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Subsynchronous resonances studies

Analyzing the risk of torsional oscillations on multi-mass generator rotor shafts

At a glance

Series compensation on transmission lines is a cost-effective method to increase the transmission capacity as well as enhance angle stability, but imposes relevant risks for the power plants connected nearby in the transmission system. In such cases, Sub-Synchronous Resonances (SSR) may arise, leading to oscillatory phenomena on the multi-mass shaft of generators which could be poorly damped, undamped or even amplified. Increasing torsional oscillation creates risk of fatigue and damage to the rotor shaft assembly of turbine-generator sets.

In conclusion “SSR is a transmission-system-based problem that may adversely affect turbine-generator sets on that system”. For the investigation of this phenomenon Siemens PTI can provide expert power system consulting services including:

- Complete SSR investigation from preliminary analysis based on passive frequency scan up to detail time domain simulations to confirm the risks.
- When necessary, recommendation of countermeasures as avoidance of certain topology, bypass capacitors, reduced power, generator trip, etc.

The challenge

In a power system which includes series-compensated transmission lines, resonance conditions may arise in the electrical circuit consisting of an inductance and a capacitance as depicted in Figure 1. The shaft structure of a turbine-generator unit has a number of inherent resonance frequencies, so-called natural frequencies, which correspond to the eigenvalues or modes of the shaft system.

A system fault or sudden load change may excite transient power oscillations at subsynchronous frequencies as shown in the electrical torque of Figure 2. The resonance frequency depends on the degree of line compensation and typically ranges between 10 and 45 Hz. If the frequency corresponds to an undamped natural frequency of a generator shaft, the electrical power system may interact with the shaft and cause subsynchronous resonance.

This condition can be seen in the growing oscillation of the shaft torque in Figure 2 after the disturbance. Whether or not SSR occurs depends on the system conditions after the disturbance.

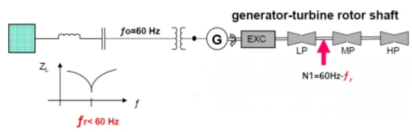

Figure 1: Series compensated line and mode shape diagram of generator-turbine rotor shaft

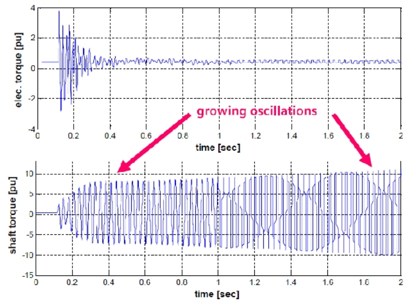

Figure 2: Electrical and shaft torque after a disturbance in the electrical network

Our solution

There are four study techniques that can be applied to analyze SSR phenomena, they are:

- Passive frequency scan;
- Transfer function analysis;
- Eigenvalue analysis;
- Simulation in time domain.

The passive frequency scan method is most widely used for preliminary investigation of SSR. It evaluates the frequency-dependent impedance of the passive network in the frequency range of interest as viewed from the investigated generator.

The transfer function analysis is based on small perturbation theory and determines the complex synchronizing coefficients and damping torques of the electrical system as seen from the investigated generator.

Eigenvalue analysis is based upon the calculation of the natural frequencies (modes) of the coupled electric system and mechanical multi-mass-spring system.

Time-domain simulation uses full three-phase electrical representation of network and generators, and permits detailed modeling of the multi-mass shaft systems. Detailed representation of nonlinear effects is also possible. SSR can be identified by observing the time response of the torques at a particular shaft system. If they persist or grow in time, then the system almost surely has an SSR problem as shown in Figure 3.

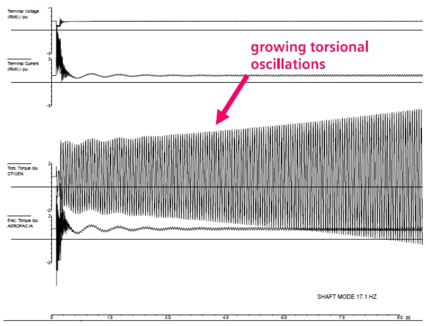

Figure 3: Time-domain simulation

Application example 1

The upgrade of a 230 kV transmission line by fixed series compensation (FSC) to allow transfer of more power motivates the analysis of SSR for 4 different nearby connected power plants. The analysis is performed based on passive frequency scan which shows that contingencies with 4 or more line outages have a high potential to exhibit a subsynchronous resonance frequency in the electrical network as seen from the analyzed generator unit. An excitation of this frequency would have a corresponding rotor shaft excitation frequency which is the system frequency (60 Hz in this case) minus the network resonance frequency. Rotor shafts that possess natural torsional frequencies in the ranges are likely to response to an excitation from the network side. For one generation unit of power plant No. 4 the electrical network resonance range is 25.0 Hz – 30.9 Hz (Figure 4) and the excited frequency range at the rotor shaft is 29.1 Hz – 35.0 Hz. The natural torsional rotor shaft frequencies of the generation unit are 18.9 Hz, 33.6 Hz, 42.6 Hz and 43.9 Hz. A comparison with the above range shows that the 33.6 Hz mode is within the range of excited rotor shaft frequencies so there is a potential risk of Torsional interaction between the rotor shaft and the electrical network at this frequency.

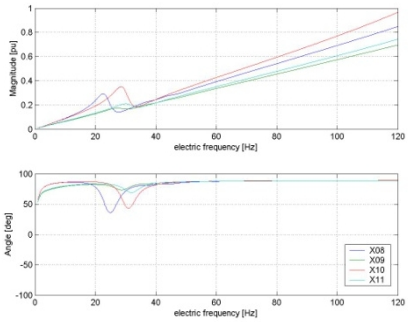

Figure 4: Frequency scan with series resonances

In order to gain more insight of the particular behavior of the Torsional interaction, Transfer Function Analysis has been carried out. This analysis evaluates the damping characteristics of the electrical network and answers whether subsynchronous torsional oscillations would damp out or possibly grow with time. Growing oscillations would represent a subsynchronous resonance condition with the risk of fatigue and damage to the rotor shaft assembly of a machine.

The analysis for this generator unit has shown that there is negative damping for the 33.6 Hz-mode. The electrical network has a strong negative damping component at this frequency, so that the mechanical damping would not be sufficient to damp out subsynchronous torsional oscillations. Therefore, a likelihood of subsynchronous resonance must be expected at this unit.

This generator unit should be equipped with an SSR relay to trip the unit in the event of growing torsional oscillations and to protect it from experiencing fatigue or severe damage. Furthermore, means of mitigation should be studied such as bypassing the series capacitors in the event of a high number of simultaneous equipment outages.

Application example 2

During a tender request for 400kV series compensation equipment (35% compensation level), Siemens offered suitable equipment not only to meet the specification requirements, but also to provide a technical solution to the SSR phenomenon that could possibly arise. The key questions to be answered were:

- Considering the price is a TCSC (Thyristor-Controlled Series Capacitor) needed, or would perhaps an FSC suffice?
- Would an FSC solution cause subsynchronous resonance?
- Would a TCSC solution cause subsynchronous resonance?
- How much better is a TCSC solution over an FSC solution regarding SSR?

The analysis has been carried out for closest power plant to the proposed location of the FSC.

It could be shown that the electrical network may contribute to torsional instability at the generator units if FSCs are installed. By contrast, the TCSC solution provides a far superior damping of torsional oscillations especially of the higher frequency shaft modes. For lower frequency shaft modes, say below 10Hz, both the FSC solution and TCSC solution provide approx. equal torsional oscillation damping for the generator units.

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