Attachment F: Technical Justification WECC-0107 Power System Stabilizer Requirement 3

VAR-501-WECC-3

WECC-0107 Drafting Team (DT)

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Executive Summary

The white paper was commissioned in response to a comment by Arizona Public Service (APS) in response to Posting 4 of the WECC-0107 project.

APS raised the following concerns:

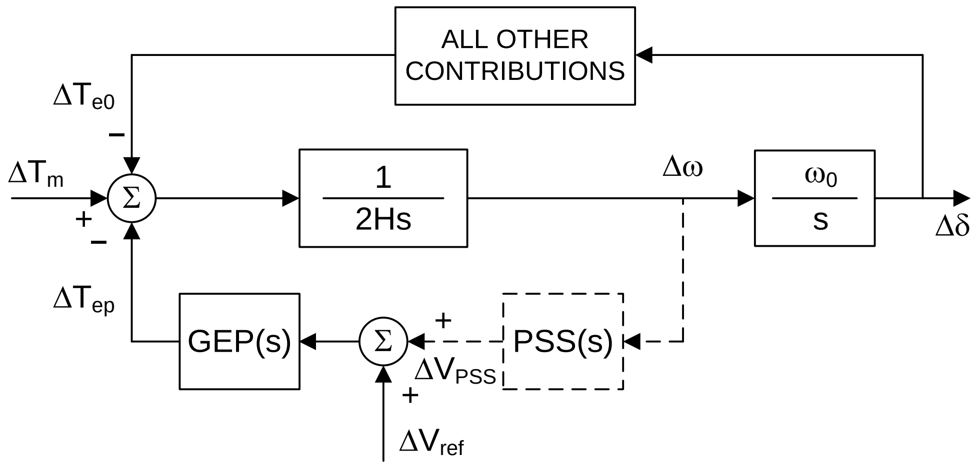
> "R3 implies that Vt/Vref must be measured at minimum load. AZPS recommends that the minimum load requirement be removed for the following reasons:
>
> - For many units, full load is a better measurement point for Vt/Vref for tuning PSS. This is how it has been done historically.
> - Many units are barely stable at minimum load and hence it is problematic to measure Vt/Vref at minimum load. Even if it can be measured it may not be possible to measure instability gain at the minimum load.
> - If PSS settings are based upon calculations it is simple to use any load; however, many utilities, including AZPS, prefer to set PSS based upon actual field measurements so that there are no errors related to system models.
> - If minimum loading requirements are maintained, all of the existing settings will become invalid and will require that PSS of all units in AZPS system (and in other systems) be retuned and the frequency response re-measured.
> - If the drafting team believes Vt/Vref must absolutely be measured at minimum load, please provide sufficient technical background and solutions to the problems mentioned above."

The conclusion of the paper is that conducting tuning at minimum-load is an acceptable approach to tuning; albeit, only one approach. Not all members of the drafting team agree with the conclusion of the paper. As such, the reader is encouraged to review the data, determine the entity-specific impacts, and proceed accordingly within the parameters of the Reliability Standards Development Procedures (Procedures) posted on the WECC Standards home page.

Using Minimum Load for PSS Tuning

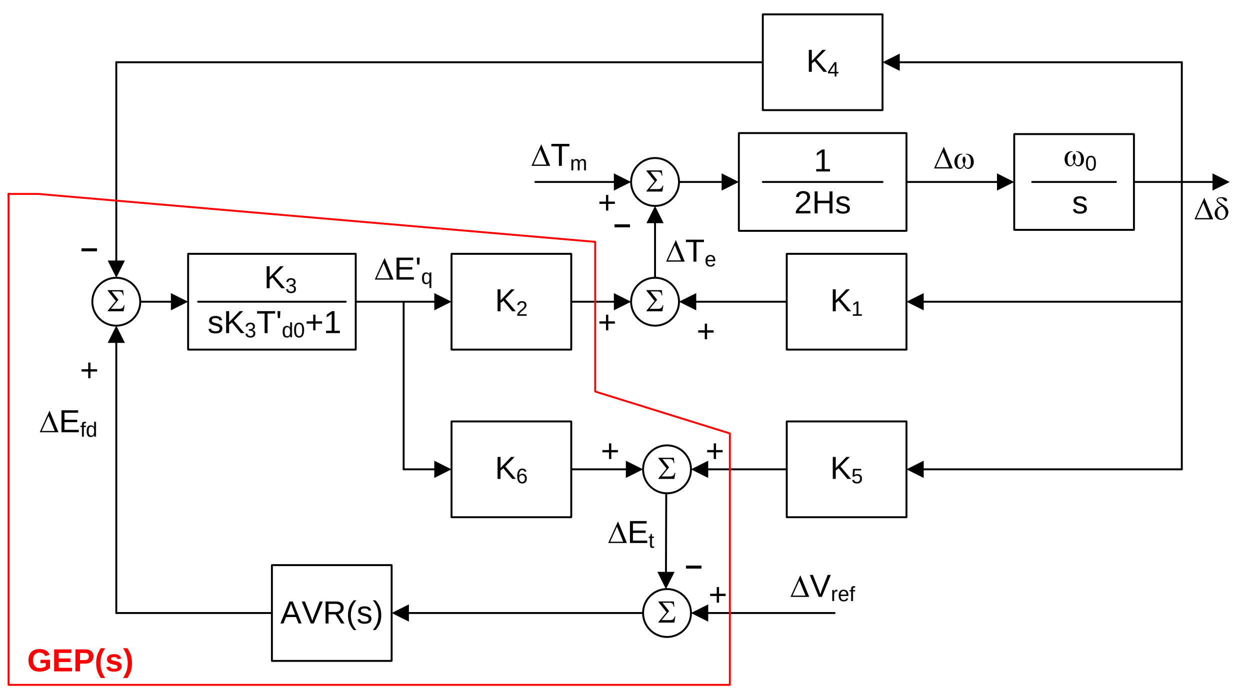
To provide damping over the frequency range of interest, the PSS transfer function PSS(s) should compensate the phase characteristic of the transfer function GEP(s) shown as Figure 1 in [2] and reproduced here (see Figure 1).

