Transient Stability Analysis with PowerWorld Simulator

T11: Single Machine Infinite Bus Modeling (SMIB)

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Single Machine Infinite Bus (SMIB) Eigenvalue Analysis

- SMIB Eigenvalue Analysis internally builds a dynamic model of one generator connected to an infinite bus
  - All of that generator's dynamic models (machine model, exciter, governor, stabilizer, etc…) are included
  - A matrix (often called the "A Matrix") of all the dynamic states is the constructed at the steady state solution and eigenvalue and eigenvector analysis is performed on this matrix
- These SMIB models can also be saved out as two-bus models consisting of the machine bus and an infinite bus
  - Choose the "Save Two-Bus Equivalent" action
  - These two-bus models can then be further analyzed

SMIB Eigenvalues

- Click Run SMIB Eigen Analysis
  - Positive Eigenvalues = Problem
    - Indicates an unstable dynamic state
  - Negative Eigenvalues with extremely large magnitudes = Problem
    - Indicate a dynamic state that is extremely fast
    - This will cause numerical problems in the integration routines
  - What do these mean?
    - May be a model data error
    - May be a problem with how Simulator is modeling something
- Although this is the last page on the Transient Stability Analysis dialog, it is often one of the first places to look when examining a case

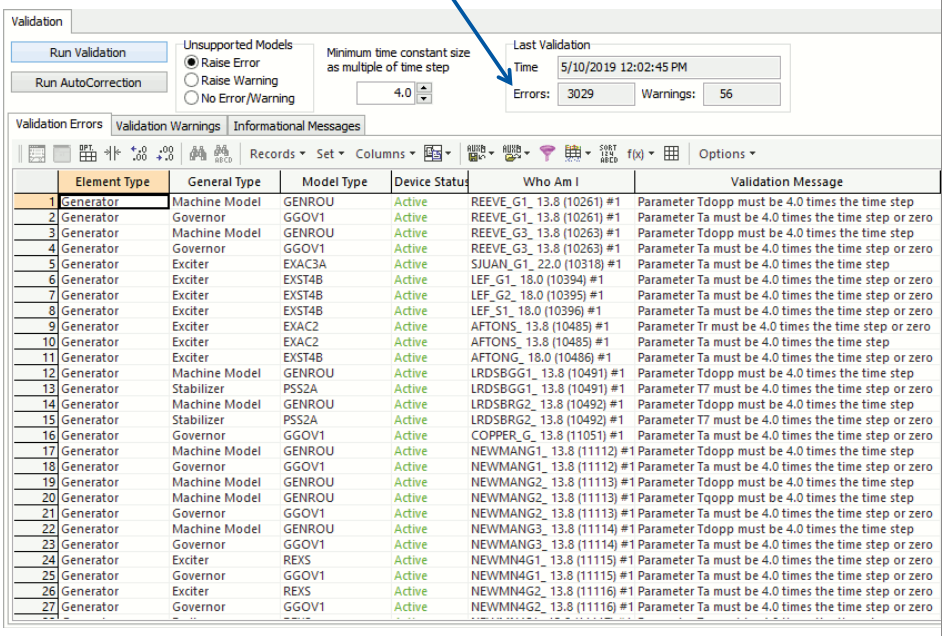
SMIB Eigenvalues

- Extremely large negative eigenvalues are often caused by particular exciter models such as EXST1_GE and REXS which contain extremely fast feedback loops
- These models require special consideration in the numerical integration algorithm and are dealt with by using sub-interval integration

SMIB Eigenvalues Example

- Open the Validation page, click “Run Validation”
- There are many errors and warnings
- Correcting these may help fix some of the large eigenvalues
- Click “Run AutoCorrection”
- Then, view Validation Warnings and Informational Messages to see what was changed

Initial errors and warnings for the case



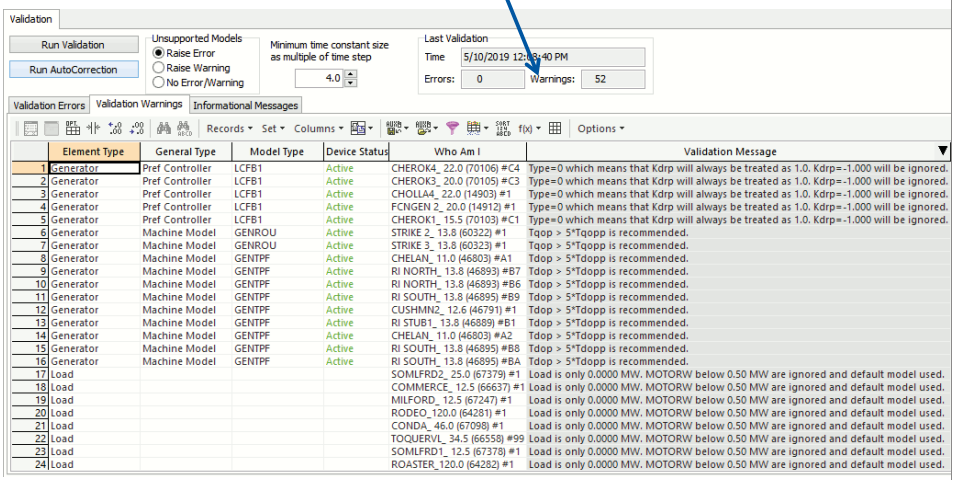
	Element Type	General Type	Model Type	Device Status	Who Am I	Validation Message
1	Generator	Machine Model	GENROU	Active	REEVE_G1_ 13.8 (10261) #1	Parameter Tdopp must be 4.0 times the time step
2	Generator	Governor	GGOV1	Active	REEVE_G1_ 13.8 (10261) #1	Parameter Ta must be 4.0 times the time step or zero
3	Generator	Machine Model	GENROU	Active	REEVE_G3_ 13.8 (10263) #1	Parameter Tdopp must be 4.0 times the time step
4	Generator	Governor	GGOV1	Active	REEVE_G3_ 13.8 (10263) #1	Parameter Ta must be 4.0 times the time step or zero
5	Generator	Exciter	EXAC3A	Active	SJUAN_G1_ 22.0 (10318) #1	Parameter Ta must be 4.0 times the time step
6	Generator	Exciter	EXST4B	Active	LEF_G1_ 18.0 (10394) #1	Parameter Ta must be 4.0 times the time step or zero
7	Generator	Exciter	EXST4B	Active	LEF_G2_ 18.0 (10395) #1	Parameter Ta must be 4.0 times the time step or zero
8	Generator	Exciter	EXST4B	Active	LEF_S1_ 18.0 (10396) #1	Parameter Ta must be 4.0 times the time step or zero
9	Generator	Exciter	EXAC2	Active	AFTONS_ 13.8 (10485) #1	Parameter Tr must be 4.0 times the time step or zero
10	Generator	Exciter	EXAC2	Active	AFTONS_ 13.8 (10485) #1	Parameter Ta must be 4.0 times the time step
11	Generator	Exciter	EXST4B	Active	AFTONG_ 18.0 (10486) #1	Parameter Ta must be 4.0 times the time step or zero
12	Generator	Machine Model	GENROU	Active	LRDSBGG1_ 13.8 (10491) #1	Parameter Tdopp must be 4.0 times the time step
13	Generator	Stabilizer	PSS2A	Active	LRDSBGG1_ 13.8 (10491) #1	Parameter T7 must be 4.0 times the time step or zero
14	Generator	Machine Model	GENROU	Active	LRDSBRG2_ 13.8 (10492) #1	Parameter Tdopp must be 4.0 times the time step
15	Generator	Stabilizer	PSS2A	Active	LRDSBRG2_ 13.8 (10492) #1	Parameter T7 must be 4.0 times the time step or zero
16	Generator	Governor	GGOV1	Active	COPPER_G_ 13.8 (11051) #1	Parameter Ta must be 4.0 times the time step or zero
17	Generator	Machine Model	GENROU	Active	NEWMANG1_ 13.8 (11112) #1	Parameter Tdopp must be 4.0 times the time step
18	Generator	Governor	GGOV1	Active	NEWMANG1_ 13.8 (11112) #1	Parameter Ta must be 4.0 times the time step or zero
19	Generator	Machine Model	GENROU	Active	NEWMANG2_ 13.8 (11113) #1	Parameter Tdopp must be 4.0 times the time step
20	Generator	Machine Model	GENROU	Active	NEWMANG2_ 13.8 (11113) #1	Parameter Tqopp must be 4.0 times the time step
21	Generator	Governor	GGOV1	Active	NEWMANG2_ 13.8 (11113) #1	Parameter Ta must be 4.0 times the time step or zero
22	Generator	Machine Model	GENROU	Active	NEWMANG3_ 13.8 (11114) #1	Parameter Tdopp must be 4.0 times the time step
23	Generator	Governor	GGOV1	Active	NEWMANG3_ 13.8 (11114) #1	Parameter Ta must be 4.0 times the time step or zero
24	Generator	Exciter	REXS	Active	NEWMN4G1_ 13.8 (11115) #1	Parameter Ta must be 4.0 times the time step or zero
25	Generator	Governor	GGOV1	Active	NEWMN4G1_ 13.8 (11115) #1	Parameter Ta must be 4.0 times the time step or zero
26	Generator	Exciter	REXS	Active	NEWMN4G2_ 13.8 (11116) #1	Parameter Ta must be 4.0 times the time step or zero
27	Generator	Governor	GGOV1	Active	NEWMN4G2_ 13.8 (11116) #1	Parameter Ta must be 4.0 times the time step or zero

