IEEE PES Task Force on Benchmark Systems for Stability Controls

Report on the EMTP-RV 39-bus system

(New England Reduced Model)

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The present report refers to a small-signal stability study carried over the New England reduced order model using the EMTP-RV package. This report has the objective to show how the simulation of this system must be done using this package in order to get results that are comparable (and exhibit a good match with respect to the electromechanical modes). To facilitate the comprehension, this report is divided in three sections (according to the software to be used):

- Load Flow ;
- Time Domain Simulation of the Nonlinear Model;

To use the EMTP-RV software, a GUI (EMTPWorks) is requiring to entering data. All components as line, transformer, load, machine and AVR have them own data forms.

Transformer and synchronous machines use mainly units in pu. Line, load and all others S.I. unit (Ω, H, F, W, VAR or Wb). Consequently some assumptions for impedance translations are required.

1. Models and parameters

1.1 Line

Two line components are used in this benchmark: Constant Parameter Line (Ω/km) and PI(Ω/). Both use direct and zero sequence impedance; CP line require length. From the p.u. unit, the flowing assumptions are defined for these two components in EMTP.

R0/R1=10, L0/L1=3, B0/B1=0,6 and L1(ohm)/km = 0,373

For simplification aspect, except one or two all the 500kV lines use the same Z1 and Z0 /km based on the line2-3; only the lengths are different to respect de X1 parameter. The parameters are documented in Appendix A.

1.2 Generator transformers

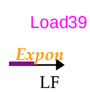
The transformer rated power and impedances are change as following. The voltages ratio are 500/20 kV for all transformers of the machines and 500/25 kV for the two 450MVA transformers of the loads.

		Rated Power	R	X	Rated Power	R	X
12	11	100	0.0016	0.0435	450	0.0072	0.196
12	13	100	0.0016	0.0435	450	0.0072	0.196
6	31	100	0	0.025	1000	0	0.250
10	32	100	0	0.02	1000	0	0.200
19	33	100	0.0007	0.0142	1000	0.007	0.142
20	34	100	0.0009	0.018	600	0.0054	0.108
22	35	100	0	0.0143	1000	0	0.143
23	36	100	0.0005	0.0272	1000	0.005	0.272
25	37	100	0.0006	0.0232	1000	0.006	0.232
2	30	100	0	0.0181	1000	0	0.181
29	38	100	0.0008	0.0156	1000	0.008	0.156
19	20	100	0.0007	0.0138	1400	0.0098	0.1932

1.3 Loads

In time-domain, this load model is an exponential load [1]. A controlled current source gives power in parallel of the R-L component to satisfy the equations bellow.

$$P(t) = P_{ic}\left(\frac{V(t)}{V_{ic}}\right)^{K_{pV}}(1+K_{pf}\Delta f)\frac{(1+T_{p1}s)}{(1+T_{p2}s)}$$



$$Q(t) = Q_{ic}\left(\frac{V(t)}{V_{ic}}\right)^{K_{qV}}(1+K_{qf}\Delta f)\frac{(1+T_{q1}s)}{(1+T_{q2}s)}$$

The parameters are unique for all loads:
// Static behavior
Kpv = 1, Kqv = 1.8, Kpf = 0, Kqf = 0
// Dynamic behavior
Tp1 = 0, Tp2 = 0, Tq1 = 0, Tq2 = 0

1.4 Generators

The 39-bus system is composed by 10 generators, and all of them are represented by a synchronous machine (SM). The help document of this component is given in Appendix. The connection in the drawing between the LF-device, SM and theirs AVR is as bellow. The power ratings of the machine are changed. The 100MVA value cannot be used in time-domain when LF-device asks 500MW. The table 3 indicates the news values.

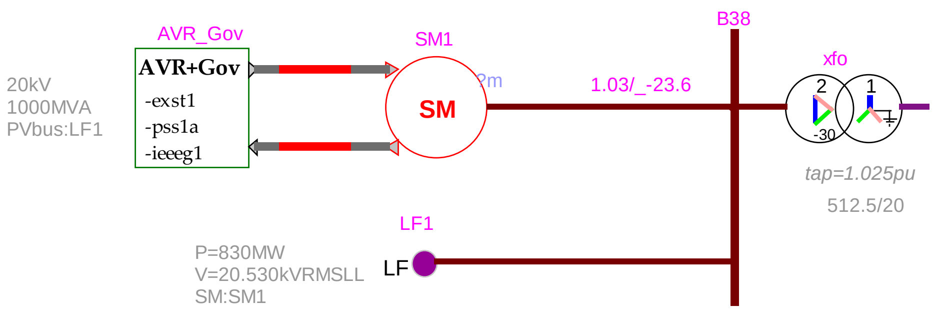


Figure 1- Connection in EMTPWorks for LF-device, SM/AVR and transformer

Table 3: Generator parameters

Unit No.	Rated Power	H	R_a	x'_d	x'_q	x_d	x_q	T'_{do}	T'_{qo}	x_l
1	10000	5.000	0.000	0.600	0.800	2.000	1.900	7.000	0.700	0.300
2	1000	3.030	0.000	0.697	1.700	2.950	2.820	6.560	1.500	0.350
3	1000	3.580	0.000	0.531	0.876	2.495	2.370	5.700	1.500	0.304
4	1000	2.860	0.000	0.436	1.660	2.620	2.580	5.690	1.500	0.295
5	600	4.333	0.000	0.792	0.996	4.020	3.720	5.400	0.440	0.324
6	1000	3.480	0.000	0.500	0.814	2.540	2.410	7.300	0.400	0.224
7	1000	2.640	0.000	0.490	1.860	2.950	2.920	5.660	1.500	0.322
8	1000	2.430	0.000	0.570	0.911	2.900	2.800	6.700	0.410	0.280
9	1000	3.450	0.000	0.570	0.587	2.106	2.050	4.790	1.960	0.298
10	1000	4.200	0.000	0.310	0.080	1.000	0.690	10.200	0.000	0.125

1.5 Controllers

All generators in this system are equipped with automatic voltage regulators [2], power system stabilizers [2] and governor [3]. The governor doesn't change the mechanical power Pm during fault and after. They will work only if perturbation is a load or generator disconnection. These generators use the same controller model, only altering the corresponding parameter values according to the specifications given in the website.

1.5.1 PSS – pss1a

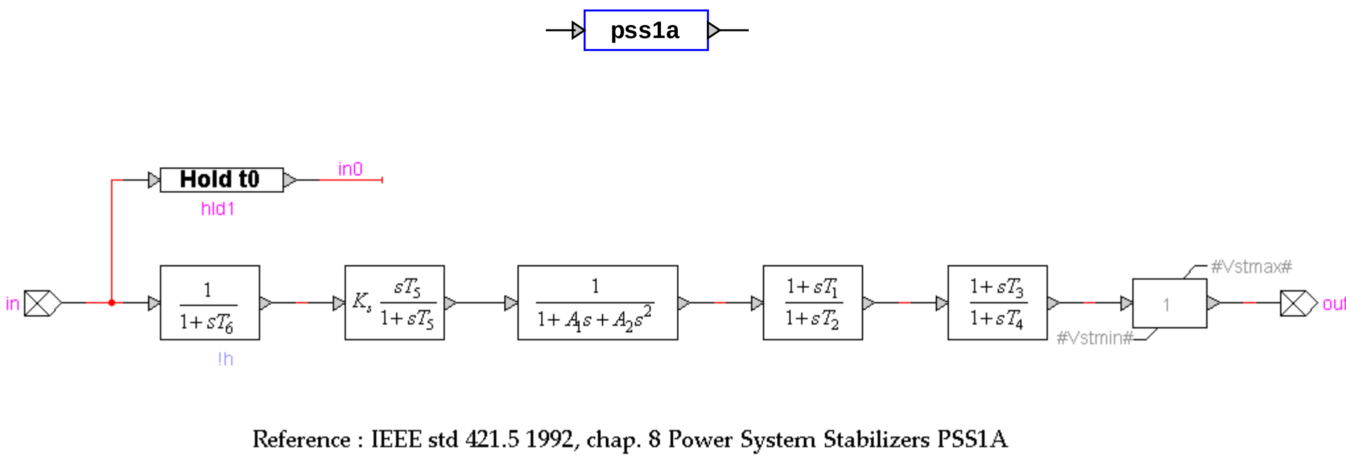
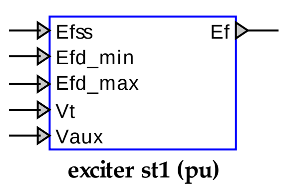


