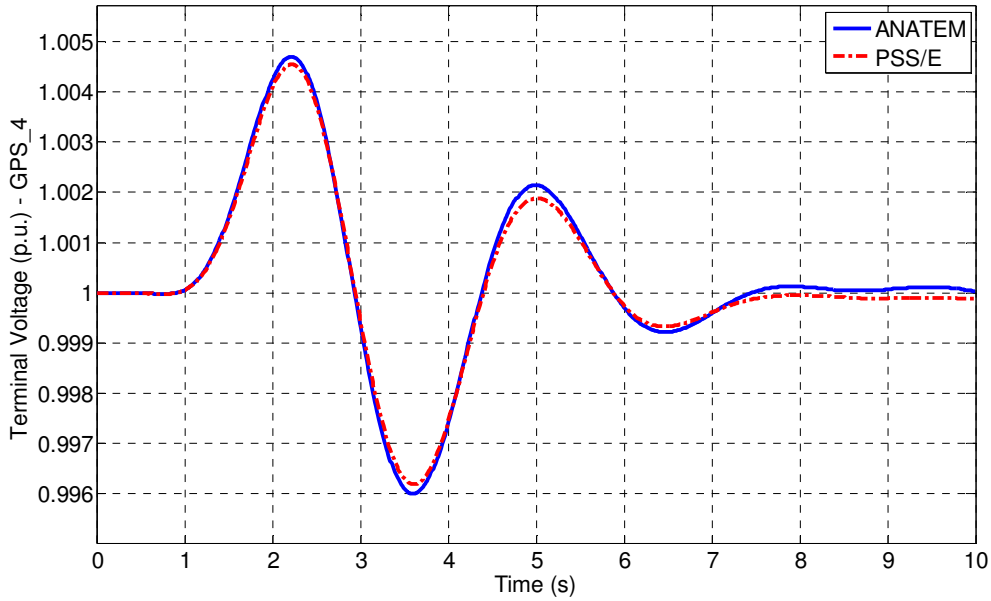

Figure 182 - Terminal voltage of generator GPS_4 for Fault C

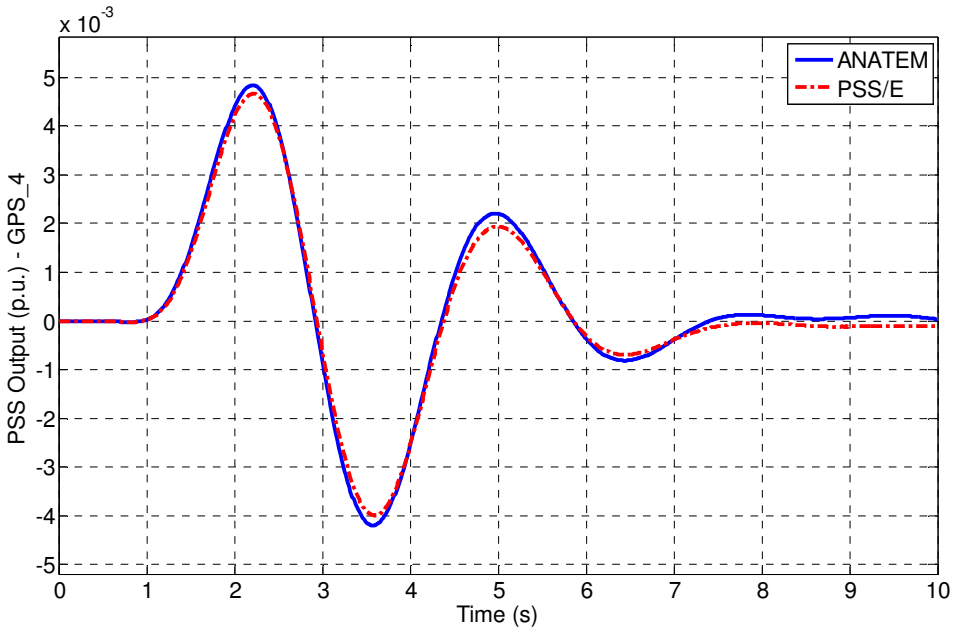

Figure 183 - PSS output of generator GPS_4 for Fault C

A.3.12 Generator NPS_5 – Bus 501

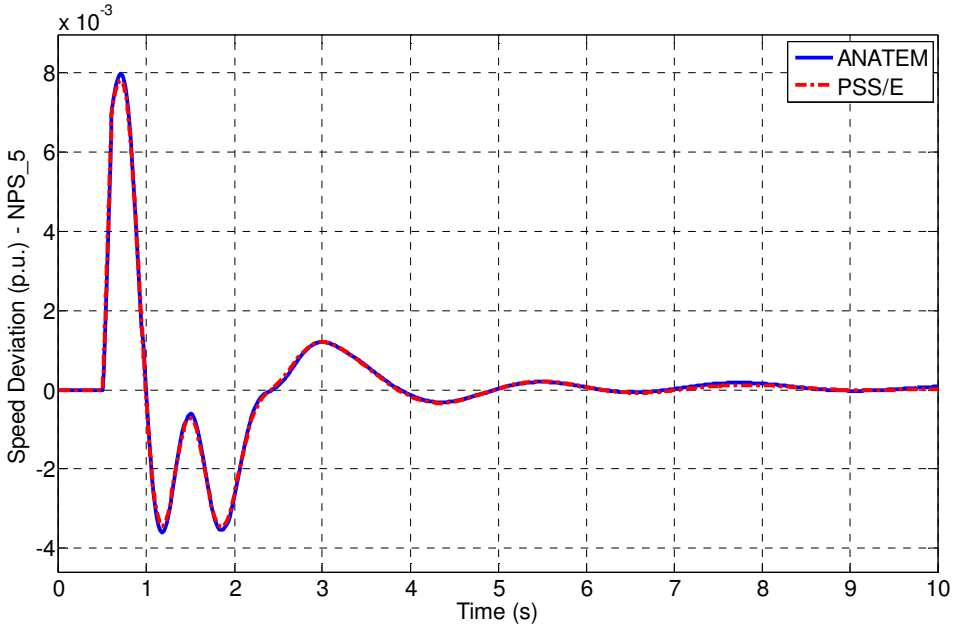

Figure 184 - Speed deviation of generator NPS_5 for Fault C

