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Subsynchronous Oscillation Risks of Wind Power Plants Connecting to Finnish Series Compensated Network

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1 Background

The large-scale integration of renewables have brought into attention new aspects to traditional dynamic power system phenomena. One of these aspects is related to high amplitude, undamped subsynchronous oscillations (SSO) which may under certain conditions appear as a result of subsynchronous interaction between wind power plants (WPP) and series compensated transmission network. If high amplitude sustained or undamped oscillations appear, they may damage wind power plant or series compensation equipment unless proper countermeasures are implemented both at generation and transmission equipment. In the beginning of 2010 the first incidents [1], [2] related to extremely high amplitude of subsynchronous oscillations (SSO) due to subsynchronous interaction between wind power plants and series compensated network were reported. These were also the first incidents, which resulted into equipment failures due to excessive subsynchronous current stresses, and consequently, development of countermeasures. In the recent years, the amount of documented SSO incidents [3] have been raised dramatically due to large-scale integration of the renewables. This document elaborates the nature and the ultimate risks that the undamped or sustained subsynchronous oscillations could cause to the wind power plants connected in proximity to the series compensated network. This document describes also the countermeasures, which are required from the wind power plants to manage the risks related to adverse subsynchronous interaction.

In the Finnish transmission system, series compensation has been utilized since 1997 at the 400 kV North-South power transmission corridor and cross-border interconnections to Sweden. Series compensation is applied to enhance the North-South transmission capability of Finnish transmission system, and at present the series compensation is estimated to more than double the North to South transmission capacity as compared with the transmission capability without series compensation. In Finland, the risk of the wind power plant related SSO is becoming increasingly relevant, due to the increase of the planned wind generation sites located in vicinity of the series compensated network in Central and North Finland. In the recently made generic SSO risk assessment studies, rather significant risk of subsynchronous interaction was observed between the series capacitors and the wind power plants connected in vicinity of the series compensated network. Based on the study results, the rough estimation of the SSO related main risk areas were located. The figure 1 represents the main SSO risk area. If the connection point or the connecting grid of the wind power plant is located within the main risk area, then the risks related to undamped or sustained subsynchronous oscillations shall be taken into account.

The subsynchronous oscillations is likely to appear in the series compensated transmission networks, because the connection of capacitance of the series capacitor in the inherently inductive transmission network creates an electrical resonance in so called subsynchronous frequency range (5-45 Hz). Subsynchronous oscillations in series compensated network are inherently well damped, but they may become sustained or undamped due to interaction between wind power plant and series compensation as further elaborated in the chapter 2. Sustained or undamped oscillations appear at the wind power plant and series compensation equipment mainly as high amplitude currents, which can cause physical damages unless detected and mitigated promptly. In case of high amplitude oscillations between a wind power plant and a series capacitor, the most vulnerable component suffering damage is typically the wind turbine converter and the generator. Possible damage can occur also to the series capacitors and other grid components due to the high amplitude current components.

In series compensated network, the subsynchronous resonance frequencies vary depending on different grid topologies and transmission line contingencies throughout the subsynchronous frequency range. In addition, the parallel wind power plants may also affect the frequency of the resonance points around which the interaction is most likely to appear and result possibly into sustained or undamped oscillations. This leads to the fact that the wind turbines (DFIGs [1-3] and Full Converters [4]) connected to series compensated network may be subject to high amplitude subsynchronous currents with any frequency within the subsynchronous range (5-45 Hz). Therefore, in the main risk areas, Fingrid requires the WPP owner countermeasures to manage, control and ultimately protect the WPP asset against subsynchronous oscillation, which might occur throughout the subsynchronous range. In addition, Fingrid requires the WPP owner to ensure the installation of the sufficient transient fault records, which will be needed to investigate the root cause of the possible subsynchronous phenomena experienced by the WPP.

