NERC

NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Lesson Learned

Sub-Synchronous Interaction between Series-Compensated Transmission Lines and Generation

Primary Interest Groups
Generator Operators
Generator Owners
Transmission Operators
Transmission Owners
Transmission Planners
Planning Coordinators

Problem Statement
Sub-synchronous oscillations between wind turbines and a series capacitor in the transmission network resulted in significant damage to the wind turbines.

A normally cleared fault on a 345 kV transmission line resulted in a post-contingency system configuration in which two wind farms were radially connected to a series compensated 345 kV transmission line. This configuration produced sub-synchronous control instability (SSCI) between the wind turbines and the series compensated transmission line, resulting in severe over-voltages, current distortion, tripping of additional transmission facilities, and damage to the wind farm control circuits.

Details
In October 2009, an instance of sub-synchronous control instability occurred as follows:

- A single phase-to-ground fault developed on a 345 kV transmission line when an overhead static wire failed and was cleared as expected approximately 2.5 cycles.
- After the faulted line was removed from service, two wind plants with a capacity of 485 MW from approximately 300 doubly-fed induction generator (DFIG) wind turbines (type 3) were left connected to the transmission grid through a single 50% series-compensated 345 kV transmission line which was 80 miles long.
- Within 200 milliseconds, sub-synchronous oscillations between the series capacitor and the wind turbine controls developed and grew sufficiently large to damage the wind turbines as voltages exceeded 1.5 volts per unit.
- Voltage continued to increase to nearly 2 volts per unit before the series capacitors bypassed 1.5 seconds after the initiating line trip.
- During the event, control interaction between the voltage sourced converters of the Type 3 wind turbines and the series compensated transmission line caused un-damped voltage oscillations with a magnitude of approximately 195% of rated voltage and significant current waveform distortion.

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- Additional transmission facilities tripped and numerous crowbar circuits[1] failed at the wind farms.

Corrective Actions
A detailed dynamic study of this event was conducted by impacted entities with the assistance of industry experts. The study results confirmed that an electrical sub-synchronous resonance occurred between the induction machines at the wind farms and the series capacitors causing voltage and current distortion. Additionally, the studies showed that ensuing crowbar circuit initiation can cause machine self-excitation and interaction of the power electronic controls of the Type 3 wind turbines contribute to negative damping and further aggravation of system instability.

Several mitigating measures are being considered:

- Replacing series capacitors with thyristor-controlled series capacitors (TCSC)
- Install SSR filters at the series capacitor and/or wind turbine locations
- Install SSR relays to bypass the series capacitors
- Install protection scheme to transfer trip / bypass series capacitors based on network topology

Lessons Learned
SSR and SSCI problems can develop anywhere there are series capacitors used in the transmission system. System planners need to be aware of this potential and plan the system to minimize potential exposure to new and existing generators and power electronic equipment. Similarly, System Operators must be aware of operating configurations that can increase exposure to SSR and SSCI when planning switching and operate accordingly.

Interconnection studies for any generator or power electronic equipment in the vicinity of a series capacitor should account for system configurations that can give rise to sub-synchronous oscillations. Any generation or power electronic equipment connected in a radial series-compensated configuration is particularly susceptible to these phenomena. It is also important to perform this analysis whenever series-compensation is being added to a transmission system.

A number of wind farms are being planned and installed in remote areas, often very far from load centers. This requires construction of new, long line transmission systems, often built with series compensation to electrically bring the resource closer to the load center. However, this increases the potential for creating SSR or SSCI problems not only for the new resources, but also for existing generation and power electronic equipment.

Isolation of wind farms into series compensated transmission lines in either a radial configuration or otherwise weak system can result in electrical SSCI conditions. These conditions are the result of interaction between the induction machines of the wind farms and/or power electronic controls of DFIGs with the series compensated transmission system. The resonant conditions can lead to severe system over-voltages, un-damped oscillations, and instability, all of which have the potential to cause cascading outages and equipment damage.

Sufficient studies should be performed that identify locations that are susceptible to isolation of generation or power electronic equipment with series compensated transmission lines. In addition, integration of

[1] Crowbar circuits are essentially surge arrestors that short-out the power supply during an over-voltage condition.

Sub-Synchronous Resonance (SSR)

Series capacitors in conjunction with the inherent impedance of transmission lines create an RLC circuit with resonant frequencies in the range of 10 to 50 Hz. Synchronous generators are generally built with shaft torsional modes in this same frequency range. These torsional modes are capable of interacting with the resonant modes of the transmission network, producing damaging oscillations. This phenomenon is known as sub-synchronous resonance (SSR) and has occurred several times between traditional generators and series-compensated lines, most notably at the Mohave generating station in 1970.

Sub-Synchronous Control Instability (SSCI)

More recently, power electronic control systems have been found to be similarly capable of interacting with these sub-synchronous modes of the network as well. Power electronic systems are used in a variety of power system gadgets, such as static VAR systems, FACTS devices, HVDC controls, and wind turbine controls. Interaction of such control systems with sub-synchronous modes of the network is known as sub-synchronous control instability (SSCI).

wind farms into systems where the short circuit ratio (SCR) is low (<5) should be identified as potential locations for SSR (SCR = Ssc / Pwind).

Appropriate transmission system design enhancements need to be considered when studying integration of large scale wind farms. Some measures that may be considered include:

- Limiting series compensation to safe levels
- Installing thyristor controlled series capacitors
- Installing SSR blocking filters
- Installing additional protection systems to detect SSR and take corrective action
- Installing additional protection systems to avoid SSR based on system topology
- Exploring alternatives to increase system strength
- Exploring modifications to turbine control technology

The NERC Transmission Issues Subcommittee is preparing a technical paper on the issues of SSR and SSCI for use by the industry.

For more information please contact:

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