

ECEN 667

Power System Stability

Lecture 23: Mode Visualization, Stabilizers

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Announcements

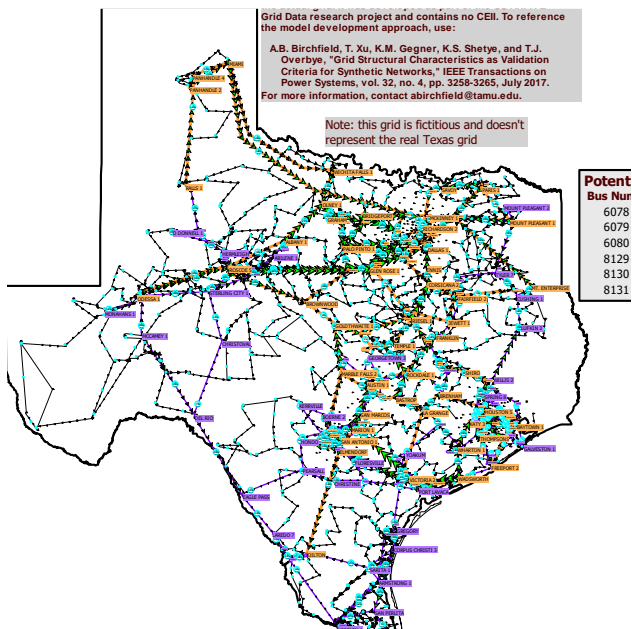


- Read Chapter 9
- Homework 7 should be done before the second exam but need not be turned in

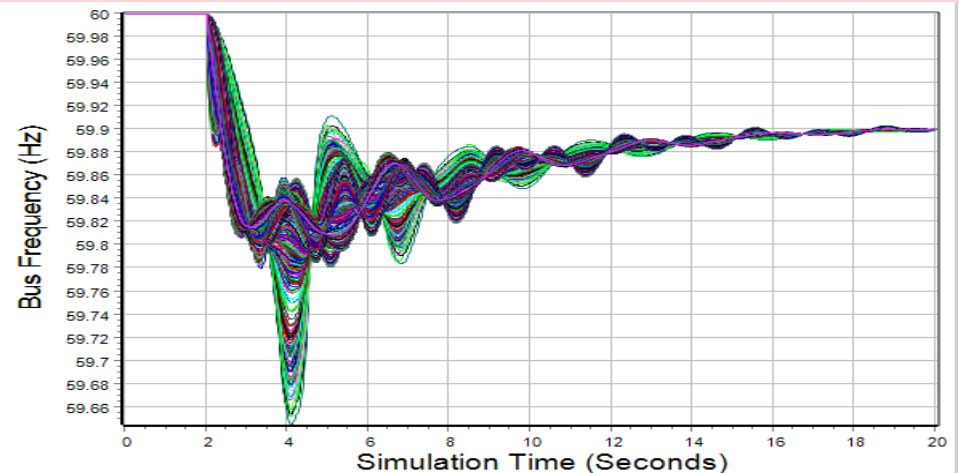
Texas 2000 Bus Synthetic Grid Example



- For this example we'll again use the Texas 2000 bus grid, saved as **TSGC_2000_GenDrop**
- We'll use the Iterative Matrix Pencil Method to examine its modes
 - The contingency is the loss of two large generators (at bus 7098 and 7099)



The measurements will be the frequencies at all 2000 buses



2000 Bus System Example, Iterative Matrix Pencil



- The Iterative Matrix Pencil intelligently adds signals until a specified number is met
 - Doing ten iterations takes about four seconds

Number of Complex and Real Modes	<input type="text" value="11"/>	<input checked="" type="checkbox"/> Include Detrend in Reproduced Signals						
Lowest Percent Damping	<input type="text" value="6.082"/>	<input type="checkbox"/> Subtract Reproduced from Actual						
<input type="button" value="Update Reproduced Signals"/>								
Real and Complex Modes - Editable to Change Initial Guesses								
	Frequency (Hz)	Damping (%) ▲	Largest Component in Mode, Unscaled	Name of Signal with Largest Component in Mode, Unscaled	Largest Component in Mode, Scaled	Name of Signal with Largest Component in Mode, Scaled	Lambda	Include in Reproduced Signal
1	0.631	6.082	0.10313	Bus BROWNSVI	3.292	Bus BROWNSVI	-0.2415	YES
2	0.959	7.068	0.04897	Bus SAN ANTOI	1.890	Bus SAN ANTOI	-0.4269	YES
3	1.364	7.246	0.03780	Bus ODESSA 1	1.420	Bus CHRISTINE	-0.6228	YES
4	0.593	7.897	0.07205	Bus BROWNSVI	2.300	Bus BROWNSVI	-0.2949	YES
5	1.602	8.562	0.04887	Bus FANNIN 2 F	2.032	Bus FANNIN 2 F	-0.8650	YES
6	0.732	11.936	0.21348	Bus MONAHAN	4.054	Bus MONAHAN	-0.5529	YES
7	0.324	14.207	0.19906	Bus ODESSA 1	5.268	Bus WHARTON	-0.2917	YES
8	0.324	39.346	0.55936	Bus MONAHAN	12.994	Bus WHARTON	-0.8722	YES
9	0.060	39.972	0.03815	Bus ODESSA 1	1.196	Bus POINT COM	-0.1645	YES
10	0.964	57.683	0.61264	Bus ODESSA 1	18.504	Bus POINT COM	-4.2760	YES
11	0.000	100.000	0.59650	Bus ODESSA 1	14.434	Bus WHARTON	-2.5257	YES

Takeaways So Far



- Modal analysis can be quickly done on a large number of signals
 - Computationally is an $O(N^3)$ process for one signal, where N is the number of sample points; it varies linearly with the number of included signals
 - The number of sample points can be automatically determined from the highest desired frequency (the Nyquist-Shannon sampling theory requires sampling at twice the highest desired frequency)
 - Determining how all the signals are manifested in the modes is quite fast!!

Getting Mode Details



- An advantage of this approach is the contribution of each mode in each signal is directly available

Modal Analysis Mode Details

Frequency (Hz) and Damping (%) 0.631 Hz, Damping = 6.082%

Transfer Results from Selected Column to Object Custom Floating Point Field

Custom Floating Point Field 1 Transfer Results

Type	Name	Units	Description	Post-Detrend Standard Deviation	Angle (Deg)	Magnitude, Unscaled	Magnitude Scaled by SD	Cost Function
1 Bus	Bus BROWNSVILLE 1 0 Frequency		Frequency	0.031	176.451	0.10313	3.29203	0.0019
2 Bus	Bus BROWNSVILLE 1 1 Frequency		Frequency	0.031	176.451	0.10248	3.27853	0.0019
3 Bus	Bus BROWNSVILLE 3 0 Frequency		Frequency	0.031	176.454	0.10148	3.25747	0.0018
4 Bus	Bus BROWNSVILLE 2 0 Frequency		Frequency	0.031	176.525	0.10041	3.23684	0.0017
5 Bus	Bus OLMITO 0 Frequency		Frequency	0.031	176.456	0.10032	3.23265	0.0018
6 Bus	Bus BROWNSVILLE 2 1 Frequency		Frequency	0.031	176.522	0.09964	3.22005	0.0017
7 Bus	Bus SAN BENITO 0 Frequency		Frequency	0.031	176.452	0.09836	3.19018	0.0017
8 Bus	Bus PORT ISABEL 0 Frequency		Frequency	0.031	176.519	0.09817	3.18788	0.0016
9 Bus	Bus LOS FRESNOS 0 Frequency		Frequency	0.031	176.480	0.09601	3.13896	0.0016
10 Bus	Bus CORPUS CHRISTI 3 3 Frequency		Frequency	0.030	177.479	0.09573	3.15533	0.0013
11 Bus	Bus CORPUS CHRISTI 3 2 Frequency		Frequency	0.030	177.619	0.09533	3.14610	0.0013
12 Bus	Bus RIO HONDO 0 Frequency		Frequency	0.030	176.500	0.09462	3.10807	0.0015
13 Bus	Bus CORPUS CHRISTI 3 5 Frequency		Frequency	0.030	177.488	0.09393	3.11626	0.0013
14 Bus	Bus SAN PERLITA 0 Frequency		Frequency	0.030	176.760	0.09338	3.08711	0.0014
15 Bus	Bus SEBASTIAN 2 1 Frequency		Frequency	0.030	176.485	0.09249	3.05864	0.0014
16 Bus	Bus SEBASTIAN 2 0 Frequency		Frequency	0.030	176.500	0.09234	3.05579	0.0014
17 Bus	Bus CORPUS CHRISTI 3 4 Frequency		Frequency	0.030	177.256	0.09203	3.06646	0.0013
18 Bus	Bus SANTA ROSA 1 4 Frequency		Frequency	0.030	176.457	0.09189	3.04368	0.0014
19 Bus	Bus SANTA ROSA 1 8 Frequency		Frequency	0.030	176.462	0.09183	3.04122	0.0014
20 Bus	Bus SEBASTIAN 1 0 Frequency		Frequency	0.030	176.504	0.09153	3.03706	0.0014
21 Bus	Bus SAN PERLITA 1 Frequency		Frequency	0.030	176.588	0.09134	3.03507	0.0014
22 Bus	Bus HARLINGEN 1 0 Frequency		Frequency	0.030	176.483	0.09114	3.02757	0.0014
23 Bus	Bus CORPUS CHRISTI 1 3 Frequency		Frequency	0.030	178.815	0.09102	3.06810	0.0019
24 Bus	Bus MERCEDES 0 Frequency		Frequency	0.030	176.459	0.09095	3.02245	0.0014
25 Bus	Bus SANTA ROSA 1 6 Frequency		Frequency	0.030	176.377	0.09081	3.01773	0.0014
26 Bus	Bus SANTA ROSA 1 5 Frequency		Frequency	0.030	176.439	0.09075	3.01600	0.0014
27 Bus	Bus SANTA MARIA 0 Frequency		Frequency	0.030	176.423	0.09065	3.01479	0.0014
28 Bus	Bus HARLINGEN 2 0 Frequency		Frequency	0.030	176.455	0.09043	3.01019	0.0014
29 Bus	Bus SANTA ROSA 1 2 Frequency		Frequency	0.030	176.315	0.09034	3.00472	0.0014
30 Bus	Bus PROGRESO 0 Frequency		Frequency	0.030	176.363	0.09016	3.00188	0.0015
31 Bus	Bus SANTA ROSA 1 9 Frequency		Frequency	0.030	176.399	0.08996	2.99744	0.0014
32 Bus	Bus SANTA ROSA 1 3 Frequency		Frequency	0.030	176.399	0.08996	2.99744	0.0014
33 Bus	Bus SANTA ROSA 1 1 Frequency		Frequency	0.030	176.399	0.08996	2.99744	0.0014
34 Bus	Bus SANTA ROSA 1 7 Frequency		Frequency	0.030	176.399	0.08996	2.99744	0.0014