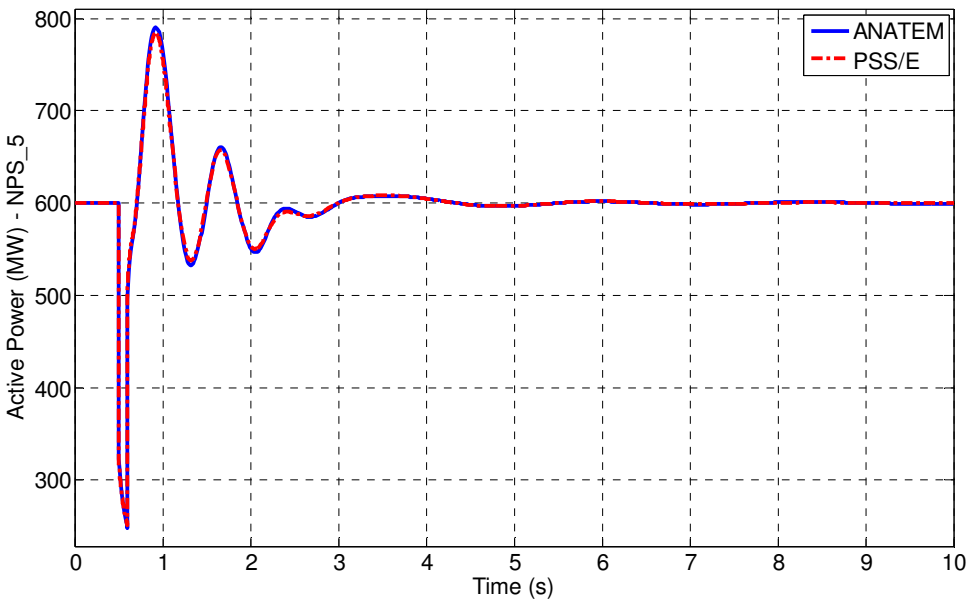

Figure 185 - Active power output of generator NPS_5 for Fault C

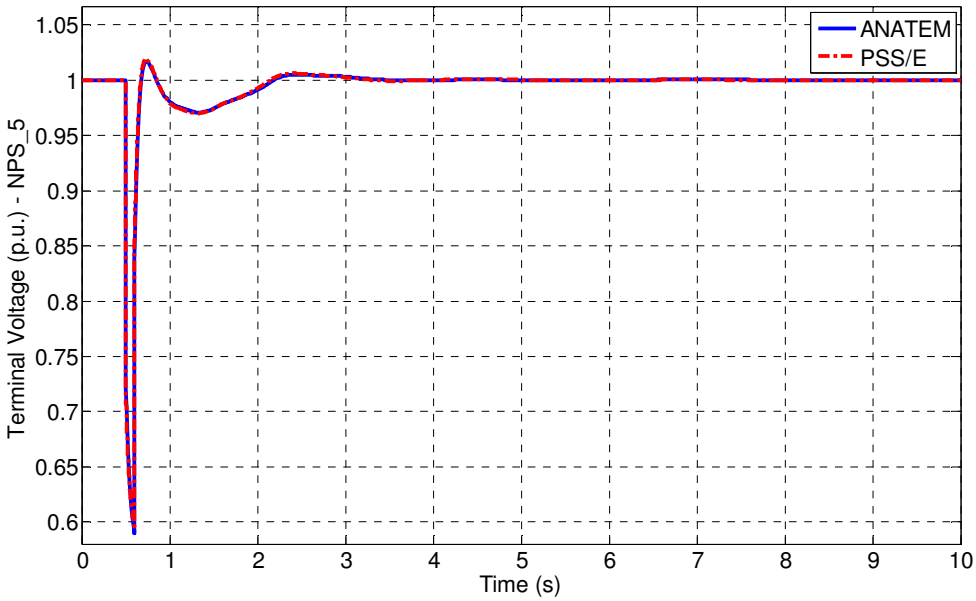

Figure 186 - Terminal voltage of generator NPS_5 for Fault C

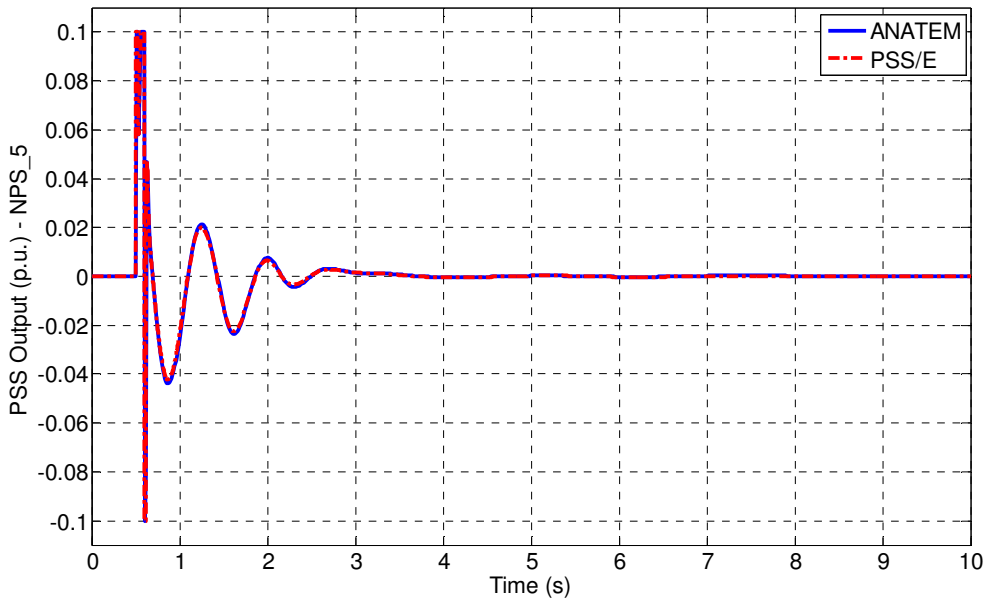

Figure 187 - PSS output of generator NPS_5 for Fault C

