WECC Power System Stabilizer Tuning Guidelines

Forward

This document is not intended to be a detailed tuning procedure for a specific piece of equipment. The intent is to meet the inter-area needs of WECC; local system needs may dictate additional requirements. It is intended for the experienced tuning engineer as the minimum criteria needed to tune a PSS. A detailed tuning procedure should be developed for the specific PSS being tuned. This guideline is meant to be an aid in the development of the tuning procedure.

Background

The basic intent of adding a Power System Stabilizer (PSS) is to enhance damping to extend power transfer limits. The very nature of a PSS limits its effectiveness to small excursions about a steady state operating point. The small excursions about an operating point are typically the result of an electrical system that is lightly damped which can cause spontaneous growing oscillations, known as system modes of oscillation.

Enhanced damping is required when a weak transmission condition exists along with a heavy transfer of load. In the WECC, inter-area modes of oscillation occur between 0.1 and 1.0 Hz. with the predominant mode at approximately 0.3 Hz.

A PSS works in conjunction with the excitation system of a synchronous machine to modify the torque angle of the shaft to increase damping. The performance of the excitation system is critical in the overall capability of a PSS. Tuning of a PSS shall only be accomplished after the excitation system has been tuned and calibrated.

On new equipment, PSS may be software incorporated in digital automatic voltage regulators. AVR terminal voltage and current measurements are used to compute accelerating power and synthetic speed (integral of accelerating power). PSS cost can be low if PSS is required in competitive power plant procurement specifications. Procurement specifications should include requirement for tuning during commissioning and a requirement for stability program model and data.

Objective

PSS typically utilizes phase compensation and adjusting phase compensation is the main task in PSS tuning. Phase compensation is accomplished by adjusting the PSS to compensate for phase lags through the generator, excitation system, and power system such that PSS provides torque changes in phase with speed changes. Tuning should be performed when system configurations and operating conditions result in the least damping. Verification should demonstrate that instability is not introduced through normal operating ranges as well as expected faults.

Items of concern

PSS benefits to the WECC system are significant, however, there is potential for equipment damage. Some areas of concern are:

- PSSs are manufactured as both analog and digital types. Testing methods may not be identical with both types of PSSs.
- PSS modification of torque angles by varying excitation can excite turbine generator shaft torsionals where shaft torsionals are less than 20 hertz. This is especially true for PSSs that utilize speed as input. Typically torsional filters are used to remove the torsional contribution to the input to the PSS.
- PSS output can interfere with transient response of excitation systems. Therefore output limits are usually incorporated in the PSS scheme.
- PSS can interact with underexcitation limiters. Thus the limiters must be tuned to work in conjunction with the PSS.
- Rapid load changes can result in large VAR swings from PSS response that utilize electric power. Upgrading to type 2 PSS input (integral of accelerating power) may solve this problem.

PSS Input Types

PSS are designed with various types of inputs. They include speed, frequency, power, accelerating power and integral of accelerating power. The PSS may derive these quantities from generator terminal voltage and current measurements. Current practice is to digitally derive a synthetic speed measurement (integral of accelerating power) from generator terminal voltage and current measurements.

PSS Tuning

The tuning of PSS differs based on the type of input. However, in general tuning of PSS consists of the following:

Verifying the functionality of all aspects of the PSS equipment.

This includes the compensating features, limits, and protections. All potentiometers, if so equipped, should have smooth and continuous control throughout their range.

PSS Output Limiter

Set output limits so that PSS cannot move generator terminal voltage beyond a predetermined value. Typical range of settings is from ±5% to ±10% of rated generator terminal voltage. Asymmetrical limits may be employed.

Protection and Alarms

PSS output protection should be coordinated with the output limiter. Since the output limiter provides a wider range of signals than can be tolerated in steady-state operation, several methods may be used to obtain security from driving the excitation system beyond the normal operating limits. These methods include voltage-sensitive switches, auxiliary timing circuits and limiter meters.

The voltage sensitive switch usually measures generator terminal voltage and disconnects the PSS signal from the excitation system when the terminal voltage exceeds a preset limit. The auxiliary timer method uses a circuit to monitor the PSS output level, and if the level exceeds a preset limit for a given time, the PSS signal is removed from the excitation system.

If protection removes the PSS from service an alarm should actuate.

Washout

There is an interrelationship between the phase compensation and the washout time constant. Short washout time constants provide additional phase compensation in frequency-based PSS at the lower frequencies while dramatically reducing the gain.

A washout time constant of 10 seconds or less is recommended to quickly remove low frequency components (below 0.1 Hz) from the PSS output. The smaller time constant will reduce the influence on the system voltage from the PSS during any sustained/extended frequency deviation (i.e., loss of generation), especially if the PSS has a high gain setting.