WestExample.pwb

SMIB Eigenvalues Example

- After AutoCorrection, there are no more errors
- Some warnings and informational messages are still present
- Many of the warnings indicate that certain generators had no machine model, so they are being treated as a negative load

Errors and Warnings after AutoCorrection



	Element Type	General Type	Model Type	Device Status	Who Am I	Validation Message
1	Generator	Pref Controller	LCFB1	Active	CHEROK4_ 22.0 (70106) #C4	Type=0 which means that Kdrp will always be treated as 1.0. Kdrp=-1.000 will be ignored.
2	Generator	Pref Controller	LCFB1	Active	CHEROK3_ 20.0 (70105) #C3	Type=0 which means that Kdrp will always be treated as 1.0. Kdrp=-1.000 will be ignored.
3	Generator	Pref Controller	LCFB1	Active	CHOLLA4_ 22.0 (14903) #1	Type=0 which means that Kdrp will always be treated as 1.0. Kdrp=-1.000 will be ignored.
4	Generator	Pref Controller	LCFB1	Active	FCNGEN 2_ 20.0 (14912) #1	Type=0 which means that Kdrp will always be treated as 1.0. Kdrp=-1.000 will be ignored.
5	Generator	Pref Controller	LCFB1	Active	CHEROK1_ 15.5 (70103) #C1	Type=0 which means that Kdrp will always be treated as 1.0. Kdrp=-1.000 will be ignored.
6	Generator	Machine Model	GENROU	Active	STRIKE 2_ 13.8 (60322) #1	Tqop > 5*Tqopp is recommended.
7	Generator	Machine Model	GENROU	Active	STRIKE 3_ 13.8 (60323) #1	Tqop > 5*Tqopp is recommended.
8	Generator	Machine Model	GENTPF	Active	CHELAN_ 11.0 (46803) #A1	Tdop > 5*Tdopp is recommended.
9	Generator	Machine Model	GENTPF	Active	RI NORTH_ 13.8 (46893) #B7	Tdop > 5*Tdopp is recommended.
10	Generator	Machine Model	GENTPF	Active	RI NORTH_ 13.8 (46893) #B6	Tdop > 5*Tdopp is recommended.
11	Generator	Machine Model	GENTPF	Active	RI SOUTH_ 13.8 (46895) #B9	Tdop > 5*Tdopp is recommended.
12	Generator	Machine Model	GENTPF	Active	CUSHMN2_ 12.6 (46791) #1	Tdop > 5*Tdopp is recommended.
13	Generator	Machine Model	GENTPF	Active	RI STUB1_ 13.8 (46889) #B1	Tdop > 5*Tdopp is recommended.
14	Generator	Machine Model	GENTPF	Active	CHELAN_ 11.0 (46803) #A2	Tdop > 5*Tdopp is recommended.
15	Generator	Machine Model	GENTPF	Active	RI SOUTH_ 13.8 (46895) #B8	Tdop > 5*Tdopp is recommended.
16	Generator	Machine Model	GENTPF	Active	RI SOUTH_ 13.8 (46895) #BA	Tdop > 5*Tdopp is recommended.
17	Load				SOMLFRD2_ 25.0 (67379) #1	Load is only 0.0000 MW. MOTORW below 0.50 MW are ignored and default model used.
18	Load				COMMERCE_ 12.5 (66637) #1	Load is only 0.0000 MW. MOTORW below 0.50 MW are ignored and default model used.
19	Load				MILFORD_ 12.5 (67247) #1	Load is only 0.0000 MW. MOTORW below 0.50 MW are ignored and default model used.
20	Load				RODEO_120.0 (64281) #1	Load is only 0.0000 MW. MOTORW below 0.50 MW are ignored and default model used.
21	Load				CONDA_ 46.0 (67098) #1	Load is only 0.0000 MW. MOTORW below 0.50 MW are ignored and default model used.
22	Load				TOQUERVL_ 34.5 (66558) #99	Load is only 0.0000 MW. MOTORW below 0.50 MW are ignored and default model used.
23	Load				SOMLFRD1_ 12.5 (67378) #1	Load is only 0.0000 MW. MOTORW below 0.50 MW are ignored and default model used.
24	Load				ROASTER_120.0 (64282) #1	Load is only 0.0000 MW. MOTORW below 0.50 MW are ignored and default model used.

WestExample.pwb

SMIB Eigenvalues Example

- Open the case WestExample.pwb
- This case provides an example of using SMIB eigenvalues to identify input parameters which cause instability
- Open the SMIB Eigenvalues page on the Transient Stability Analysis dialog
- Click “Run SMIB Eigen Analysis”
- Different fields available- Number of Eigenvalues, Number of Zero Eigenvalues, Max Eigenvalue, Min Eigenvalue, all eigenvalues
- You can click on the Max Eigenvalue Column to sort by Max Eigenvalue and view the largest eigenvalues; positive eigenvalues are present

Positive Maximum Eigenvalues

Sort by Max Eigenvalue

SMIB Eigenvalues

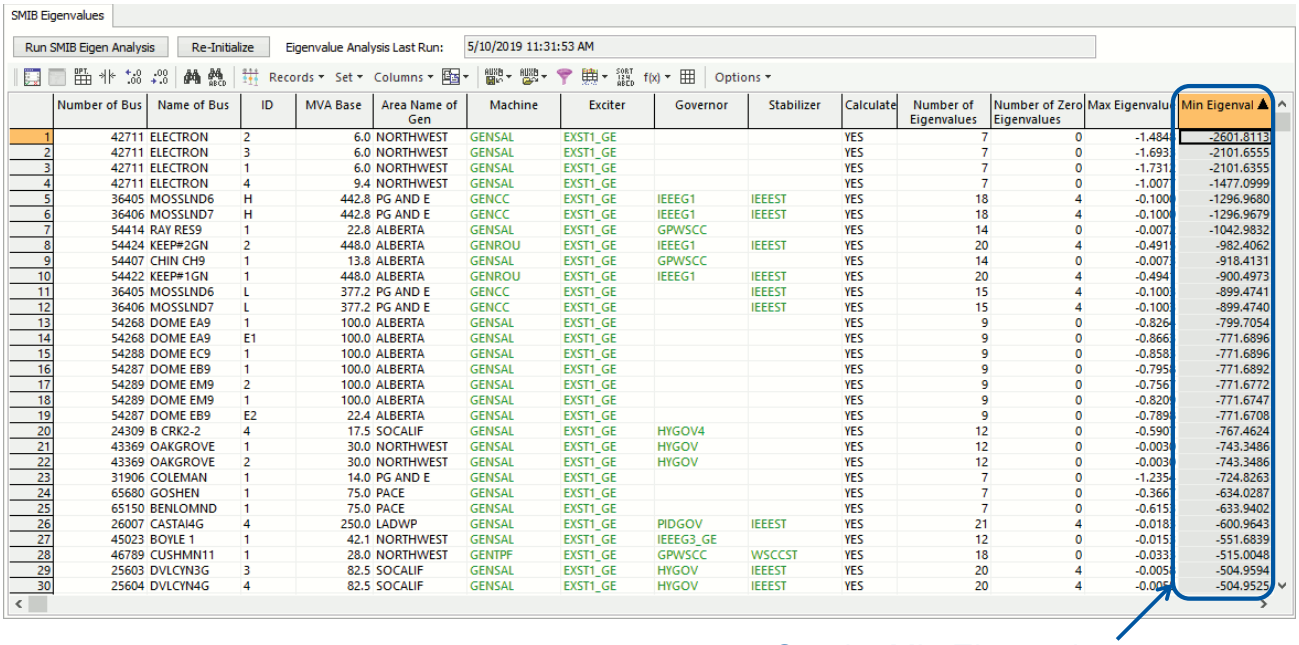
Run SMIB Eigen Analysis | Re-Initialize | Eigenvalue Analysis Last Run: 5/10/2019 11:31:53 AM