A.3.13 Generator TPS_5 – Bus 502

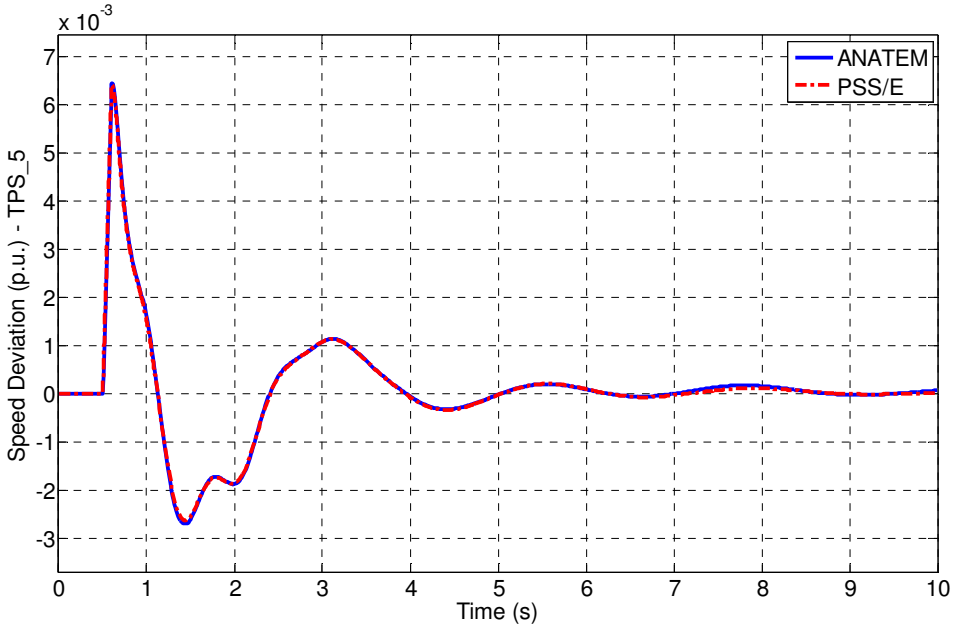

Figure 188 - Speed deviation of generator TPS_5 for Fault C

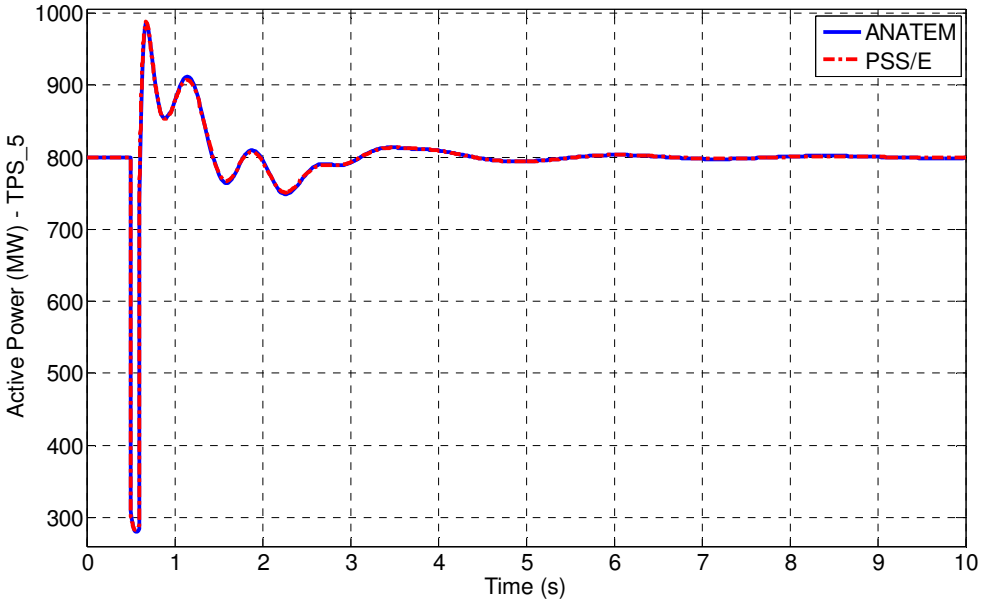

Figure 189 - Active power output of generator TPS_5 for Fault C

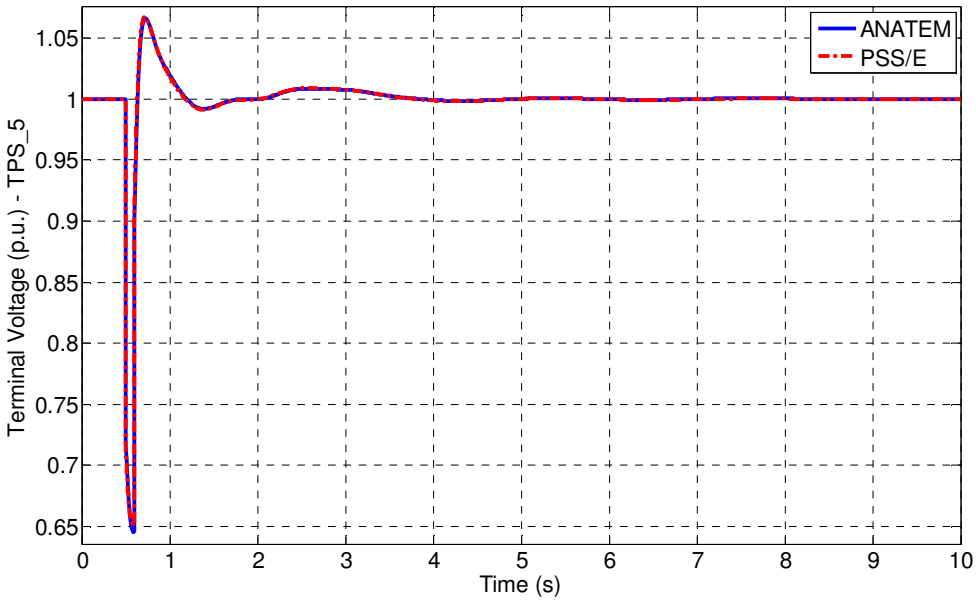

Figure 190 - Terminal voltage of generator TPS_5 for Fault C

