SSCI Detailed Evaluation Using PSCAD Rev. 0

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1. Background

This document discusses EMT modelling considerations and assumptions for SSCI evaluation in bulk electric systems.

For the purpose of this discussion, Sub-Synchronous Control Interaction (SSCI) is defined as an interaction between power electronic controls and series compensated transmission systems, occurring at sub-synchronous frequencies. Sub-Synchronous interactions may also occur for other reasons, for example due to low system strength conditions even without series capacitors, but these are generally not termed SSCI. Because these phenomena involve the inner controllers of power electronic devices, conventional transient stability tools are not suitable for this analysis, and EMT tools must be used with highly detailed and specific models of the plants being considered. Generally, these studies are performed using frequency scanning based screening techniques (evaluating the combined impedance of the plant and the system at a range of sub-synchronous frequencies), and with detailed time-domain simulations to finally determine the stability of the overall system in both large and small signal contexts.

2. EMT Modelling for SSCI

Modeling of a detailed system for SSCI studies with multiple wind/solar plants in EMT is a relatively complex task. Recent developments in parallel EMT type simulations make it possible to model large numbers of wind/solar plants (100s in some studies) thanks to high performance desktop computers and specialized software. Since SSCI is impacted by the specific characteristics of the network, it is required to model all close by wind/solar plants, power electronic devices, MOVs and frequency dependant line models for high risk SSCI type studies. EMT plant models must be of very high quality, representing all model accuracy and usability features presented in [1].

2.1 Size of the Network:

Series and parallel resonance conditions in the network affect the solar/wind plant performance. Most of the EMT tools have size limitations and the boundaries of the EMT case must be carefully selected to capture system resonance (series and parallel) conditions. Frequency scanning techniques can be used to determine the size of the EMT cases and boundaries. For example, the number of buses in the EMT case can be increased until no change is observed in passive scan R & X curves at the interconnecting point of the wind/solar plant.

The area of the interconnection may have multiple parallel and series resonance conditions. The control of the wind/solar plant may have negatively damped regions closer to the network resonance conditions and may show unstable operation. This behaviour may not be captured correctly if the correct network size is not selected.

2.2 Transformer Saturation:

All transformers near the plant under study should have saturation modeled (in time domain simulations). Transformer saturation effect can impact post fault plant recovery and instigate resonant issues. Transformers of the solar/wind plant can be saturated with close by 3 phase fault conditions, which impacts system recovery in several ways. First, saturation of transformers can have a positive impact on wind plant ride through by clipping transient voltage peaks at the plant terminals. On the other hand, transformer saturation may instigate resonance-type oscillations between the saturated transformer and the series capacitor and network. In most of the cases where this occurs, the resonance type oscillations are undamped causing wind/solar plant ride through failure. It is highly recommended to use correct wind plant transformer data for SSCI type simulations. Transformer data may include:

- Correct transformer MVA and impedances
- No load and load losses
- Selecting correct winding to model saturation and correct saturation data such as air core reactance, magnetizing current and knee point voltage.

2.3 Plant Arrester Data

The post fault POI voltage levels of wind/solar plants closer to a series capacitor may reach plant arrester clipping voltage levels with radial connections. It is advisable to model plant line entrance, transformer and collector system arresters in detail in high risk SSCI studies as plant arresters may absorb energy coming from series capacitor and may help plant to ride through and damp out oscillations.

2.4 Detailed Generator, HVDC, and FACTs Models

Detailed models of nearby wind, solar, SVCs, STATCOM, HVDC and thermal plants are required in the vicinity of the series capacitor. Close by plants can have significant impact on the collective damping and the resonance conditions. The wind/solar plant under study may be SSCI stable when operating by itself when other close by plants are not in service due to positive damping of the turbine controls at the series resonant frequency, and this should be evaluated to provide a baseline for the study. Adding the impact of nearby plants may make the combined system more vulnerable for undamped SSCI oscillations. The following steps can be followed in general:

1. Study the wind/solar plant in service with no other nearby plants in service to ensure no SSCI type oscillations. The wind/solar plant may be stable if plant controls provide enough damping at the combined (plant and system) resonant frequencies. Generally, wind/ solar plants exhibit positive inductance (X) at the system resonant frequencies which makes the combined (plant + system) resonant frequencies move to lower frequencies. Also, wind/solar plants tend to exhibit more positive resistance (higher damping) at lower frequencies which helps to damp out SSCI oscillations. On the other hand, some plants may exhibit negative inductance (X) at system resonant frequencies. This combination makes capacitance (from wind/solar plant), inductance (from plant transformer plus lines) and capacitance (from series capacitor) series resonance. The majority of these cases show SSCI instability in time domain studies when radial with series capacitor connections, unless there is unusually high positive damping from the wind/solar plant and the system. It is

therefore highly advisable to tune the controls to make the plant impedance positive at series resonance frequencies.

2. Once the stability of the plant on its own has been evaluated, all other close by plants (on both sides of the series capacitor and in the vicinity) should be added to the system with the wind/solar plant under study. It is advisable to model plants in detail at the both side of the series capacitor as they can make drastic changes to the system resonance conditions which need to be captured during the study. Generally, thermal plants provide positive damping at the SS frequencies and can move resonances to higher frequencies. The thermal plants should be modeled with detailed multimass models if the plants are close to the series capacitor. There can be two outcomes from addition of close by plants.

   I. Addition of other wind/solar plants add more parallel inductance to the system which makes the combined system resonances moves to higher sub-synchronous frequencies. Generally, most wind/solar plants have lower damping at these higher frequencies which can make the combined system unstable.