This slide shows the mode with the lowest damping, sorted by the signals with the largest magnitude in the mode

Visualizing the Some or All of the Modes



- Some or all of the modes can be shown using the **Update Reproduced Signals** option
 - Select the modes to include using the **Include in Reproduced Signal** selection

Modal Analysis Form

Modal Analysis Status: Solved at 9/30/2019 10:24:33 AM

Data Source Type:

- From Plot
- File, WECC CSV 2
- File, JSSIS Format
- File, Comtrade CFG
- File, CSV (Data Starts Line 2)
- File, Comtrade CFG

Calculation Method:

- Matrix Pencil (Once)
- Iterative Matrix Pencil
- Dynamic Mode Decomposition

Data Source Inputs from Plots or Files:

- From Plot: Bus Frequency Ten
- From File: [Browse]

Save in JSSIS Format [Save] Save to CSV [Save]

Optimal Matrix Pencil Options:

- Number of Iterations: 10
- Initial All Signals to be Not Included
- Current Iteration: []
- Store Results in PWB File
- Always Reload Signals from Source

Data Sampling Time (Seconds) and Frequency (Hz):

- Start Time: 2.000 End Time: 17.000
- Maximum Hz: 5.000 Update Sampled Data [Update]

Results

Number of Complex and Real Modes: 11 Include Detrend in Reproduced Signals

Lowest Percent Damping: 6.742 Subtract Reproduced from Actual Update Reproduced Signals

Real and Complex Modes - Editable to Change Initial Guesses

Frequency	Damping (%)	Largest Component in Mode, Unscaled	Name of Signal with Largest Component in Mode, Unscaled	Average Component in Mode, Unscaled	Ratio Average to Largest Component in Mode, Unscaled	Largest Component in Mode, Scaled	Name of Signal with Largest Component in Mode, Scaled	Average Component in Mode, Scaled	Ratio Average to Largest Component in Mode, Scaled	Lambda	Include in Reproduced Signal
2	0.000	100.000	0.33511 Substation OD	0.06493	0.1938	8.560	Substation WH	2.17239	0.2538	-6.1001	YES
3	0.064	31.750	0.02488 Substation MO	0.02321	0.9330	0.918	Substation FAF	0.79268	0.8632	-0.1354	YES
4	0.332	13.368	0.10639 Substation LAP	0.06331	0.5951	4.173	Substation THC	2.26039	0.5417	-0.2730	YES
5	0.376	12.375	0.35529 Substation MO	0.22100	0.5549	9.055	Substation FAF	7.48875	0.8219	-0.8244	NO
6	0.511	7.596	0.20648 Substation BRC	0.07897	0.3825	6.598	Substation BRC	2.63740	0.3997	-0.2916	NO
7	0.642	6.742	0.20814 Substation BRC	0.07814	0.3754	6.651	Substation BRC	2.56754	0.3860	-0.2681	NO
8	11.347	0.13195	Substation MO	0.04009	0.3038	2.705	Substation MO	1.27938	0.4730	-0.5581	NO
9	0.954	7.335	0.04423 Substation SAH	0.01463	0.3307	1.734	Substation SAH	0.52113	0.3005	-0.4408	NO
10	1.140	16.751	0.07213 Substation MO	0.01966	0.2726	2.397	Substation WH	0.64146	0.2676	-1.3658	NO
11	1.488	8.654	0.02815 Substation FAF	0.00390	0.1387	1.175	Substation FAF	0.13396	0.1149	-0.8107	NO

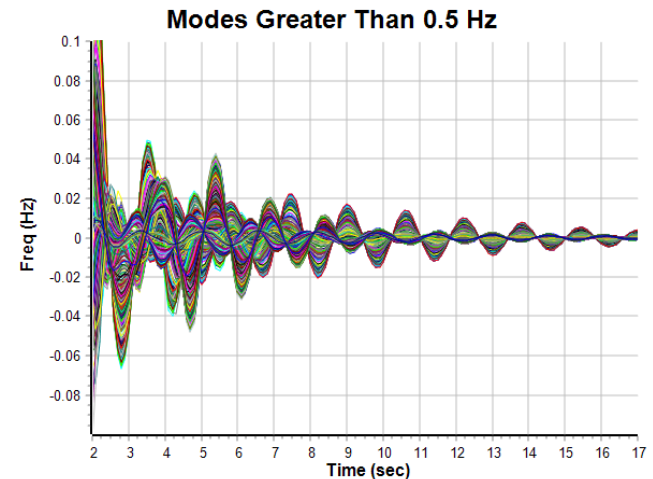
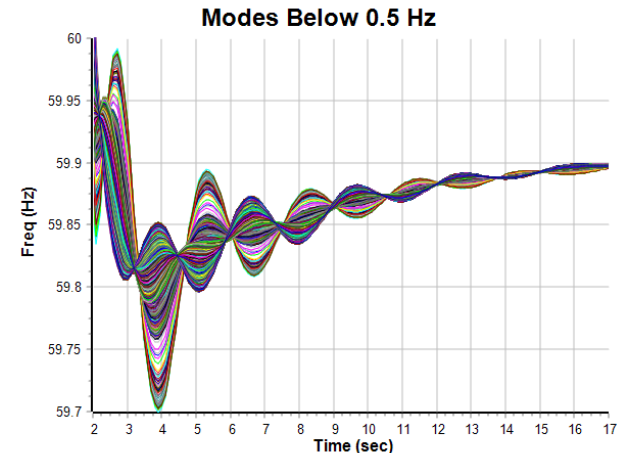
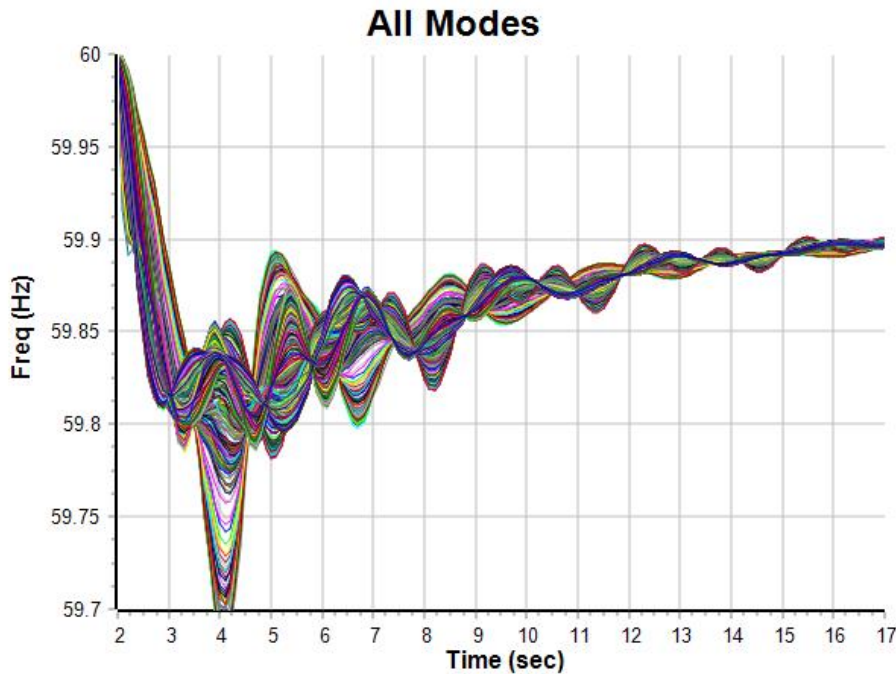
Input Data, Actual | Sampled Input Data | Signals | Options | Reproduced Data | Iterative Matrix Pencil Iteration Details