Figure 2- PSS1a control schema in EMTPWorks

1.5.2 Voltage regulator (exc ST1)



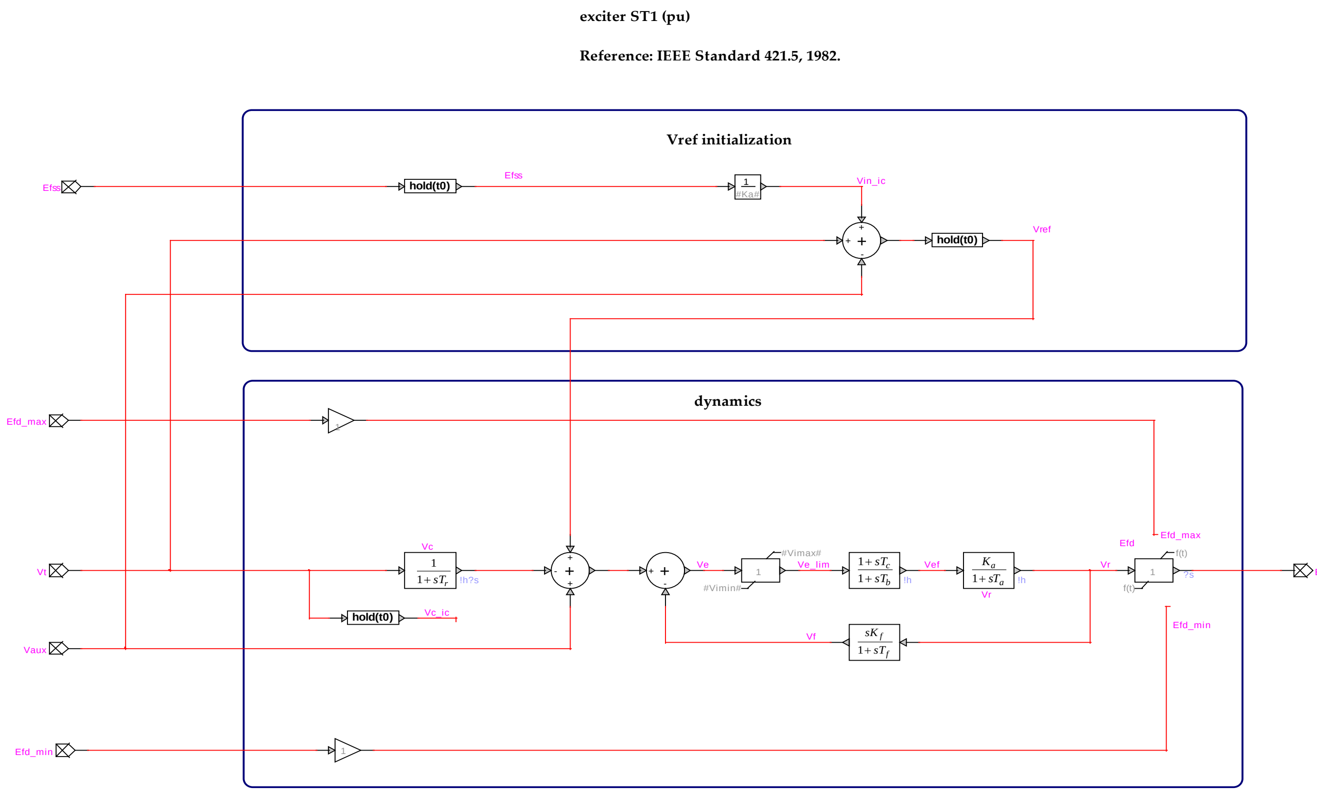
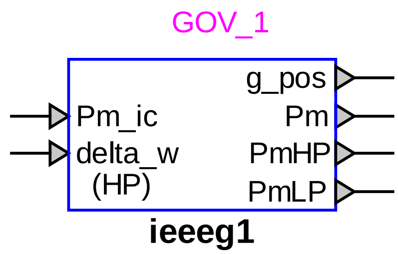


Figure 3– EXCST1 control schema in EMTPWorks

1.5.3 Governor – ieeeg1



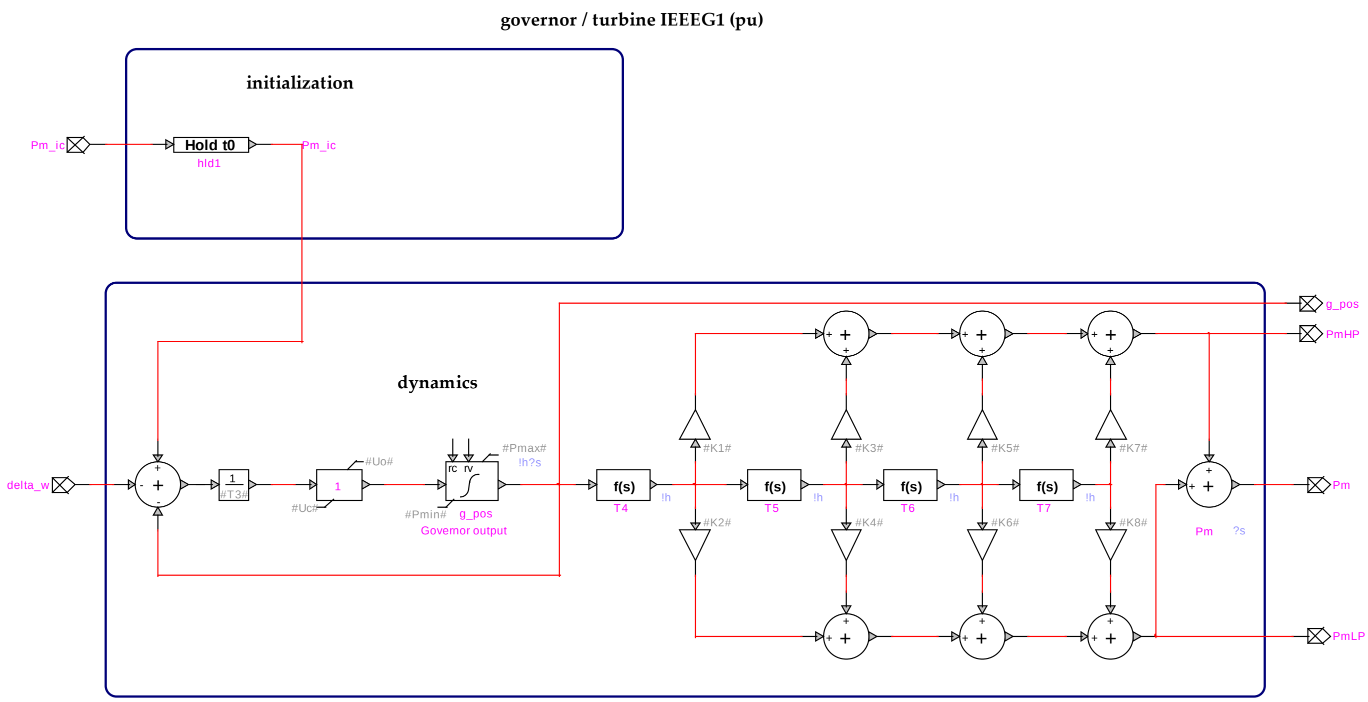


Figure 4– IEEEG1 control schema in EMTPWorks

1.5.4 AVR/GOV parameters

The parameters are documented in Appendix B. The governor parameters-set is unique for all machines.

2. Results

2.1 Load Flow

The load flow of the 39-bus system was calculated using the EMTP-RV software. The electrical network equations are solved using complex phasors. The active (source) devices are only the Load-Flow devices (LF-devices). They could be Slack, PQ or PV. A load device is used to enter PQ load constraint equations, np and nq could be set between 0 and 2. For the present case, np=nq=0 (constant power).

2.1.1 Generator

Table 1: Results of the load flow calculation for the generators

Reference Case			EMTP			
Unit No.	P(MW)	V(pu)	P(MW)	V(kVRMSLL)	Q(MVAR)	Bus id
1	1000.0	1.030	1000.00	1.03	222.0	39
2 (slack)	520.8	0.982	539.41	0.98	254.0	31
3	650.0	0.983	650.00	0.98	260.0	32
4	632.0	0.997	632.00	1.00	147.0	33
5	508.0	1.012	508.00	1.01	203.0	34
6	650.0	1.049	650.00	1.05	255.0	35
7	560.0	1.064	560.00	1.06	135.0	36
8	540.0	1.028	540.00	1.03	38.0	37
9	830.0	1.027	830.00	1.03	76.0	38
10	250.0	1.048	250.00	1.04	178.0	30

2.1.2 Bus

The results obtained by this load flow calculation can be analyzed from 2. It is shows on the drawing too. When comparing these results to the ones provided in the website, it is possible to observe a very good match between them. Note the 30° differences caused by the Yd transformers.

Table 2: Results of the load flow calculation for the bus.

Reference Case			EMTP	
Bus	V [PU]	Angle [deg]	V1 [PU]	Angle [deg]
1	1.047	-8.44	1.04	-9.8
2	1.049	-5.75	1.04	-7.1
3	1.030	-8.60	1.01	-9.9
4	1.004	-9.61	0.98	-10.8
5	1.005	-8.61	0.99	-9.6
6	1.008	-7.95	0.99	-8.9
7	0.997	-10.12	0.98	-11.2
8	0.996	-10.62	0.98	-11.7
9	1.028	-10.32	1.02	-11.6
10	1.017	-5.43	1.00	-6.4
11	1.013	-6.28	1.00	-7.2
12	1.000	-6.24	0.97	-37.3
13	1.014	-6.10	1.00	-7.1
14	1.012	-7.66	0.99	-8.8
15	1.015	-7.74	1.00	-9.1
16	1.032	-6.19	1.02	-7.6
17	1.034	-7.30	1.02	8.7
18	1.031	-8.22	1.01	-9.6
19	1.050	-1.02	1.04	-2.4
20	0.991	-2.01	0.98	-3.4
21	1.032	-3.78	1.02	-5.1
22	1.050	0.67	1.04	-0.7
23	1.045	0.47	1.04	-0.9
24	1.037	-6.07	1.02	-7.5
25	1.058	-4.36	1.05	-5.7
26	1.052	-5.53	1.04	-6.9
27	1.038	-7.50	1.02	-8.9
28	1.050	-2.01	1.04	-3.4
29	1.050	0.74	1.04	-0.7

2.2 Time–domain solution

Steady-state solution. The electrical network equations are solved using complex phasors. All devices are given a lumped circuit model. This option can be used in the stand-alone mode or for initializing the time-domain solution. The control system devices are disconnected and not solved. Some nonlinear devices are linearized or disconnected. All devices have a specific steady state model.

Time-domain solution. The electrical network and control system equations are solved using a numerical integration technique. All nonlinear devices are solved simultaneously with network equations. A Newton method is used when nonlinear devices exist. The solution can optionally start from the steady-state solution for initializing the network variables and achieving quick steady-state conditions in time-domain waveforms. The steady-state conditions provide the solution for the time-point t=0. The user can also optionally manually initialize state-variables. The first time-domain solution is found at $t = \Delta t$ or $t = \Delta t / 2$ depending on the selected numerical integration method explained below.

The time-domain solution in EMTP-RV is performed after the Load-flow solution and the Steady-State Solution. That give a perfect three phases solution at 0+. The total simulation time was 20 s and the integration step was 100 μs

2.2.1 Perturbation

The applied perturbation was a three-phase-to-ground fault at bus 16, on t = 0.5 s, with a fault impedance of 1.0Ω and a duration of 0,1 s.