   II. There can be plants which add very high positive damping at the sub-synchronous frequencies of concern. There can be plant combinations (when more positively damped plants are not in service) where combined damping is negative at sub-synchnous frequency. The simulations engineer should use judgment about the capabilities of the each device when studying complex conditions when multiple plants are interconnected close to series capacitors to determine which scenarios to run.

3. Releasing of synchronous machine dynamics should be delayed until all wind/solar plants ramp up to full power and stable reactive power to ensure a properly initialized EMT case. A contingency should be applied with stable flat run conditions. This can be time consuming for complex system, as it may take as long as 20 seconds before the case is properly initialized.

2.5 Frequency dependent line models

Frequency dependent line models exhibit slightly lower resistance at sub-synchronous frequencies and higher resistance at super-synchronous frequencies due to the skin effect on the current flowing through the conductors. It is advisable to model frequency dependent line models in the region of study for this reason, particularly when system stability and damping is marginal, as this effect can be non-negligible, and the addition of frequency dependence in line models has a detrimental effect for SSCI stability.

2.6 Series capacitors with MOVs and bypass logics

Series capacitors with MOVs and bypass logic should be modeled in detail. The series capacitor MOVs will add a significant amount of damping during the fault recovery period, and this may allow wind/solar plant controls to stay within limits and successfully damp out sub-synchronous oscillations without tripping. The series capacitor may also bypass itself for close-in 3LG faults and may unbypass after a pre-defined interval. The bypassing may affect the wind/solar plant SSCI performance, contributing to damping oscillations while simultaneously reducing active power transfer capability, which can lead to other issues, such as voltage collapse or weak system instability. Also wind plants may have adaptive controls which may activate during transients, and unbypassing may interfere with these controls.

2.7 Switched shunts on and off

Sensitivities studies may be necessary with nearby switched shunt capacitors and reactors in and out of service, as the status of these switched shunts may affect the system parallel resonance conditions. Generally, these sub-synchronous parallel resonance frequencies are close to the series resonance frequencies and can shift problematic resonant frequencies. It is advisable to test sensitivity to these effects for radial cases.

2.8 Nearby thermal generators on/off

Sensitivity studies may be necessary with nearby conventional generators turned on and off. The statuses of machines change system resonant conditions as well add positive damping for SSCI frequencies. Thermal machines may also have SSR-type issues and should be modelled including a detailed multimass system for their shaft system.

2.9 Load flow conditions:

Sensitivity studies with peak and light load conditions may be required. Peak load conditions may have higher load levels in the region which makes overall damping higher (better), meaning that typically light load conditions tend to be more severe for SSCI. Additionally, light load conditions may have SSCI issues coupled with weak system conditions, and SSCI issues are often exaggerated when system is weak. However, these conditions mainly depend on the local load distribution and generation balance and it may not be always conservative to consider light load dispatches.

2.10 Fault Response

Although many aspects of the SSCI phenomenon can be evaluated in the small signal domain (eg. Through frequency scan screening techniques), most modern renewable plants contain many non-linear elements which impact SSCI stability, particularly during fault conditions. These include adaptive control schemes which vary the response for different magnitudes of disturbance or oscillations. The nature of the fault transient can cause inverter controls to behave in different ways. For example, a 3LG fault close to series capacitors creates voltage and current transients in the vicinity of the fault. These transients can saturate transformers and also cause damping controllers to effectively run out of “headroom”, and become less effective, resulting in instability or plant tripping. Alternately, a SLG fault close to the wind/solar plant may case the wind/solar plant to not enter full ride through behaviour with assocated reduction in active power, leading to high transient power flows in potentially weakened systems following a line outage. Similarly, a check is required for line opening conditions with no fault.

2.11 Inverter Dispatch Level and Units in Service

A check is required with inverters operating at 100% and 10% capacity with 100% of the inverters in operation. Wind/solar plant controls behave differently at low and high generation levels and are highly depend on turbine manufacturer.

A check is required at 100% capacity with a reduced number (e.g. 10% and 20%) of inverter units in operation. Typically, scenarios with low numbers of inverters in service are more SSCI stable than those with all the units in service due to a resulting lower combined resonant resonance frequency.

A check is required at unity, capacitive and inductive reactive power generation operating conditions. Controls of wind/solar inverters often behave differently when operating at extreme reactive power generating conditions.

3. EMT SSCI Evaluation Criteria

The SSCI evaluation criterion is dependent upon the specific region. For example, it may be considered acceptable performance if sub-synchronous oscillations are damped with in 1-2 seconds with all study scenarios described in the modeling requirement section. Wind/solar plants may trip due to ride through failure with some critical cases, which may prevent possible SSCI issues. This may or may not be considered acceptable behaviour depending on the region and severity of the outage, but is generally considered problematic. If the plant is tripping and preventing further SSCI analysis, the following alternative methods can be used to get more confidence with SSCI instability:

- Perform remote 3 phase faults if the plant trips do to close-in 3 phase faults
- Evaluate 1 phase fault
- Check with line opening with no fault
- Disable protection of the tripping plant if possible, and repeat fault analysis.

Wind/solar plant control models may need to be retuned and tested again if any undamped oscillations are observed during studies. Addition of new wind/solar plants to an existing positively damped system may make system unstable. In many regions, restoring of the system SSCI stability then becomes the responsibility of the last device added to the system, which may be a difficult task if the overall system instability is dominated by other devices.

References

[1] Recommended PSCAD model requirements Rev. 10 by Isaacs, A. , Unruh L. & Irwin, G. (2021, February 03)