Time (sec)	Substation ODESSA 2 Frequency Average	Substation PRESIDIO 2 Frequency Average	Substation DONNELL 2 Frequency Average	Substation SPRING 5 Frequency Average	Substation VARI WORN Frequency Average	Substation RUSSELL 2 Frequency Average	Substation PRESIDIO 1 Frequency Average	Substation SANDERSON Frequency Average	Substation MONTEHANS 2 Frequency Average	Substation GRANDFALLS Frequency Average	Substation MARIA Frequency Average	Substation GARDEN CITY Frequency Average	Substation ODESSA 4 Frequency Average	Substation NOTREES Frequency Average	Substation MIDLAND 4 Frequency Average	Substation SPRING 1 Frequency Average	Substation DONNELL 2 Frequency Average	Substation ODESSA 6 Frequency Average	Substation SPRINGS Frequency Average	Substation MIDLAND 2 Frequency Average	Substation COAHOMA Frequency Average	Substation MIDLAND 3 Frequency Average		
1	2.000	60.101	60.091	59.906	60.049	60.091	60.079	60.093	59.998	60.091	60.008	60.091	60.069	60.095	60.100	60.098	60.041	59.924	60.105	60.053	60.073	59.903	60.074	
2	2.100	59.975	59.972	59.851	59.943	59.972	59.965	59.973	59.969	59.972	59.970	59.972	59.957	59.972	59.976	59.973	59.973	59.938	59.980	59.946	59.956	59.849	59.959	
3	2.200	59.906	59.907	59.823	59.897	59.907	59.906	59.903	59.863	59.907	59.906	59.907	59.896	59.906	59.909	59.905	59.883	59.831	59.912	59.889	59.896	59.822	59.897	
4	2.300	59.868	59.870	59.810	59.856	59.870	59.865	59.871	59.838	59.870	59.869	59.870	59.863	59.869	59.871	59.868	59.853	59.816	59.873	59.857	59.862	59.809	59.862	
5	2.400	59.846	59.847	59.805	59.838	59.847	59.844	59.847	59.825	59.846	59.846	59.847	59.843	59.846	59.848	59.845	59.845	59.809	59.849	59.849	59.839	59.841	59.804	59.842
6	2.500	59.830	59.830	59.803	59.825	59.810	59.820	59.810	59.813	59.813	59.813	59.813	59.813	59.813	59.813	59.813	59.813	59.813	59.813	59.813	59.813	59.813	59.813	59.813
7	2.600	59.818	59.816	59.804	59.816	59.815	59.817	59.816	59.812	59.814	59.815	59.816	59.817	59.817	59.817	59.818	59.815	59.804	59.818	59.816	59.817	59.803	59.816	
8	2.700	59.806	59.803	59.804	59.807	59.802	59.806	59.803	59.808	59.801	59.802	59.803	59.807	59.805	59.805	59.805	59.806	59.807	59.804	59.804	59.807	59.807	59.804	59.806
9	2.800	59.796	59.790	59.806	59.799	59.789	59.795	59.790	59.803	59.788	59.790	59.790	59.792	59.794	59.792	59.796	59.790	59.804	59.792	59.799	59.804	59.797	59.805	59.796
10	2.900	59.796	59.778	59.806	59.791	59.777	59.784	59.778	59.799	59.775	59.778	59.778	59.788	59.783	59.781	59.786	59.792	59.804	59.780	59.790	59.788	59.807	59.786	
11	3.000	59.776	59.767	59.807	59.783	59.766	59.775	59.767	59.795	59.764	59.767	59.779	59.773	59.770	59.776	59.776	59.785	59.804	59.768	59.783	59.780	59.807	59.778	
12	3.100	59.768	59.757	59.808	59.776	59.756	59.766	59.757	59.792	59.754	59.757	59.771	59.763	59.761	59.766	59.779	59.803	59.756	59.776	59.772	59.800	59.770	59.800	
13	3.200	59.760	59.749	59.808	59.771	59.749	59.759	59.746	59.786	59.746	59.749	59.764	59.756	59.753	59.761	59.773	59.803	59.750	59.770	59.766	59.809	59.763	59.809	
14	3.300	59.755	59.743	59.809	59.766	59.742	59.754	59.743	59.786	59.740	59.743	59.743	59.759	59.744	59.750	59.747	59.755	59.769	59.803	59.744	59.765	59.761	59.809	59.758
15	3.400	59.751	59.740	59.809	59.764	59.738	59.750	59.739	59.784	59.736	59.739	59.739	59.756	59.747	59.743	59.752	59.767	59.803	59.740	59.762	59.758	59.810	59.755	
16	3.500	59.750	59.738	59.810	59.762	59.737	59.749	59.738	59.783	59.734	59.738	59.738	59.754	59.745	59.742	59.750	59.766	59.803	59.739	59.761	59.756	59.810	59.754	
17	3.600	59.751	59.740	59.810	59.763	59.739	59.749	59.739	59.783	59.737	59.740	59.739	59.755	59.746	59.742	59.751	59.766	59.804	59.749	59.756	59.757	59.811	59.754	
18	3.700	59.753	59.743	59.811	59.765	59.742	59.752	59.743	59.785	59.741	59.743	59.743	59.757	59.749	59.746	59.754	59.768	59.805	59.743	59.764	59.760	59.812	59.757	
19	3.800	59.758	59.749	59.812	59.769	59.737	59.749	59.737	59.787	59.747	59.750	59.749	59.762	59.754	59.751	59.759	59.772	59.807	59.749	59.760	59.764	59.813	59.762	
20	3.900	59.765	59.757	59.813	59.775	59.747	59.764	59.757	59.790	59.756	59.758	59.757	59.768	59.762	59.759	59.765	59.777	59.808	59.757	59.774	59.770	59.814	59.768	
21	4.000	59.773	59.767	59.814	59.781	59.767	59.773	59.767	59.794	59.766	59.767	59.767	59.776	59.770	59.768	59.773	59.784	59.811	59.766	59.780	59.777	59.815	59.776	
22	4.100	59.782	59.778	59.816	59.789	59.778	59.782	59.779	59.779	59.778	59.778	59.779	59.782	59.779	59.782	59.782	59.791	59.813	59.777	59.786	59.786	59.817	59.785	
23	4.200	59.792	59.790	59.818	59.798	59.790	59.792	59.804	59.790	59.790	59.790	59.791	59.790	59.793	59.790	59.793	59.809	59.816	59.789	59.799	59.795	59.818	59.795	
24	4.300	59.803	59.803	59.820	59.806	59.803	59.803	59.802	59.810	59.803	59.803	59.803	59.804	59.803	59.802	59.803	59.807	59.818	59.802	59.806	59.805	59.820	59.805	

Visualizing the Some or All of the Modes



- Images show all the modes, the low frequency modes, and the high frequency modes



Visualizing the Modes

- If the grid has embedded geographic coordinates, the contributions for the mode to each signal can be readily visualized utilizing geographic data views (GDVs)

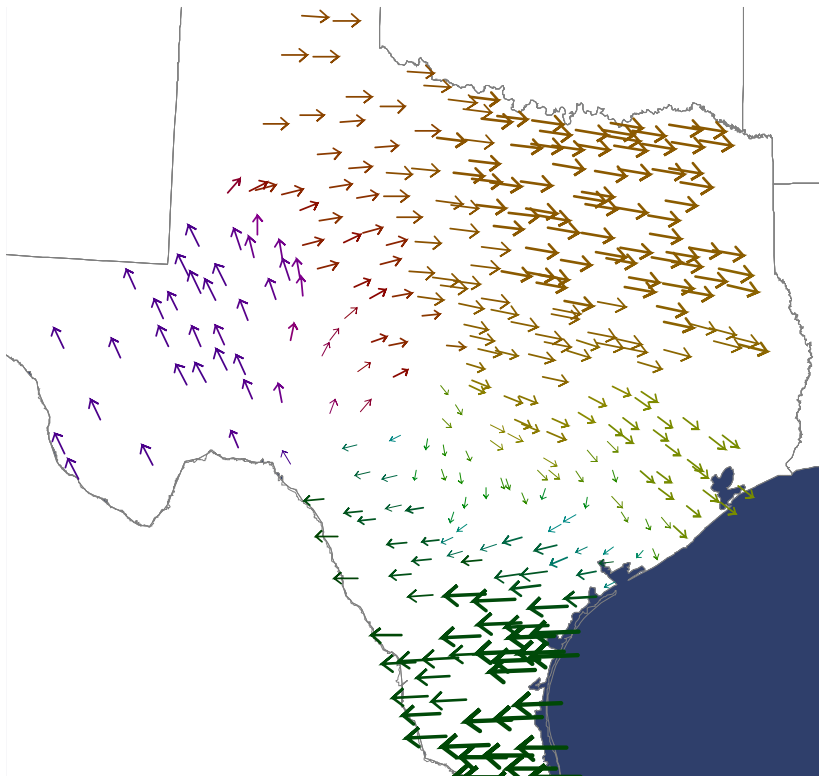


Image shows the magnitudes of the components for the 0.63 Hz mode; the display was pruned to only show some of the values