Records | Set | Columns | Options

	Number of Bus	Name of Bus	ID	MVA Base	Area Name of Gen	Machine	Exciter	Governor	Stabilizer	Calculate	Number of Eigenvalues	Number of Zero Eigenvalues	Max Eigenva	Min Eigenvalue
1	21081	NLNDGT#1	1	71.2	IMPERIALCA	GENROU	ESAC7B		PSS2A	YES	22	0	7.2083	-71.7206
2	21083	NLNDGT#2	1	71.2	IMPERIALCA	GENROU	ESAC7B		PSS2A	YES	22	0	7.2083	-71.7206
3	57236	MUSKEG4	1	104.7	ALBERTA	GENROU	ESAC7B	GGOV1	PSS2A	YES	31	1	6.2734	-49.3014
4	57836	MUSKEG6	2	104.7	ALBERTA	GENROU	ESAC7B	GGOV1	PSS2A	YES	31	1	6.2372	-49.3023
5	51444	BKL 1S1	1	12.0	B.C.HYDRO	GENROU				YES	6	0	1.2344	-45.0356
6	58290	BALZ 1&2	3	33.0	ALBERTA	GENSAL	EXAC8B	IEEEG1	PSS2A	YES	23	0	0.7590	-80.2470
7	57273	FIREBAG7	G7	103.2	ALBERTA	GENROU	ESAC7B	GGOV1	PSS2A	YES	31	1	0.4662	-49.2391
8	32171	HIGHWND3	1	44.0	PG AND E	GENWRI	EXWTG1			YES	6	0	0.3338	-25.8852
9	46439	ROSS 42	2	100.0	NORTHWEST	GENSAL		PIDGOV	PSS2A	YES	23	0	0.1985	-33.0781
10	21062	ROCKWOD1	1	37.0	IMPERIALCA	GENROU	REXS	GGOV1		YES	17	2	0.0669	-40.1002
11	50307	JHT 13G1	1	25.0	B.C.HYDRO	GENSAL	EXDC4	HYGOV		YES	11	0	0.0541	-44.7875
12	50308	JHT 13G2	2	25.0	B.C.HYDRO	GENSAL	EXDC4	HYGOV		YES	11	0	0.0527	-41.8892
13	50310	JHT 13G4	4	25.0	B.C.HYDRO	GENSAL	EXDC4	HYGOV		YES	11	0	0.0372	-52.6239
14	58392	ALPAC2	1	71.2	ALBERTA	GENROU	IEEET1	GGOV1	WSCCST	YES	21	1	0.0362	-32.2519
15	58392	ALPAC2	2	71.2	ALBERTA	GENROU	IEEET1	GGOV1	WSCCST	YES	21	1	0.0362	-32.2519
16	50311	JHT 13G5	5	25.0	B.C.HYDRO	GENSAL	EXDC4	HYGOV		YES	11	0	0.0354	-46.0763
17	51499	HAC 4G1	1	3.8	B.C.HYDRO	GENROU				YES	6	0	0.0328	-46.0796
18	43557	SULIVAN	1	22.0	NORTHWEST	GENTPF				YES	6	0	0.0256	-64.6841
19	50309	JHT 13G3	3	25.0	B.C.HYDRO	GENSAL	EXDC4	HYGOV		YES	11	0	0.0250	-39.8359
20	50513	PCN 13G1	1	184.0	B.C.HYDRO	GENSAL	EXST1_GE	PIDGOV	PSS2A	YES	25	0	0.0119	-98.3553
21	51214	SSH 4G1	1	5.5	B.C.HYDRO	GENROU				YES	6	0	0.0069	-44.5018
22	50515	PCN 13G3	3	184.0	B.C.HYDRO	GENSAL	EXST1_GE	PIDGOV	PSS2A	YES	24	0	0.0059	-60.3494
23	51213	M3C 4G1	1	5.0	B.C.HYDRO	GENROU				YES	6	0	0.0053	-44.7986
24	51307	HYC 4G1	2	3.6	B.C.HYDRO	GENROU				YES	6	0	0.0047	-44.3283
25	51307	HYC 4G1	1	3.6	B.C.HYDRO	GENROU				YES	6	0	0.0047	-44.3283
26	52143	COR-G3	3	15.0	FORTISBC	GENSAL	EXDC4	GPWSCC		YES	14	0	0.0029	-78.7623
27	24815	GARNET	QF	162.0	SOCALIF	GENROU		GGOV1	PSS2A	YES	26	1	0.0004	-50.7027
28	70714	PTZLOGN4	W4	185.0	PSCOLORADO	GEWTG	EXWTGE	WNDTGE		YES	22	5	0.0000	-30.7208
29	27119	WTGGE	GE	65.0	LADWP	GEWTG	EXWTGE	WNDTGE		YES	25	5	0.0000	-30.6982
30	70710	PTZLOGN1	W1	185.0	PSCOLORADO	GEWTG	EXWTGE	WNDTGE		YES	22		0.0000	-30.7260

Positive eigenvalues are present

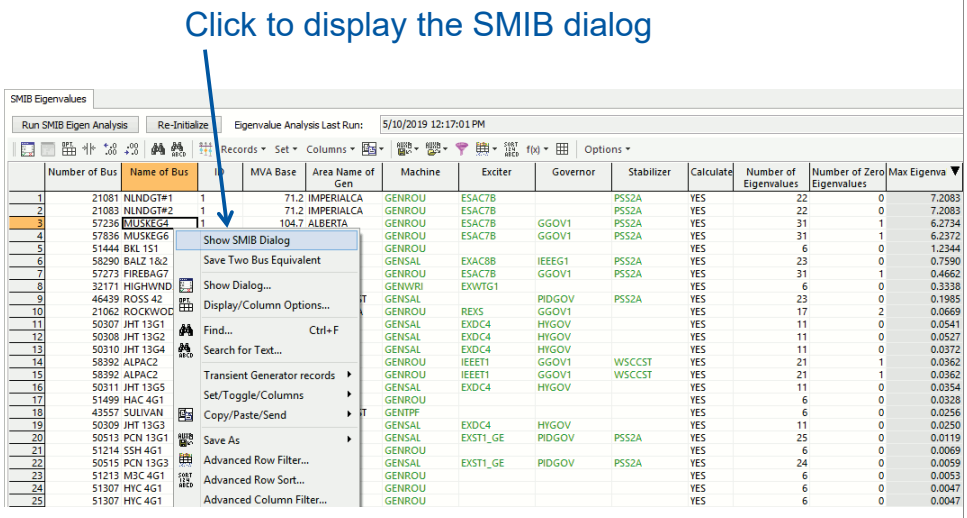
Extremely Large Negative Minimum Eigenvalues



WestExample.pwb

SMIB Eigenvalues Dialog

- Sort by Max Eigenvalue
- Look for Bus 57236
- Right-click, then “Show SMIB Dialog”
- Three tabs are available- General Info, A Matrix, Eigenvalues

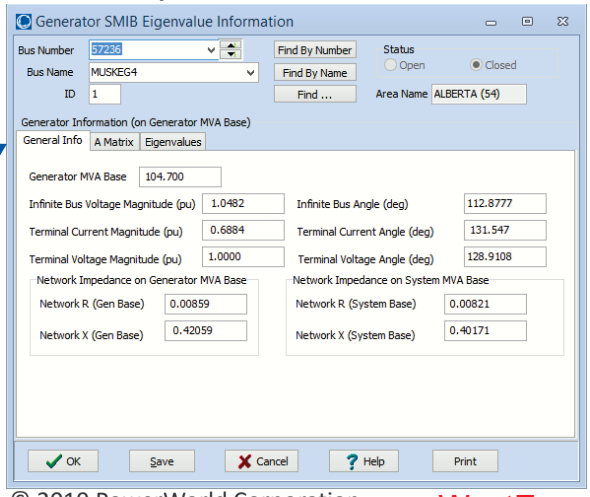


WestExample.pwb

SMIB Eigenvalues Dialog

- General Info Tab
  - Generator MVA Base
  - Infinite bus magnitude and angle, terminal voltage and current magnitude and angle
  - Network impedance on System MVA base and Generator MVA Base

SMIB dialog- General Info tab



WestExample.pwb

SMIB Eigenvalues Dialog

- A Matrix Tab
  - Sensitivity of each SMIB dynamic state equation to each state of the generator
  - Values in Eigenvalues tab are evaluated from this matrix
  - Can right click and save out SMIB info
    - CSV
    - Excel
    - Aux file

Generator Information (on Generator MVA Base)

