






Webinar # 3:
Power System Stabilizer (PSS) Tuning

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Background

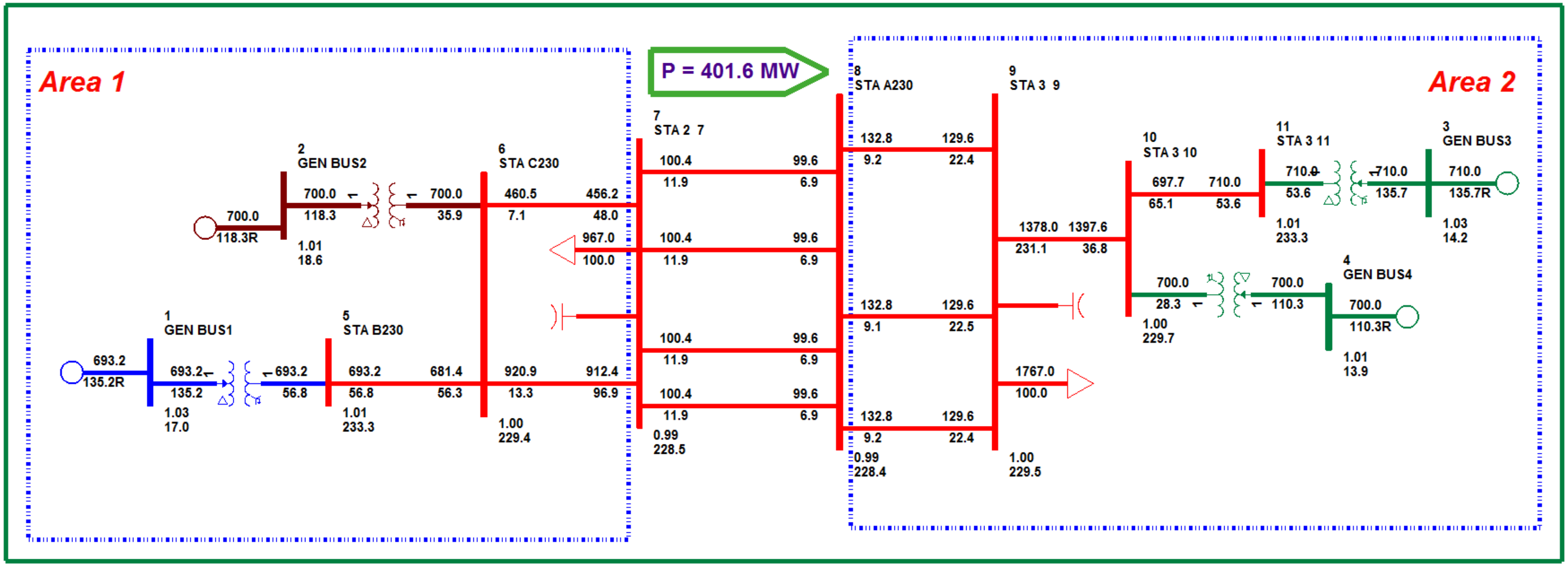
Power system oscillations

- Power system oscillations
  - Sub-synchronous oscillations (~10 Hz to 60 Hz): SSTI, SSCI
  - Electro-mechanical oscillations (~0.1 Hz – 5 Hz)
- PSS provides an auxiliary input to the exciter to improve damping of electro-mechanical oscillations.
  - Generator local mode oscillations
  - Inter-plant oscillations
  - **Inter-area oscillations**
- Case study: Inter-area oscillations

Inter-area oscillations

Case study

Two area 4 generator study example



Operating scenarios

Potential operating scenarios

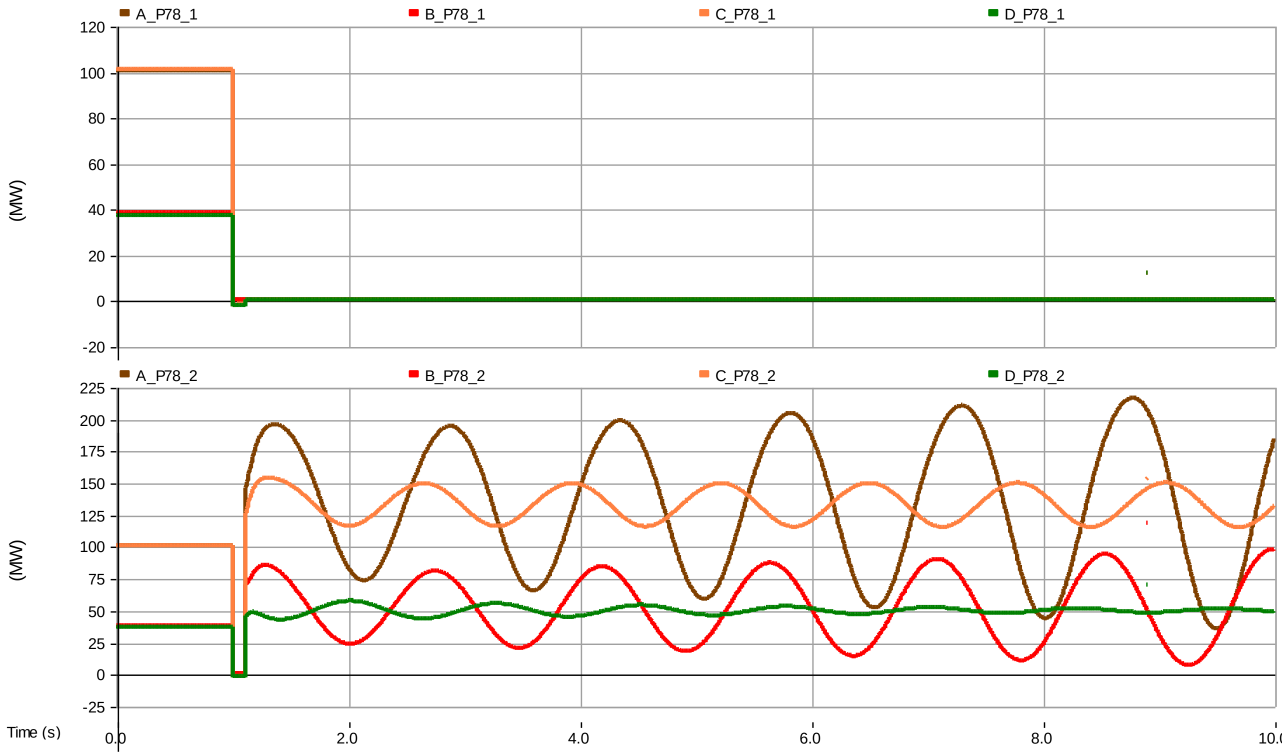
Scenario	Area 1		Area 2		Inter Area Power Transfer (MW)
	Load (MW)	Generation (MW)	Load (MW)	Generation (MW)	
A	**967**	**1393**	**1767**	**1410**	**402**
B	967	1135	1767	1660	152
C	267	689*	1087	710**	405
D	267	421*	840	710**	149