Aside: Visualizing Results Using Geographic Data Views (GDVs)



- The GDV concept arose about 13 years back as a way to auto-create oneline displays using geographic information embedded in power system models
- GDVs can be created from Model Explorer displays by right-clicking and selecting **Geographic Data View** and then either **Geographic Data View** to create a display of the selected objects or **Select Column, then Geographic Data View** for all the objects
 - As always, filters can limit the column objects
- Once defined, the GDVs are grouped based on an associated GDV Style

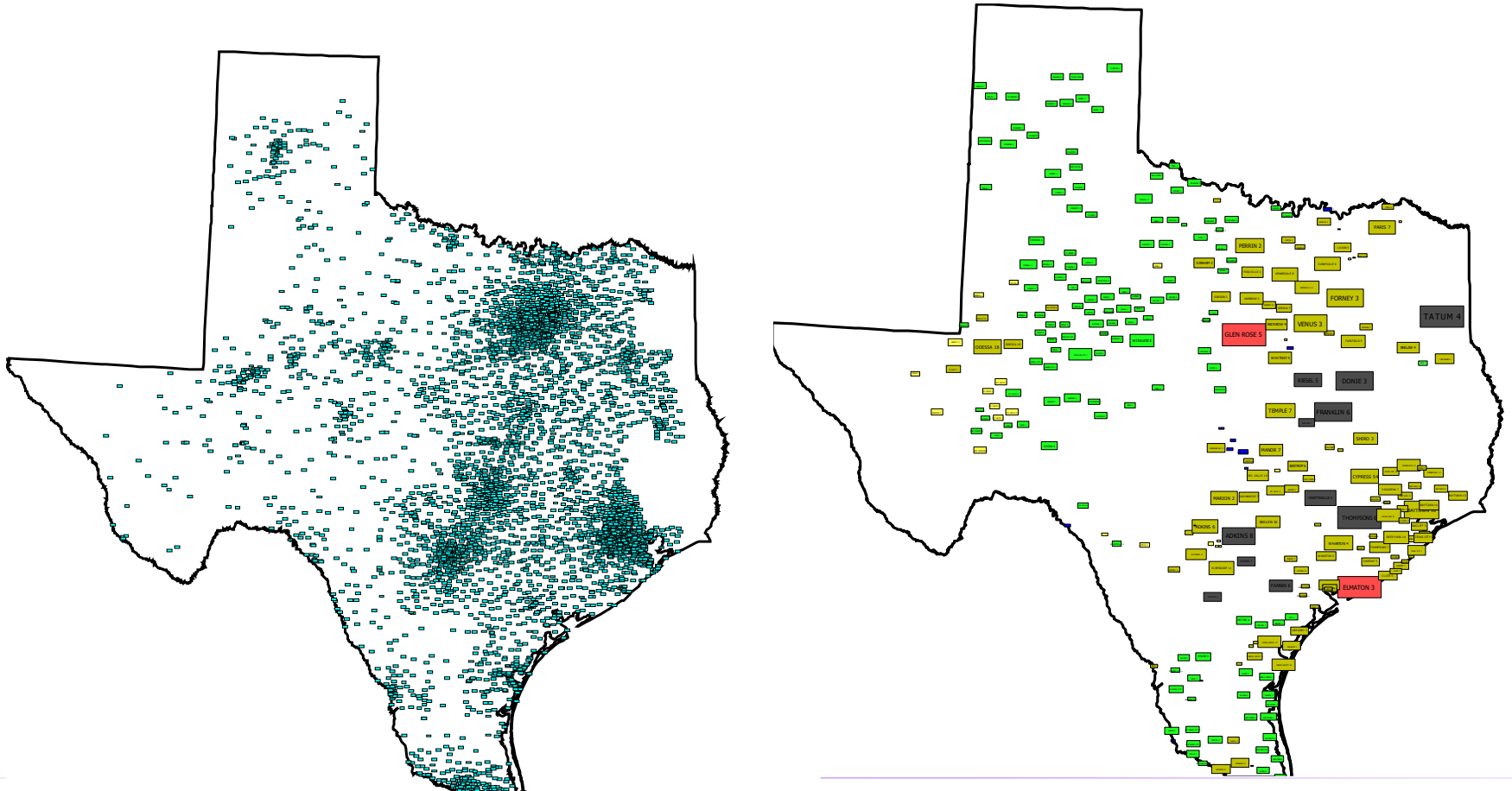
GDV Overview, cont.



- The GDV Style is then used to customize their appearance on the displays
- The GDVs themselves are ultimately display objects that can be saved in a pwd or axd file
 - The requirement is that they also be saved with the definition for their style
 - Like other *.pws, the GDVs can be used with multiple power systems
- The GDVs are meant to leverage the growing amount of geographic information that is embedded in power system models

GDV Example 2

Left image shows the substations unscaled, and the right shows the substation GDVs sized by generation (MW), with color based on the fuel type (red: nuclear, black: coal, brown: natural gas, green: wind, yellow: solar).



Aside: Making a Frequency Movie



- In class demonstration of how to make a frequency movie (I am only storing every 0.25 seconds in demo)
- In **Transient Stability, Options, General** check the **Store Full Power Flow State** on Update option
- Have a oneline that can contour bus (or substation) frequency, with the **Contours, Continuously Update Contours** checked
- Once the case has been run (with the power flow state saved), select in transient stability **Results from RAM, Power Flow States**; click on **Show Power Flow Transfer Control Dialog**; make sure the jpegs are saved somewhere

Using GDVs to Visualize a Mode



- GDVs used to quickly visualize mode information
- To visualize mode magnitude and angles, we'll use the substation custom fields to store the mode values
- Rerun modal analysis using the substation average frequency field. That is,
 - Start from the **Results From RAM, Aggregations, Substation display**
 - Show just the Frequency Average field
 - Right-click to select “Modal Analysis All Columns” to show the **Modal Analysis Form**
 - Select the Iterative Matrix Pencil method and click on **Do Modal Analysis**; view the **Mode Details** dialog for 0.63 Hz

Visualizing Mode Magnitude and Angle Components



- We'll use the custom fields to tell the substation objects about this mode's data
 - Select the Angle field, set the Custom Floating Point Field to 1; click Transfer Results
 - Repeat, except click on the Magnitude Unscaled field and set the Custom Floating field to 2
- Then we'll create a new GDV display using the **Texas_withBackground** online display (the customizations are on the next slides)