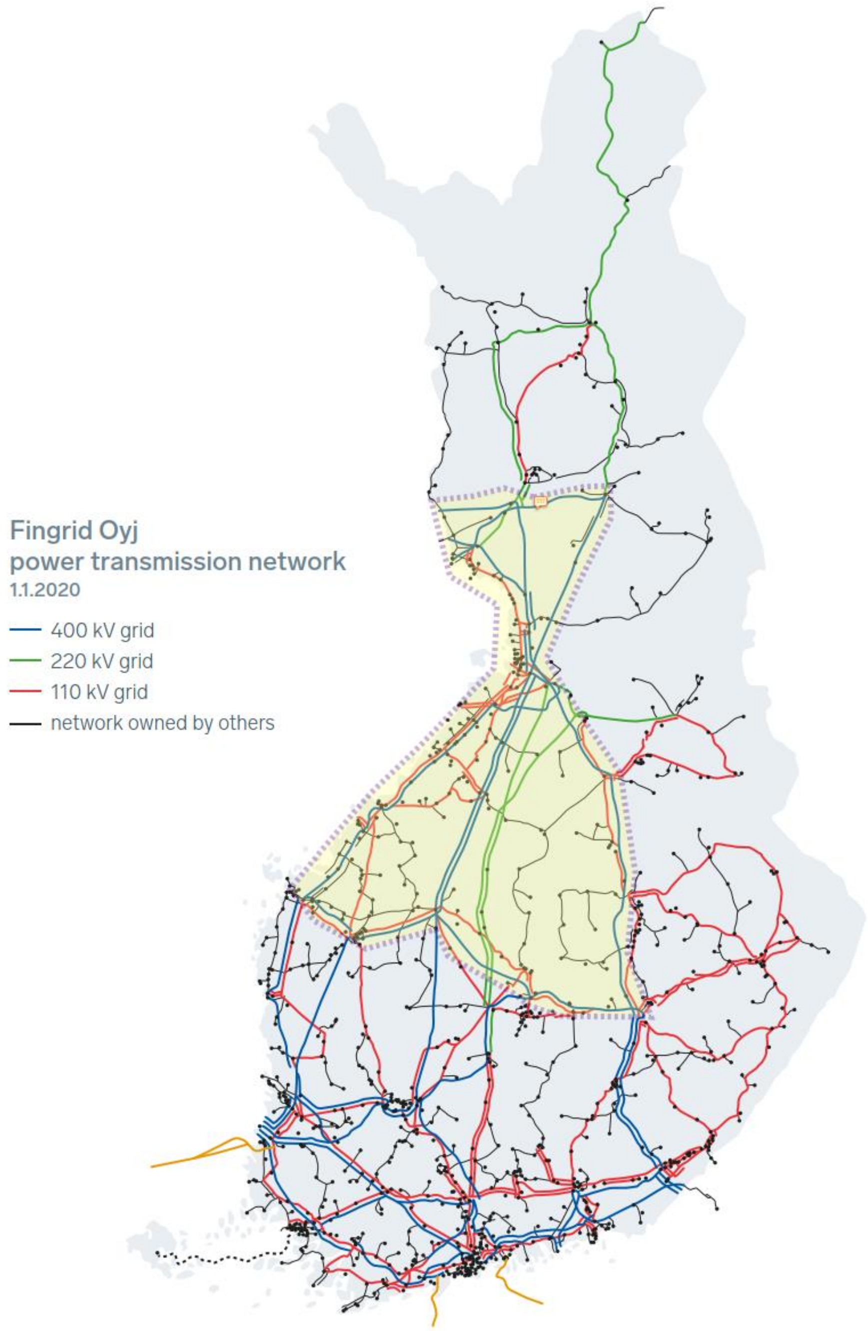

Figure 1. Present view of the main SSO risk area highlighted in yellow. If the connection point or the connecting grid of the wind power plant is located within the main risk area, then the risks related to undamped or sustained subsynchronous oscillations shall be taken into account.