2.2.2 Output request

The angle of generator 1 (placed at bus 39) was taken as a reference for angle differences. Electric power (Pe), Field voltage (Efd), the output of PSS (Vaux) and Omega are also showed.

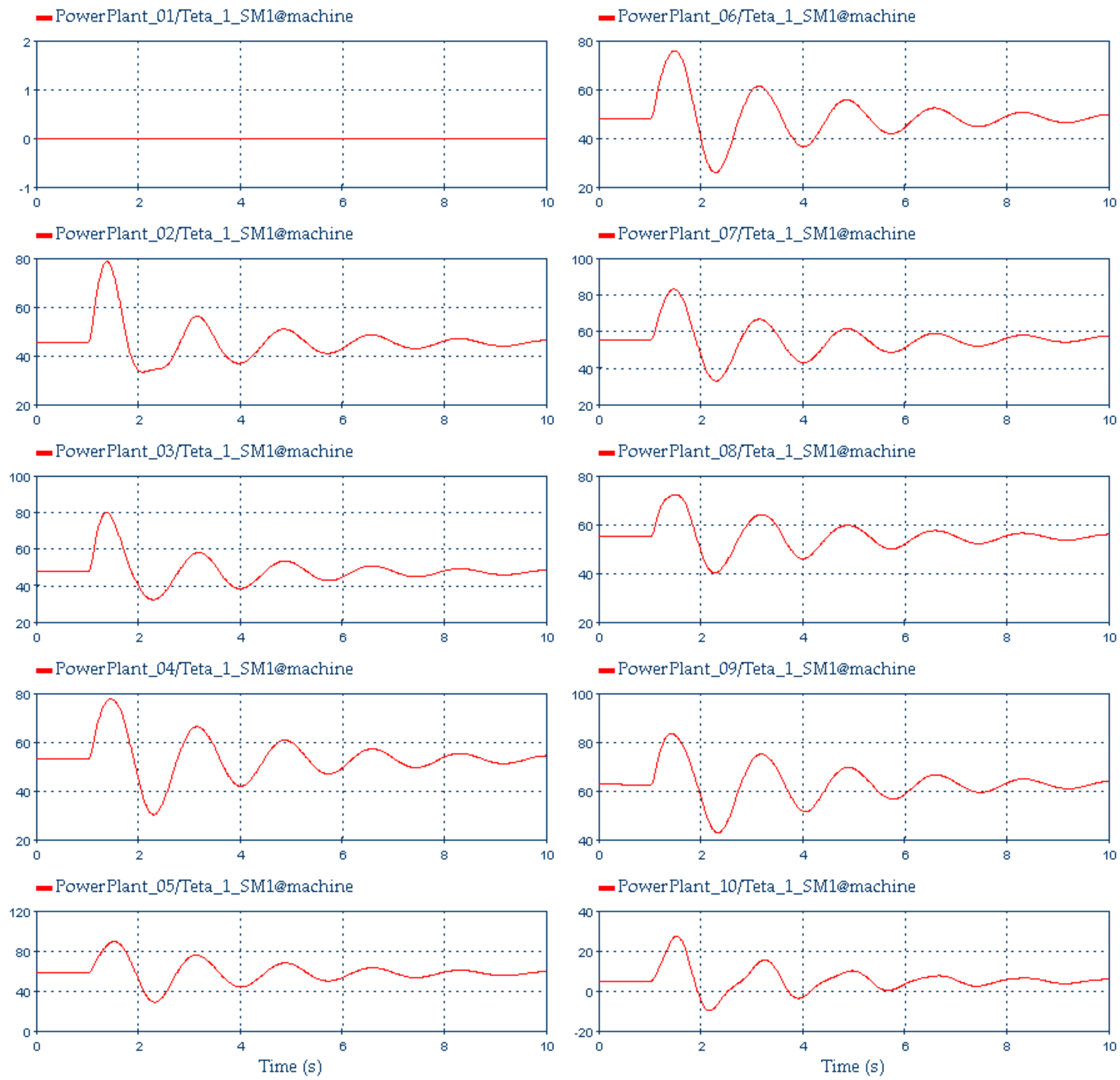


Figure 5 - Rotor angles of generators 1 to 10 respectively, referenced to generator 1.

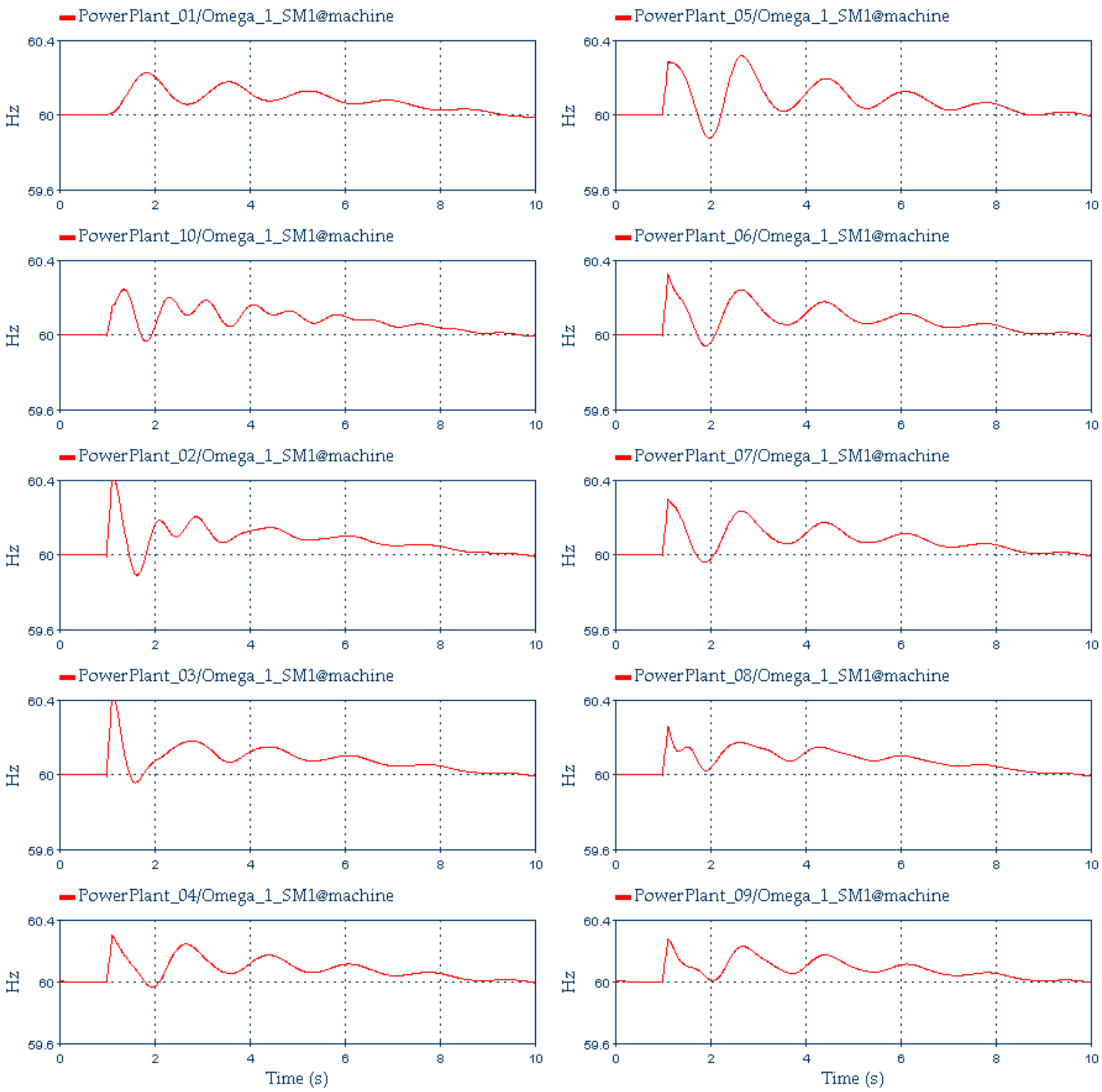


Figure 6 - Rotor speed.