Modal Analysis Mode Details

Frequency (Hz) and Damping (%) 0.628 Hz, Damping = 7.975%

Transfer Results from Selected Column to Object Custom Floating Point Field

Custom Floating Point Field 1 Transfer Results

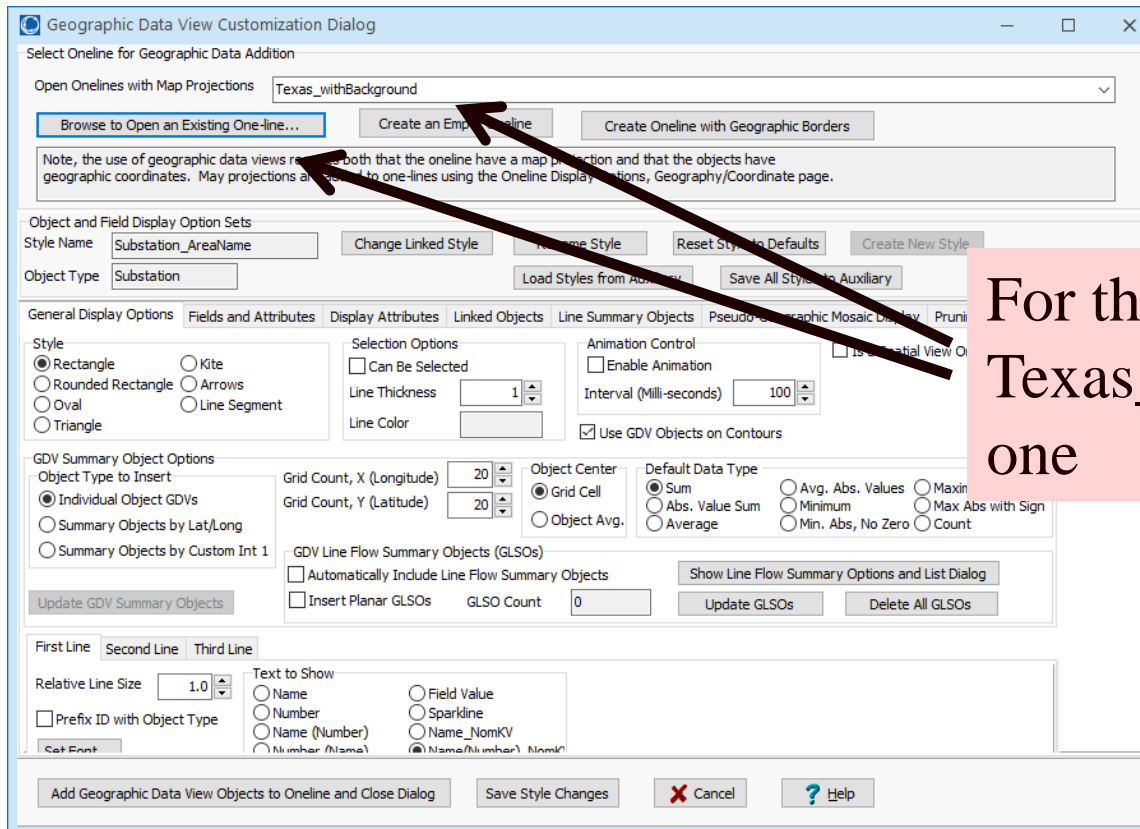
Type	Name	Units	Description	Peak Standard Deviation	Angle (Deg)	Magnitude, Unscaled	Magnitude Scaled by SD	Cost Function
1	Substation ODESSA 2 F		Average Freq	0.046	116.768	0.055	1.198	0.0040
2	Substation PRESIDIO 2		Average Freq	0.049	117.069	0.045	0.918	0.0032
3	Substation O DONNELLI		Average Freq	0.035	14.460	0.040	1.136	0.0026
4	Substation BIG SPRING		Average Freq	0.043	100.690	0.040	0.936	0.0030
5	Substation VAN HORN		Average Freq	0.049	116.821	0.044	0.885	0.0033
6	Substation HOKA		Average Freq	0.046	117.576	0.048	1.034	0.0030
7	Substation PRESIDIO 1		Average Freq	0.049	117.263	0.046	0.936	0.0032
8	Substation ANDERSON		Average Freq	0.038	113.247	0.030	0.791	0.0028
9	Substation MCKAY		Average Freq	0.050	116.018	0.040	0.806	0.0034
10	Substation GRANDPAU		Average Freq	0.049	116.506	0.043	0.873	0.0033
11	Substation MARFA Fre		Average Freq	0.049	117.035	0.045	0.910	0.0032
12	Substation GARDEN CI		Average Freq	0.045	108.532	0.046	1.018	0.0030
13	Substation ODESSA 4 F		Average Freq	0.047	115.720	0.050	1.055	0.0036
14	Substation NOTREES F		Average Freq	0.048	116.389	0.050	1.044	0.0035
15	Substation MIDLAND 4		Average Freq	0.046	116.008	0.054	1.177	0.0039
16	Substation BIG SPRING		Average Freq	0.042	98.551	0.039	0.913	0.0030
17	Substation O DONNELLI		Average Freq	0.036	22.476	0.035	0.993	0.0025
18	Substation ODESSA 6 F		Average Freq	0.049	117.031	0.051	1.041	0.0035
19	Substation BIG SPRING		Average Freq	0.043	102.401	0.042	0.965	0.0029
20	Substation MIDLAND 2		Average Freq	0.045	108.925	0.047	1.044	0.0035
21	Substation CARIOMA		Average Freq	0.035	13.182	0.041	1.167	0.0026
22	Substation MIDLAND 3		Average Freq	0.045	109.561	0.045	0.999	0.0034
23	Substation ALPINE Fre		Average Freq	0.048	117.313	0.047	0.971	0.0031
24	Substation FORT DAV		Average Freq	0.050	116.465	0.042	0.846	0.0033
25	Substation MCCAMEY		Average Freq	0.043	112.305	0.040	0.929	0.0031
26	Substation BIG SPRING		Average Freq	0.045	107.672	0.047	1.031	0.0030
27	Substation CRANE Fre		Average Freq	0.045	114.219	0.046	1.009	0.0030
28	Substation ODESSA 3 F		Average Freq	0.047	116.395	0.053	1.124	0.0037
29	Substation FORT STOC		Average Freq	0.048	118.639	0.051	1.046	0.0030
30	Substation ANDREWS 1		Average Freq	0.048	117.021	0.053	1.092	0.0036
31	Substation ANDREWS Fre		Average Freq	0.045	105.872	0.046	1.010	0.0030
32	Substation BIG LAKE Fr		Average Freq	0.038	90.177	0.027	0.704	0.0029
33	Substation MIDLAND 5		Average Freq	0.046	115.213	0.053	1.160	0.0039

Close

Creating the GDV Display



- On the **Case Information, Aggregation, Substations**, select **Geographic Data View, Select Column, Then Geographic Data View**

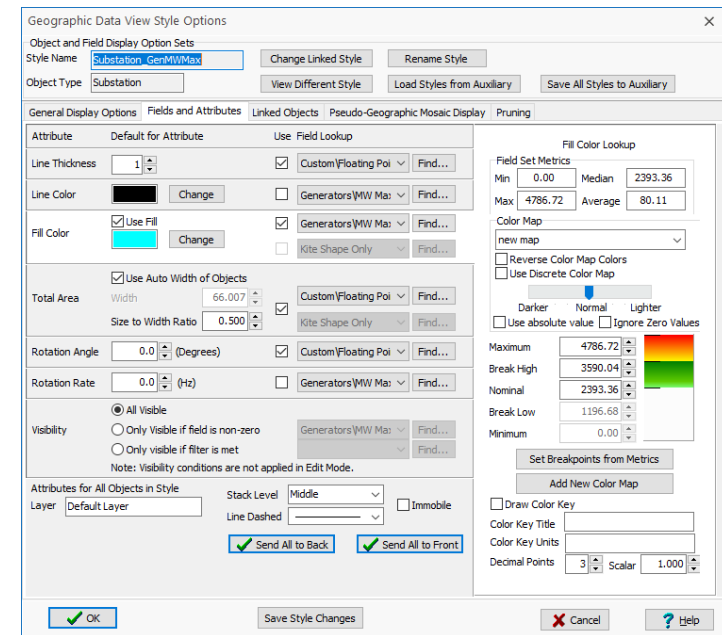


For the One-Line, pick the Texas_withBackground one

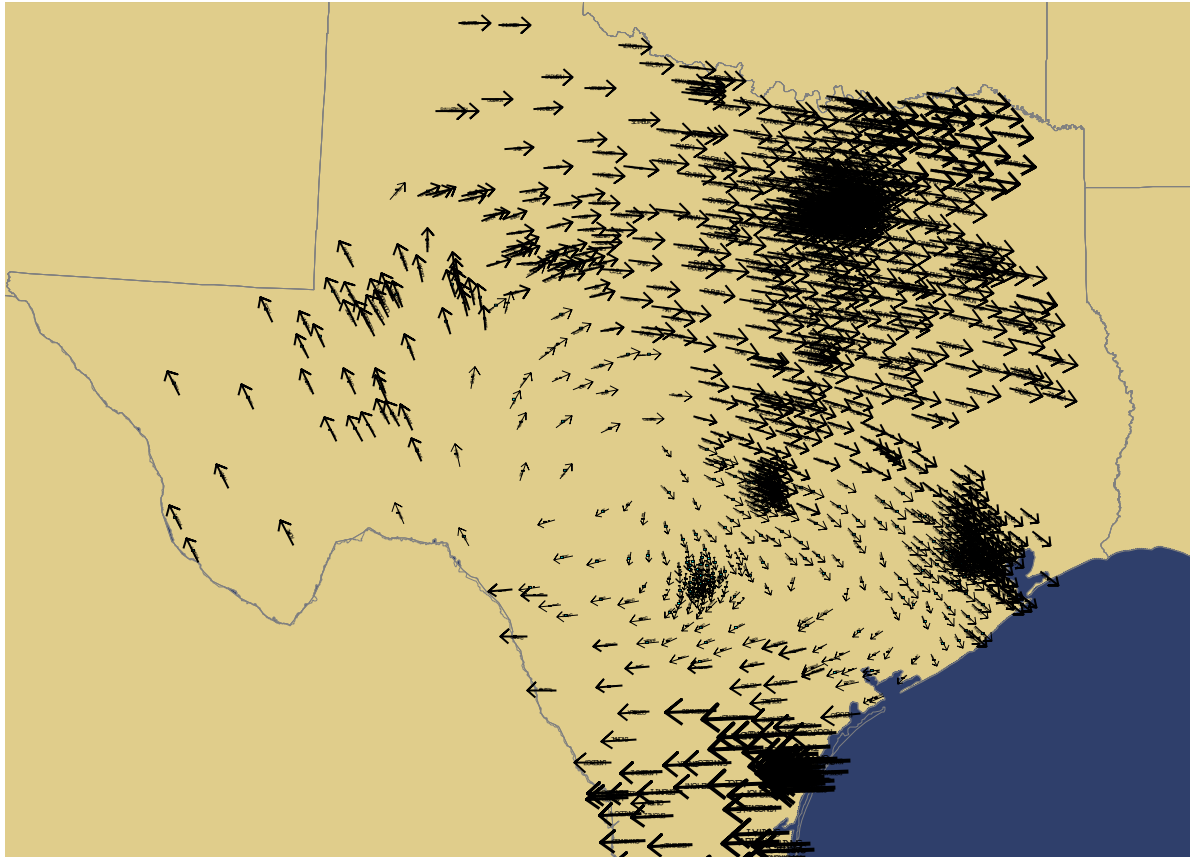
GDV Visualization of Mode Magnitude and Angle Components



- Set the GDV Style as
 - On the **General Display Options** page set the **Style** to **Arrows** and the **Text to Show** field to **None**.
 - On the **Fields and Attributes** page
 - Total Area uses the Custom Float 2 field (magnitude); a ballpark largest size should be 50000.
 - Rotation Angle uses the Custom Float 1 field (angle)
 - Line Thickness uses the Custom Float 2 field (magnitude)
- Once a oneline has been setup, it can be saved for repeated use
- Save oneline as **TSGC_2000_Modes**



Visualization of 0.63 Hz Mode



In this display the arrows show the magnitude and angle (direction) for the mode at each substation.