* - Unit 2 out of service

** - Unit 4 out of service

Disturbance recovery performance

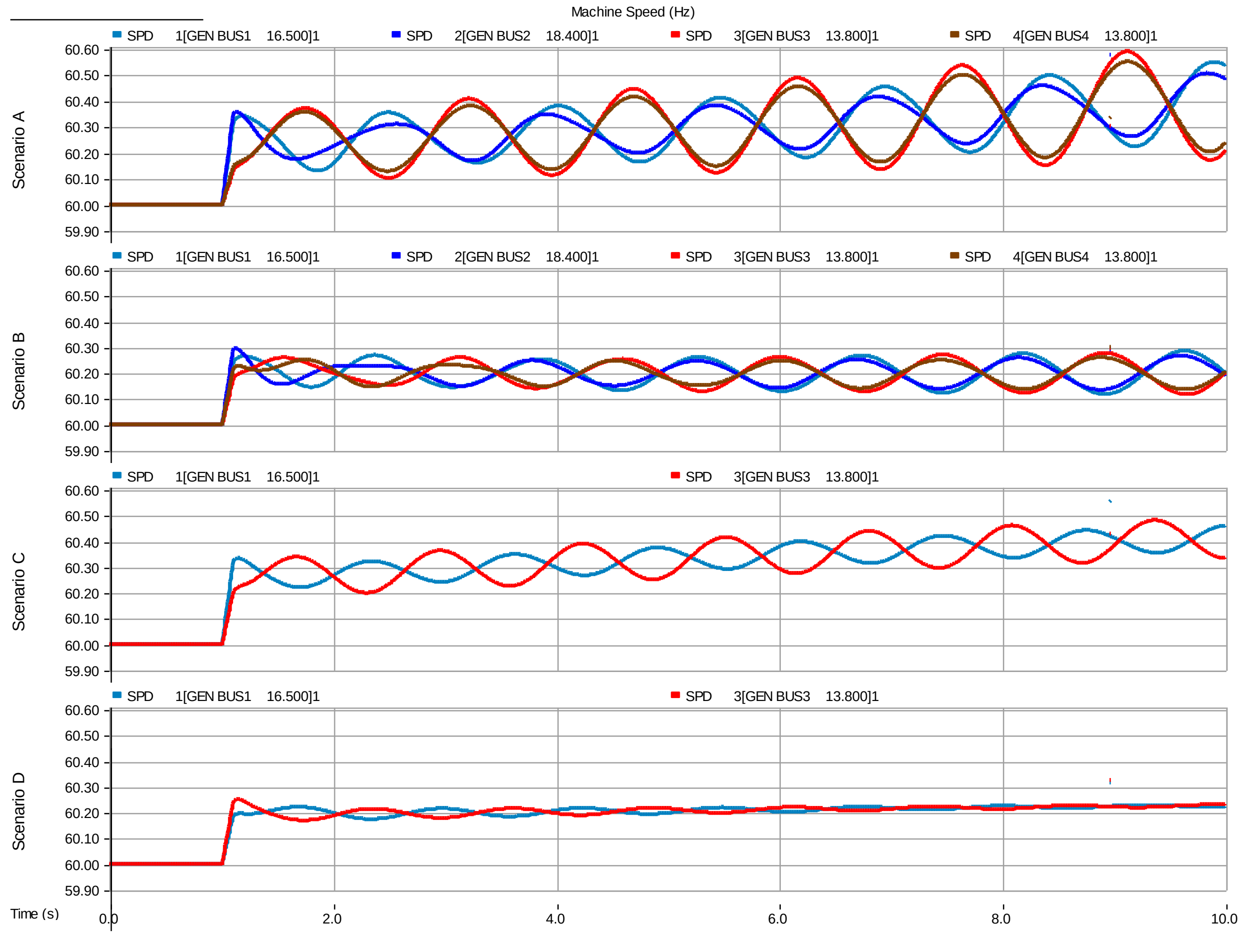
Power oscillations in inter-area tie lines



Disturbance: 3 Phase to ground fault near bus 7 cleared after tripping circuit 1 of quadruple circuit line between bus 7 and 8