Phase Compensation

Identify inter-area modes of oscillation. Measure generator and excitation system response without PSS. Tune PSS to provide as close to 0 degrees of phase shift as possible at the inter-area frequency or frequencies.

If local stability concerns require PSS settings resulting in an inter-area phase shift other than zero, the setting shall in no case result in a phase shift in excess of 30 degrees at inter-area modes.

The PSS provides substantial phase shift so that the electrical torque provided by the generator is approximately in phase with speed. The goal is to eliminate phase lag as best as possible throughout a wide range of frequencies of interest, then adjust gain as outlined below.

Gain Test

A gain as high as practicable is required for best contribution to system damping. Since the maximum gain that is safely usable depends upon many factors, it is best determined by test. The gain test shall be performed under operating conditions that result in maximum overall system gain so that the true gain margin is identified. Generally, this occurs with the unit loaded to at least 80% of full load. If shaft torsionals are of concern, the torsionals shall be monitored during the gain test.

A test for the maximum safely usable gain may be made with the PSS fully operative and either PSS output, field voltage, or generator terminal voltage deviation being recorded, by slowly advancing the gain until a small rapid oscillation, usually in the frequency range from 1 to 3 hertz, is just sustained or growing. High initial response systems may oscillate at 4 to 8 hertz. Record per unit gain at this point. For good stability of the control loop, the gain should be reduced to 1/2 to 1/3 of this value. In this determination of gain, care must be taken that the PSS signal is not being clipped by the limits. Noise in the control signal increases as the gain is increased. If they should reach the point of being clipped by the limits before the oscillation is sustained, influence of the PSS is diminished and a false indication of allowable gain will result. In severe cases, the limits may so nullify PSS action that no oscillation can be produced. If a sustained oscillation cannot be obtained because of large blocks of parallel generation not controlled by PSS, then set the gain to 1/2 the point of clipping.

It’s difficult to test effectiveness and optimal gain for interarea oscillations. Special tests and signal processing, however, may be devised for certain large units at critical locations. It’s generally not possible to test for robustness under stressed conditions including major outages; therefore it is strongly recommend that the optimal gain and effectiveness of the PSS be validated by simulation.

Commissioning Tests:

Perform an impulse response by injecting a large signal into the AVR (5-10%) and identify local mode damping. Verify local mode oscillation damping has improved, or, at a minimum, has not been degraded.

Additionally, non-take over type underexcitation limiters (UEL) must be coordinated with the PSS to ensure stable performance during limiter operation. After the gain is set, underexcite the machine until the UEL becomes active and perform a step and/or an impulse response test while monitoring the output power (MW). Ensure that the UEL is not interacting with the PSS in such a way that the damping level is reduced or instability is observed (since the PSS reduces the gain margin in the UEL control and vice versa). If instability is observed, retuning of the UEL or PSS is required. Coordination should be performed with all appropriate limiters in the AVR.

Appendix A: Simplified Power System Stabilizer Tuning Procedure for Hydro Units with Static Exciters

This procedure assumes that the unit in test will remain stable when the Power System Stabilizer is removed from service.

1. Attach equipment as indicated in Figure 1. Disconnect the Power System Stabilizer (PSS) from the Automatic Voltage Regulator (AVR) summing junction. Perform a frequency response of the terminal voltage (V_t) vs. V_{signal} with the unit at full load. See Figure 7 for an example result of a machine equipped with a static exciter.

2. From the V_t frequency plot, establish the phase delay of the exciter and generator (for example 154^o at 0.4Hz).

3. Tune the Washout and PSS to provide phase lead in the frequency range of 0.1Hz to 1.0Hz equal the phase lag of V_t. The phase lead angle is equal to $90^o+180^o-{}^{-}26^o=296^o$ or ${}^{-}64^o$. 90^o is derived from Pe lagging the terminal voltage by 90^o. The 180^o is to compensated for the ${}^{-}1$ of the PSS.

4. Turn the gain of the PSS to near 0. Synchronize the unit. Ensure that the PSS output is not connected to the AVR summing junction (test switch 2 is open).

5. Perform a frequency response of Pe vs. V_{signal}. This will indicate the frequency of the local mode oscillation. However this will not indicate the inter-area oscillations, as they are very difficult to excite with a single machine connected to a very strong bus.

6. Now that the local mode phase and frequency are known with the help of pole-zero placement techniques, the PSS settings can be calculated.

7. Use a modeling program or equivalent mathematical program to verify PSS settings are going to result in the proper phase in the inter-area (0.1Hz to 1.0Hz), and provide indication of the local mode damping.