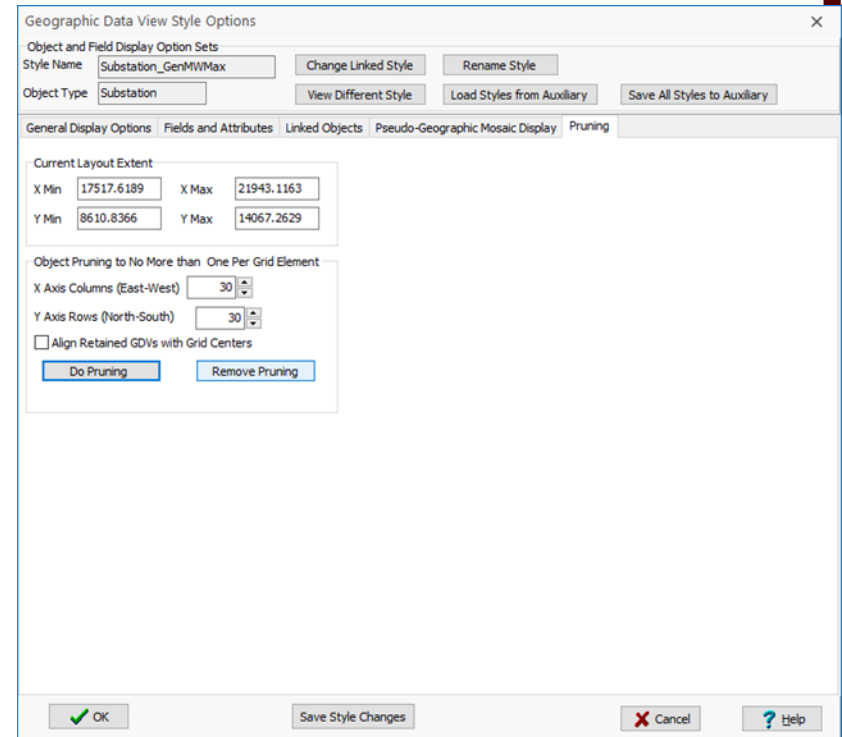
However, the problem is there are too many arrows!

The solution is so dynamically prune the display using the GDV Options, Pruning command

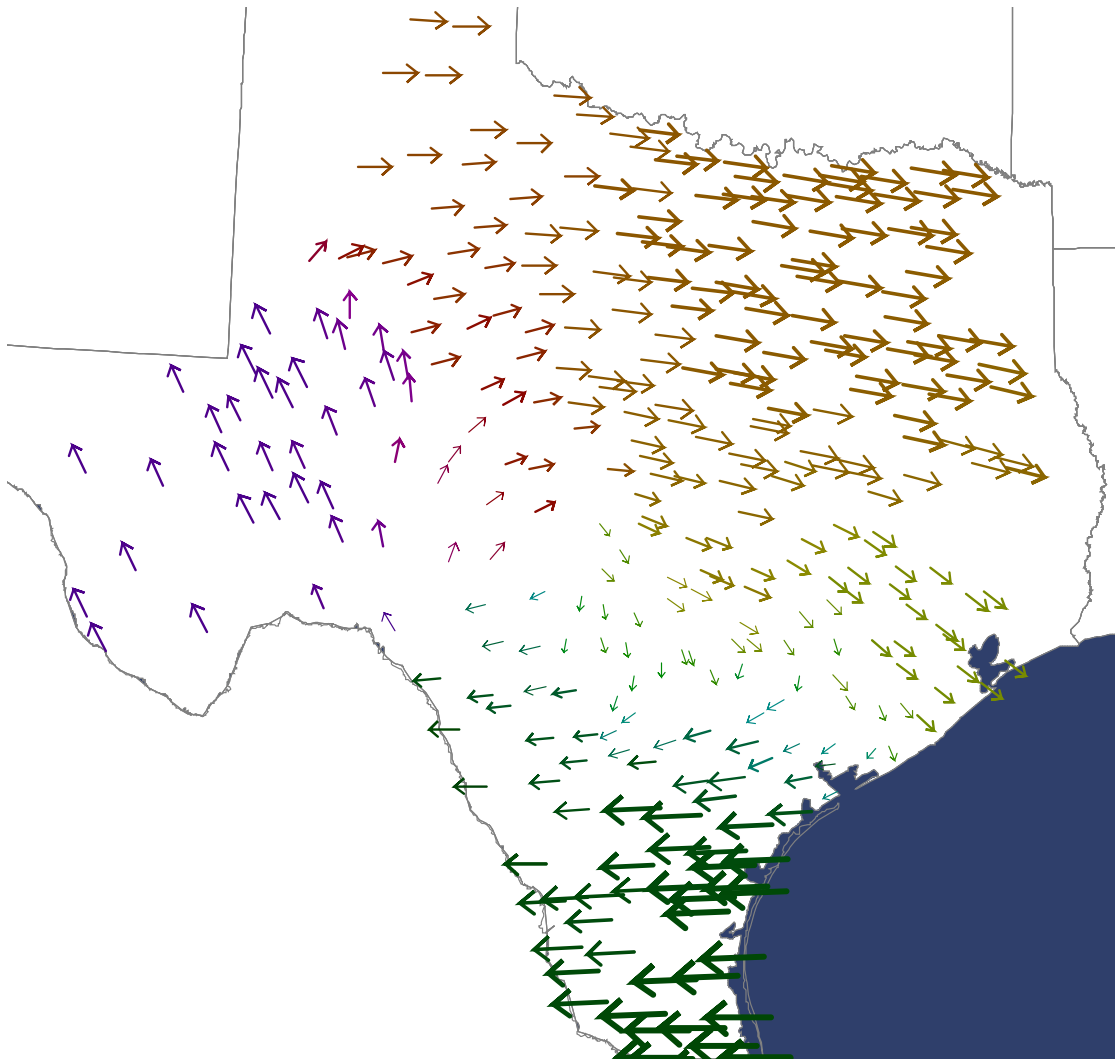
GDV Display Pruning



- This page allows GDVs to be selectively displayed
- Select **Do Pruning** to modify the oneline so an invisible grid is added to the display and only one GDV arrow is visible in each grid area
- I also added some color, using a circular color map to highlight the angles



