Small Signal Stability Analysis Module

Network Eigenvalue Analysis for PSS®E

Figure 1: Analysis of electromechanical phenomena

Eigenvalue and modal analysis describe the small signal behavior of the system – the behavior linearized around one operating point – but not the non-linear behavior of, for instance, controllers during large perturbations. Therefore, time domain simulation and modal analysis in the frequency domain complement each other in the analysis of power systems.

Eigenvalue analysis investigates the dynamic behavior of a power system under different characteristic frequencies (modes). In a power system, it is required that all modes be stable. Moreover, it is desired that all electromechanical oscillations be damped out as quickly as possible. The results of an eigenvalue analysis are given as frequency and relative damping for each oscillatory mode.

A damping ratio of -5 % means that in three oscillation periods the amplitude is damped to about 32 % of its initial value. However, the minimum acceptable level of damping is not clearly known.

A damping ratio of more than -3 % must be accepted with caution. Damping is considered adequate if all electromechanical modes have a predicted damping ratio of max. -5 %. Figure 2 depicts how the damping of a system can be easily analyzed.

At a glance

Stability problems, such as inter-area oscillations, have become increasingly common in large interconnected power systems. The Small Signal Stability Analysis add-on module provides an extension of the classical large-signal analytical methods in the time-domain with small-signal methods in the frequency-domain to examine these oscillations.

The Small Signal Stability Analysis add-on module:

- provides methods to investigate long-term stability,
- allows a deeper view into eigenvectors,
- determines the best damping locations and,
- allows an evaluation of damping strategies.

The challenge

Power systems are steadily growing with ever larger installed capacity. Formerly separated systems are now interconnected. Modern power systems have evolved into systems with a very large size, stretching out over hundreds and thousands of kilometers. With growing generation capacity, different areas in a power system grow, with the effect of adding ever larger inertias.

Furthermore, the unbundling of generation, transmission and supply is less oriented towards the physical nature of the synchronously interconnected power systems that span a large area and share interactions among the different sub-networks and power plants. However, in a market-driven environment with potentially higher transmission system loading, the operators may be forced to operate the system closer to its stability limits.

As a consequence, the small signal stability performance of large interconnected power systems has gained in importance. Inter-area oscillation has been found to be a common problem in large power systems worldwide. Many electric systems have experienced poorly damped low frequency (0.2-0.8 Hz) inter-area oscillations as a result of system growth and interconnection.

Our solution

The Small Signal Stability Analysis module can be used in many products of the PSS® product suite, such as PSS®E, PSS®SINCAL, PSS®NETOMAC.
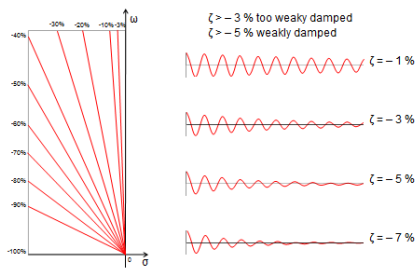
Figure 2: Criteria of weakly and well-damped system

The modal system analysis allows for a much deeper analysis by not only interpreting the eigenvalues, but by also analyzing the eigenvectors of a system. The latter are automatically calculated during the modal analysis:

- The right eigenvector gives information about the observability of oscillations

- The left eigenvector gives information about the controllability

- The combination of the right and left eigenvectors (residues) indicates the location of the damping-controllers

The damping of inter-area oscillations is very important. The oscillations can be damped when extra energy is injected into the system, which instantaneously decelerates the system, and/or vice-versa when extra energy is consumed in the system.

$$f = \frac{1}{2\pi} \sqrt{\frac{\omega_N\, E'V \cos\delta_0}{T_A\, X}}$$

In real power systems the damping energy is obtained from the modulation of load or generation for some period of time, typically in the range of five to ten seconds.

The damping energy must have the correct phase shift relative to the accelerated/decelerated systems. Incorrect phase angles can even excite power oscillations.

Using the system eigenvectors (figure 3), the best damping location can be found. Depending on the selected damping strategy the residues chart shows the location(s) for a power system stabilizer (PSS). In this example, other devices that were studied for comparison include a static Var compensator (SVC), and a thyristor-controlled static compensator (TCSC).

Omega/VFd Residuum Magnitude	Omega/VFd Residuum Phase [°]	Machine Y(s)	Mode - Fre... [Hz]	Mode - Rel.... [%]
1.000	0.000	3018G1	1.549	-13.210
0.406	290.622	206G1	1.549	-13.210
0.044	324.927	211G1	1.549	-13.210
0.024	27.006	3011G1	1.549	-13.210
0.006	331.907	102G1	1.549	-13.210
0.006	331.907	101G1	1.549	-13.210

Figure 3: Eigenvectors of an inter-area mode

Application example

Figures 4 to 7 show the results of an Eigenvalue calculation/modal analysis for the ENTSO-E CGMES 1-machine benchmark network with or without stabilizer (PSS).
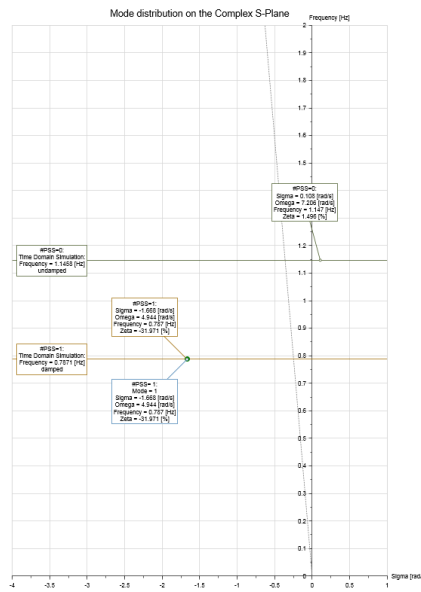

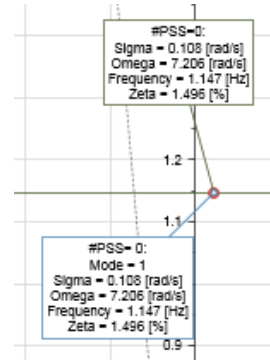Figure 4: Results of the Eigenvalue Analysis

Figure 5: Results of the eigenvalue analysis (Details: Documentation of specific values)
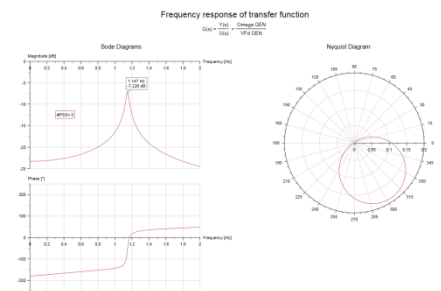

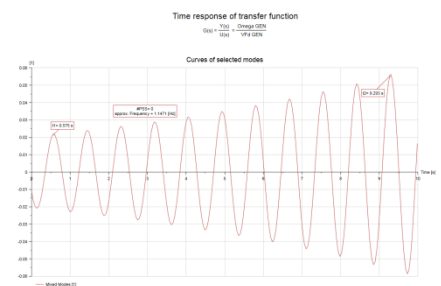Figure 6: Results of the modal analysis (Bode-Diagram)

Figure 7: Results of the modal analysis (Time response)