Disturbance recovery performance Cont’d

Generators in two areas oscillating against each other



402 MW

152 MW

405 MW

149 MW

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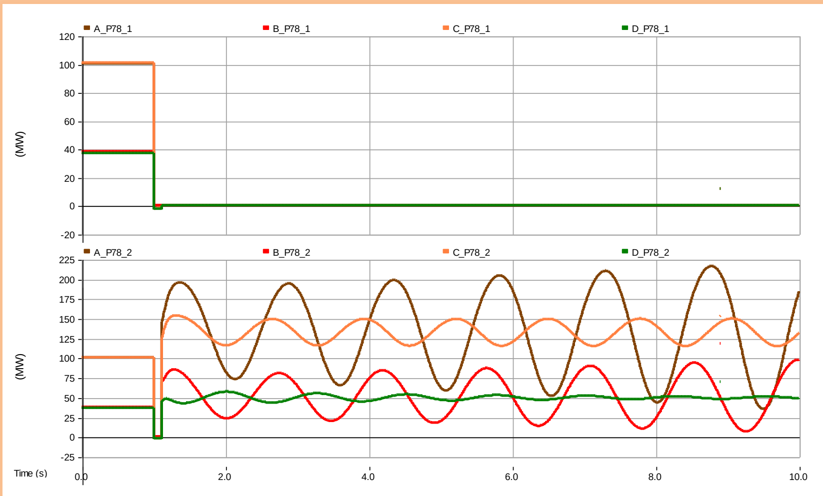
Disturbance recovery performance

Inter area oscillations before and after installing PSS



Without PSS

With suitably tuned PSS in all 4 units

Software tools

Time domain simulation tool

- Eg: PSS/E®, PowerFactory®, PSLF®, TSAT®, PSCAD®

Small signal stability assessment tool

- Eg: SSAT®, NEVA®

PSS Tuning: Eigenvalue analysis

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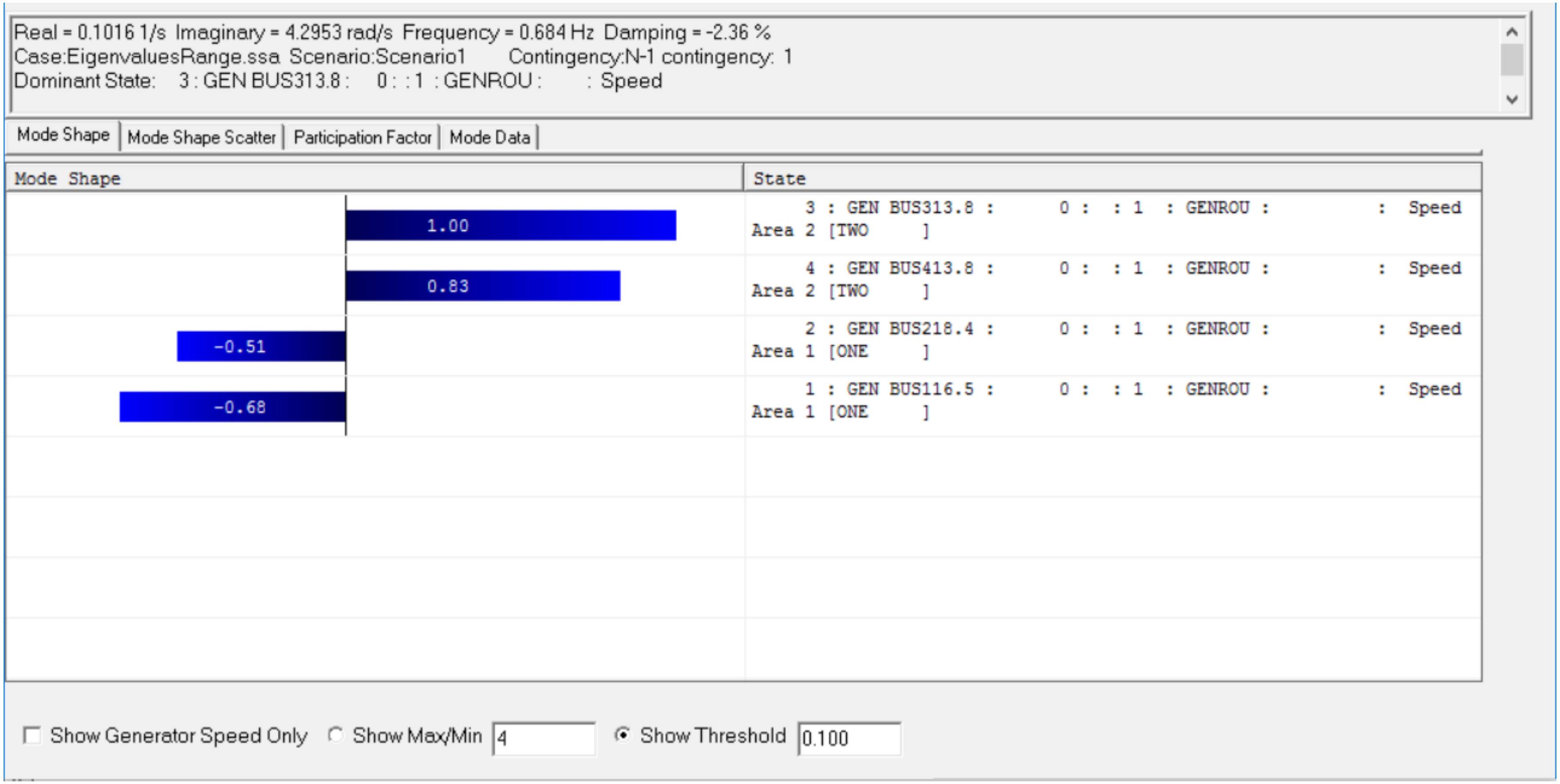
Eigenvalues for pre and post disturbance conditions