Figure 1 – Definition of the GEP(s) Transfer Function



The transfer function GEP(s) is (in the associated theory) defined with the machine operating connected to a large system (infinite bus) at near full power output. This transfer function GEP(s) can also be defined based on the Heffron-Phillips diagram presented in [1], as shown in Figure 2.

Figure 2 – Definition of GEP(s) Based on the Heffron-Phillips Diagram



Mathematically, the transfer function GEP(s) is defined as the transfer function from voltage reference to electrical torque disregarding all contributions to electrical torque that are derived from changes in the rotor angle position δ (or, equivalently, considering a constant rotor speed [2]):

$$GEP(s) = \left.\frac{\Delta T_e}{\Delta V_{ref}}\right|_{\delta=const}$$

In practice, the GEP(s) transfer function cannot be directly measured:

a) There are no transducers to measure the electrical (air-gap) torque
b) There is no practical way to hold the rotor angle position δ constant (or, equivalently, to hold the rotor speed constant) and, thus, eliminate the contributions to electrical torque derived from changes in rotor angle.

From Figure 2, it is possible to see that the GEP(s) transfer function could be indirectly obtained by measuring the transfer function from ΔV_{ref} to ΔE_t, considering the rotor angle δ constant:

$$GEP(s) \approx \left.\frac{K_2}{K_6}\frac{\Delta E_t}{\Delta V_{ref}}\right|_{\delta=const}$$

Since K_2 and K_6 in Figure 2 are real values (constants), the phase characteristic of GEP(s) is identical to the phase characteristic of the transfer function $\Delta E_t/\Delta V_{ref}$, **if the frequency response between V_{ref} and E_t can be measured without the influence from changes in rotor angle position δ**.

Another way to look at the same problem is to eliminate or minimize the contributions coming from the gains K_1, K_4 and K_5. The gain K_1 does not (directly) impact the transfer function from ΔV_{ref} to ΔE_t, as long as contributions from gains K_4 and K_5 are indeed eliminated or minimized.

The expressions for the gains K_4 and K_5, shown in [1], show that these constants approach zero as the initial rotor angle δ_0 approaches zero. This is a condition associated with the operation of the generator synchronized to the large system at minimum load (theoretically with power output equal to zero, although this is a very difficult condition to sustain in a stable manner on most power plants). Therefore, the Standard requires measuring the frequency response from ΔV_{ref} to ΔE_t at the minimum stable load of the generation unit.

Additionally, the frequency response test performed with the generation unit at higher loads or near full load will have the risk of reaching a resonance with any poorly damped electromechanical oscillations modes, particularly the local mode of the unit.

Practical Example

Figure 3 illustrates the practical aspects related to the field measurement of the frequency response between ΔV_{ref} to ΔE_t. The simulated phase characteristic of the transfer function was obtained with the generator synchronized to the large system (infinite bus) at zero power output, the theoretical condition that leads to the gains K_4 and K_5 to become zero.