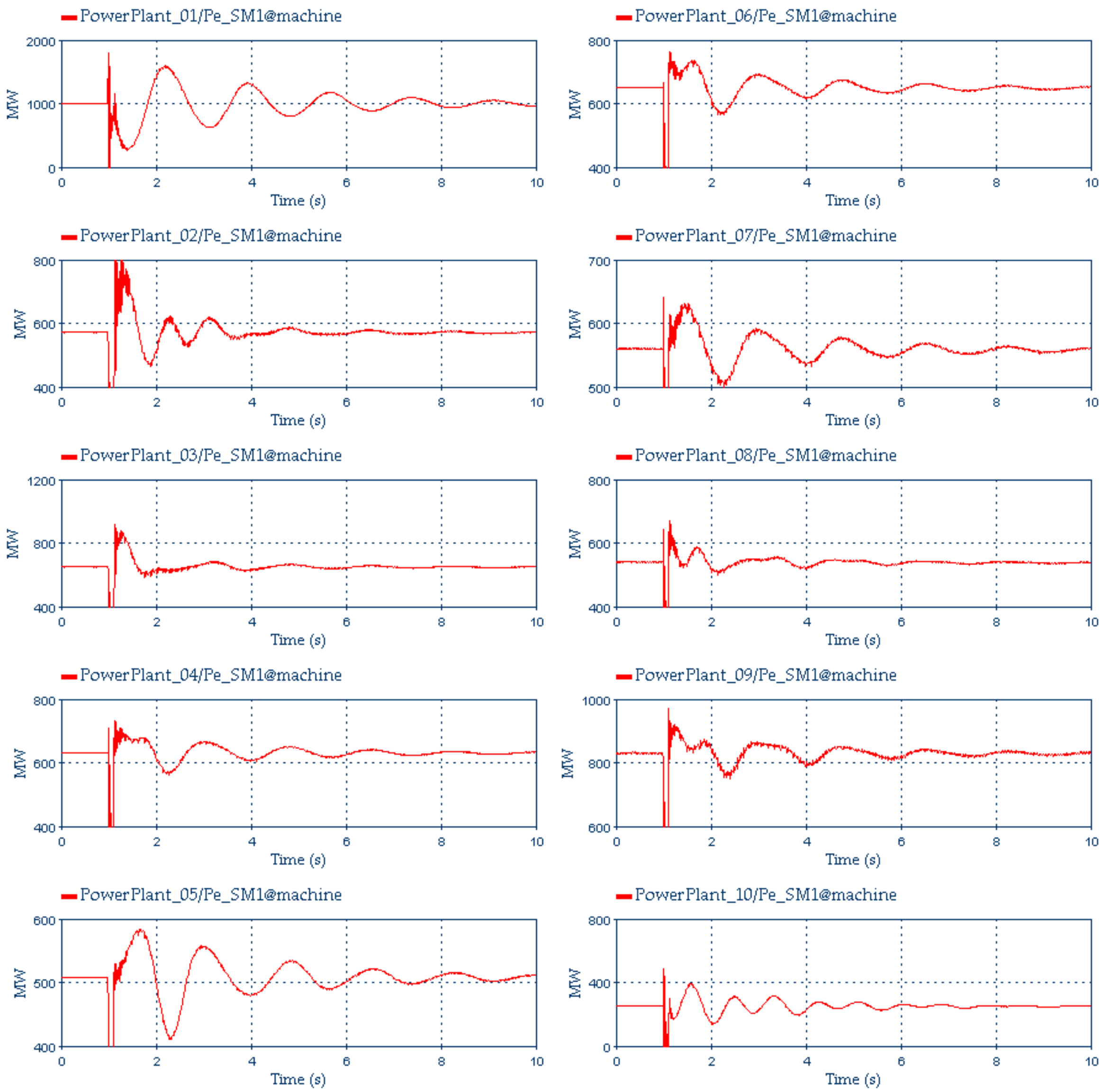


Figure 7 – Total electric power.

2.3 Modal analysis

The modal analysis is performed for the number of ten synchronous machines from small-signal perturbations results in time-domain [1]. These curves where imported in MATLAB to perform [A,B,C,D] state-space matrices with minimum acceptable error. The input Vs (PSS output) which is added to Vref and the output Pe are the transfer function of the state-space system. The superimposed results bellow confirms the *quality* in term of calibration of the state-space matrices. Note that the system is not a total of ten individual SISO (Single Input Single Output) but one MIMO (Multiple Input Multiple Output) including oscillations mode between synchronous machines.

With the validated state-space matrices, for each synchronous machine a Bode Diagram is generated as shown in the Figure 9. Afterword for each main oscillations mode, eight in this case, the polar plots are generated according to the observable and controllable vectors (see Figure 10). These plots indicates whish machine take the lead in term of effect on the oscillation mode.

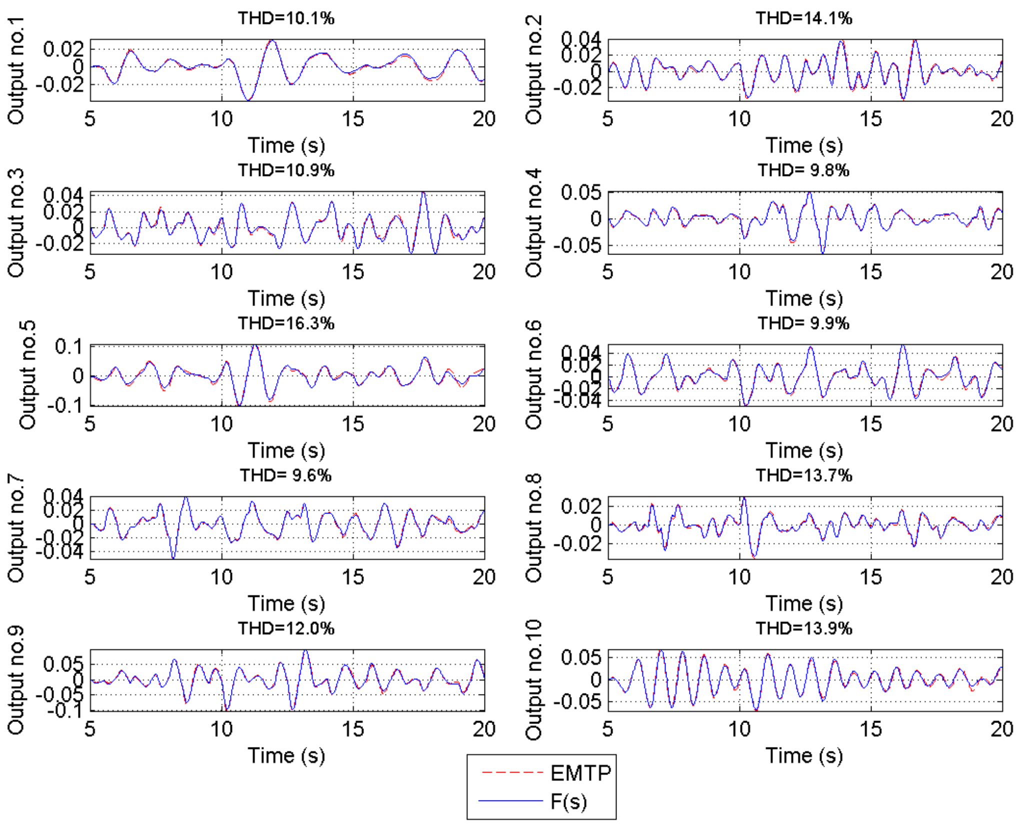
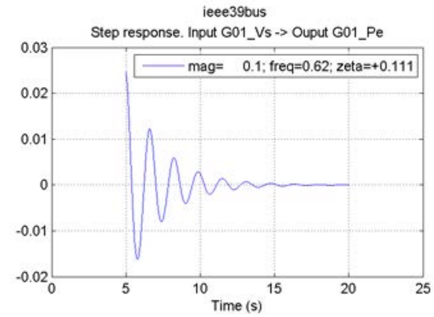
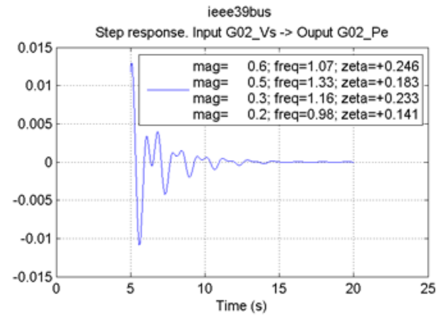
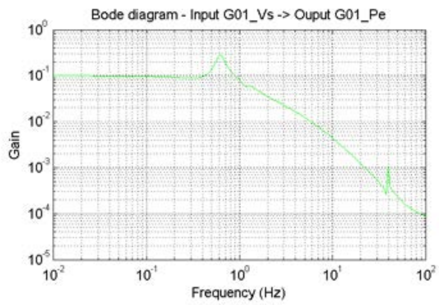


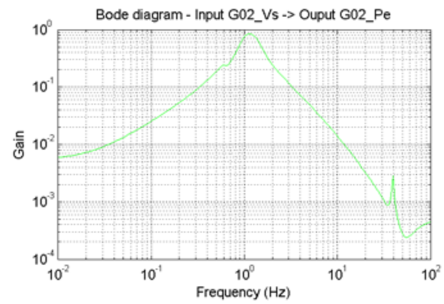
Figure 8 – Comparison of EMTP and state-space matrices

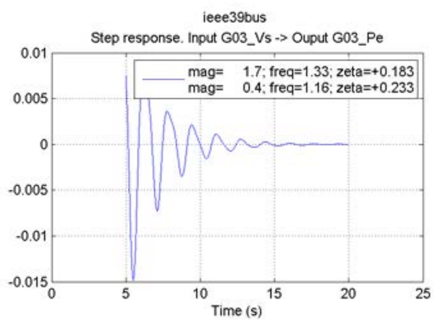
1. L. Gérin-Lajoie. *Plant Identification and tuning controls – An EMTP case*. Presented at the Internal Conference on Power Systems Transient (IPST'09) in Kyoto, Japan, 2009.

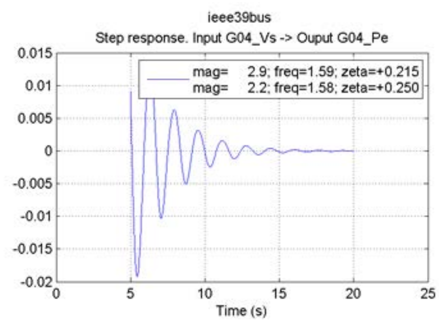

ieee39bus
Step response. Input G01_Vs -> Ouput G01_Pe
mag= 0.1; freq=0.62; zeta=+0.111
Time (s)

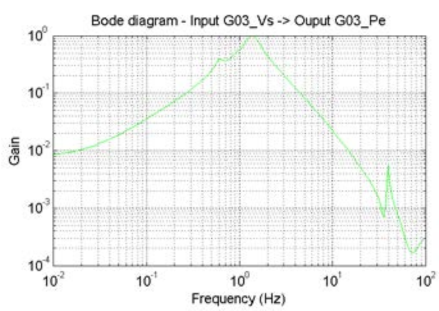

ieee39bus
Step response. Input G02_Vs -> Ouput G02_Pe
mag= 0.6; freq=1.07; zeta=+0.246
mag= 0.5; freq=1.33; zeta=+0.183
mag= 0.3; freq=1.16; zeta=+0.233
mag= 0.2; freq=0.98; zeta=+0.141
Time (s)

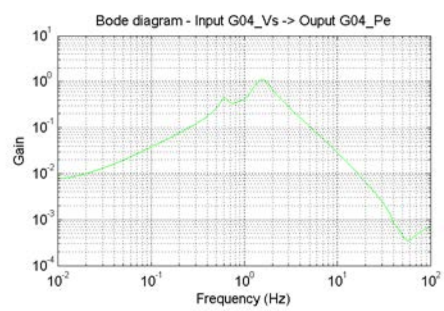

Bode diagram - Input G01_Vs -> Ouput G01_Pe
Gain
Frequency (Hz)