Eigenvalues within the frequency range from 0.1 Hz to 5.0 Hz

Mode	Real (Np/s)	Imaginary (rad/s)	Frequency(Hz)	Damping(%)	Outage
Scenario A					
1	0.10	4.40	0.70	**-2.35**	None
2	-0.50	7.04	1.12	**7.13**	
3	-0.51	7.25	1.15	**7.03**	
1	0.10	4.30	**0.68**	**-2.36**	Line 7-8
2	-0.51	7.03	1.12	**7.17**	
3	-0.51	7.25	1.15	**7.08**	
Scenario B					
1	0.09	4.44	0.71	**-2.13**	None
2	-0.74	6.97	1.11	**10.56**	
3	-0.29	7.30	1.16	**3.98**	
1	0.10	4.34	0.69	**-2.20**	Line 7-8
2	-0.74	6.96	1.11	**10.62**	
3	-0.29	7.30	1.16	**4.00**	
Scenario C					
1	0.05	5.02	0.80	**-0.90**	None
2	0.05	4.88	0.78	**-1.01**	Line 7-8
Scenario D					
1	-0.19	5.09	**0.81**	**3.81**	None
2	-0.18	5.01	0.80	**3.67**	Line 7-8

Participation factors and Mode shape

Scenarios A with line outage (Circuit 1 of line from bus 7 to bus 8)



PSS Tuning: Theoretical Background

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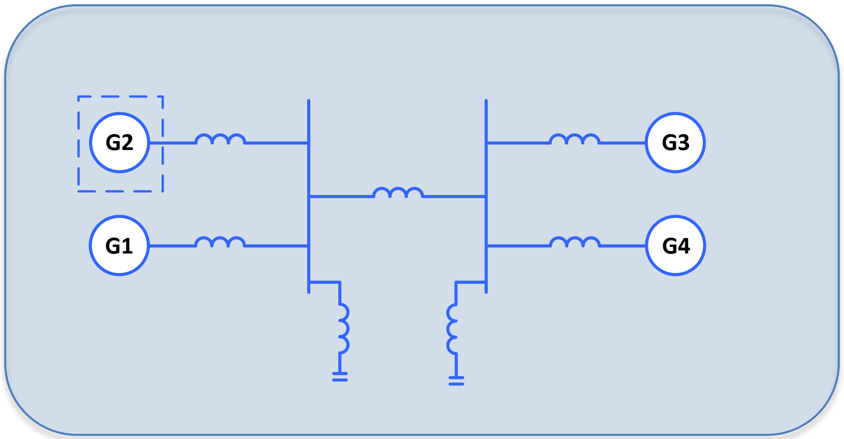
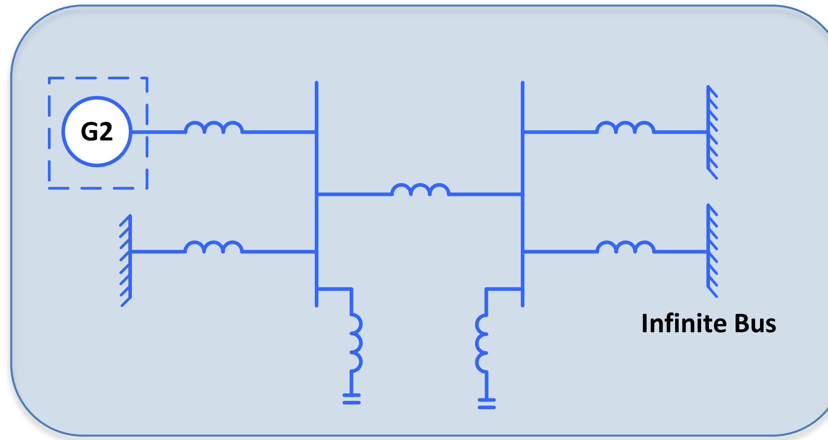
Tuning Procedure