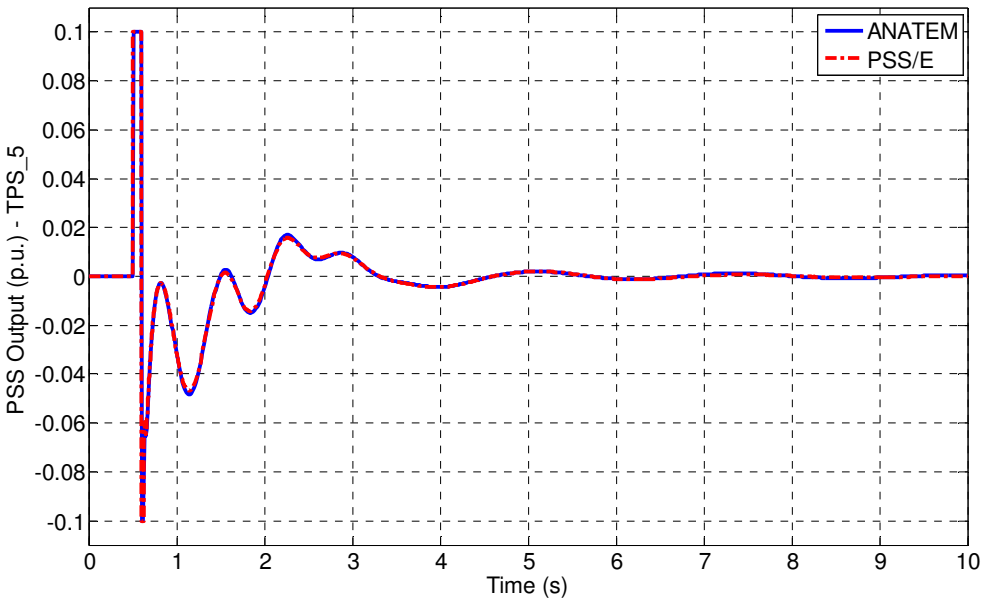

Figure 191 - PSS output of generator TPS_5 for Fault C

A.3.14 Generator PPS_5 – Bus 503

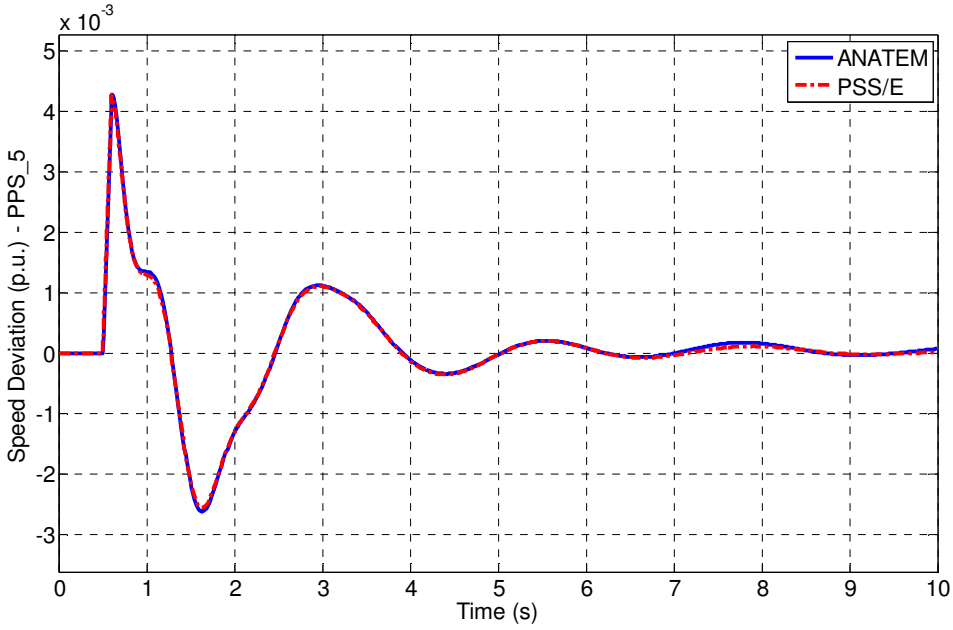

Figure 192 - Speed deviation of generator PPS_5 for Fault C

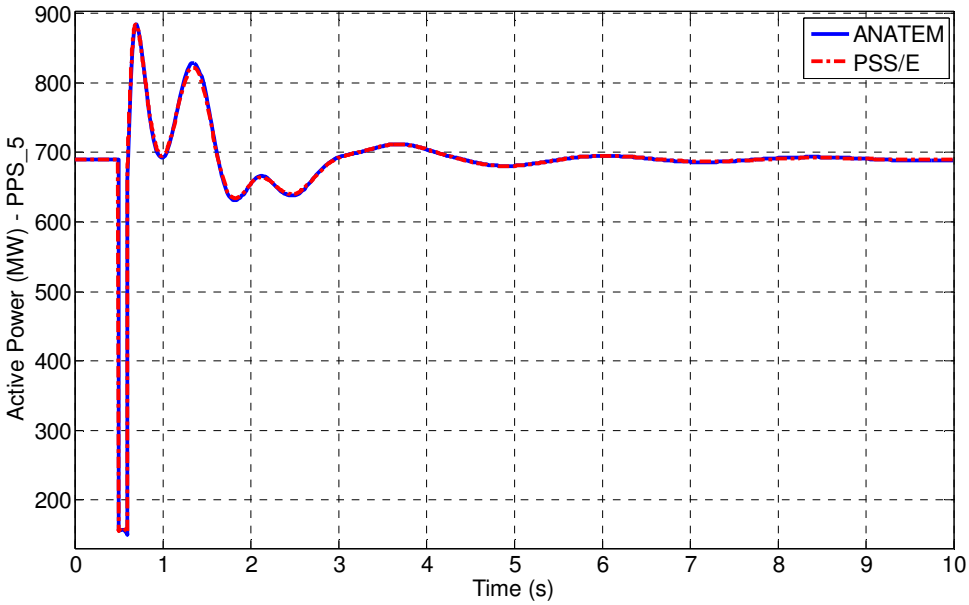

Figure 193 - Active power output of generator PPS_5 for Fault C