8. Apply settings to PSS with gain turned down. Ensuring test switch 2 is open. Connect test equipment to the PSS, replacing the Watt Transducer output (PSS input) with V_{signal}. Connect the PSS output to test equipment as in Figure 2.

9. Compare the frequency response of the model and actual equipment (Figure 4) to ensure correct operation of the PSS. Note the –1 illustrated in the model is sometimes achieved by reversing the output of the watt transducer, or by reversing the PT/CT connection to the watt transducer.

10. Reconnect the watt transducer to the PSS. With the machine on-line at a reasonable loading, connect the PSS (test switch 2).

11. Slowly increase the PSS gain until Pe begins to oscillate. Turn the gain down to 1/3.

12. Replace V_{signal} with a variable isolated DC source. Adjust the DC source to provide a step in V_t equivalent to 0.5% change.

13. Close test switch 1 while monitoring Pe (Figure 5). If unit starts to become unstable, remove PSS from service (open test switch 2).

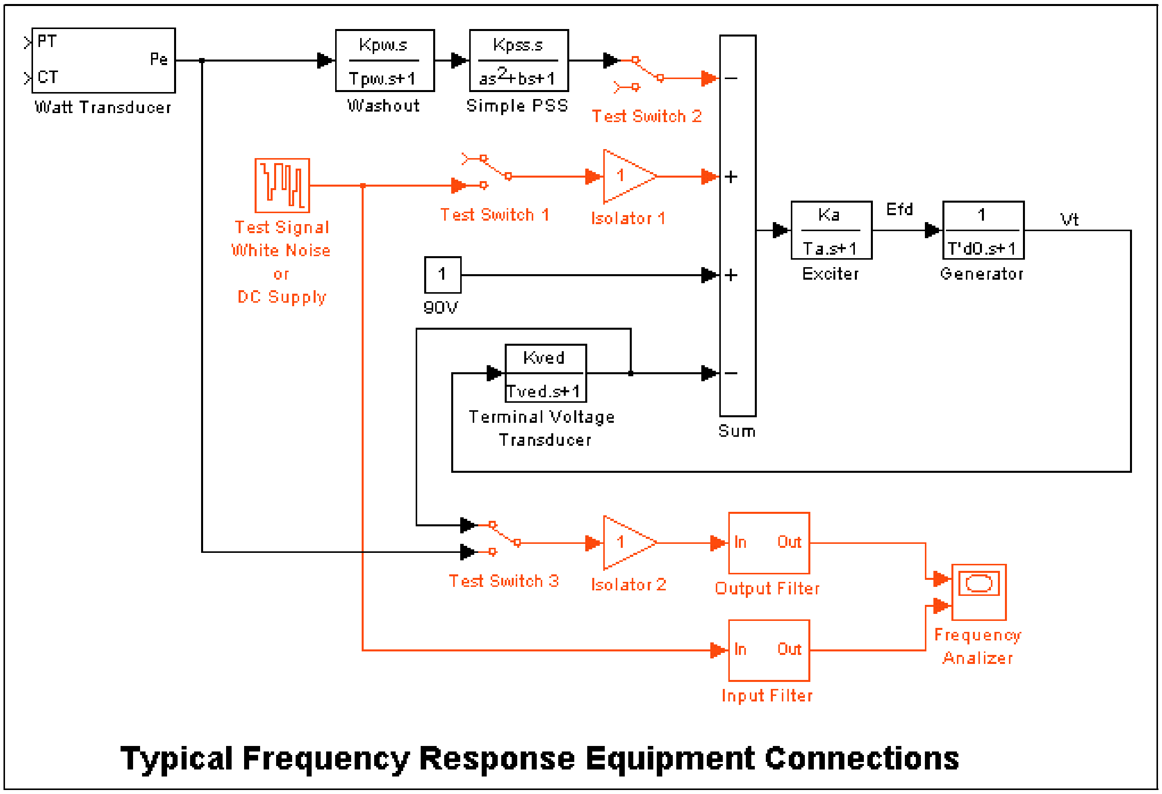

Figure 1

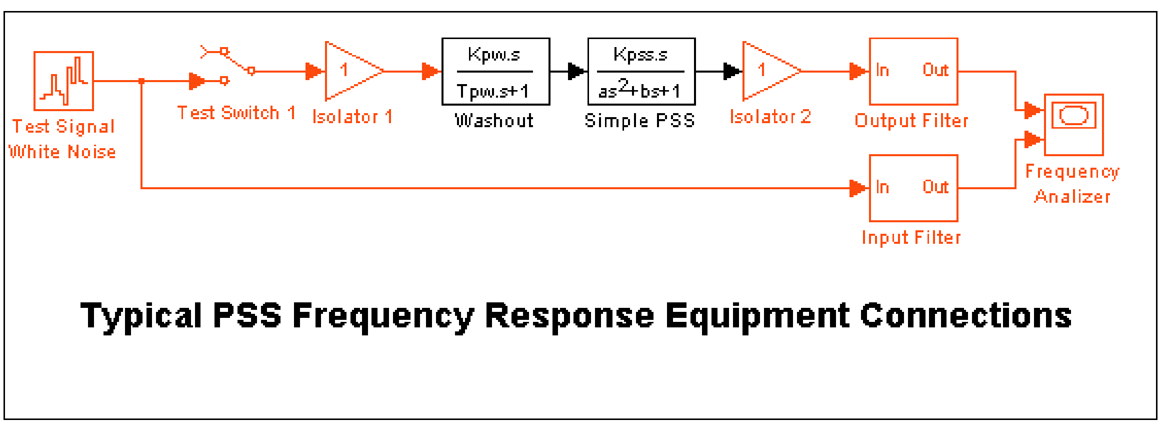

Figure 2

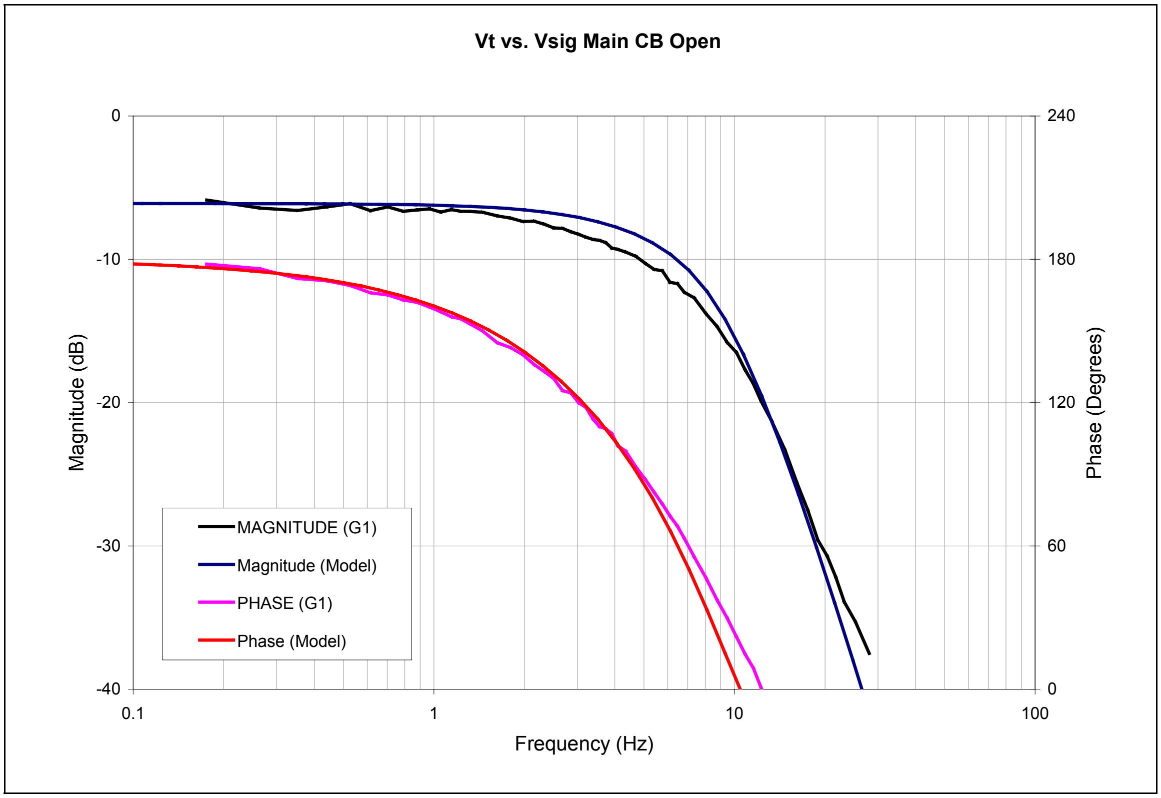

Figure 3

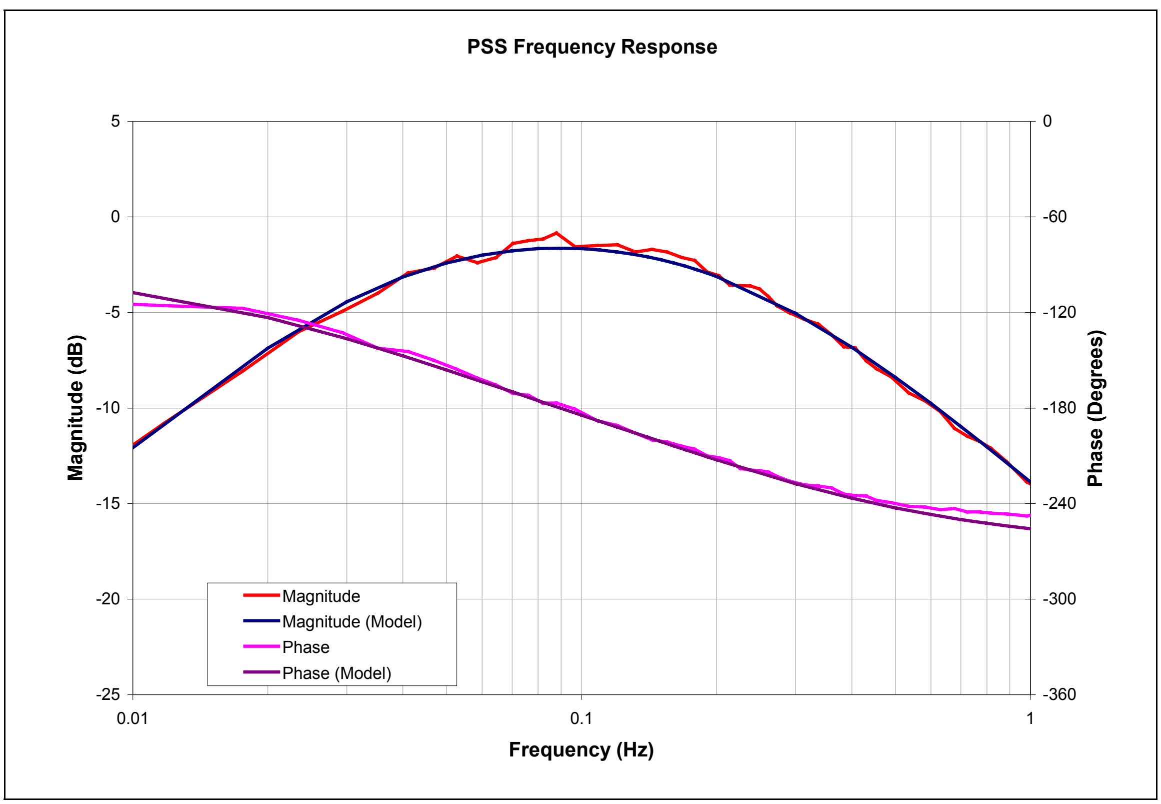

Figure 4

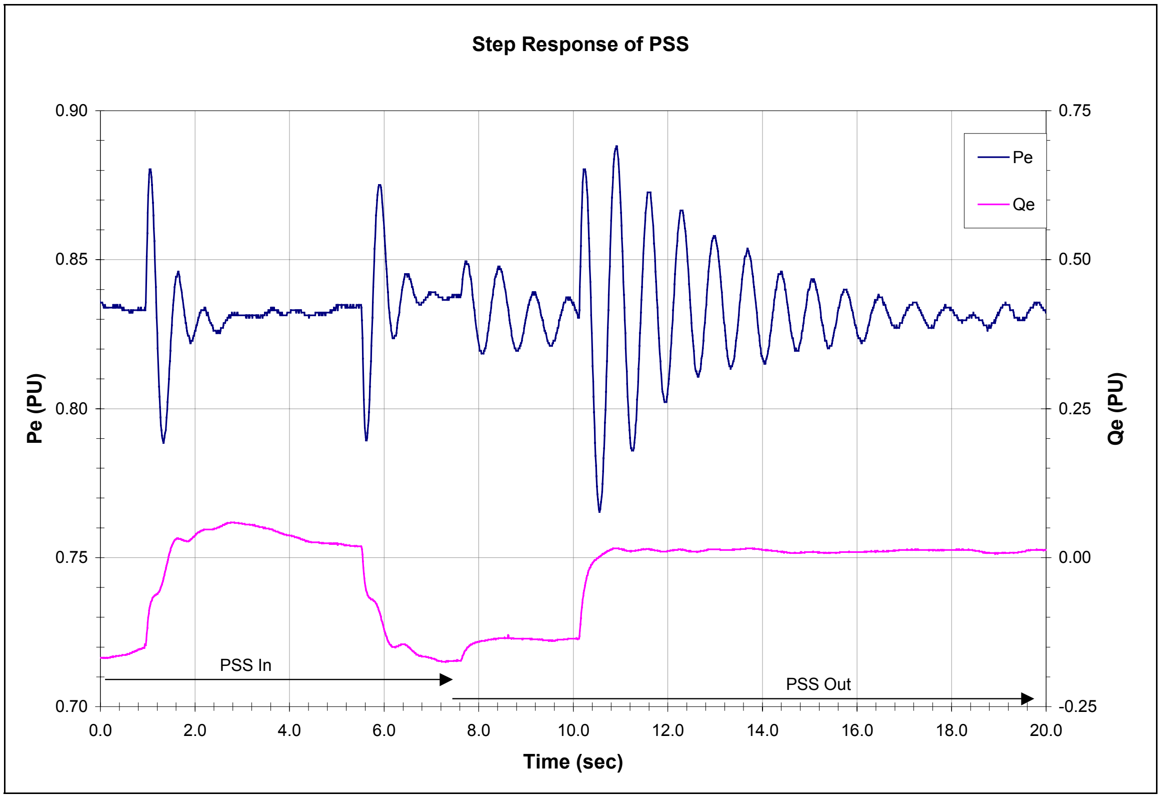

Figure 5