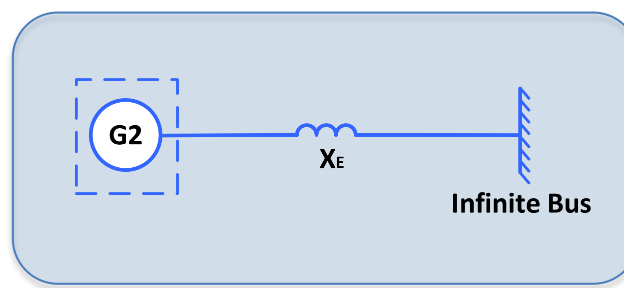
System Modelling



Original Model



Model to estimate frequency response

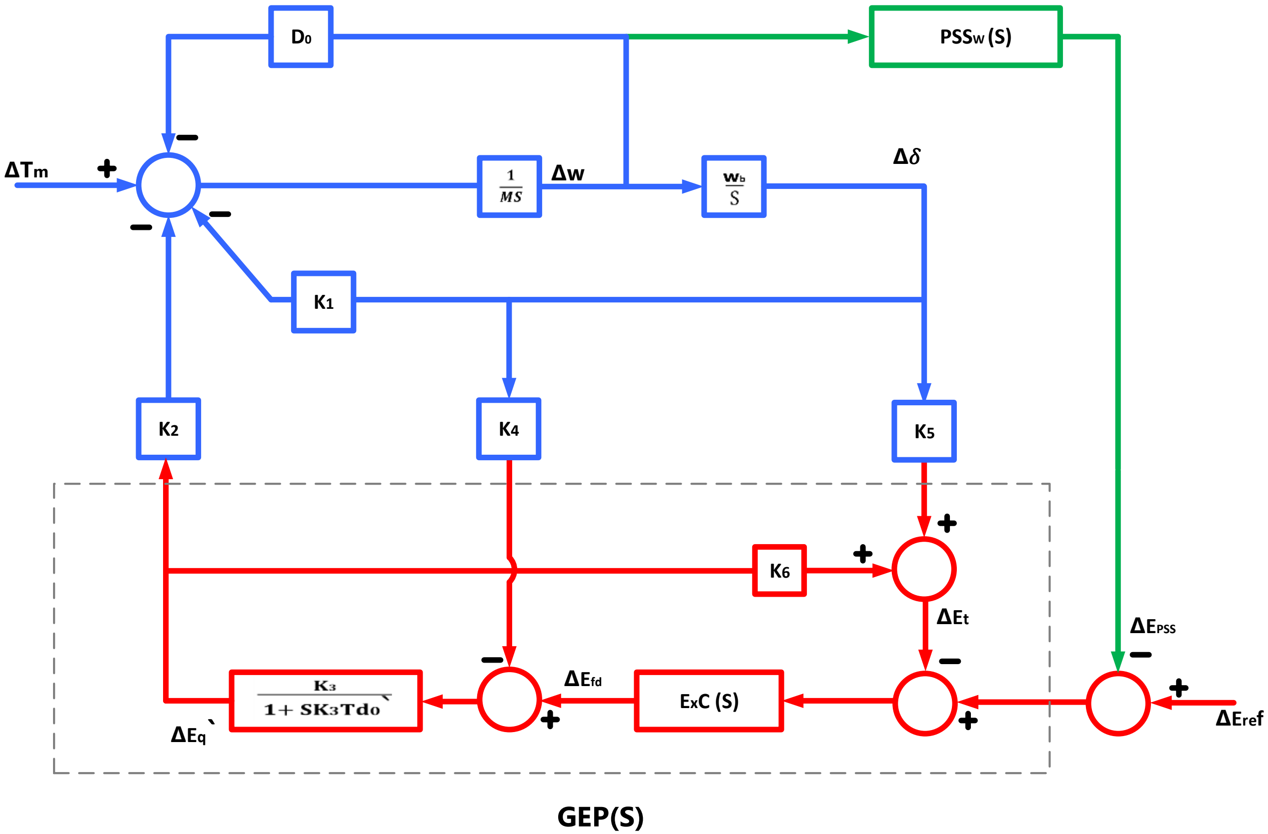


Model for theoretical analysis

Theoretical Background

Small signal disturbance model

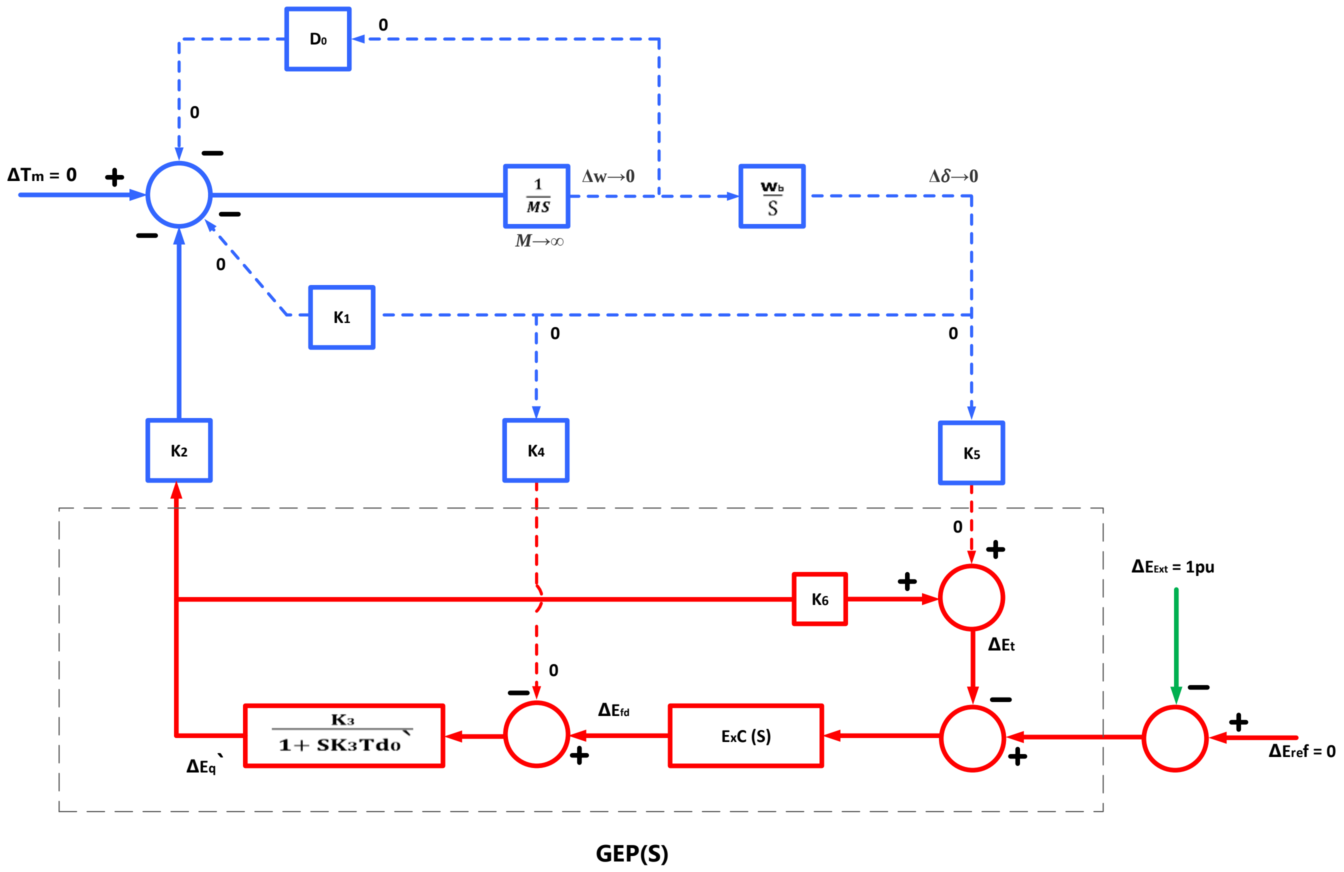
PSS Provides appropriate amount of phase lead compensation