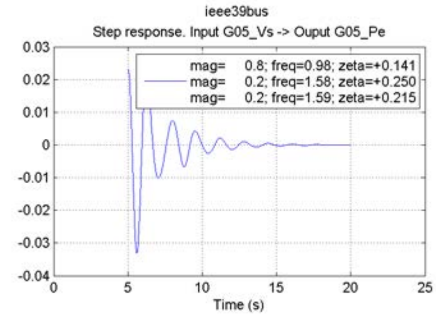

Bode diagram - Input G02_Vs -> Ouput G02_Pe
Gain
Frequency (Hz)

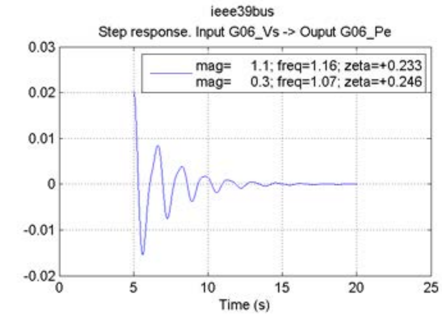

ieee39bus
Step response. Input G03_Vs -> Ouput G03_Pe
mag= 1.7; freq=1.33; zeta=+0.183
mag= 0.4; freq=1.16; zeta=+0.233
Time (s)

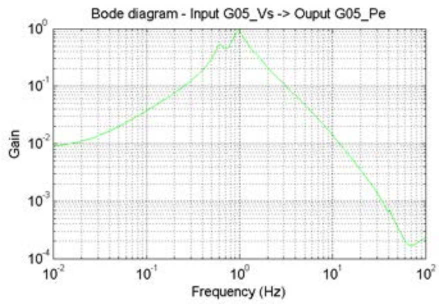

ieee39bus
Step response. Input G04_Vs -> Ouput G04_Pe
mag= 2.9; freq=1.59; zeta=+0.215
mag= 2.2; freq=1.58; zeta=+0.250
Time (s)

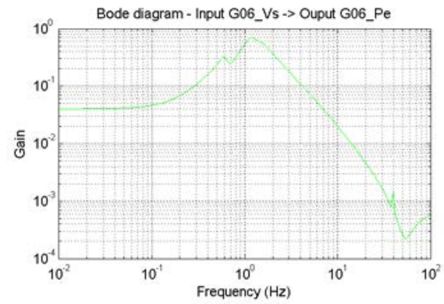

Bode diagram - Input G03_Vs -> Ouput G03_Pe
Gain
Frequency (Hz)

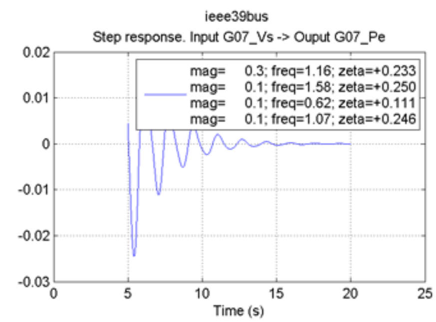

Bode diagram - Input G04_Vs -> Ouput G04_Pe
Gain
Frequency (Hz)

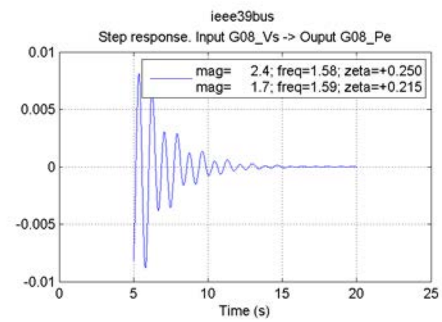

ieee39bus
Step response. Input G05_Vs -> Ouput G05_Pe
mag= 0.8; freq=0.98; zeta=+0.141
mag= 0.2; freq=1.58; zeta=+0.250
mag= 0.2; freq=1.59; zeta=+0.215
Time (s)

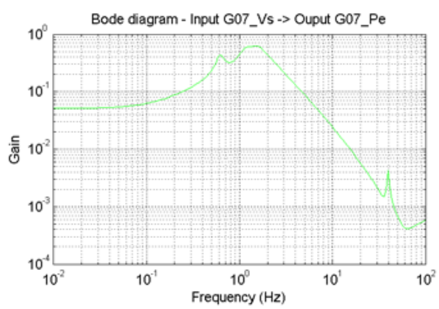

ieee39bus
Step response. Input G06_Vs -> Ouput G06_Pe
mag= 1.1; freq=1.16; zeta=+0.233
mag= 0.3; freq=1.07; zeta=+0.246
Time (s)

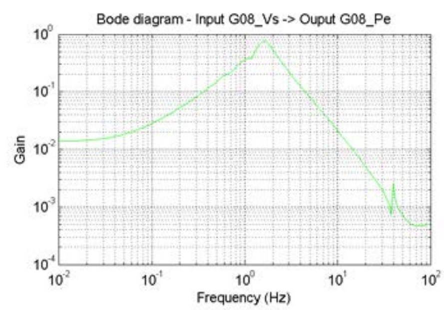

Bode diagram - Input G05_Vs -> Ouput G05_Pe
Gain
Frequency (Hz)


Bode diagram - Input G06_Vs -> Ouput G06_Pe
Gain
Frequency (Hz)


ieee39bus
Step response. Input G07_Vs -> Ouput G07_Pe
mag= 0.3; freq=1.16; zeta=+0.233
mag= 0.1; freq=1.58; zeta=+0.250
mag= 0.1; freq=0.62; zeta=+0.111
mag= 0.1; freq=1.07; zeta=+0.246
Time (s)


ieee39bus
Step response. Input G08_Vs -> Ouput G08_Pe
mag= 2.4; freq=1.58; zeta=+0.250
mag= 1.7; freq=1.59; zeta=+0.215
Time (s)


Bode diagram - Input G07_Vs -> Ouput G07_Pe
Gain
Frequency (Hz)


Bode diagram - Input G08_Vs -> Ouput G08_Pe
Gain
Frequency (Hz)

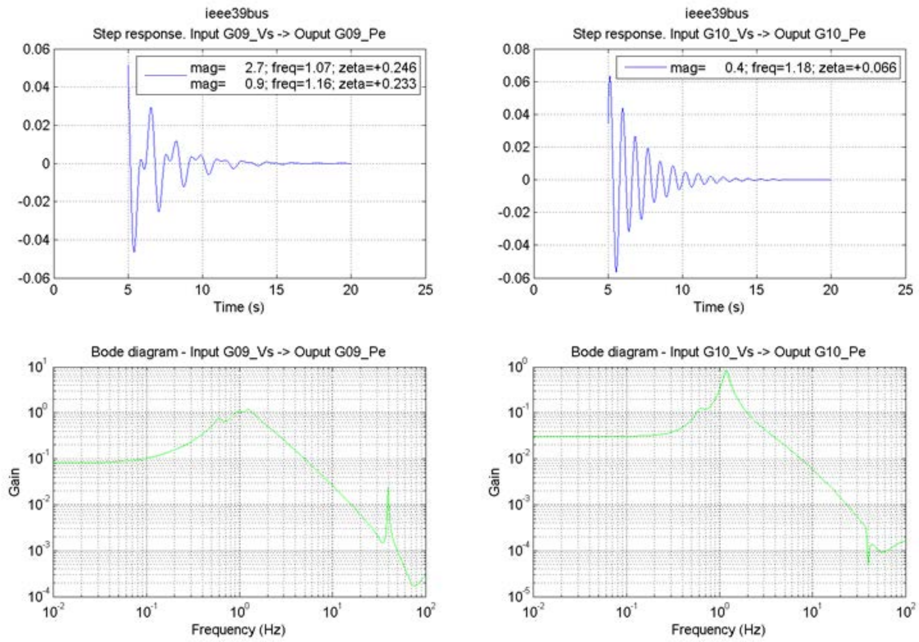
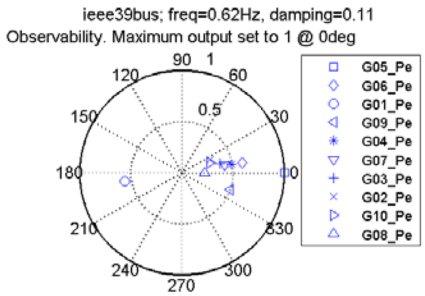
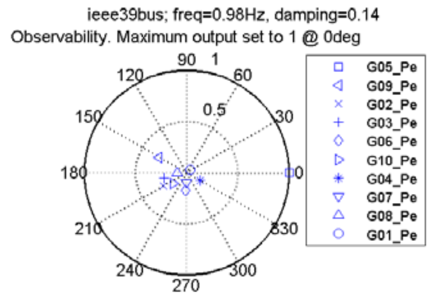
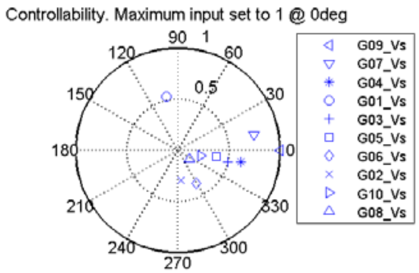
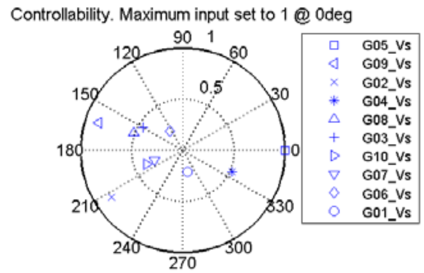


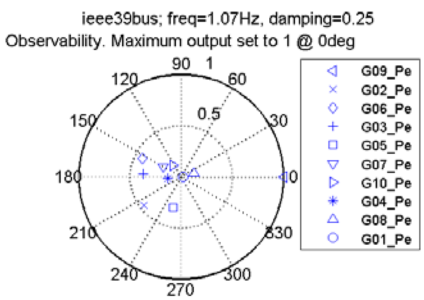
Figure 9 – Impulse response and Bode diagram for each generator.