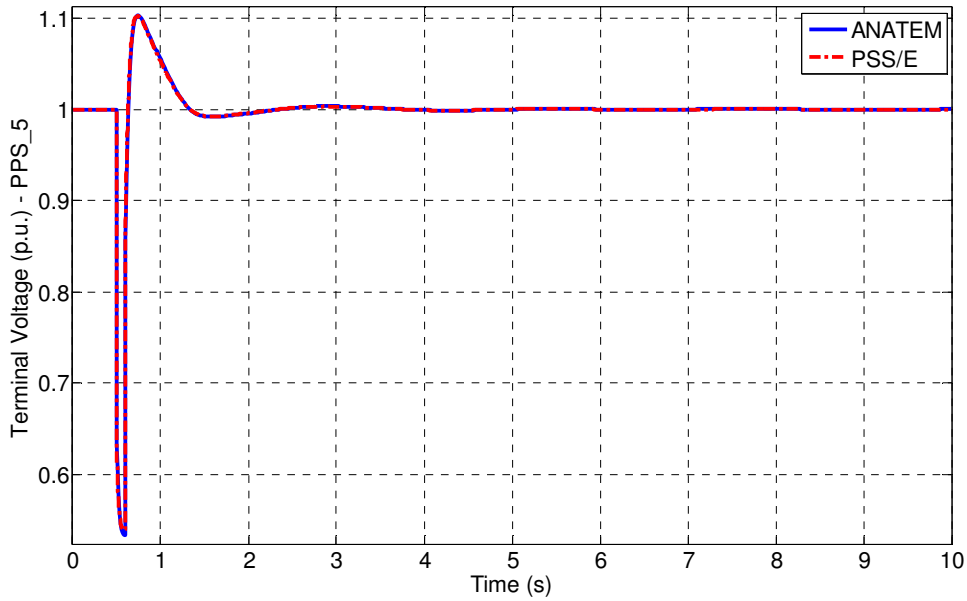

Figure 194 - Terminal voltage of generator PPS_5 for Fault C

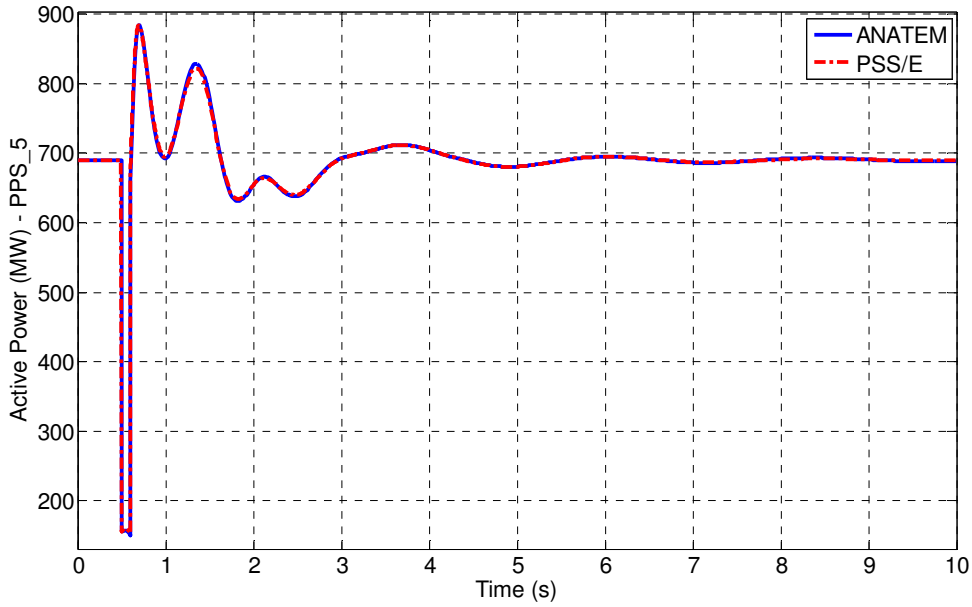

Figure 195 - PSS output of generator TPS_5 for Fault C

A.3.15 SVC ASVC_2 – Bus 205

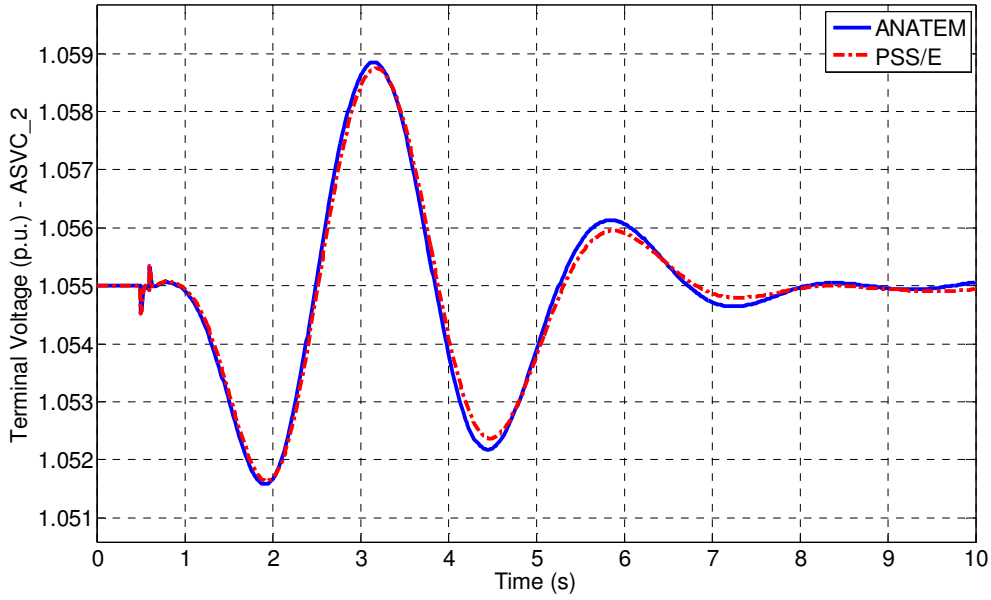

Figure 196 - Terminal voltage of SVC ASVC_2 for Fault C