GEP has a phase lag contributed by the exciter and the generator

Theoretical Background Cont'd

Calculation of GEP Phase lag: frequency characteristics of GEP system:



PSS Tuning: Parameter estimation

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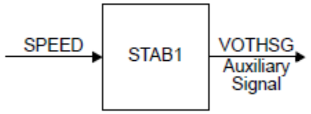
Stabilizer Types

- **Single input** and dual input stabilizers
- **Inputs:**
  - **Rotor speed deviation**
  - Bus frequency deviation
  - Generator electrical Power
  - Generator accelerating power
  - Bus voltage

3.15 STAB1

Speed Sensitive Stabilizing Model

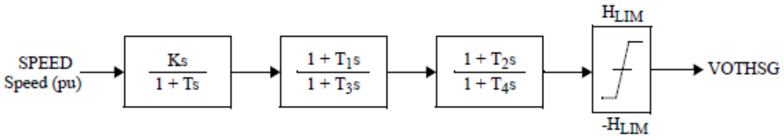
This model is located at system bus #_______ IBUS,
Machine identifier #_______ ID,
This model uses CONs starting with #_______ J,
and STATEs starting with #_______ K.



CONs	#	Value	Description
J			K/T $(sec)^{-1}$
J+1			T (sec) (>0)
J+2			T_1/T_3
J+3			T_3 (sec) (>0)
J+4			T_2/T_4
J+5			T_4 (sec) (>0)
J+6			H_{LIM}

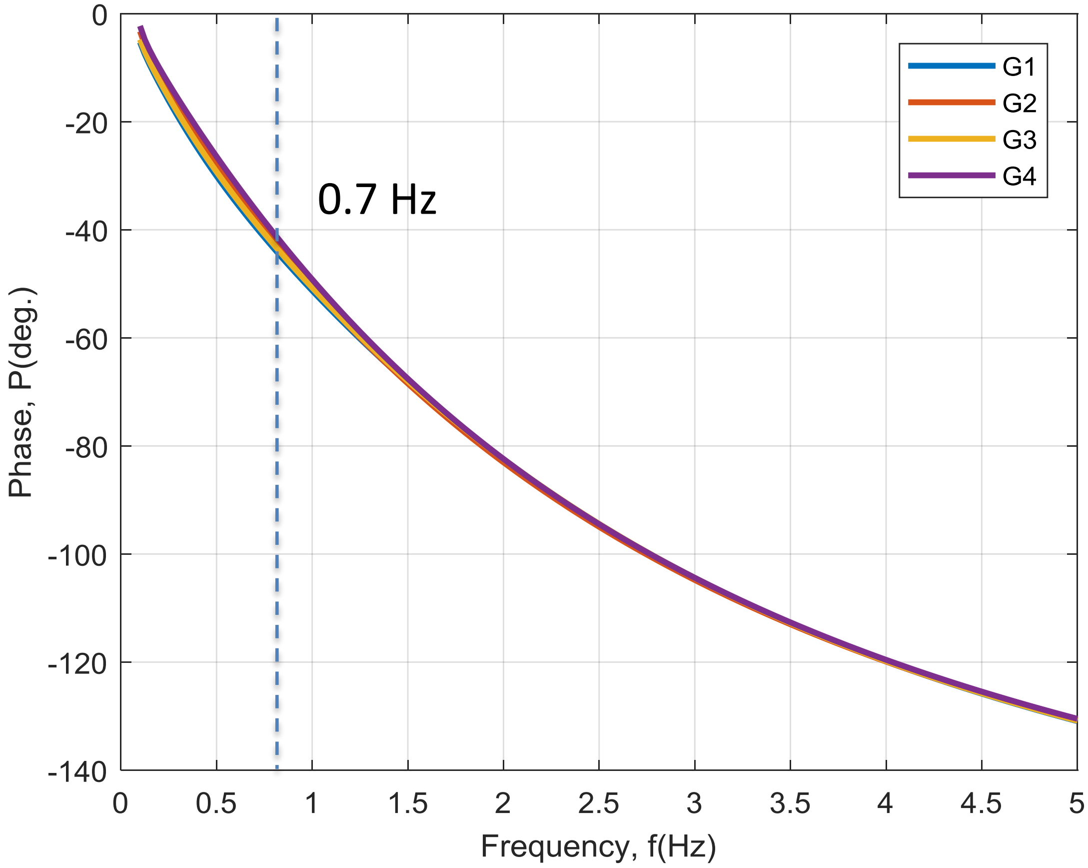
STATEs	#	Description
K		Washout
K+1		First lead-lag
K+2		Second lead-lag

