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Eigenvalue Analysis

PSS® Product Suite

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

Eigenvalue analysis enables the investigation of the dynamic behavior of a linearized power system model regarding its oscillation behavior (modes). In general, it is required that all modes are stable. Moreover, it is desired that all electromechanical oscillations are appropriately damped. The results of an eigenvalue calculation are given in a complex plane or tabular overview of eigenvalues with damping, frequency and damping ratios.

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 % has to be taken with caution. Damping is considered adequately if all electromechanical modes have a 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 eigenvalue and modal analysis module (NEVA) 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 eigenvalue analysis module (NEVA)

- provides methods to investigate small-signal and long-term stability,
- allows a deeper view into eigenvectors, participations and residues,
- enables the determination of the best damping locations, and
- allows the evaluation of planned 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 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 oscillations have 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) oscillations as a result of system growth and interconnection.

Our solution

The eigenvalue and modal analysis module (NEVA) can be used in all products of the PSS® product suite, such as PSS®E, PSS®SINCAL, PSS®NETOMAC.

Large Signal Stability dynamic transition from one working point to another nonlinear	**Small Signal Stability** dynamics around a given working point linear
Simulation Method by numerical integration in the time domain	
	Modal Analysis by eigenvalue calculation in the frequency domain

Figure 1: Matrix of analysis methods

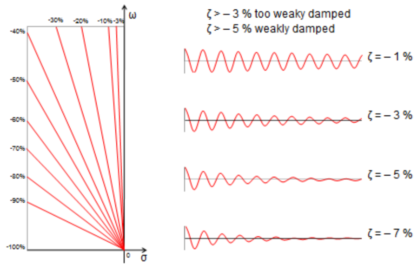

Figure 2: Impact of different damping ratios

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

- The right eigenvectors give information about the observability of oscillatory modes
- The left eigenvector gives information about their controllability
- The combination of right and left eigenvectors indicates good locations for damping countermeasures

The damping of inter-area oscillations is very important. The oscillations can be damped, if 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 loads 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 for specific oscillation modes 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

The eigenvalue analysis module NEVA can be utilized within the development process of damping strategies in large power systems exhibiting low-frequency oscillations.

Figures 4 to 6 show the results of an eigenvalue calculation and modal analysis for the ENTSO-E CGMES single machine infinite bus system benchmark with and without a power system stabilizer (PSS). The figures show the impact of the designed controller on the mode damping. It significantly improves the damping of the existing electromechanical mode. The identified residues have predicted the impact of the power system stabilizer already in the planning phase.

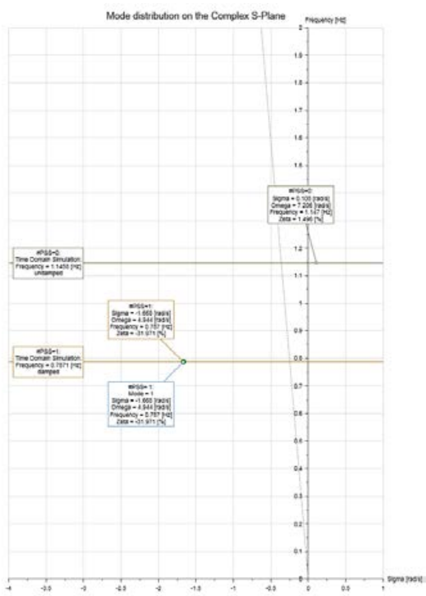

Figure 4: Results of the eigenvalue calculation in the complex plane

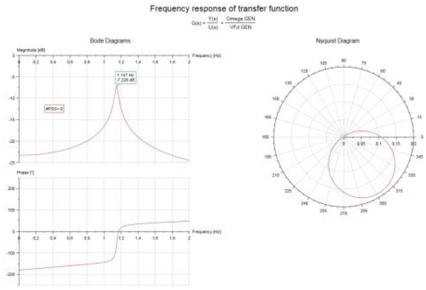

Figure 5: Frequency response of the state variable machine speed at perturbation at the excitation voltage

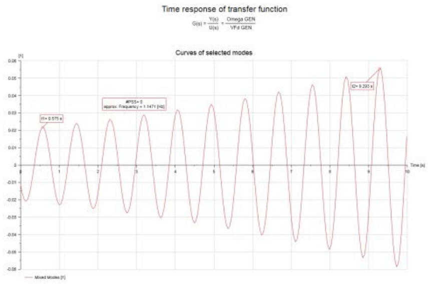

Figure 6: Impulse response of the state variable machine speed at perturbation at the excitation voltage

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