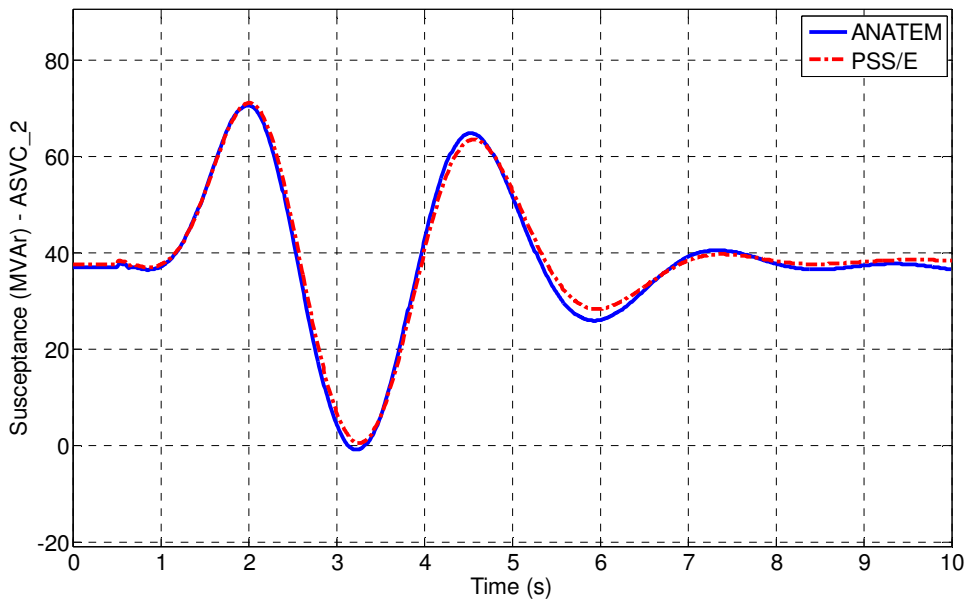

Figure 197 - Susceptance of SVC ASVC_2 for Fault C

A.3.16 SVC RSVC_3 – Bus 313

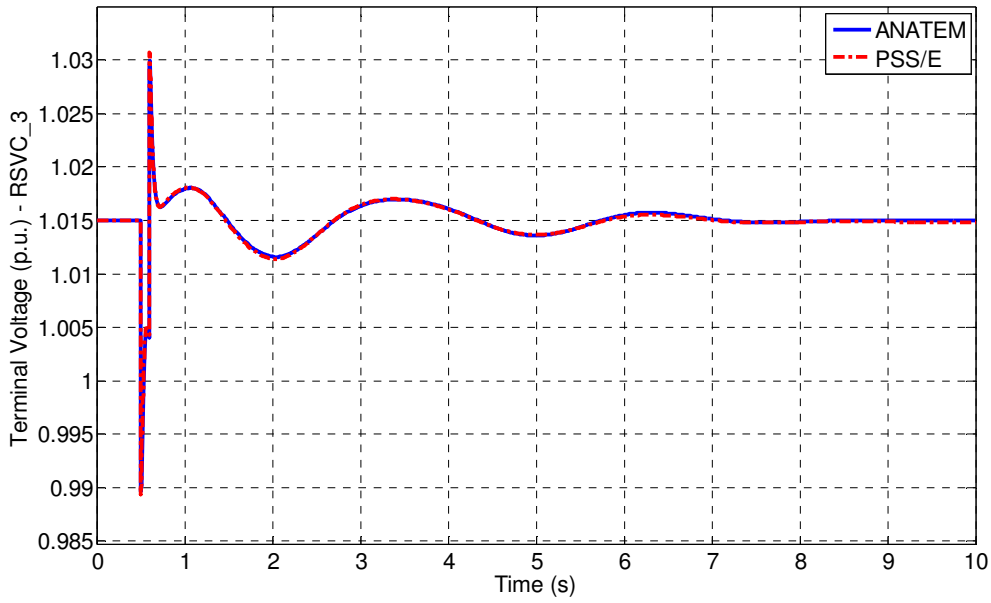

Figure 198 - Terminal voltage of SVC RSVC_3 for Fault C

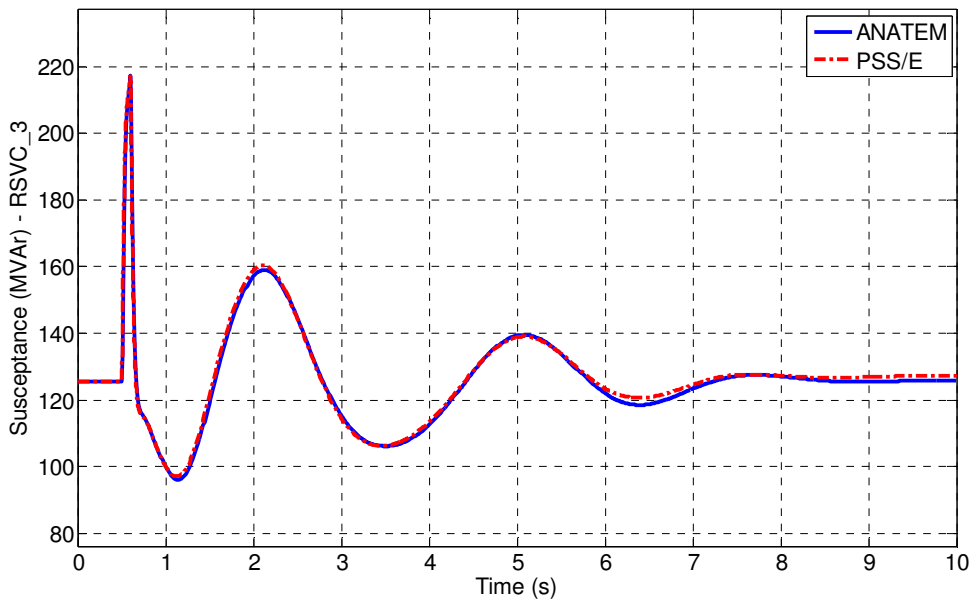

Figure 199 - Susceptance of SVC RSVC_3 for Fault C