General Info | A Matrix | Eigenvalues

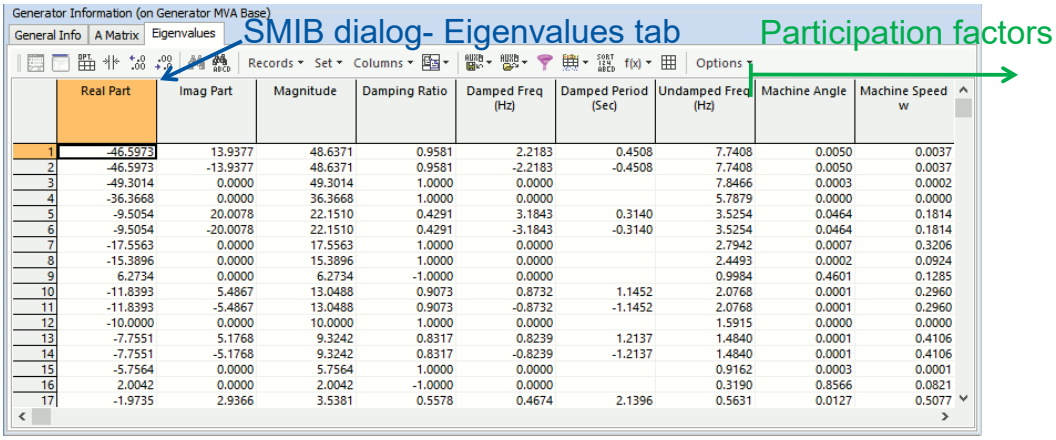
Records | Set | Columns | Options

	Row Name	Machine Angle	Machine Speed w	Machine Eqp	Machine PsiDp	Machine PsiQpp	Machine Edp
1	Machine Angle	0.0000	376.9911	0.0000	0.0000	0.0000	0.0000
2	Machine Speed w	-0.1286	-0.0597	-0.0337	-0.0990	0.0427	0.0054
3	Machine Eqp	-0.1010	0.1586	-1.7471	1.4215	-0.0692	-0.0087
4	Machine PsiDp	-5.6784	-4.1858	28.5208	-34.3420	-0.0805	-0.0101
5	Machine PsiQpp	3.5240	-6.4391	0.0363	0.1066	-28.9846	19.8061
6	Machine Edp	0.2292	-0.4189	-0.2796	-0.8208	9.0511	-13.1429
7	Exciter VE	-22.2900	-4.1733	-357.2854	297.0940	-6.2901	-0.7927
8	Exciter Sensed Vt	-4.6256	33.2879	5.1048	14.9852	23.7605	2.9942
9	Exciter Kir	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
10	Exciter VA	-2.4894	-1.8350	-43.0789	35.0506	-1.7072	-0.2151
11	Governor PElec Measured	3.0705	1.4259	0.8052	2.3638	-1.0190	-0.1284
12	Governor Governor Differer	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13	Governor Governor Integra	0.0000	-3.5000	0.0000	0.0000	0.0000	0.0000
14	Governor Turbine Actuator	0.0000	-21.2500	0.0000	0.0000	0.0000	0.0000
15	Governor Turbine LL	0.0000	4.9412	0.0000	0.0000	0.0000	0.0000
16	Governor Turbine Load Lim	0.0000	0.1757	0.0000	0.0000	0.0000	0.0000
17	Governor Turbine Load Inte	0.0000	-1.4238	0.0000	0.0000	0.0000	0.0000
18	Governor Surpervisory Loac	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
19	Governor Accel Control	0.0000	-100.0000	0.0000	0.0000	0.0000	0.0000
20	Governor Temp Detection L	0.0000	0.0264	0.0000	0.0000	0.0000	0.0000
21	Stabilizer WOTW1	0.0000	-0.5000	0.0000	0.0000	0.0000	0.0000
22	Stabilizer WOTW2	0.0000	-0.5000	0.0000	0.0000	0.0000	0.0000
23	Stabilizer WOTW3	-0.7676	-0.3565	-0.2013	-0.5909	0.2548	0.0321
24	Stabilizer Transducer2	0.1305	0.0606	0.0342	0.1005	-0.0433	-0.0055
25	Stabilizer LL1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
26	Stabilizer LL2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
27	Stabilizer RampFilter1	0.0000	99999.9925	0.0000	0.0000	0.0000	0.0000
28	Stabilizer RampFilter2	0.0000	49999.9963	0.0000	0.0000	0.0000	0.0000
29	Stabilizer RampFilter3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
30	Stabilizer RampFilter4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

WestExample.pwb

SMIB Eigenvalues Dialog

- Eigenvalues
  - The SMIB eigenvalues
  - Each row corresponds to an eigenvalue
  - Columns contain real part, imaginary part, damping ratio, damping frequency, participation factors, and more
  - Participation factors show how system states contribute to ("participate in") a particular eigenvalue



	Real Part	Imag Part	Magnitude	Damping Ratio	Damped Freq (Hz)	Damped Period (Sec)	Undamped Freq (Hz)	Machine Angle	Machine Speed w
1	-46.5973	13.9377	48.6371	0.9581	2.2183	0.4508	7.7408	0.0050	0.0037
2	-46.5973	-13.9377	48.6371	0.9581	-2.2183	-0.4508	7.7408	0.0050	0.0037
3	-49.3014	0.0000	49.3014	1.0000	0.0000		7.8466	0.0003	0.0002
4	-36.3668	0.0000	36.3668	1.0000	0.0000		5.7879	0.0000	0.0000
5	-9.5054	20.0078	22.1510	0.4291	3.1843	0.3140	3.5254	0.0464	0.1814
6	-9.5054	-20.0078	22.1510	0.4291	-3.1843	-0.3140	3.5254	0.0464	0.1814
7	-17.5563	0.0000	17.5563	1.0000	0.0000		2.7942	0.0007	0.3206
8	-15.3896	0.0000	15.3896	1.0000	0.0000		2.4493	0.0002	0.0924
9	6.2734	0.0000	6.2734	-1.0000	0.0000		0.9984	0.4601	0.1285
10	-11.8393	5.4867	13.0488	0.9073	0.8732	1.1452	2.0768	0.0001	0.2960
11	-11.8393	-5.4867	13.0488	0.9073	-0.8732	-1.1452	2.0768	0.0001	0.2960
12	-10.0000	0.0000	10.0000	1.0000	0.0000		1.5915	0.0000	0.0000
13	-7.7551	5.1768	9.3242	0.8317	0.8239	1.2137	1.4840	0.0001	0.4106
14	-7.7551	-5.1768	9.3242	0.8317	-0.8239	-1.2137	1.4840	0.0001	0.4106
15	-5.7564	0.0000	5.7564	1.0000	0.0000		0.9162	0.0003	0.0001
16	2.0042	0.0000	2.0042	-1.0000	0.0000		0.3190	0.8566	0.0821
17	-1.9735	2.9366	3.5381	0.5578	0.4674	2.1396	0.5631	0.0127	0.5077

WestExample.pwb

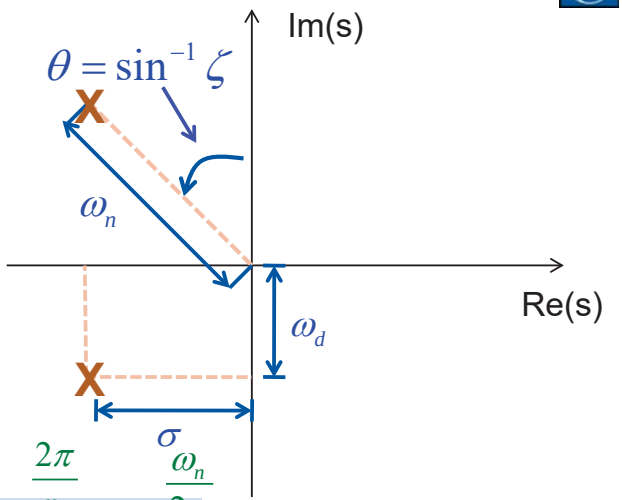
SMIB Eigenvalues Dialog

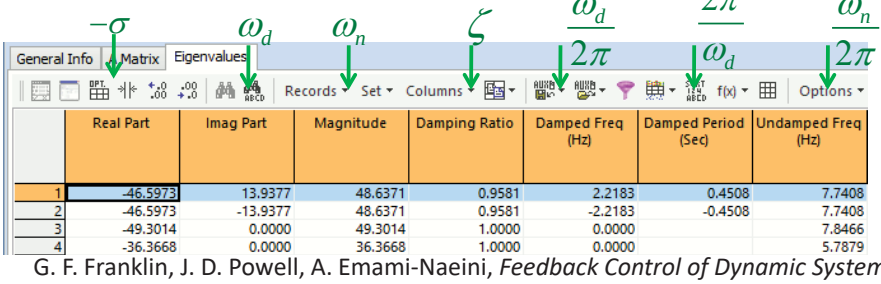
Pole locations $s = -\sigma \pm j\omega_d$

$$\sigma = \zeta\omega_n$$

$$\omega_d = \omega_n\sqrt{1-\zeta^2}$$

Damping ratio ζ
Damped natural frequency ω_d
Undamped natural frequency ω_n
Decay rate of exponential envelope σ