IBUS, 'STAB1', ID, CON(J) to CON(J+6) /



GEP Characteristics

Frequency response of GEP for scenario A: All four units



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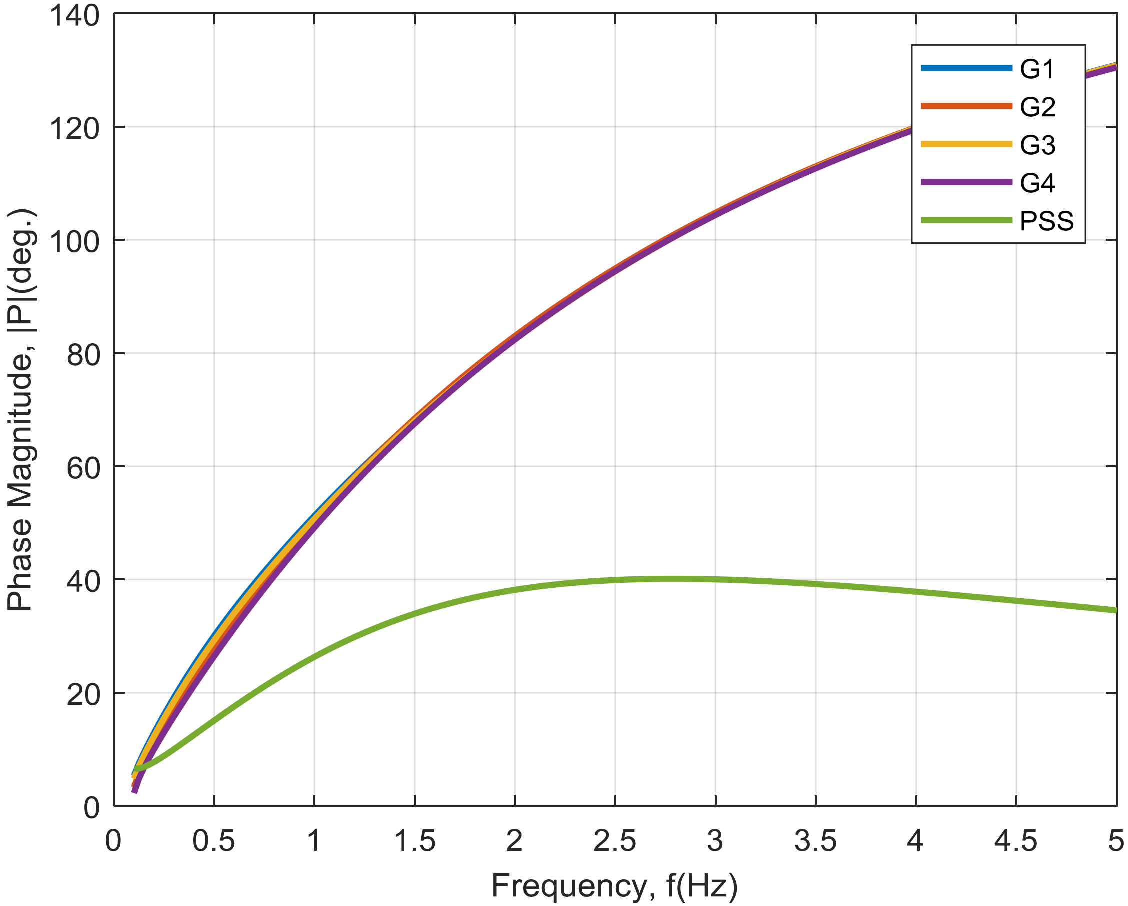
Parameter estimation for washout filter (Time constant)



Washout filter:

$$T = 25.0$$
$$\frac{K}{T} = 10.0$$

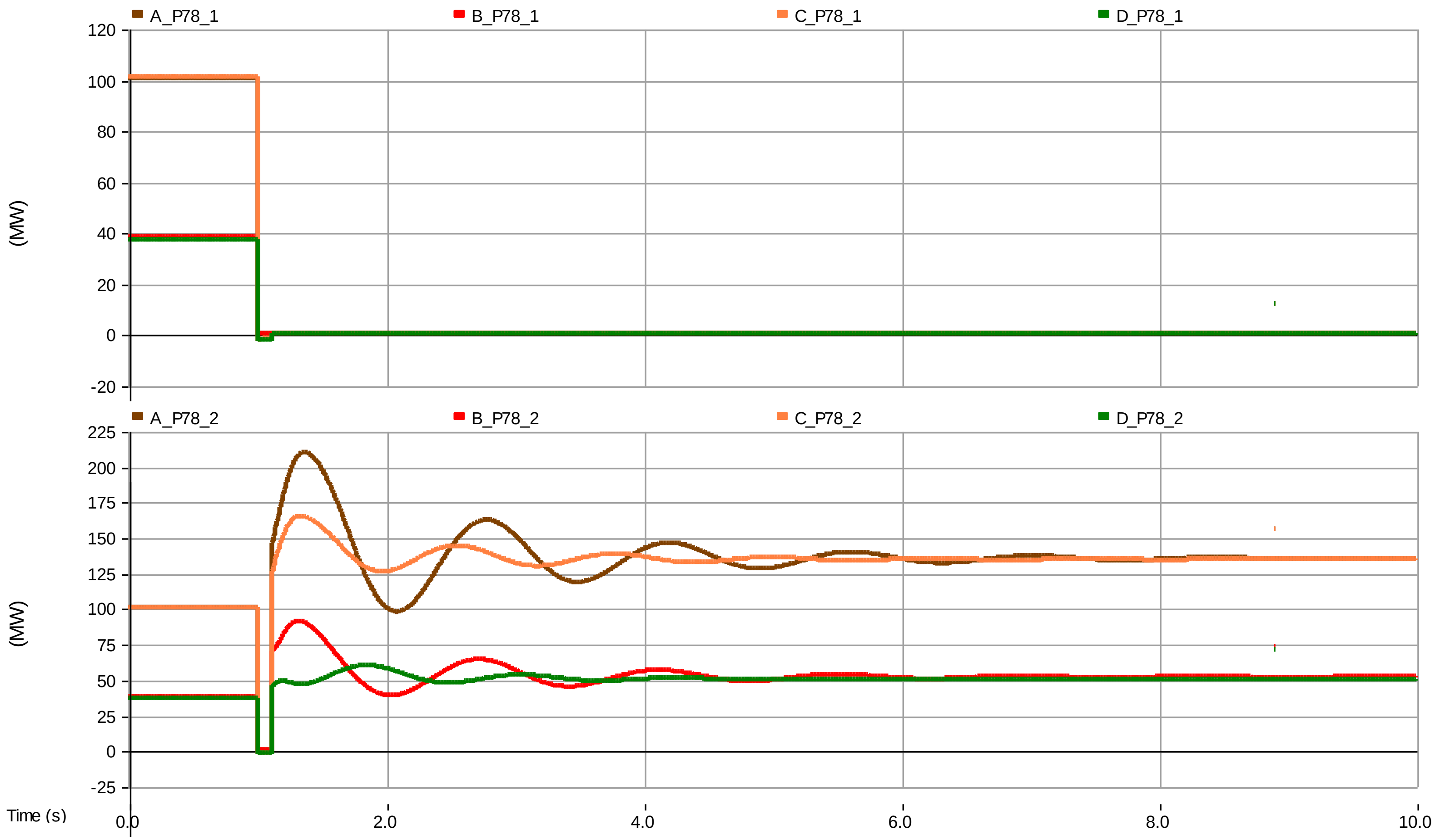
Lead/lag block:

$$T_3 = 0.04$$
$$\frac{T_1}{T_3} = 2.0$$
$$T_4 = 0.04$$
$$\frac{T_2}{T_4} = 2.0$$

Parameter estimation for washout filter (Gain)

Mode	Real (Np/s)	Imaginary (rad/s)	Frequency(Hz)	Damping(%)	Outage
Scenario A					
1	-1.36	8.25	1.31	16.3	None
2	-1.32	7.97	1.27	16.3	
3	**-0.58**	**4.56**	**0.73**	**12.5**	
1	-1.37	8.23	1.31	16.4	Line 7-8
2	-1.32	7.95	1.27	16.4	
3	**-0.57**	**4.43**	**0.71**	**12.8**	
Scenario B					
1	-1.18	8.31	1.32	14.0	None
2	-1.53	7.89	1.26	19.0	
3	**-0.57**	**4.60**	**0.73**	**12.4**	
1	-1.18	8.31	1.32	14.0	Line 7-8
2	-1.53	7.87	1.25	19.1	
3	**-0.57**	**4.49**	**0.72**	**12.5**	
Scenario C					
1	-0.64	5.26	0.84	12.1	None
2	-0.62	5.10	0.81	12.1	Line 7-8
Scenario D					
1	-0.84	5.34	0.85	15.5	None
2	-0.82	5.25	0.84	15.5	Line 7-8

Disturbance recovery performance



Thank you

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Additional Slides

$$K_1 = \frac{X_q - X_d'}{X_e + X_d'} i_{qo} E_o \sin \delta_o + \frac{E_{qo} E_o \cos \delta_o}{X_e + X_q}$$

$$K_2 = \frac{E_o \sin \delta_o}{X_e + X_d'}$$

$$K_3 = \frac{X_d' + X_e}{X_d + X_e}$$

$$K_4 = \frac{X_d - X_d'}{X_e + X_d'} E_o \sin \delta_o$$

$$K_5 = \frac{X_q}{X_e + X_q} \frac{e_{do}}{e_{to}} E_o \cos \delta - \frac{X_d'}{X_e + X_d'} \frac{e_{qo}}{e_{to}} E_o \sin \delta_o$$

$$K_6 = \frac{X_e}{X_e + X_d'} \frac{e_{qo}}{e_{to}}.$$

NOMENCLATURE

All quantities in per unit on machine base.

- i_d, i_q — armature current, direct and quadrature axis components
- e_d, e_q — armature voltage, direct and quadrature axis components
- e_t — terminal voltage
- E_q' — voltage proportional to direct axis flux linkages
- E_{fd} — generator field voltage (one per unit is the value for 1 per unit terminal voltage on the air gap line, open circuit)
- X_e, X_E — equivalent system reactances
- R_E — system shunt resistance
- S — Laplace operator, or magnitude of stabilizing signal
- δ — angle between quadrature axis and infinite bus
- $p\delta$ — per unit speed deviation from synchronous
- T_e — electrical torque
- H — inertia constant, seconds
- M — inertia coefficient $= 2H$, seconds
- D — damping coefficient
- E — infinite bus voltage.

Subscript o means steady-state value.
Prefix Δ indicates small change.