Subsynchronous Resonance in Doubly-Fed Induction Generator-Based Wind Farms

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BACKGROUND

As wind power is transmitted over long lines, series compensation is often considered as a means of increasing the power transfer capability of an existing transmission line. However, a factor hindering the extensive use of series-capacitive compensation is the potential risk of subsynchronous resonance (SSR), which may severely damage a wind farm if not prevented.

Traditionally, SSR phenomena were thought to be associated strictly with turbine generators, when series-compensated lines create an electrical resonance that corresponds to a torsional mode of the turbine-generator shaft. However, in the case of doubly-fed induction generator (DFIG) turbines, control schemes can mimic the same effect through the rotor controls. The Electric Reliability Council of Texas (ERCOT) experienced this type of SSR in 2009.

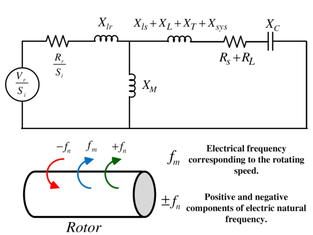
OBJECTIVE

Identification and definition of the main types of SSR that may occur in DFIG wind farms, including:

- Induction generator effect (SSIGE)
- Torsional interactions (SSTI)
- Control interactions (SSCI)

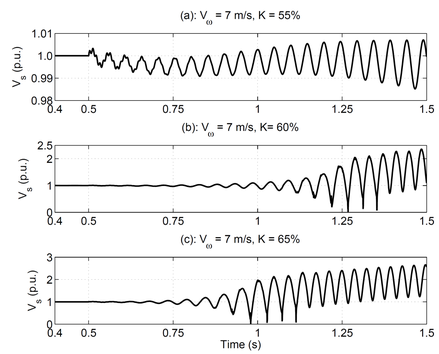
1. INDUCTION GENERATOR EFFECT (SSIGE)

- Equivalent circuit of the system under subsynchronous and supersynchronous frequencies.



- If the magnitude of the equivalent rotor resistance exceeds the sum of the resistances of the armature and the network, there will be a negative resistance at the subsynchronous frequency, and the subsynchronous current will increase with time. This is the SSIGE phenomenon.

IMPACT OF COMPENSATION LEVEL AND WIND VARIATIONS ON SSIGE

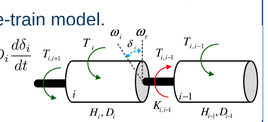


2. TORSIONAL INTERACTIONS (SSTI)

- Structure of a typical drive-train model.

$$2H_i\frac{d\Delta\omega_i}{dt} = T_i + T_{i,i+1} - T_{i,i-1} - D_i\frac{d\delta_i}{dt}$$

$$\frac{d\delta_i}{dt} = \omega_i - \omega_r = \Delta\omega_i$$



- If generator rotor oscillates at a torsional natural frequency, this phenomenon induces armature voltage component in the generator at frequencies given by:

$$f_{mi} = \frac{\omega_{ni}\sqrt{1-\zeta_i^2}}{2\pi}$$

- If f_{emi} is close to f_n, which is the electric natural frequency due to series compensation, the subsynchronous torques generated by this subsynchronous-induced armature voltage can be sustained. This energy exchange between the electric part of the DFIG wind farm and its mechanical part is called SSTI.

DOES SSTI OCCUR IN WIND FARMS?

- Low shaft stiffness coefficient in wind turbines leads to low torsional natural frequencies (from 1-5 Hz).
- In order to cause SSTI in a wind farm, the electric natural frequency of the network should be in the range of 55-59 Hz.

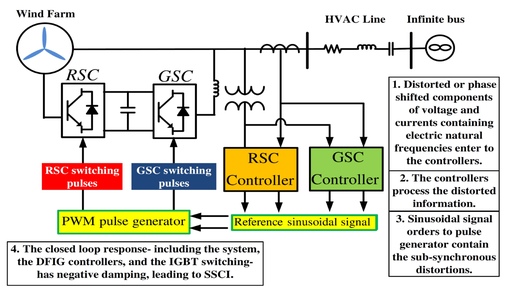
DOES SSTI OCCUR IN WIND FARMS?

- In order to obtain such a large electric natural frequency in the network, a very high series-compensation level is needed.
- In practice, the series compensation is normally not larger than 70% to 75%.
- Hence, SSTI is not a concern in wind turbine generators.

3. CONTROL INTERACTIONS (SSCI)

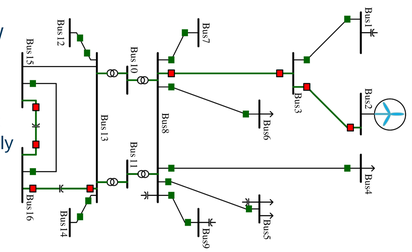
- SSCI is mainly due to the interactions between DFIG wind turbine controllers and the series-compensated transmission line, to which the wind farm is connected.
- Unlike the other SSR types, SSCI does not have well-defined frequencies of concern.
- The reason is that the frequency of oscillations in SSCI depends not only on the configuration of the series-compensated transmission line and induction generator parameters, but also on the wind turbine controller configuration and parameters.
- The oscillations caused by SSCI may grow faster compared to other SSR types, since the undamped oscillation in SSCI completely depends on the electrical and controller interactions, which have a smaller time constant.

SSCI MECHANISM IN DFIG-BASED WIND FARMS



ERCOT SSCI EVENT IN 2009

- Section of the ERCOT grid, where a 200-MW DFIG wind farm is connected to Bus 2.
- The thick green line is the worst-case scenario, where all other lines in the network are open, and thereby the wind farm is radially connected to the series-compensated lines.



CONCLUSIONS

- At lower wind speeds and higher compensation levels, the possibility of SSIGE in DFIG becomes greater.
- SSIGE is not related to the mechanical part of the system and is a purely electrical phenomenon.
- Because of the low-shaft stiffness coefficient in wind turbine generators, SSTI is not a concern.
- SSCI does not have well-defined frequencies of concern.
- Oscillations caused by SSCI may grow faster compared to SSIGE and SSTI.

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