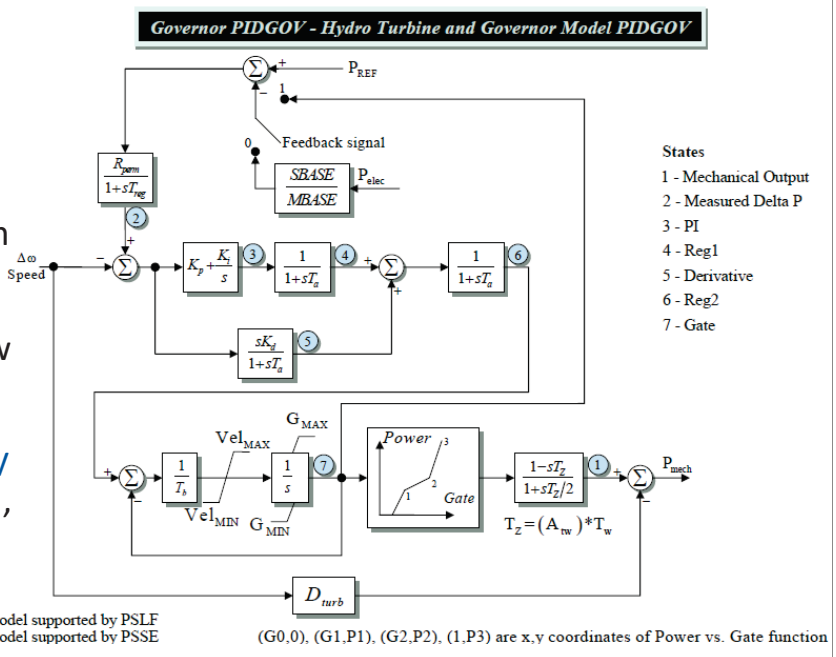
	Real Part	Imag Part	Magnitude	Damping Ratio	Damped Freq (Hz)	Damped Period (Sec)	Undamped Freq (Hz)
1	-46.5973	13.9377	48.6371	0.9581	2.2183	0.4508	7.7408
2	-46.5973	-13.9377	48.6371	0.9581	-2.2183	-0.4508	7.7408
3	-49.3014	0.0000	49.3014	1.0000	0.0000		7.8466
4	-36.3668	0.0000	36.3668	1.0000	0.0000		5.7879

G. F. Franklin, J. D. Powell, A. Emami-Naeini, *Feedback Control of Dynamic Systems*, 5th edition, Prentice Hall, 2006.

WestExample.pwb

SMIB Eigenvalues Example

- One problem is that several PIDGOV models have parameters Rperm (droop) which are negative
- This creates a positive feedback instead of a negative feedback and eventually causes the system to become unstable
- Open the Model Explorer to the Governors page and view the data for the PIDGOV models
- There are two active PIDGOV models with negative Rperm, located at buses 50515 and 50513



WestExample.pwb

SMIB Eigenvalues Example

- Going back to the SMIB page, we can confirm that these generators are associated with positive eigenvalues

SMIB Eigenvalues

Run SMIB Eigen Analysis | Re-Initialize | Eigenvalue Analysis Last Run: 5/10/2019 12:17:01 PM

Records | Set | Columns | Options

	Number of Bus	Name of Bus	ID	MVA Base	Area Name of Gen	Machine	Exciter	Governor	Stabilizer	Calculate	Number of Eigenvalues	Number of Zero Eigenvalues	Max Eigenva
1	21081	NLNDGT#1	1	71.2	IMPERIALCA	GENROU	ESAC7B		PSS2A	YES	22	0	7.2083
2	21083	NLNDGT#2	1	71.2	IMPERIALCA	GENROU	ESAC7B		PSS2A	YES	22	0	7.2083
3	57236	MUSKEG4	1	104.7	ALBERTA	GENROU	ESAC7B	GGOV1	PSS2A	YES	31	1	6.2734
4	57836	MUSKEG6	2	104.7	ALBERTA	GENROU	ESAC7B	GGOV1	PSS2A	YES	31	1	6.2372
5	51444	BKL 1S1	1	12.0	B.C.HYDRO	GENROU				YES	6	0	1.2344
6	58290	BALZ 1&2	3	33.0	ALBERTA	GENSAL	EXAC8B	IEEEG1	PSS2A	YES	23	0	0.7590
7	57273	FIREBAG7	G7	103.2	ALBERTA	GENROU	ESAC7B	GGOV1	PSS2A	YES	31	1	0.4662
8	32171	HIGHWND3	1	44.0	PG AND E	GENWRI	EXWTG1			YES	6	0	0.3338
9	46439	ROSS 42	2	100.0	NORTHWEST	GENSAL		PIDGOV	PSS2A	YES	23	0	0.1985
10	21062	ROCKWOD1	1	37.0	IMPERIALCA	GENROU	REXS	GGOV1		YES	17	2	0.0669
11	50307	JHT 13G1	1	25.0	B.C.HYDRO	GENSAL	EXDC4	HYGOV		YES	11	0	0.0541
12	50308	JHT 13G2	2	25.0	B.C.HYDRO	GENSAL	EXDC4	HYGOV		YES	11	0	0.0527
13	50310	JHT 13G4	4	25.0	B.C.HYDRO	GENSAL	EXDC4	HYGOV		YES	11	0	0.0372
14	58392	ALPAC2	1	71.2	ALBERTA	GENROU	IEEET1	GGOV1	WSCCST	YES	21	1	0.0362
15	58392	ALPAC2	2	71.2	ALBERTA	GENROU	IEEET1	GGOV1	WSCCST	YES	21	1	0.0362
16	50311	JHT 13G5	5	25.0	B.C.HYDRO	GENSAL	EXDC4	HYGOV		YES	11	0	0.0354
17	51499	HAC 4G1	1	3.8	B.C.HYDRO	GENROU				YES	6	0	0.0328
18	43557	SULIVAN	1	22.0	NORTHWEST	GENTPF				YES	6	0	0.0256
19	50309	JHT 13G3	3	25.0	B.C.HYDRO	GENSAL	EXDC4	HYGOV		YES	11	0	0.0250
20	50513	PCN 13G1	1	184.0	B.C.HYDRO	GENSAL	EXST1_GE	PIDGOV	PSS2A	YES	25	0	0.0119
21	51214	SSH 4G1	1	5.5	B.C.HYDRO	GENROU				YES	6	0	0.0069
22	50515	PCN 13G3	3	184.0	B.C.HYDRO	GENSAL	EXST1_GE	PIDGOV	PSS2A	YES	24	0	0.0059
23	51213	M3C 4G1	1	5.0	B.C.HYDRO	GENROU				YES	6	0	0.0053
24	51307	HYC 4G1	2	3.6	B.C.HYDRO	GENROU				YES	6	0	0.0047
25	51307	HYC 4G1	1	3.6	B.C.HYDRO	GENROU				YES	6	0	0.0047

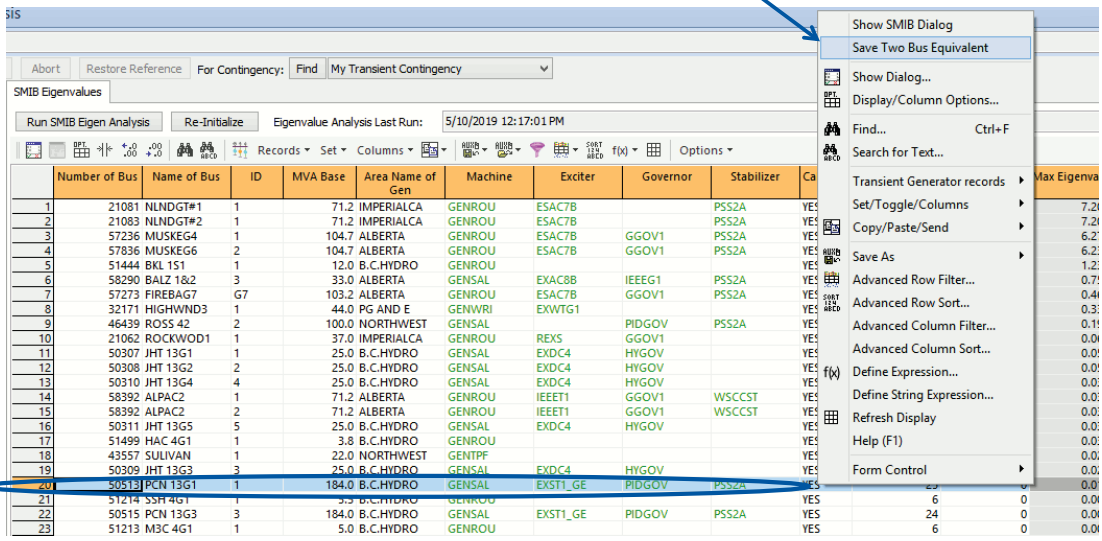
Two PIDGOV models with negative Rperm

WestExample.pwb

SMIB Two-Bus Equivalent

- Let's save out the two-bus equivalent for the bus 50513
- Save it as Gen_50513_1.pwb (this should be the default name that appears in the save dialog)