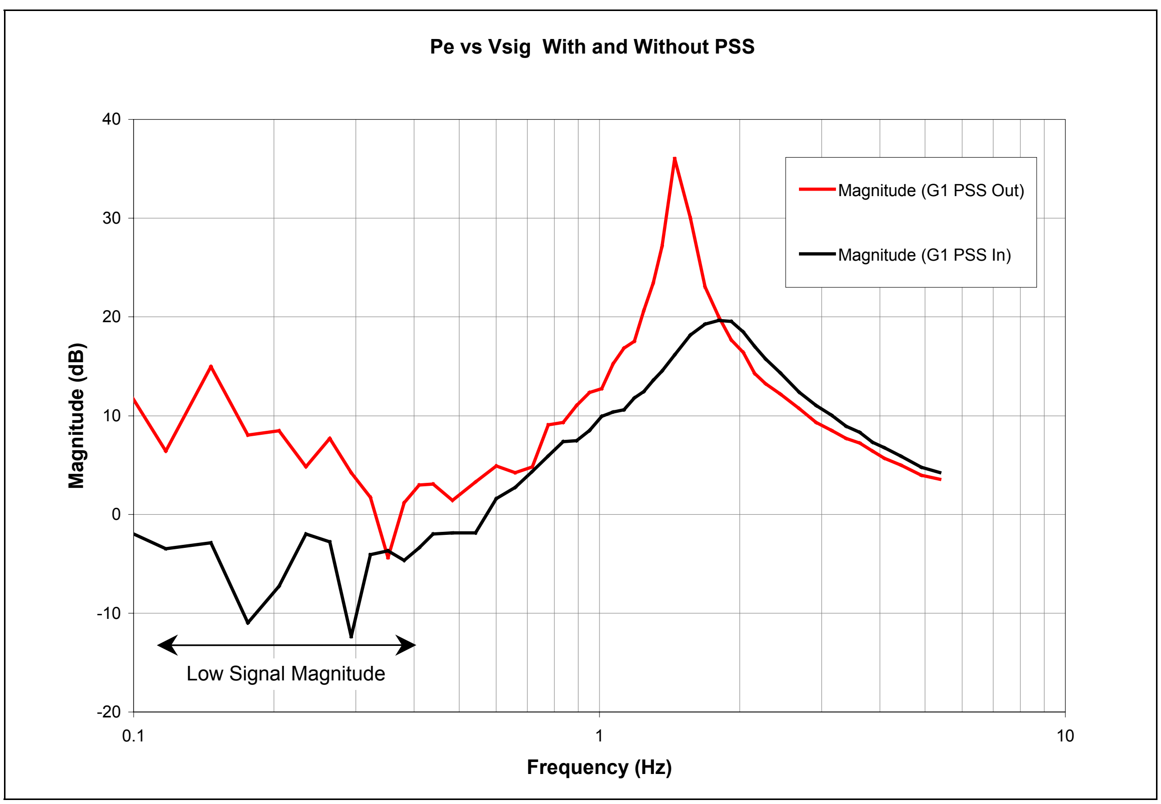

Figure 6

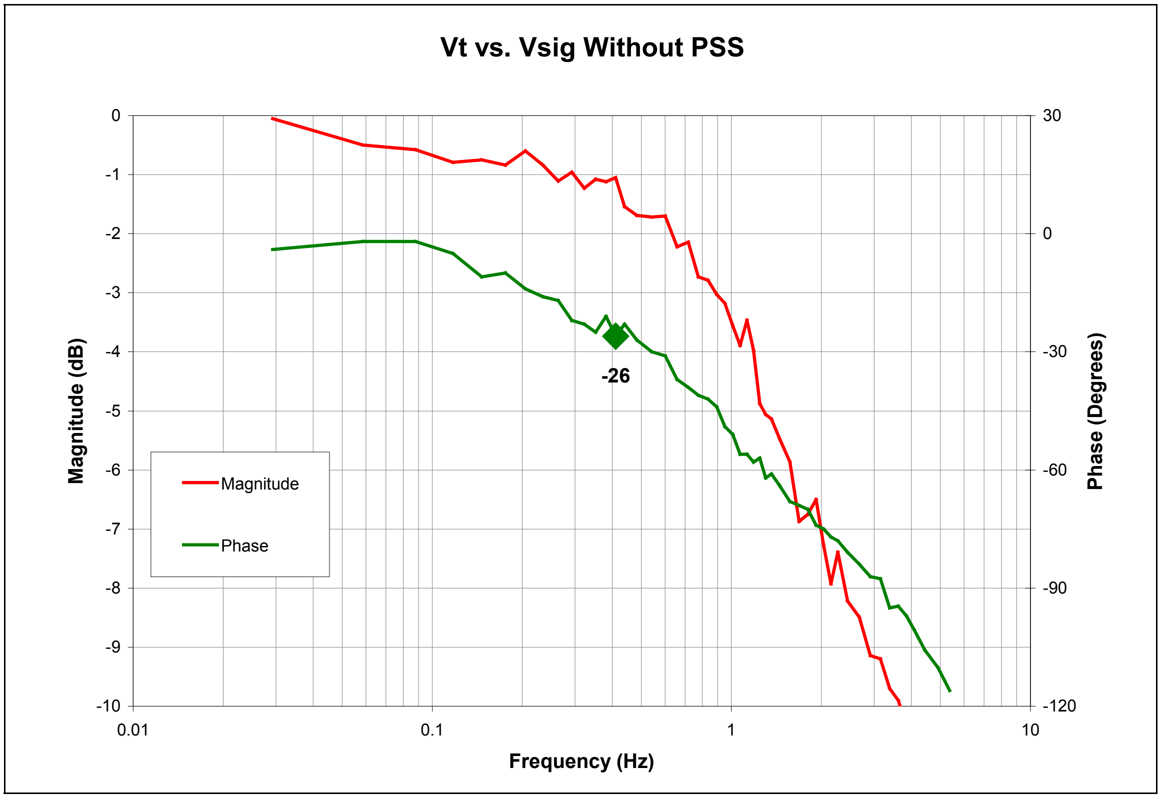
Vt vs. Vsig Without PSS
Magnitude (dB)
Phase (Degrees)
Frequency (Hz)
Magnitude
Phase
-26
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
30
0
-30
-60
-90
-120
0.01
0.1
1
10

Figure 7

WECC Submission:

Model Verification:

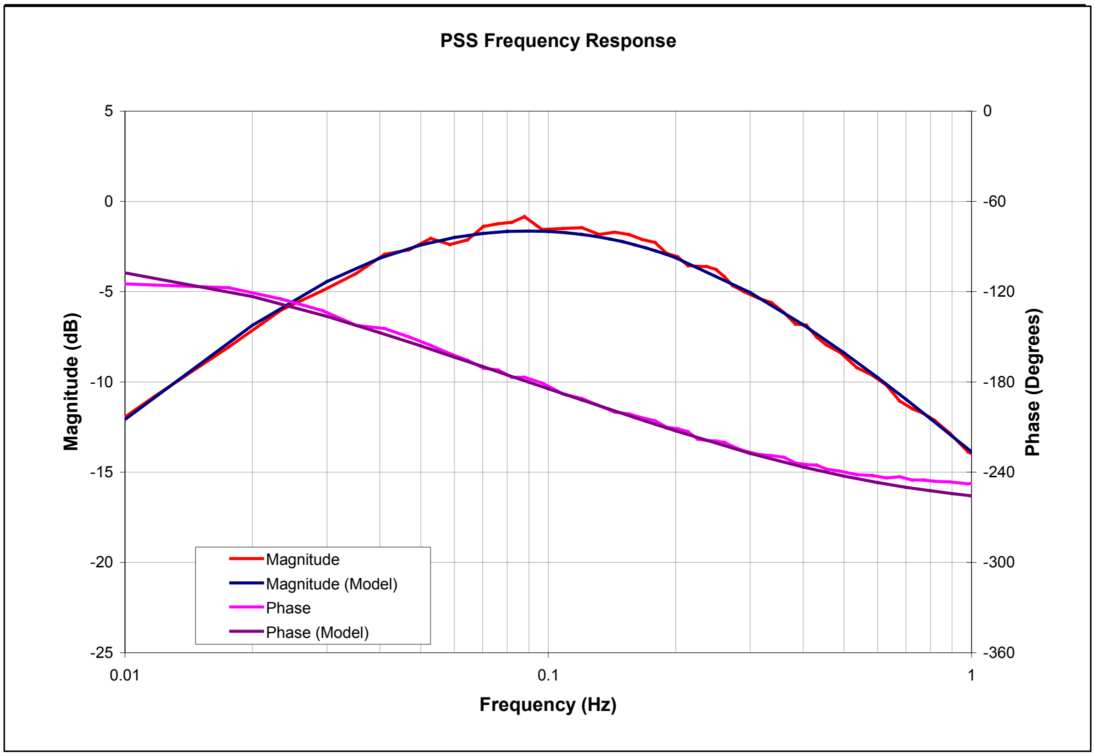

Figure 8 Model Verifcation

IEEEST Model for WECC

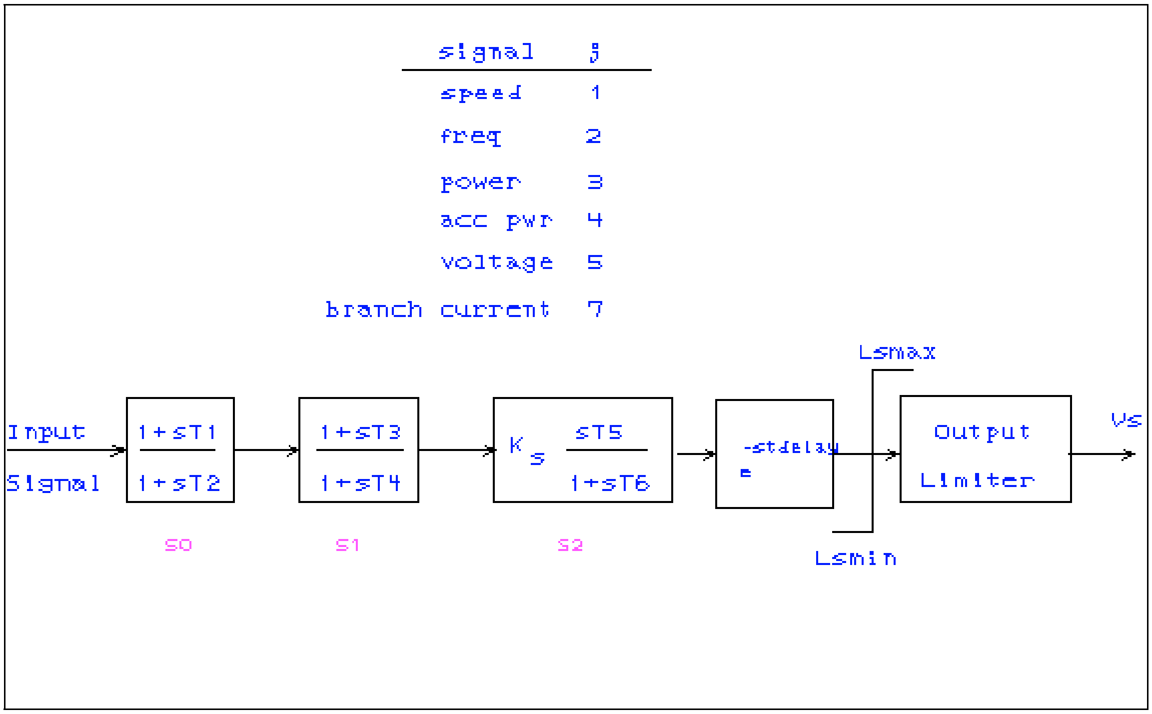

Figure 9 IEEEST Model

Bus No.	Bus Name	PSS/E MODEL	ID	T1	T2	T3	T4	T5	T6	Ks	Lsmax	Lsmin	Tdelay
6021	KCL G1 13.8	IEEEST	1	0.00	0.00	0.00	0.75	1.00	4.20	-4.10	0.10	-0.10	0.00
6022	KCL G2 13.8	IEEEST	1	0.00	0.00	0.00	0.75	1.00	4.20	-4.10	0.10	-0.10	0.00
6023	KCL G3 13.8	IEEEST	1	0.00	0.00	0.00	0.75	1.00	4.20	-4.10	0.10	-0.10	0.00
6024	KCL G4 13.8	IEEEST	1	0.00	0.00	0.00	0.75	1.00	4.20	-4.10	0.10	-0.10	0.00

Figure 10 Model Parameters