A.3.17 SVC BSVC_4 – Bus 412

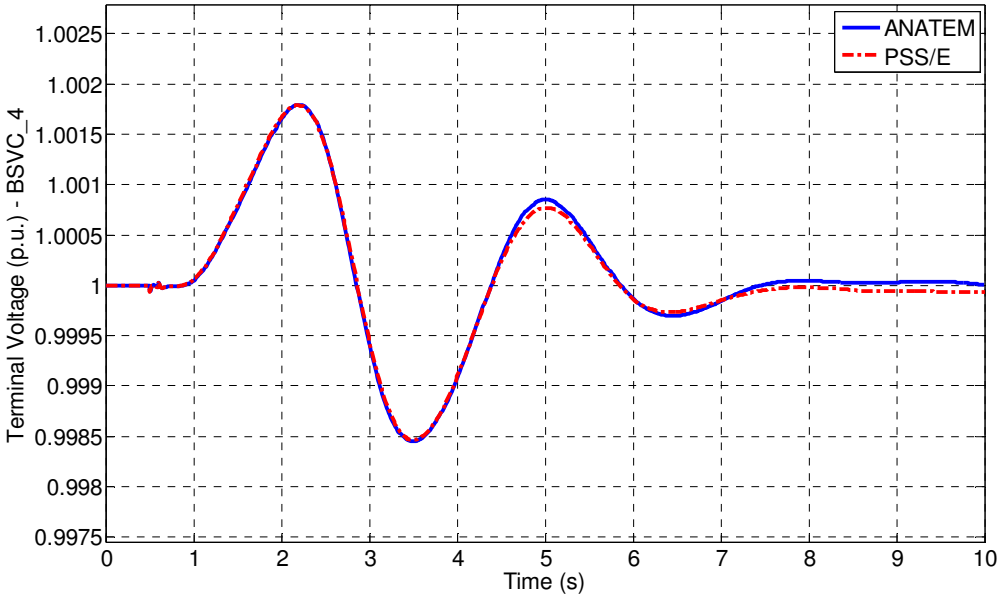

Figure 200 - Terminal voltage of SVC BSVC_4 for Fault C

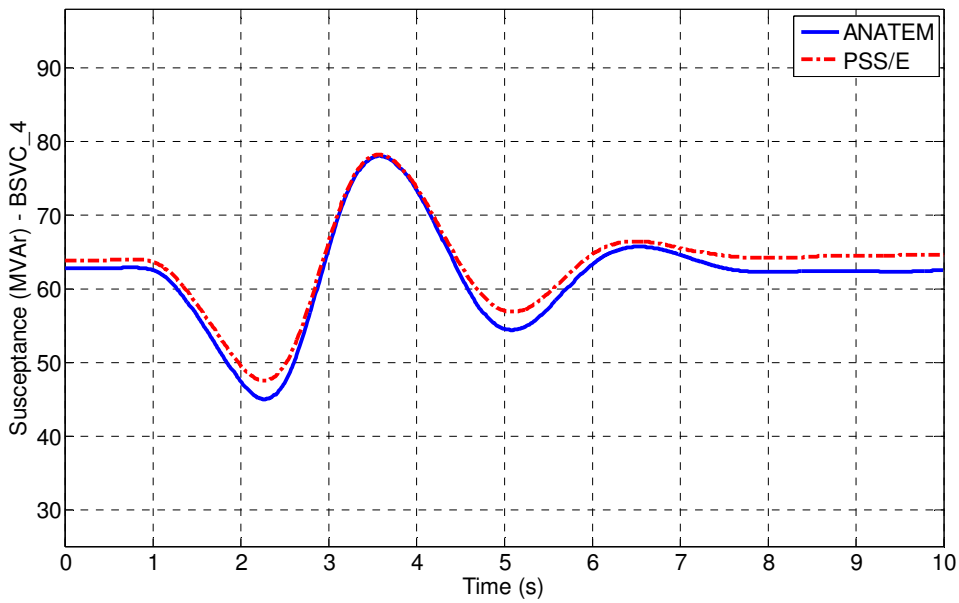

Figure 201 - Susceptance of SVC BSVC_4 for Fault C

A.3.18 SVC PSVC_5 – Bus 507

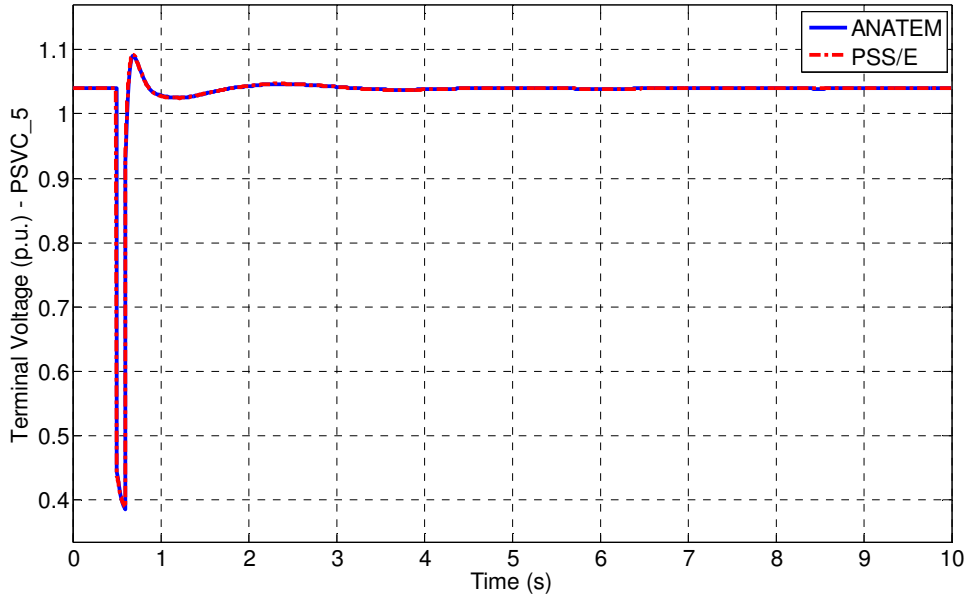

Figure 202 - Terminal voltage of SVC PSVC_5 for Fault C