Save two-bus equivalent for this bus

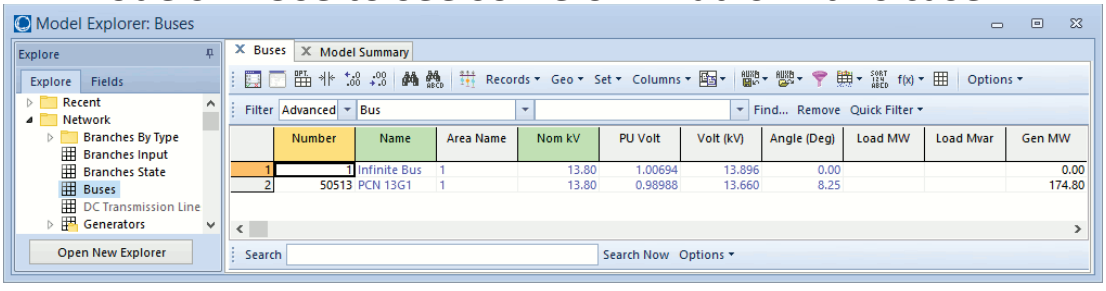


	Number of Bus	Name of Bus	ID	MVA Base	Area Name of Gen	Machine	Exciter	Governor	Stabilizer	Ca	Max Eigenva
1	21081	NLNDGT#1	1	71.2	IMPERIALCA	GENROU	ESAC7B		PSS2A	YE	7.2
2	21083	NLNDGT#2	1	71.2	IMPERIALCA	GENROU	ESAC7B		PSS2A	YE	7.2
3	57236	MUSKEG4	1	104.7	ALBERTA	GENROU	ESAC7B	GGOV1	PSS2A	YE	6.2
4	57836	MUSKEG6	2	104.7	ALBERTA	GENROU	ESAC7B	GGOV1	PSS2A	YE	6.2
5	51444	BKL 1S1	1	12.0	B.C.HYDRO	GENROU				YE	1.2
6	58290	BALZ 1&2	3	33.0	ALBERTA	GENSAL	EXAC8B	IEEEG1	PSS2A	YE	0.7
7	57273	FIREBAG7	G7	103.2	ALBERTA	GENROU	ESAC7B	GGOV1	PSS2A	YE	0.4
8	32171	HIGHWND3	1	44.0	PG AND E	GENWRI	EXWTG1			YE	0.3
9	46439	ROSS 42	2	100.0	NORTHWEST	GENSAL		PIDGOV	PSS2A	YE	0.1
10	21062	ROCKWOD1	1	37.0	IMPERIALCA	GENROU	REXS	GGOV1		YE	0.0
11	50307	JHT 13G1	1	25.0	B.C.HYDRO	GENSAL	EXDC4	HYGOV		YE	0.0
12	50308	JHT 13G2	2	25.0	B.C.HYDRO	GENSAL	EXDC4	HYGOV		YE	0.0
13	50310	JHT 13G4	4	25.0	B.C.HYDRO	GENSAL	EXDC4	HYGOV		YE	0.0
14	58392	ALPAC2	1	71.2	ALBERTA	GENROU	IEEET1	GGOV1	WSCCST	YE	0.0
15	58392	ALPAC2	2	71.2	ALBERTA	GENROU	IEEET1	GGOV1	WSCCST	YE	0.0
16	50311	JHT 13G5	5	25.0	B.C.HYDRO	GENSAL	EXDC4	HYGOV		YE	0.0
17	51499	HAC 4G1	1	3.8	B.C.HYDRO	GENROU				YE	0.0
18	43557	SULIVAN	1	22.0	NORTHWEST	GENTPF				YE	0.0
19	50309	JHT 13G3	3	25.0	B.C.HYDRO	GENSAL	EXDC4	HYGOV		YE	0.0
20	50513	PCN 13G1	1	184.0	B.C.HYDRO	GENSAL	EXST1_GE	PIDGOV	PSS2A	YE	0.0
21	51214	SSH 4G1	1	5.5	B.C.HYDRO	GENROU				YES	6	0	0.0
22	50515	PCN 13G3	3	184.0	B.C.HYDRO	GENSAL	EXST1_GE	PIDGOV	PSS2A	YES	24	0	0.0
23	51213	M3C 4G1	1	5.0	B.C.HYDRO	GENROU				YES	6	0	0.0

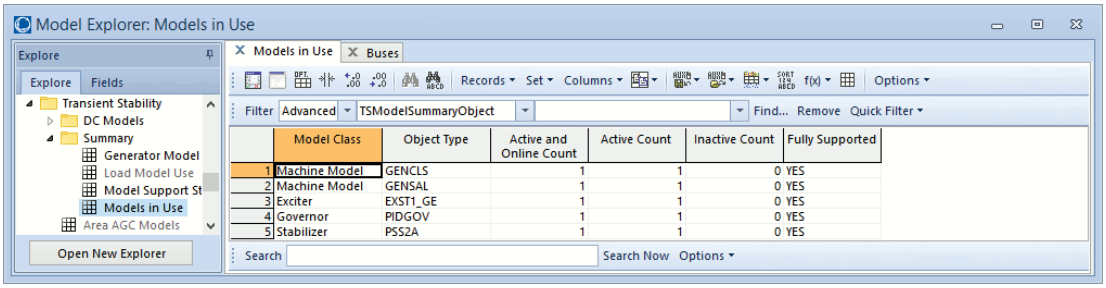
WestExample.pwb

SMIB Two-Bus Equivalent

- Now open Gen_50513_1.pwb, the two-bus equivalent
- Open the Model Explorer to the bus records or the Models in Use to see some of what is in this case



	Number	Name	Area Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)	Load MW	Load Mvar	Gen MW
1	1	Infinite Bus	1	13.80	1.00694	13.896	0.00			0.00
2	50513	PCN 13G1	1	13.80	0.98988	13.660	8.25			174.80

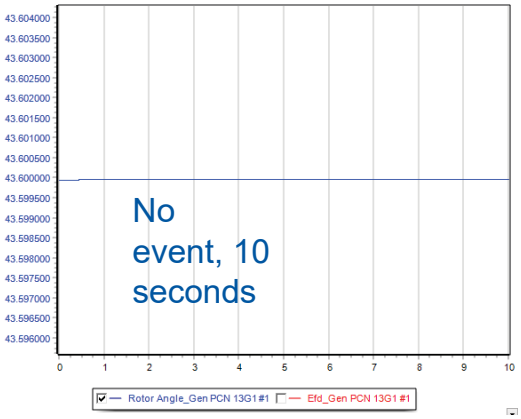


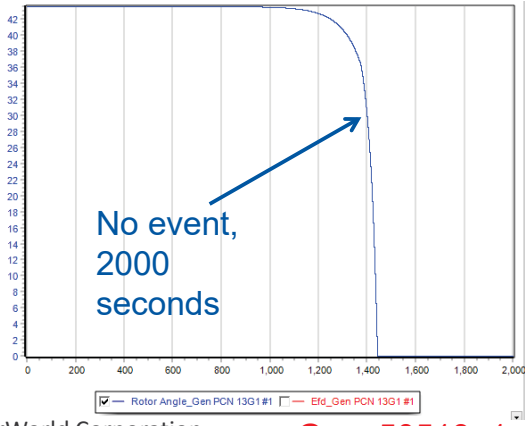
	Model Class	Object Type	Active and Online Count	Active Count	Inactive Count	Fully Supported
1	Machine Model	GENCLS	1	1	0	YES
2	Machine Model	GENSAL	1	1	0	YES
3	Exciter	EXST1_GE	1	1	0	YES
4	Governor	PIDGOV	1	1	0	YES
5	Stabilizer	PSS2A	1	1	0	YES

Gen_50513_1.pwb

SMIB Two-Bus Equivalent

- Open the Transient Stability Analysis dialog
- Go to the Plots tab and quickly create a plot definition for the Rotor Angle of bus 50513
- Do not insert any events; keep the End Time set to the default 10 seconds
- Click “Run Transient Stability”
- Now change the simulation time to 2000 seconds and run it again