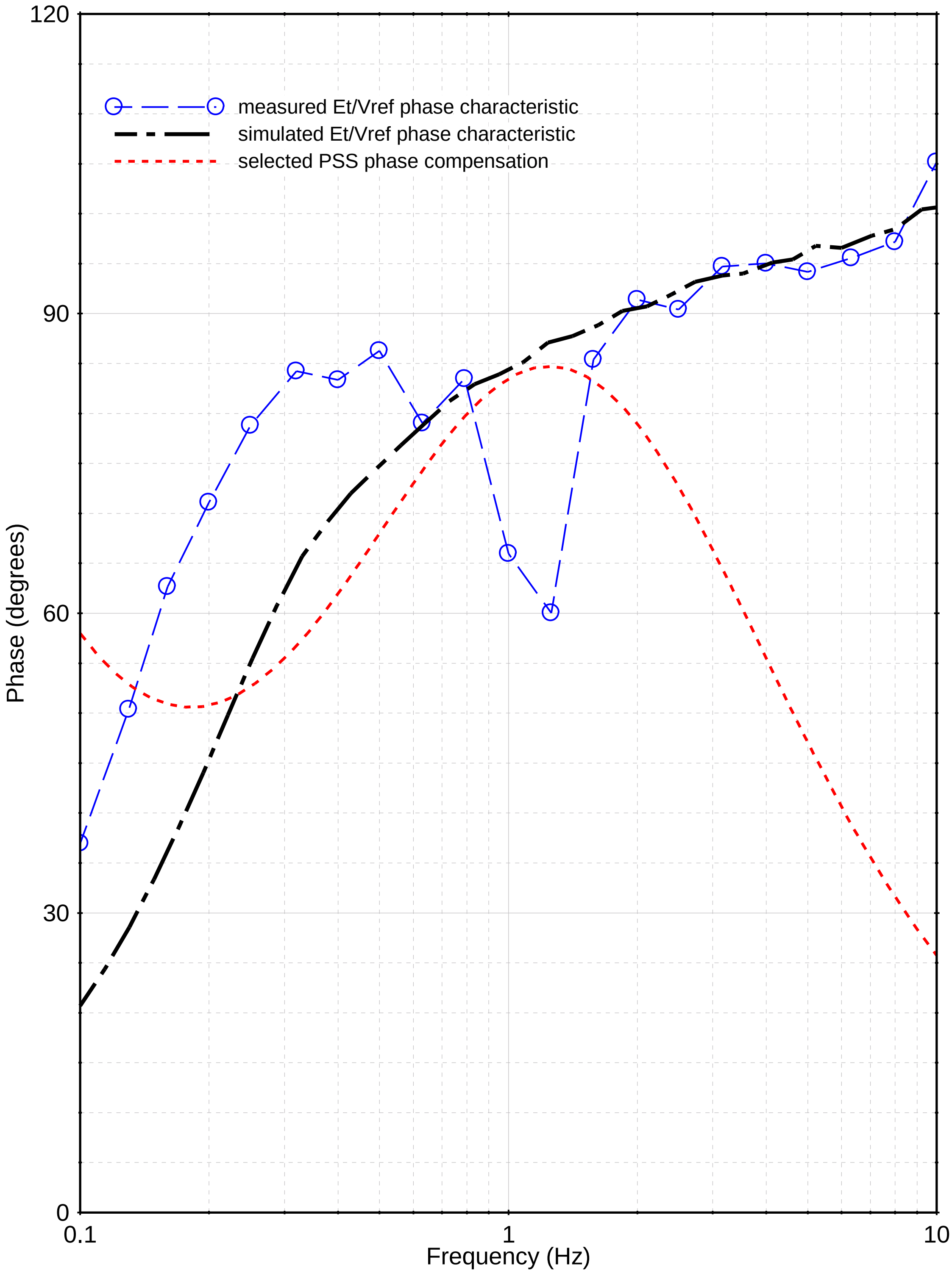
The simulated phase characteristic of $\Delta E_t/\Delta V_{ref}$ (or, equivalently, the phase characteristic of GEP(s)) results in a phase lag, with negative values for the phase. This phase lag characteristic has been plotted in Figure 3 with a positive value, to make it easier to compare with the required phase lead compensation of the PSS transfer function that should compensate the phase lag of GEP(s).

The frequency response test could not be performed at a very low load, and was performed with the unit dispatched near 50% of its load, due to emissions control and limits on how long the unit could operate at such low loads. Once again, the measurements result in phase lag characteristics (negative phase angles) that are plotted in Figure 3 with a positive sign.

A comparison of the simulated and measured phase characteristics show a very good agreement for frequencies above 0.6 Hz, with the exception of the measured points near the resonance with the local mode of oscillation for this unit, around 1.3 Hz. On the other hand, the field measurements resulted in significant additional phase lag for lower frequencies (below 0.6 Hz), as much as 25 degrees at 0.2 Hz.

Considering the requirement that the PSS phase compensation should be within +/– 30 degrees of the requirement, this difference of 25 degrees at 0.2 Hz is very significant. This difference is sufficient to modify the effectiveness of the PSS in providing damping at the lower oscillation frequencies associated with inter-area modes, the fundamental objective behind this proposed Regional Variance.

Figure 3 – Practical Example of the Measurement and Simulation of the PSS Phase Compensation Requirement



References

[1] F. P. de Mello and C. Concordia, “Concepts of Synchronous Machine Stability as Affected by Excitation Control,” IEEE Trans. on Power Apparatus and Systems, vol. 88, no. 4, April 1969, pp. 316-329

[2] E. V. Larsen and D. A. Swann, “Applying Power System Stabilizers – Part I: General Concepts,” IEEE Trans. on Power Apparatus and Systems, vol. 100, no. 6, June 1981, pp. 3017-3024