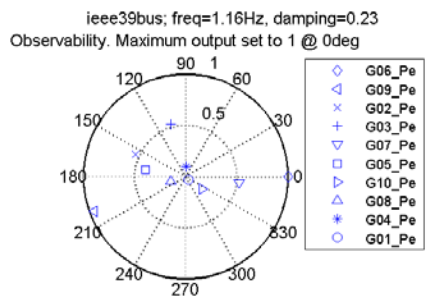

ieee39bus; freq=0.62Hz, damping=0.11
Observability. Maximum output set to 1 @ 0deg
90 1 120 60 0.5 150 30 180 0 210 330 240 300 270
G05_Pe
G06_Pe
G01_Pe
G09_Pe
G04_Pe
G07_Pe
G03_Pe
G02_Pe
G10_Pe
G08_Pe

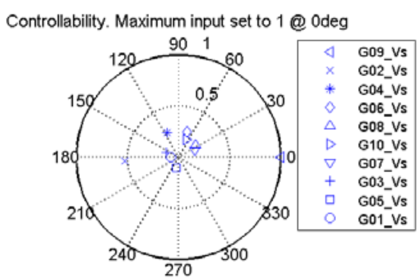

ieee39bus; freq=0.98Hz, damping=0.14
Observability. Maximum output set to 1 @ 0deg
90 1 120 60 0.5 150 30 180 0 210 330 240 300 270
G05_Pe
G09_Pe
G02_Pe
G03_Pe
G06_Pe
G10_Pe
G04_Pe
G07_Pe
G08_Pe
G01_Pe

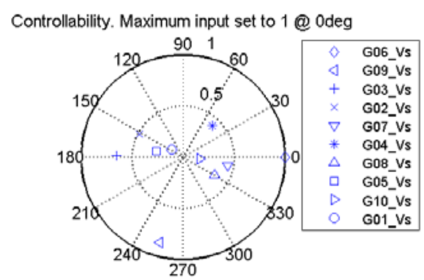

Controllability. Maximum input set to 1 @ 0deg
90 1 120 60 0.5 150 30 180 0 210 330 240 300 270
G09_Vs
G07_Vs
G04_Vs
G01_Vs
G03_Vs
G05_Vs
G06_Vs
G02_Vs
G10_Vs
G08_Vs


Controllability. Maximum input set to 1 @ 0deg
90 1 120 60 0.5 150 30 180 0 210 330 240 300 270
G05_Vs
G09_Vs
G02_Vs
G04_Vs
G08_Vs
G03_Vs
G10_Vs
G07_Vs
G06_Vs
G01_Vs


ieee39bus; freq=1.07Hz, damping=0.25
Observability. Maximum output set to 1 @ 0deg
90 1 120 60 0.5 150 30 180 0 210 330 240 300 270
G09_Pe
G02_Pe
G06_Pe
G03_Pe
G05_Pe
G07_Pe
G10_Pe
G04_Pe
G08_Pe
G01_Pe


ieee39bus; freq=1.16Hz, damping=0.23
Observability. Maximum output set to 1 @ 0deg
90 1 120 60 0.5 150 30 180 0 210 330 240 300 270
G06_Pe
G09_Pe
G02_Pe
G03_Pe
G07_Pe
G05_Pe
G10_Pe
G08_Pe
G04_Pe
G01_Pe


Controllability. Maximum input set to 1 @ 0deg
90 1 120 60 0.5 150 30 180 0 210 330 240 300 270
G09_Vs
G02_Vs
G04_Vs
G06_Vs
G08_Vs
G10_Vs
G07_Vs
G03_Vs
G05_Vs
G01_Vs


Controllability. Maximum input set to 1 @ 0deg
90 1 120 60 0.5 150 30 180 0 210 330 240 300 270
G06_Vs
G09_Vs
G03_Vs
G02_Vs
G07_Vs
G04_Vs
G08_Vs
G05_Vs
G10_Vs
G01_Vs

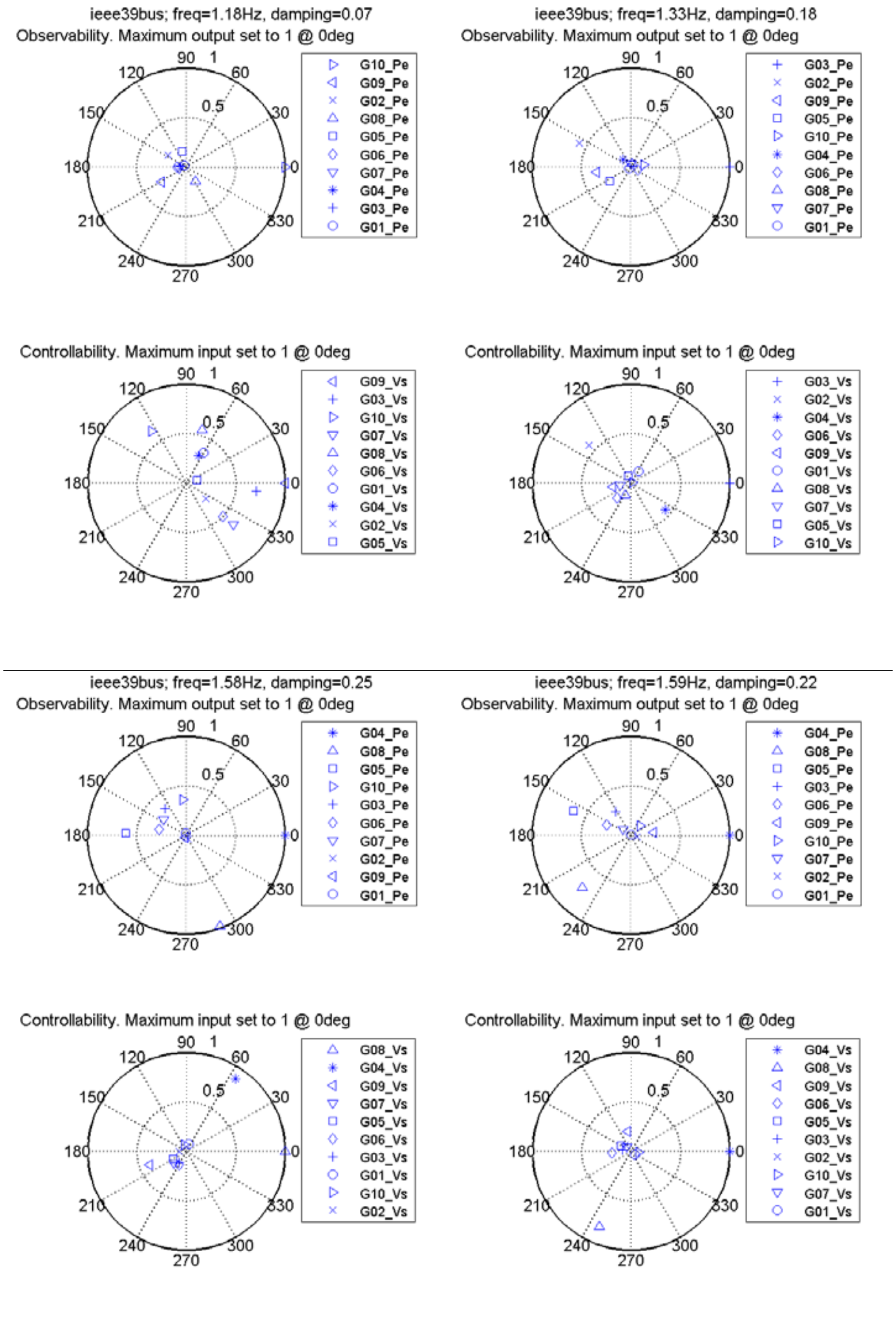


Figure 10 – Polar observability and controllability plots for the principal modes.

3. Conclusions

A benchmark of the 39bus system in EMTP-RV was developing for this TF. The results seem very close to the originals dynamics results.

This benchmark in EMTP-RV / EMTPWorks may perform all these study type:

- Drawing, what you see is what you get.
- Power device
- Control device
- Load-Flow
- Stability with the three sequence admittance
- Short-circuit analysis

Appendix A – lines data

		R1(pu)	X1(pu)	B1(pu)	km	R1(ohm/km)	X1(ohm/km)	B1(uS/km)	R0(ohm/km)	X0(ohm/km)	B0(uS/km)
1	2	0.0035	0.0411	0.6987	275.5	0.032	0.373	1.015	0.318	1.119	0.609
1	39	0.001	0.025	0.75	167.6	0.015	0.373	1.790	0.149	1.119	1.074
2	**3**	**0.0013**	**0.0151**	**0.2572**	**101.2**	**0.032**	**0.373**	**1.017**	**0.321**	**1.119**	**0.610**
2	25	0.007	0.0086	0.146	57.6	0.304	0.373	1.013	3.036	1.119	0.608
3	4	0.0013	0.0213	0.2214	142.8	0.023	0.373	0.620	0.228	1.119	0.372
3	18	0.0011	0.0133	0.2138	89.1	0.031	0.373	0.959	0.308	1.119	0.576
4	5	0.0008	0.0128	0.1342	85.8	0.023	0.373	0.626	0.233	1.119	0.375
4	14	0.0008	0.0129	0.1382	86.5	0.023	0.373	0.639	0.231	1.119	0.384
5	6	0.0002	0.0026	0.0434	17.4	0.029	0.373	0.996	0.287	1.119	0.598
5	8	0.0008	0.0112	0.1476	75.1	0.027	0.373	0.786	0.266	1.119	0.472
6	7	0.0006	0.0092	0.113	61.7	0.024	0.373	0.733	0.243	1.119	0.440
6	11	0.0007	0.0082	0.1389	55.0	0.032	0.373	1.011	0.318	1.119	0.607
7	8	0.0004	0.0046	0.078	30.8	0.032	0.373	1.012	0.324	1.119	0.607
8	9	0.0023	0.0363	0.3804	243.3	0.024	0.373	0.625	0.236	1.119	0.375
9	39	0.001	0.025	1.2	167.6	0.015	0.373	2.865	0.149	1.119	1.719
10	11	0.0004	0.0043	0.0729	28.8	0.035	0.373	1.012	0.347	1.119	0.607
10	13	0.0004	0.0043	0.0729	28.8	0.035	0.373	1.012	0.347	1.119	0.607
13	14	0.0009	0.0101	0.1723	67.7	0.033	0.373	1.018	0.332	1.119	0.611
14	15	0.0018	0.0217	0.366	145.4	0.031	0.373	1.007	0.309	1.119	0.604
15	16	0.0009	0.0094	0.171	63.0	0.036	0.373	1.086	0.357	1.119	0.651