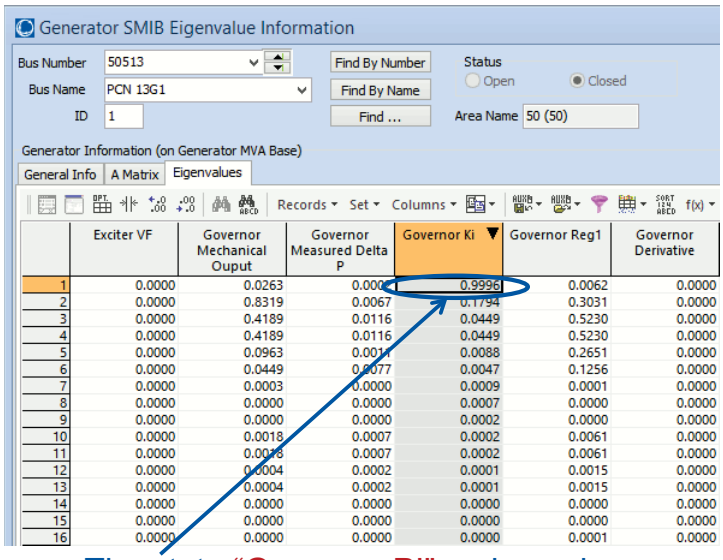


The model is unstable

Gen_50513_1.pwb

SMIB Participation Factors

- Open the SMIB Eigenvalue Information dialog
- Open the Eigenvalues tab and sort by “Real Part” so that the positive eigenvalue is at the top
- Scroll over and look at the participation factors for this eigenvalue
- These tell how the states map to a particular eigenvalue



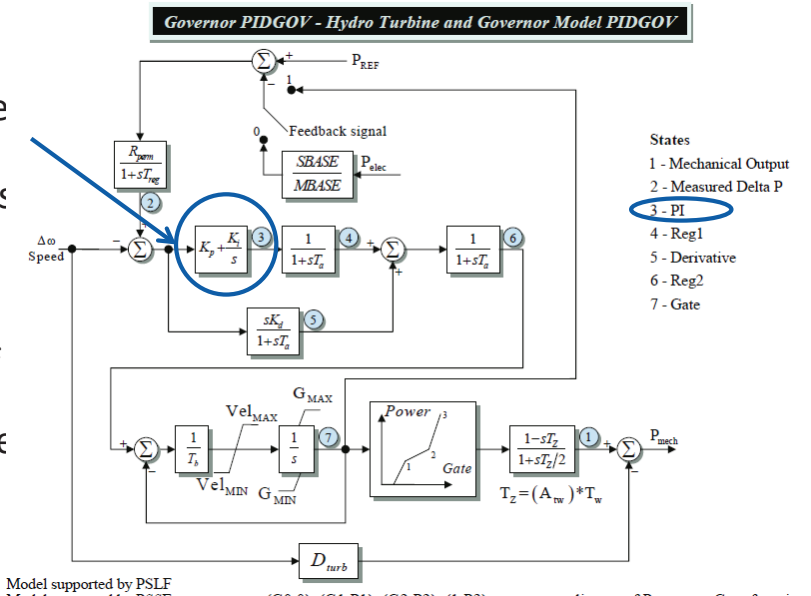
	Exciter VF	Governor Mechanical Ouput	Governor Measured Delta P	Governor Ki	Governor Reg1	Governor Derivative
1	0.0000	0.0263	0.0000	0.9996	0.0062	0.0000
2	0.0000	0.8319	0.0067	0.1794	0.3031	0.0000
3	0.0000	0.4189	0.0116	0.0449	0.5230	0.0000
4	0.0000	0.4189	0.0116	0.0449	0.5230	0.0000
5	0.0000	0.0963	0.0011	0.0088	0.2651	0.0000
6	0.0000	0.0449	0.0077	0.0047	0.1256	0.0000
7	0.0000	0.0003	0.0000	0.0009	0.0001	0.0000
8	0.0000	0.0000	0.0000	0.0007	0.0000	0.0000
9	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000
10	0.0000	0.0018	0.0007	0.0002	0.0061	0.0000
11	0.0000	0.0018	0.0007	0.0002	0.0061	0.0000
12	0.0000	0.0004	0.0002	0.0001	0.0015	0.0000
13	0.0000	0.0004	0.0002	0.0001	0.0015	0.0000
14	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000

The state “Governor PI” makes a large contribution (0.9996) to the positive eigenvalue, while other contributions are zero or close to zero

Gen_50513_1.pwb

SMIB Participation Factors

- From the block diagram for PIDGOV, the state "Governor PI" is right after the point where Rperm contributes to the feedback loop
- The positive eigenvalue is indeed due to the governor
- Note that this discussion is the same regardless of whether you use the Gen_50513_1 case or the full WestExample



SMIB Eigenvalues Example

- Also, you can easily make certain models for a particular generator inactive to see how it impacts the SMIB eigenvalues
- This can help you narrow down some of the other sources of positive eigenvalues
- Recall that bus 57236 currently has the largest maximum eigenvalue with 3.5259
- Run Validation and AutoCorrection; then, for bus 57236, make everything inactive except the machine, GENROU
- Re-Initialize and do the analysis again

Disabling all geneator models except GENROU makes SMIB Eigenvalues negative

	Number of B	Name of Bus	ID	Area Name of Gen	Machine	Exciter	Governor	Stabilizer	Calculated	Number of Eigenvalues	Number of Zero Eigenvalues	Max Eigenvalue	Min Eigenvalue
697	57259	HORUP8	1B	ALBERTA					NO	0	0		
698	57249	LNGLKCG2	G1	ALBERTA	GENROU	REXS	GGOV1	PSS2A	YES	31	2	-0.0537	-179.0248
699	57236	MUSKEG4	1	ALBERTA	GENROU	IESAC7B	(GGOV1)	(PSS2A)	YES	6	0	-0.1138	-36.5528
700	57233	SYNC_UE4	11	ALBERTA	GENROU	EXAC1	IEEEG1	PSS2A	YES	24	0	-0.0999	-61.7009

- This generator now has only negative eigenvalues
- Can we narrow down which model is contributing to this small-signal instability?

WestExample.pwb

SMIB Eigenvalues Example

- Re-enable the ESAC7B exciter; Re-Initialize and re-run the analysis

Disabling GGOV1 and PSS2A makes the generator's SMIB Eigenvalues negative

	Number of B	Name of Bus	ID	Area Name of Gen	Machine	Exciter	Governor	Stabilizer	Calculated	Number of Eigenvalues	Number of Zero Eigenvalues	Max Eigenvalue	Min Eigenvalue
697	57259	HORUP8	1B	ALBERTA					NO	0	0		
698	57249	LNGLKCG2	G1	ALBERTA	GENROU	REXS	GGOV1	PSS2A	YES	31	2	-0.0537	-179.0248
699	57236	MUSKEG4	1	ALBERTA	GENROU	ESAC7B	(GGOV1)	(PSS2A)	YES	10	0	-0.3852	-47.9088
700	57233	SYNC_UE4	11	ALBERTA	GENROU	EXAC1	IEEEG1	PSS2A	YES	24	0	-0.0999	-61.7009
701	57210	SYNC_G49	21	ALBERTA	GENSAL				NO	0	0		

- This generator still has only negative eigenvalues, so we know its positive eigenvalue was associated with its governor or stabilizer

Disabling only PSS2A still makes the generator's SMIB Eigenvalues negative

	Number of B	Name of Bus	ID	Area Name of Gen	Machine	Exciter	Governor	Stabilizer	Calculated	Number of Eigenvalues	Number of Zero Eigenvalues	Max Eigenvalue	Min Eigenvalue
697	57259	HORUP8	1B	ALBERTA					NO	0	0		
698	57249	LNGLKCG2	G1	ALBERTA	GENROU	REXS	GGOV1	PSS2A	YES	31	2	0.0537	-179.0248
699	57236	MUSKEG4	1	ALBERTA	GENROU	ESAC7B	GGOV1	(PSS2A)	YES	20	1	-0.2932	-47.9088
700	57233	SYNC_UE4	11	ALBERTA	GENROU	EXAC1	IEEEG1	PSS2A	YES	24	0	-0.0999	-61.7009
701	57210	SYNC_G49	21	ALBERTA	GENSAL				NO	0	0		

- If we disable only the stabilizer, we again find that this generator has only negative eigenvalues
- This indicates that we should more carefully consider the PSS2A model and its parameters