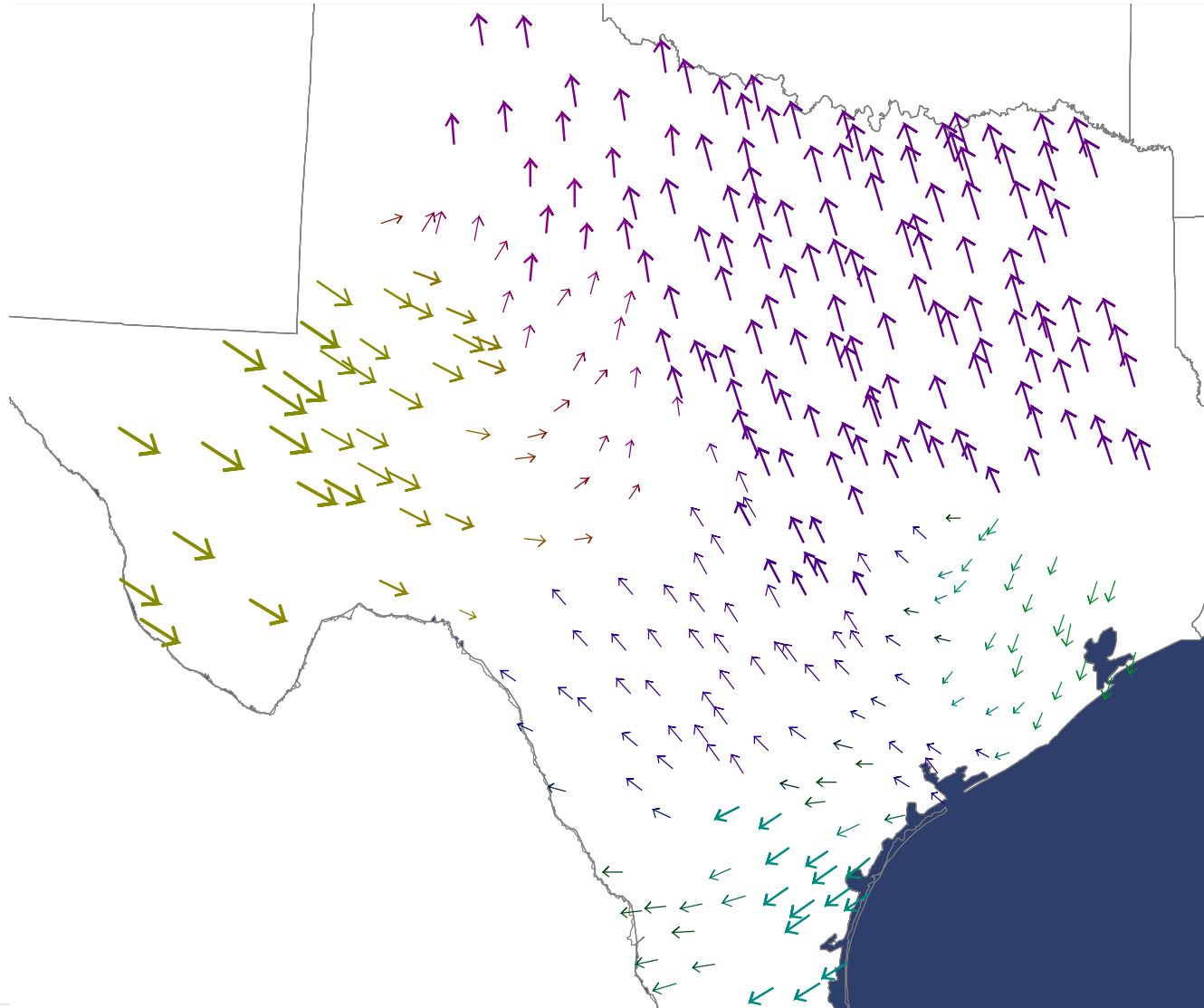
Visualization of 0.63 Hz Mode



Again save the oneline;
it can then be used to quickly visualize the other modes

To show other modes, just go to the Mode Details dialog for a different frequency and again transfer the angle and magnitude

Visualization of 0.76 Hz Mode



Damping Oscillations: Power System Stabilizers (PSSs)



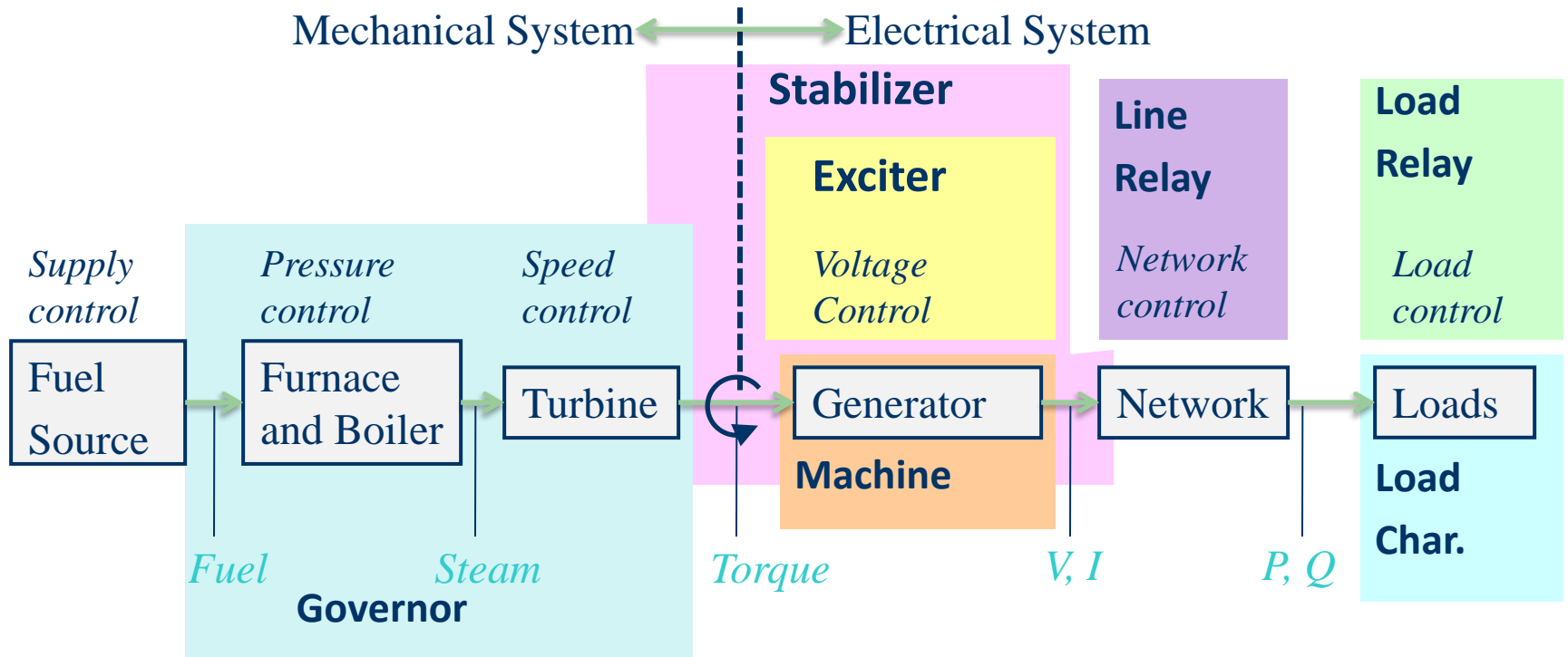
- A PSS adds a signal to the excitation system to improve the generator's damping
 - A common signal is proportional to the generator's speed; other inputs, such as like power, voltage or acceleration, can be used
 - The Signal is usually measured locally (e.g. from the shaft)
- Both local modes and inter-area modes can be damped.
- Regular tuning of PSSs is important

Stabilizer References



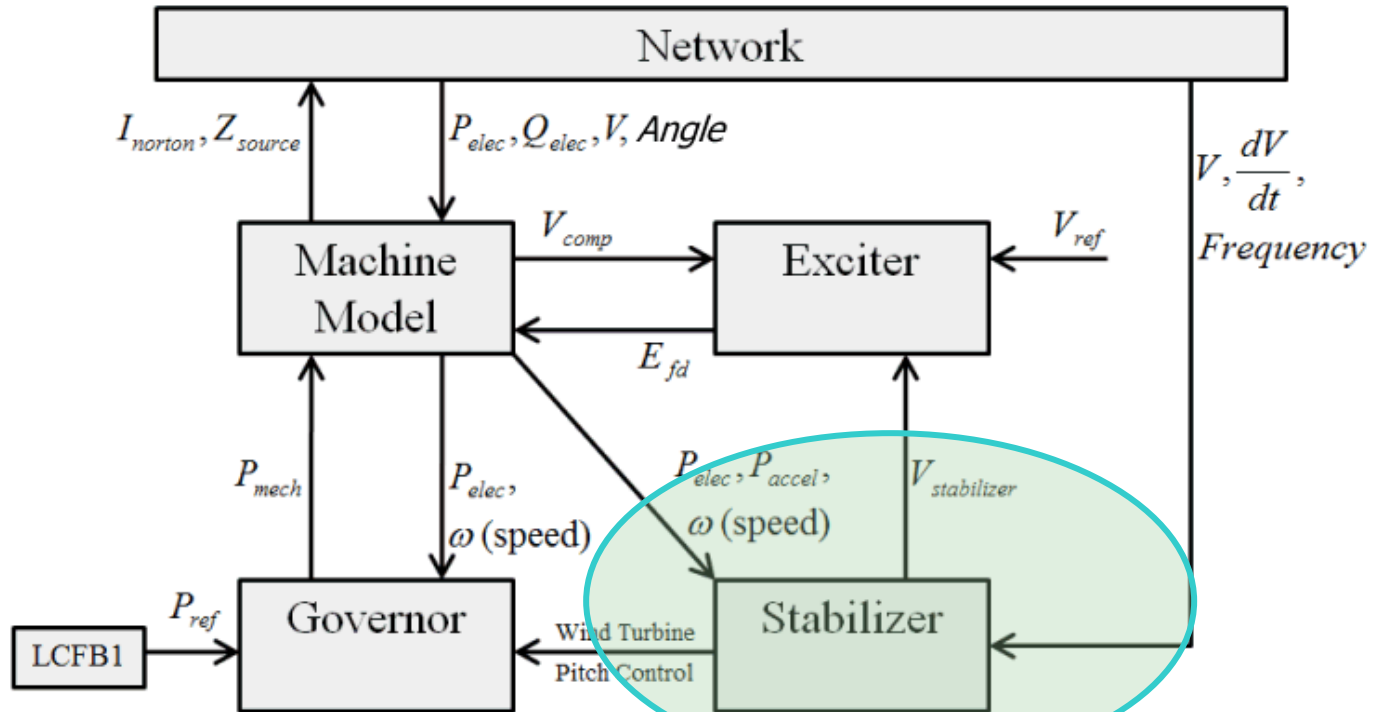
- A few references on power system stabilizers
 - E. V. Larsen and D. A. Swann, "Applying Power System Stabilizers Part I: General Concepts," in IEEE Transactions on Power Apparatus and Systems, vol.100, no. 6, pp. 3017-3024, June 1981.
 - E. V. Larsen and D. A. Swann, "Applying Power System Stabilizers Part II: Performance Objectives and Tuning Concepts," in IEEE Transactions on Power Apparatus and Systems, vol.100, no. 6, pp. 3025-3033, June 1981.
 - E. V. Larsen and D. A. Swann, "Applying Power System Stabilizers Part III: Practical Considerations," in IEEE Transactions on Power Apparatus and Systems, vol.100, no. 6, pp. 3034-3046, June 1981.
 - *Power System Coherency and Model Reduction*, Joe Chow Editor, Springer, 2013