16	17	0.0007	0.0089	0.1342	59.7	0.029	0.373	0.900	0.293	1.119	0.540
16	19	0.0016	0.0195	0.304	130.7	0.031	0.373	0.930	0.306	1.119	0.558
16	21	0.0008	0.0135	0.2548	90.5	0.022	0.373	1.126	0.221	1.119	0.676
16	24	0.0003	0.0059	0.068	39.5	0.019	0.373	0.688	0.190	1.119	0.413
17	18	0.0007	0.0082	0.1319	55.0	0.032	0.373	0.960	0.318	1.119	0.576
17	27	0.0013	0.0173	0.3216	116.0	0.028	0.373	1.109	0.280	1.119	0.666
21	22	0.0008	0.014	0.2565	93.8	0.021	0.373	1.093	0.213	1.119	0.656
22	23	0.0006	0.0096	0.1846	64.3	0.023	0.373	1.148	0.233	1.119	0.689
23	24	0.0022	0.035	0.361	234.6	0.023	0.373	0.616	0.234	1.119	0.369
25	26	0.0032	0.0323	0.513	216.5	0.037	0.373	0.948	0.370	1.119	0.569
26	27	0.0014	0.0147	0.2396	98.5	0.036	0.373	0.973	0.355	1.119	0.584
26	28	0.0043	0.0474	0.7802	317.7	0.034	0.373	0.982	0.338	1.119	0.589
26	29	0.0057	0.0625	1.029	418.9	0.034	0.373	0.983	0.340	1.119	0.590
28	29	0.0014	0.0151	0.249	101.2	0.035	0.373	0.984	0.346	1.119	0.590

Appendix B – AVR parameters

Machine no1.

```
// Exciter ST1
st1_Tr = 0.01            // voltage meter time constant [s]
st1_Vimax = 0.1          // control error high limit   [pu(V_base)]
st1_Vimin = -0.1         // control error low  limit   [pu(V_base)]
st1_Tc = 1               // transient filter lead time constant [s]
st1_Tb = 10              // transient filter lag time constant [s]
st1_Ka = 200             // regulator gain (incl base conv V_base/Efd_base)
st1_Ta = 0.015           // regulator time constant [s]
st1_Vrmax = 5            // regulator high limit
st1_Vrmin = -5           // regulator low  limit
st1_Kc=0                 // transformer fed systems
st1_Kf = 0.0             // feedback  gain (incl base conv Efd_base/V_base)
st1_Tf = 1.0             // feedback time constant [s]

// Stabilizer Input selection
// 1 - rotor speed deviation (SM device Omega_1 only)
// 2 - bus frequency deviation
// 3 - electrical power
// 4 - accelerating power
pss1a_InputSelec=1
pss1a_T1 = 5.0           // lead time constant no1
pss1a_T2 = 0.6           // lag time constant no1
pss1a_T3 = 3.0           // lead time constant no2
pss1a_T4 = 0.5           // lag time constant no2
pss1a_T5 = 10            // washout time constant
pss1a_T6 = 0.0           // transducer time constant
pss1a_Ks  = 1            // gain
pss1a_Vstmax = 0.20      // Maximum output limit
pss1a_Vstmin = -0.20     // Minimum output limit
pss1a_A1=0,pss1a_A2=0    // High frequency filter coefficients
```

```
// Governor-turbine parameters (IEEEG1)
ieeeg1_K        = 20       //
ieeeg1_T1       = 0.0      //
ieeeg1_T2       = 0        //
ieeeg1_T3       = 0.075    //
ieeeg1_Uo       = 0.6786   //
ieeeg1_Uc       = -1.0     //  gate min closing speed (pu@SM_MVABASE)
ieeeg1_Pmax     = 0.90     //
ieeeg1_Pmin     = 0.0      //
ieeeg1_T4       = 0.3      // Steam flow time cst(s)
ieeeg1_K1       = 0.2      // Fraction of LP mech power
ieeeg1_K2       = 0        // Fraction of HP mech power
ieeeg1_T5       = 10       // First reheater time cst
ieeeg1_K3       = 0.4      // Fraction of LP mech power
ieeeg1_K4       = 0        // Fraction of HP mech power
ieeeg1_T6       = 0.6      // Second reheater time cst
ieeeg1_K5       = 0.4      // Fraction of LP mech power
ieeeg1_K6       = 0        // Fraction of HP mech power
ieeeg1_T7       = 0        // Crossover reheater time cst
ieeeg1_K7       = 0        // Fraction of LP mech power
ieeeg1_K8       = 0        // Fraction of HP mech power
```

Machine no.2

```
// Exciter ST1
st1_Tr = 0.01            // voltage meter time constant [s]
st1_Vimax = 0.1          // control error high limit   [pu(V_base)]
st1_Vimin = -0.1         // control error low  limit   [pu(V_base)]
st1_Tc = 1               // transient filter lead time constant [s]
st1_Tb = 10              // transient filter lag time constant [s]
st1_Ka = 200             // regulator gain (incl base conv V_base/Efd_base)
st1_Ta = 0.015           // regulator time constant [s]
st1_Vrmax = 5            // regulator high limit
st1_Vrmin = -5           // regulator low  limit
st1_Kc=0                 // transformer fed systems
st1_Kf = 0.0             // feedback  gain (incl base conv Efd_base/V_base)
st1_Tf = 1.0             // feedback time constant [s]

// Stabilizer Input selection
// 1 - rotor speed deviation (SM device Omega_1 only)
// 2 - bus frequency deviation
// 3 - electrical power
// 4 - accelerating power
pss1a_InputSelec=1
pss1a_T1 = 5.0           // lead time constant no1
pss1a_T2 = 0.4           // lag time constant no1
pss1a_T3 = 1.0           // lead time constant no2
pss1a_T4 = 0.1           // lag time constant no2
pss1a_T5 = 10            // washout time constant
pss1a_T6 = 0.0           // transducer time constant
pss1a_Ks  = 0.5          // gain
pss1a_Vstmax = 0.20      // Maximum output limit
pss1a_Vstmin = -0.20     // Minimum output limit
pss1a_A1=0,pss1a_A2=0    // High frequency filter coefficients
```

Machine no.3

```
// Exciter ST1
st1_Tr = 0.01             // voltage meter time constant [s]
st1_Vimax = 0.1           // control error high limit   [pu(V_base)]
st1_Vimin = -0.1          // control error low  limit   [pu(V_base)]
st1_Tc = 1                // transient filter lead time constant [s]
st1_Tb = 10               // transient filter lag time constant [s]
st1_Ka = 200              // regulator gain (incl base conv V_base/Efd_base)
st1_Ta = 0.015            // regulator time constant [s]
st1_Vrmax = 5             // regulator high limit
st1_Vrmin = -5            // regulator low  limit
st1_Kc=0                  // transformer fed systems
st1_Kf = 0.0              // feedback  gain (incl base conv Efd_base/V_base)
st1_Tf = 1.0              // feedback time constant [s]

// Stabilizer Input selection
// 1 - rotor speed deviation (SM device Omega_1 only)
// 2 - bus frequency deviation
// 3 - electrical power
// 4 - accelerating power
pss1a_InputSelec=1
pss1a_T1 = 3.0            // lead time constant no1
pss1a_T2 = 0.2            // lag time constant no1
pss1a_T3 = 2.0            // lead time constant no2
pss1a_T4 = 0.2            // lag time constant no2
pss1a_T5 = 10             // washout time constant
pss1a_T6 = 0.0            // transducer time constant
pss1a_Ks  = 0.5           // gain
pss1a_Vstmax = 0.20       // Maximum output limit
pss1a_Vstmin = -0.20      // Minimum output limit
pss1a_A1=0,pss1a_A2=0     // High frequency filter coefficients
```

Machine no4

```
// Exciter ST1
st1_Tr = 0.01             // voltage meter time constant [s]
st1_Vimax = 0.1           // control error high limit   [pu(V_base)]
st1_Vimin = -0.1          // control error low  limit   [pu(V_base)]
st1_Tc = 1                // transient filter lead time constant [s]
st1_Tb = 10               // transient filter lag time constant [s]
st1_Ka = 200              // regulator gain (incl base conv V_base/Efd_base)
st1_Ta = 0.015            // regulator time constant [s]
st1_Vrmax = 5             // regulator high limit
st1_Vrmin = -5            // regulator low  limit
st1_Kc=0                  // transformer fed systems
st1_Kf = 0.0              // feedback  gain (incl base conv Efd_base/V_base)
st1_Tf = 1.0              // feedback time constant [s]
```

```
// Stabilizer Input selection
// 1 - rotor speed deviation (SM device Omega_1 only)
// 2 - bus frequency deviation
// 3 - electrical power
// 4 - accelerating power
pss1a_InputSelec=1
pss1a_T1 = 1.0          // lead time constant no1
pss1a_T2 = 0.1          // lag time constant no1
pss1a_T3 = 1.0          // lead time constant no2
pss1a_T4 = 0.3          // lag time constant no2
pss1a_T5 = 10           // washout time constant
pss1a_T6 = 0.0          // transducer time constant
pss1a_Ks  = 2           // gain
pss1a_Vstmax = 0.20     // Maximum output limit
pss1a_Vstmin = -0.20    // Minimum output limit
pss1a_A1=0,pss1a_A2=0   // High frequency filter coefficients
```