WestExample.pwb

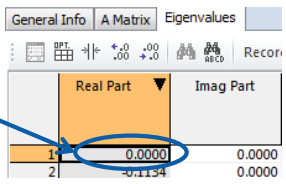
SMIB Eigenvalues Example

- However, now disable only the exciter ESAC7B and re-enable the other models
- Leave both GGOV1 and PSS2A active and Re-Initialize and run the analysis again
- Interestingly, the Max Eigenvalue for bus 57236 now changes to zero

Disabling ESAC7B makes the generator's SMIB Max Eigenvalue is negative BUT…

	Number of B	Name of Bus	ID	Area Name of Gen	Machine	Exciter	Governor	Stabilizer	Calculated	Number of Eigenvalues	Number of Zero Eigenvalues	Max Eigenvalue	Min Eigenvalue
697	57259	HORUP8	1B	ALBERTA					NO	0	0		
698	57249	LNGLKCG2	G1	ALBERTA	GENROU	REXS	GGOV1	PSS2A	YES	31	2	0.0537	-179.0248
699	57236	MUSKEG4	1	ALBERTA	GENROU	(ESAC7B)	GGOV1	PSS2A	YES	27	1	-0.1134	-36.5528
700	57233	SYNC_UE4	11	ALBERTA	GENROU	EXAC1	IEEEG1	PSS2A	YES	24	0	-0.0999	-61.7009
701	57210	SYNC_G49	21	ALBERTA	GENSAL				NO	0	0		

- Open the SMIB Dialog
- You will see that there is a negative eigenvalues
- These zero eigenvalues are caused by the ignored states- an ignored state will have a participation factor of one for one of the zero eigenvalues
- This is true for a lot (but not all) of the zero eigenvalues in the case



WestExample.pwb

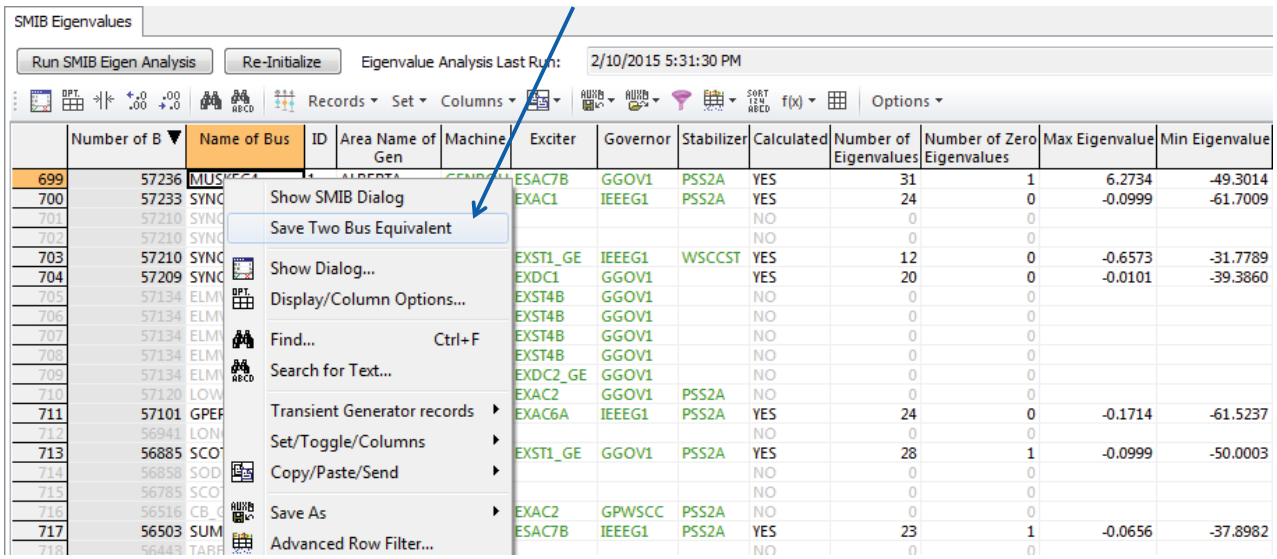
SMIB Eigenvalues Example

- Let's look at the participation factors for the maximum eigenvalue of Bus 57236
- Re-enable all of the models for Bus 57236 if you disabled them
- Click "Re-Initialize" and "Run SMIB Eigen Analysis"
- Then, right-click and "Show SMIB Dialog" for Bus 57236
- Open the Eigenvalues tab and sort by "Real Part"
- There are actually two positive eigenvalues for this generator which are complex conjugates
- The state "Stabilizer Transducer 2" has a relatively large participation factor, but it is not the largest (scroll over and look at the other states, especially some of the machine states)
- In this example, the cause of the instability does not seem as obvious to identify

SMIB Eigenvalues Example

- Let's save out the 2-bus equivalent for the bus 57236
- Save it as Gen_57236_1.pwb (this should be the default name that appears in the save dialog)

Save two-bus equivalent for this bus

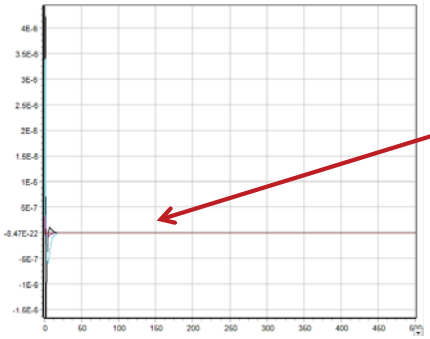


	Number of B	Name of Bus	ID	Area Name of Gen	Machine	Exciter	Governor	Stabilizer	Calculated	Number of Eigenvalues	Number of Zero Eigenvalues	Max Eigenvalue	Min Eigenvalue
699	57236	MUS	1	ALBERTA	GENROU	ESAC7B	GGOV1	PSS2A	YES	31	1	6.2734	-49.3014
700	57233	SYNC	1	ALBERTA	GENROU	EXAC1	IEEEG1	PSS2A	YES	24	0	-0.0999	-61.7009
701	57210	SYNC	1	ALBERTA	GENROU				NO	0	0		
702	57210	SYNC	2	ALBERTA	GENROU				NO	0	0		
703	57210	SYNC	3	ALBERTA	GENROU	EXST1_GE	IEEEG1	WSCCST	YES	12	0	-0.6573	-31.7789
704	57209	SYNC	1	ALBERTA	GENROU	EXDC1	GGOV1		YES	20	0	-0.0101	-39.3860
705	57134	ELM	1	ALBERTA	GENROU	EXST4B	GGOV1		NO	0	0		
706	57134	ELM	2	ALBERTA	GENROU	EXST4B	GGOV1		NO	0	0		
707	57134	ELM	3	ALBERTA	GENROU	EXST4B	GGOV1		NO	0	0		
708	57134	ELM	4	ALBERTA	GENROU	EXST4B	GGOV1		NO	0	0		
709	57134	ELM	5	ALBERTA	GENROU	EXDC2_GE	GGOV1		NO	0	0		
710	57120	LOW	1	ALBERTA	GENROU	EXAC2	GGOV1	PSS2A	NO	0	0		
711	57101	GPEP	1	ALBERTA	GENROU	EXAC6A	IEEEG1	PSS2A	YES	24	0	-0.1714	-61.5237
712	56941	LON	1	ALBERTA	GENROU				NO	0	0		
713	56885	SCO	1	ALBERTA	GENROU	EXST1_GE	GGOV1	PSS2A	YES	28	1	-0.0999	-50.0003
714	56858	SOD	1	ALBERTA	GENROU				NO	0	0		
715	56785	SCO	1	ALBERTA	GENROU				NO	0	0		
716	56516	CB_	1	ALBERTA	GENROU	EXAC2	GPWSCC	PSS2A	NO	0	0		
717	56503	SUM	1	ALBERTA	GENROU	ESAC7B	IEEEG1	PSS2A	YES	23	1	-0.0656	-37.8982
718	56443	TABR	1	ALBERTA	GENROU				NO	0	0		

WestExample.pwb

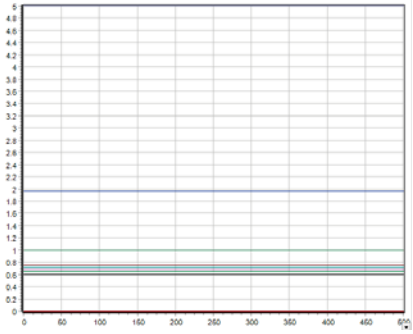
SMIB Eigenvalues Example

- Open Gen_57236_1.pwb
- It has two buses, the slack bus which is also the infinite bus, and bus 57236 with attached generator models
- Running the analysis for 500 seconds with no event does not cause numerical instability like in the earlier example
- More analysis is needed to determine what is causing the positive eigenvalues



Gen_57236_1, stabilizer states

The stabilizer is the only model with states that are not completely flat, as they should be in steady-state



Gen_57236_1, all other states