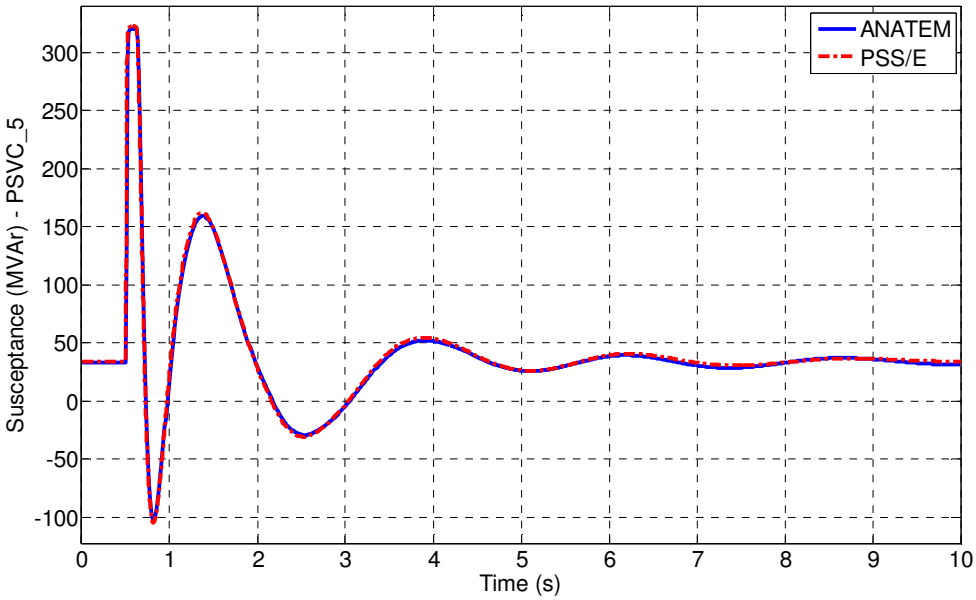

Figure 203 - Susceptance of SVC PSVC_5 for Fault C

A.3.19 SVC SSVC_5 – Bus 509

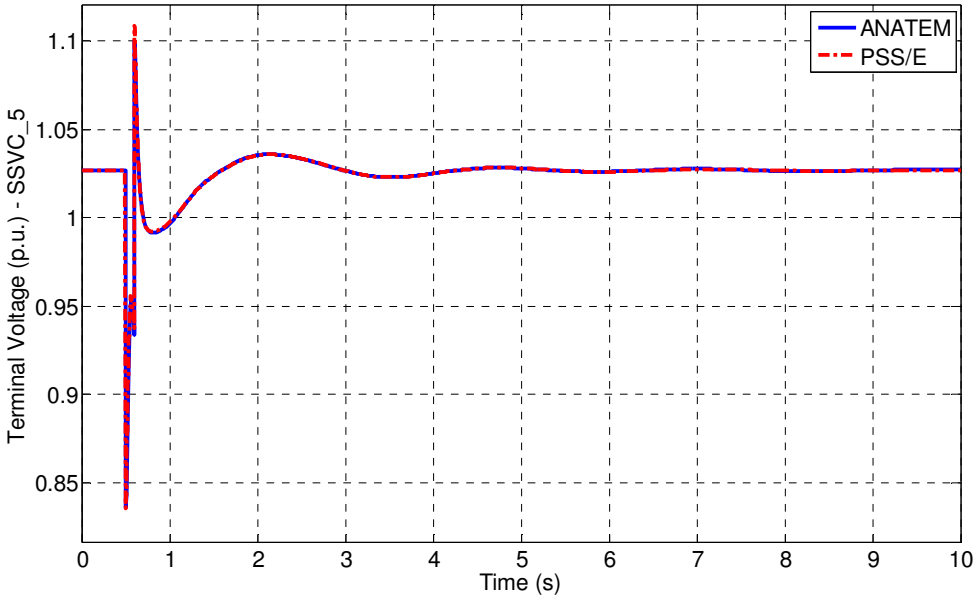

Figure 204 - Terminal voltage of SVC SSVC_5 for Fault C

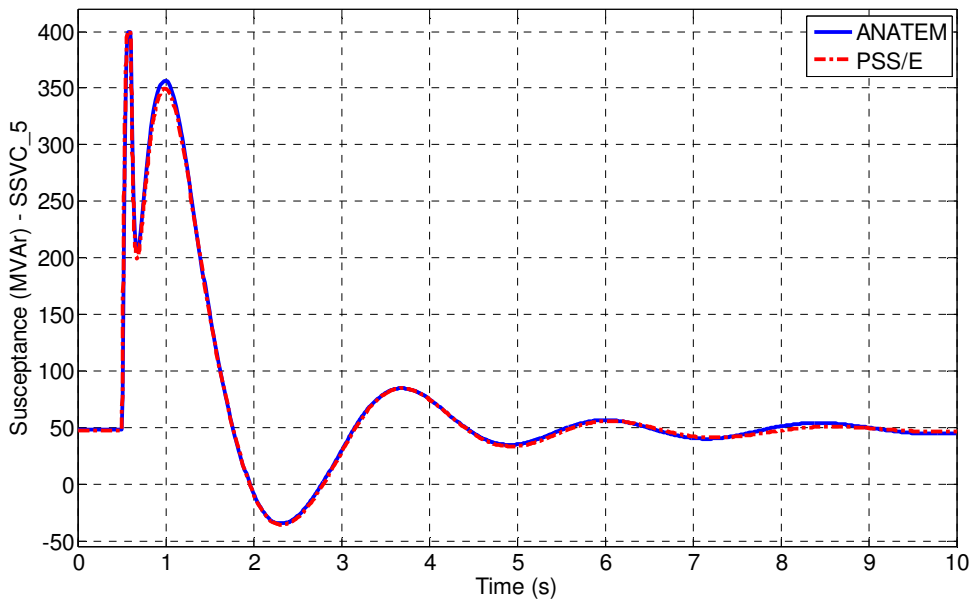

Figure 205 - Susceptance of SVC SSVC_5 for Fault C