Machine no.5

```
// Exciter ST1
st1_Tr = 0.01           // voltage meter time constant [s]
st1_Vimax = 0.1         // control error high limit   [pu(V_base)]
st1_Vimin = -0.1        // control error low  limit   [pu(V_base)]
st1_Tc = 1              // transient filter lead time constant [s]
st1_Tb = 10             // transient filter lag time constant [s]
st1_Ka = 200            // regulator gain (incl base conv V_base/Efd_base)
st1_Ta = 0.015          // regulator time constant [s]
st1_Vrmax = 5           // regulator high limit
st1_Vrmin = -5          // regulator low  limit
st1_Kc=0                // transformer fed systems
st1_Kf = 0.0            // feedback  gain (incl base conv Efd_base/V_base)
st1_Tf = 1.0            // feedback time constant [s]

// Stabilizer Input selection
// 1 - rotor speed deviation (SM device Omega_1 only)
// 2 - bus frequency deviation
// 3 - electrical power
// 4 - accelerating power
pss1a_InputSelec=1
pss1a_T1 = 1.5          // lead time constant no1
pss1a_T2 = 0.2          // lag time constant no1
pss1a_T3 = 1.0          // lead time constant no2
pss1a_T4 = 0.1          // lag time constant no2
pss1a_T5 = 10           // washout time constant
pss1a_T6 = 0.0          // transducer time constant
pss1a_Ks  = 1           // gain
pss1a_Vstmax = 0.20     // Maximum output limit
pss1a_Vstmin = -0.20    // Minimum output limit
pss1a_A1=0,pss1a_A2=0   // High frequency filter coefficients
```

Machine no.6

```
// Exciter ST1
st1_Tr = 0.01          // voltage meter time constant [s]
st1_Vimax = 0.1        // control error high limit   [pu(V_base)]
st1_Vimin = -0.1       // control error low  limit   [pu(V_base)]
st1_Tc = 1             // transient filter lead time constant [s]
st1_Tb = 10            // transient filter lag time constant [s]
st1_Ka = 200           // regulator gain (incl base conv V_base/Efd_base)
st1_Ta = 0.015         // regulator time constant [s]
st1_Vrmax = 5          // regulator high limit
st1_Vrmin = -5         // regulator low  limit
st1_Kc=0               // transformer fed systems
st1_Kf = 0.0           // feedback  gain (incl base conv Efd_base/V_base)
st1_Tf = 1.0           // feedback time constant [s]

// Stabilizer Input selection
// 1 - rotor speed deviation (SM device Omega_1 only)
// 2 - bus frequency deviation
// 3 - electrical power
// 4 - accelerating power
pss1a_InputSelec=1
pss1a_T1 = 0.5         // lead time constant no1
pss1a_T2 = 0.1         // lag time constant no1
pss1a_T3 = 0.5         // lead time constant no2
pss1a_T4 = 0.05        // lag time constant no2
pss1a_T5 = 10          // washout time constant
pss1a_T6 = 0.0         // transducer time constant
pss1a_Ks  = 4          // gain
pss1a_Vstmax = 0.20    // Maximum output limit
pss1a_Vstmin = -0.20   // Minimum output limit
pss1a_A1=0,pss1a_A2=0  // High frequency filter coefficients
```

Machine no.7

```
// Exciter ST1
st1_Tr = 0.01          // voltage meter time constant [s]
st1_Vimax = 0.1        // control error high limit   [pu(V_base)]
st1_Vimin = -0.1       // control error low  limit   [pu(V_base)]
st1_Tc = 1             // transient filter lead time constant [s]
st1_Tb = 10            // transient filter lag time constant [s]
st1_Ka = 200           // regulator gain (incl base conv V_base/Efd_base)
st1_Ta = 0.015         // regulator time constant [s]
st1_Vrmax = 5          // regulator high limit
st1_Vrmin = -5         // regulator low  limit
st1_Kc=0               // transformer fed systems
st1_Kf = 0.0           // feedback  gain (incl base conv Efd_base/V_base)
st1_Tf = 1.0           // feedback time constant [s]
```

```
// Stabilizer Input selection
// 1 - rotor speed deviation (SM device Omega_1 only)
// 2 - bus frequency deviation
// 3 - electrical power
// 4 - accelerating power
pss1a_InputSelec=1
// Stabilizer PSS1A
pss1a_T1 = 0.2          // lead time constant no1
pss1a_T2 = 0.02         // lag time constant no1
pss1a_T3 = 0.5          // lead time constant no2
pss1a_T4 = 0.1          // lag time constant no2
pss1a_T5 = 10           // washout time constant
pss1a_T6 = 0.0          // transducer time constant
pss1a_Ks  = 7.5         // gain
pss1a_Vstmax = 0.20     // Maximum output limit
pss1a_Vstmin = -0.20    // Minimum output limit
pss1a_A1=0,pss1a_A2=0   // High frequency filter coefficients
```

Machine no8

```
// Exciter ST1
st1_Tr = 0.01           // voltage meter time constant [s]
st1_Vimax = 0.1         // control error high limit   [pu(V_base)]
st1_Vimin = -0.1        // control error low  limit   [pu(V_base)]
st1_Tc = 1              // transient filter lead time constant [s]
st1_Tb = 10             // transient filter lag time constant [s]
st1_Ka = 200            // regulator gain (incl base conv V_base/Efd_base)
st1_Ta = 0.015          // regulator time constant [s]
st1_Vrmax = 5           // regulator high limit
st1_Vrmin = -5          // regulator low  limit
st1_Kc=0                // transformer fed systems
st1_Kf = 0.0            // feedback  gain (incl base conv Efd_base/V_base)
st1_Tf = 1.0            // feedback time constant [s]

// Stabilizer Input selection
// 1 - rotor speed deviation (SM device Omega_1 only)
// 2 - bus frequency deviation
// 3 - electrical power
// 4 - accelerating power
pss1a_InputSelec=1
pss1a_T1 = 1.0          // lead time constant no1
pss1a_T2 = 0.2          // lag time constant no1
pss1a_T3 = 1.0          // lead time constant no2
pss1a_T4 = 0.1          // lag time constant no2
pss1a_T5 = 10           // washout time constant
pss1a_T6 = 0.0          // transducer time constant
pss1a_Ks  = 2           // gain
pss1a_Vstmax = 0.20     // Maximum output limit
pss1a_Vstmin = -0.20    // Minimum output limit
```

```
pss1a_A1=0, pss1a_A2=0              // High frequency filter coefficients
```

Machine no.9

```
// Exciter ST1
st1_Tr = 0.01                   // voltage meter time constant [s]
st1_Vimax = 0.1                // control error high limit   [pu(V_base)]
st1_Vimin = -0.1               // control error low  limit   [pu(V_base)]
st1_Tc = 1                     // transient filter lead time constant [s]
st1_Tb = 10                      // transient filter lag time constant [s]
st1_Ka = 200                   // regulator gain (incl base conv V_base/Efd_base)
st1_Ta = 0.015                   // regulator time constant [s]
st1_Vrmax = 5                 // regulator high limit
st1_Vrmin = -5                // regulator low  limit
st1_Kc=0                      // transformer fed systems
st1_Kf = 0.0                    // feedback  gain (incl base conv Efd_base/V_base)
st1_Tf = 1.0                     // feedback time constant [s]

// Stabilizer Input selection
// 1 - rotor speed deviation (SM device Omega_1 only)
// 2 - bus frequency deviation
// 3 - electrical power
// 4 - accelerating power
pss1a_InputSelec=1
pss1a_T1 = 1.0                 // lead time constant no1
pss1a_T2 = 0.5                   // lag time constant no1
pss1a_T3 = 2.0                      // lead time constant no2
pss1a_T4 = 0.1                      // lag time constant no2
pss1a_T5 = 10                    // washout time constant
pss1a_T6 = 0.0               // transducer time constant
pss1a_Ks  = 2                  // gain
pss1a_Vstmax = 0.20             // Maximum output limit
pss1a_Vstmin = -0.20             // Minimum output limit
pss1a_A1=0, pss1a_A2=0              // High frequency filter coefficients
```

Machine no.10

```
// Exciter ST1
st1_Tr = 0.01                   // voltage meter time constant [s]
st1_Vimax = 0.1                // control error high limit   [pu(V_base)]
st1_Vimin = -0.1               // control error low  limit   [pu(V_base)]
st1_Tc = 1                     // transient filter lead time constant [s]
st1_Tb = 10                      // transient filter lag time constant [s]
st1_Ka = 200                   // regulator gain (incl base conv V_base/Efd_base)
st1_Ta = 0.015                   // regulator time constant [s]
st1_Vrmax = 5                 // regulator high limit
st1_Vrmin = -5                // regulator low  limit
st1_Kc=0                      // transformer fed systems
st1_Kf = 0.0                    // feedback  gain (incl base conv Efd_base/V_base)
st1_Tf = 1.0                     // feedback time constant [s]
```

```
// Stabilizer Input selection
// 1 - rotor speed deviation (SM device Omega_1 only)
// 2 - bus frequency deviation
// 3 - electrical power
// 4 - accelerating power
pss1a_InputSelec=1
pss1a_T1 = 1.0                  // lead time constant no1
pss1a_T2 = 0.05                 // lag time constant no1
pss1a_T3 = 3.0                  // lead time constant no2
pss1a_T4 = 0.5                  // lag time constant no2
pss1a_T5 = 10                   // washout time constant
pss1a_T6 = 0.0               // transducer time constant
pss1a_Ks  = 1                   // gain
pss1a_Vstmax = 0.20             // Maximum output limit
pss1a_Vstmin = -0.20            // Minimum output limit
pss1a_A1=0,pss1a_A2=0               // High frequency filter coefficients
```

Appendix C – Reference

[1] IEEE Task Force on Load Representation for Dynamic Performance. Load Representation for Dynamic Performance Analysis. IEEE Transactions on Power Systems, Vol. 8, No. 2, May 1993

[2] IEEE Standard 421.5, 1982.

[3] HYDRAULIC TURBINE AND TURBINE CONTROL MODELS FOR SYSTEM PYNAMIC STUDIES. Working Group on Prime Mover and Energy Supply. Models for System Dynamic Performance Studies. Transactions on Power Systems, Vol. 7, NO. 1, February 1992