Dynamic Models in the Physical Structure



P. Sauer and M. Pai, *Power System Dynamics and Stability*, Stipes Publishing, 2006.

Power System Stabilizer (PSS) Models



P_{elec} = Electrical Power

Q_{elec} = Electrical Reactive Power

V = Voltage at Terminal Bus

$\frac{dV}{dt}$ = Derivate of Voltage

V_{comp} = Compensated Voltage

P_{mech} = Mechanical Power

ω (speed) = Rotor Speed (often it's deviation from nominal speed)

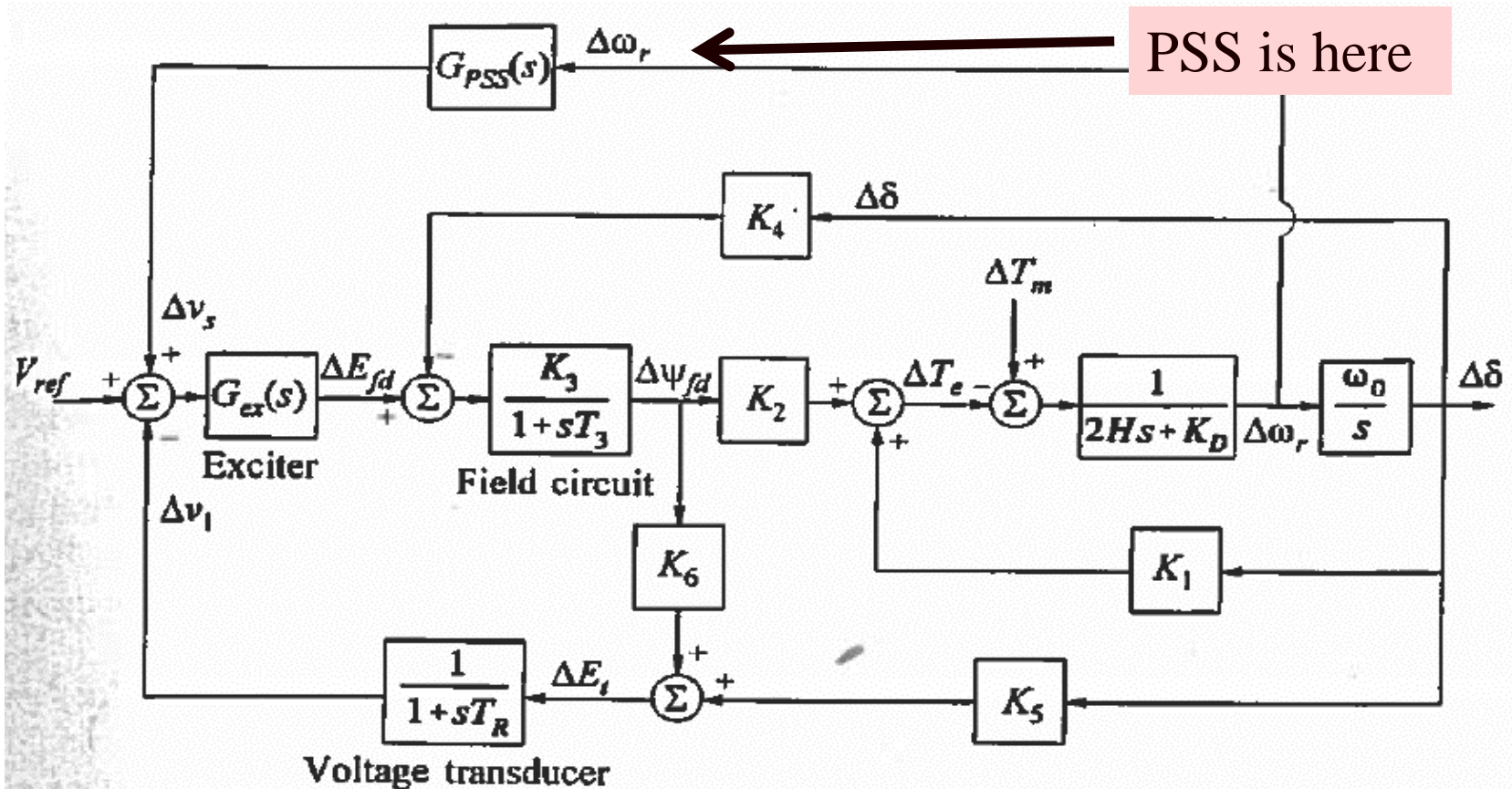
P_{accel} = Accelerating Power

$V_{stabilizer}$ = Output of Stabilizer

V_{ref} = Exciter Control Setpoint (determined during initialization)

P_{ref} = Governor Control Setpoint (determined during initialization)

Classic Block Diagram of a System with a PSS



PSS is here

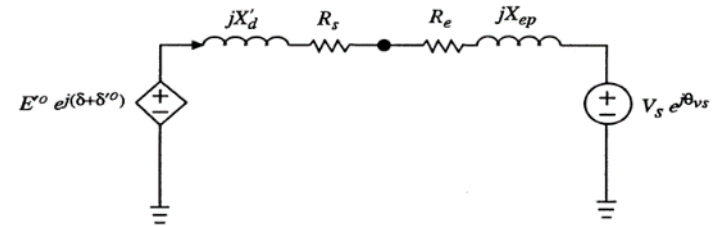
Figure 12.13 Block diagram representation with AVR and PSS

PSS Basics



- Stabilizers can be motivated by considering a classical model supplying an infinite bus

$$\frac{d\delta}{dt} = \omega - \omega_s = \Delta\omega$$



$$\frac{2H}{\omega_0} \frac{d\Delta\omega}{dt} = T_M^0 - \frac{E'V_s}{X'_d + X_{ep}} \sin(\delta) - D\Delta\omega$$

- Assume internal voltage has an additional component

$$E' = E'_{org} + K\Delta\omega$$

- This can add additional damping if $\sin(\delta)$ is positive
- In a real system there is delay, which requires compensation

PSS Focus Here

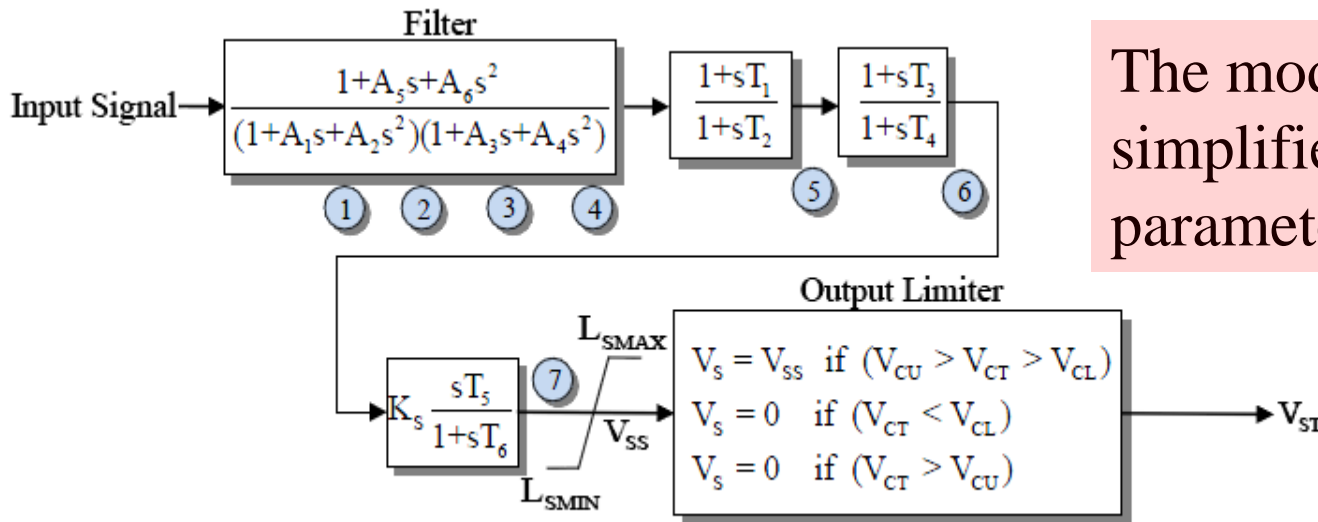


- Fully considering power system stabilizers can get quite involved
- Here we'll just focus on covering the basics, and doing a simple PSS design. The goal is providing insight and tools that can help power system engineers understand the PSS models, determine whether there is likely bad data, understand the basic functionality, and do simple planning level design

Example PSS



- An example single input stabilizer is shown below (IEEEEST)
 - The input is usually the generator shaft speed deviation, but it could also be the bus frequency deviation, generator electric power or voltage magnitude



The model can be simplified by setting parameters to zero

V_{ST} is an input into the exciter