2 Details of the phenomena

Series connection of transmission line reactance and capacitance of the series capacitor create an electrical series resonance. The series resonance frequency of a series compensated transmission line can be determined based on the capacitance of the series capacitor and the inductance of the transmission line(s). In the transmission network where series compensation is not applied, the resonance points are located well above the subsynchronous range. In case of transmission system with several series compensated lines, there are inherently several series resonance frequencies and depending on the location of interest, few resonance points become dominant. In series compensated network these series resonance points appear in the subsynchronous range (5-45 Hz). The exact dominant series resonant frequencies depend on the network topology including operational and switching conditions.

The high amplitude undamped or sustained oscillations in series compensated network appear typically only as a result of various subsynchronous interaction phenomena. In case of adverse subsynchronous interaction between wind power plants and series compensated transmission, the undamped or sustained oscillations tends to appear in the vicinity of the series resonance frequency as seen from the point of connection of the wind power plant to high voltage network. Essentially, these resonance frequencies are those where the capacitive and inductive reactances become equal ($X_{L,system} = X_{C,system}$) or nearly equal when the network characteristic are considered from the wind power plant connection point. The resonance point is observed most clearly from the WPP connection point if the WPP end up in radial or close radial connection with series capacitors. Under such conditions the risk of adverse subsynchronous interaction, and consequently to excessive subsynchronous current stresses, is at highest.

At the subsynchronous resonance frequencies, the subsynchronous oscillations are only mitigated by the network's resistance, i.e. the energy of the subsynchronous oscillations is dissipated in the network resistances only. Since a network consisting only on transmission lines, series capacitors, power transformers and other passive or "uncontrolled and static" components always have a positive resistance, in such network the subsynchronous oscillations are inherently rather well damped. For adverse interaction and consequently sustained or undamped subsynchronous oscillations to appear, a mechanism which reduces and negates the network positive resistance, i.e. damping at the subsynchronous resonance frequency, is required. The adverse subsynchronous interaction between wind power plants and series compensation is dependent on dynamic characteristics of wind power plants and two main interaction mechanisms have been identified so far: a mechanism related to the response of the power electronic converter on subsynchronous oscillations and one related to the inherent characteristics of induction generator. In case of the DFIG (doubly-fed induction generator) these two mechanisms appear simultaneously.

The power electronic converters have such inherent characteristics that they start to inject subsynchronous currents into the network if the voltage at the converter connection point contains subsynchronous voltage components. The characteristics of these injected currents may be such that they support the subsynchronous oscillations in the transmission network, and thus result into sustained or undamped SSO. The impact of converter on damping of SSO is dependent on the implementation of the converter controls, which also, at least in theory, provides also opportunities to improve the response to ensure positive damping. The induction generators applied in the DFIG wind power plants possess inherently negative damping characteristics in certain range of subsynchronous frequencies. This is due to the fact that the rotational speed of the induction generator deviates from the nominal system frequency, and this deviation may result into condition where induction generator start to inject subsynchronous currents into the network. In DFIG wind power plants, the converter controls have major impact on the DFIG's characteristics in subsynchronous frequencies as the rotor currents are controlled by the converter, but the details of the actual mechanisms and possibilities to affect the injected subsynchronous currents of the WPP are known to be very complex.

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The impact of wind power plant converter control on adverse subsynchronous interaction, as well as the possibilities to affect the severity of the interaction through design of the converter, converter controls and other equipment, is known in detail only by the equipment manufacturers. In case of DFIGs, the same applies also to the combined impact of the inherent induction generator characteristics and converter control on adverse subsynchronous interaction. Since i.e. the network characteristics and the WPP operation point in PQ diagram also affects the converter response to the subsynchronous currents, the acceptable response of the WPP to subsynchronous currents need to be validated carefully. The validation shall be performed to ensure sufficient damping of WPPs in all of the realistic operation points throughout the subsynchronous region (5 - 45 Hz).

References

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