SSCI-SSR Screening and Modeling requirement Rev. 0

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1.0 Passive and active frequency scanning techniques

1.1 Methodology – theoretical background SSR/SSCI

Series compensation of AC transmission lines can be used to increase the load carrying capability, control load sharing among parallel lines and improve transient stability. However, series compensated transmission lines introduce the risk of SSR (sub-synchronous resonance). SSR is a condition where the masses on a generator shaft oscillate and inter-change energy with a sub-synchronous resonance created by nearby series capacitors. If unchecked, undamped SSR oscillations can lead to turbine-generator shaft failures and electrical instability at sub-synchronous frequencies. SSR is not the primary topic addressed in this whitepaper.

Series capacitors also introduce the risk of a phenomenon called SSCI (sub-synchronous control interactions) which can result in negatively damped electrical oscillations when wind farms are near the series capacitor. Studies have shown that nearly all Type 3 (DFIG – doubly fed induction generator) wind turbines from nearly all manufacturers are vulnerable to instability near series capacitors, resulting in possible damage to both the wind turbines and series capacitor. Other power electronic devices like Type 4 wind turbines, battery storage devices, STATCOMS and SVCs may be vulnerable to the same SSCI phenomenon.

The effects of SSR and SSCI must be fully understood and analyzed when planning series compensation in power systems near generation of any type. SSR/SSCI studies cannot be performed with traditional phasor based loadflow and transient stability studies, so these problems are studied with EMT type analysis.

1.2 Passive frequency scans for SSR/SSCI screening studies

The passive frequency scanning method looks for electrical resonances in the system in the range of 2 Hz to 55 Hz using phasor domain calculations. Both phasor based and EMT type programs can be used to produce impedance versus frequency plots as seen from any point of the system.

Series system resonances can be observed when a series compensated line is radialy or near radially connected to a generator. If a generator is radial to a series compensated line then the system inductance is negative at lower frequencies and become positive above the series resonance frequency as shown in Figure 1. If a generator is connected to a series compensated line parallel with other lines (or with shunt devices), then a dip in the reactance can be observed as shown in Figure 2.

For SSR studies (i.e. gas turbines) the frequency of resonance is most important as torsional interactions will occur only when the electrical resonance (from the series compensated electrical network) aligns with one of the mechanical torsional modes on the shaft system of the generator turbines. For SSCI studies (e.g. wind turbines) the specific frequency of the resonance is important, but since SSCI problems occur over a wide range of sub-synchronous frequencies the impedance dip (i.e. sharpness of the resonance) is also important. Additionally, the SSCI risk is considered higher if the resonance frequency is high as many wind turbines show negative damping behaviour at higher frequencies.

As a rule of thumb, if the percentage of reactance dip near the resonant frequency is greater than 4-5% (or the obvious series resonance exists for radial cases) at a high risk frequency, then this generator should be studied in more detail using more accurate methods which consider the controls and a more detailed electrical and mechanical representation.

A significant complication of these harmonic impedance studies is how to represent the impedance of any neighboring wind plants. For these studies, the neighboring wind plants can be represented with short circuit impedance representing the impedances of the HV/MV transformer, MV/LV transformer, and the wind plant LV generator impedance (0.2 pu). DFIG (Type 3) turbines will have both a grid connected VSC as well as a directly connected generator stator connection, which will appear like a short circuit behind impedance. Type 4 full converter turbines also use VSC converters and will appear like a voltage source behind a converter reactance. However, it is understood that the impedance of these converters are dependent upon the specific controls, the system conditions, and the frequency of measurement, and so this simplification is considered an important approximation. This is discussed further below.

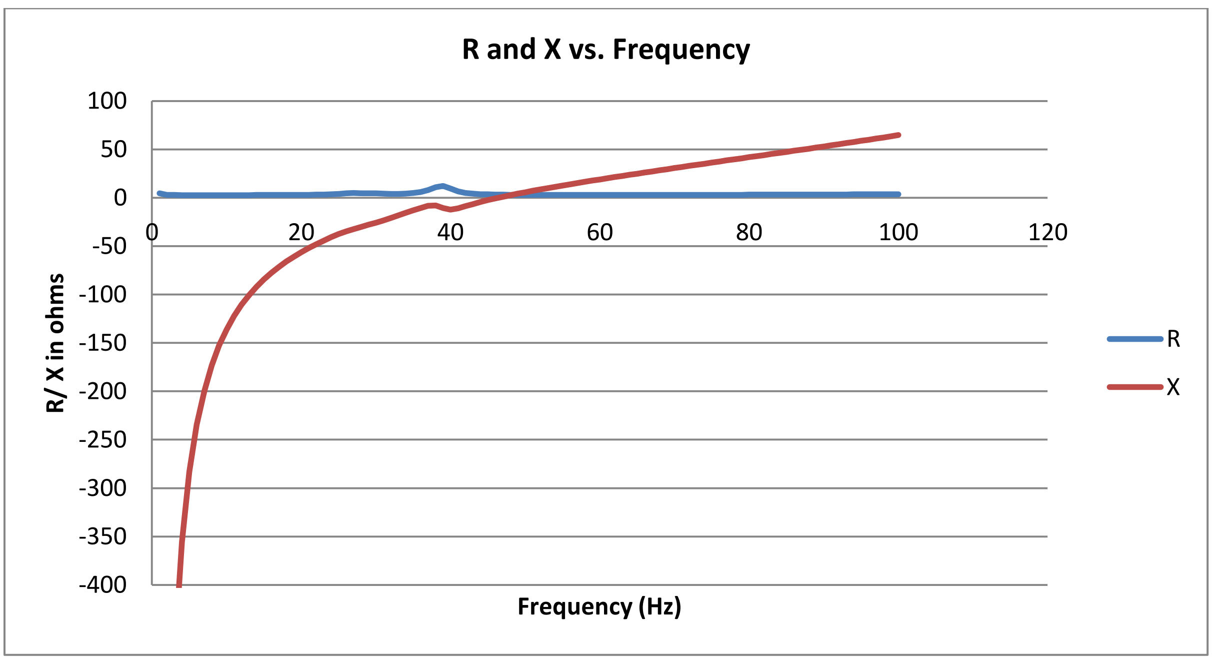

Figure 1 Frequency scan results of a radial case to a series capacitor

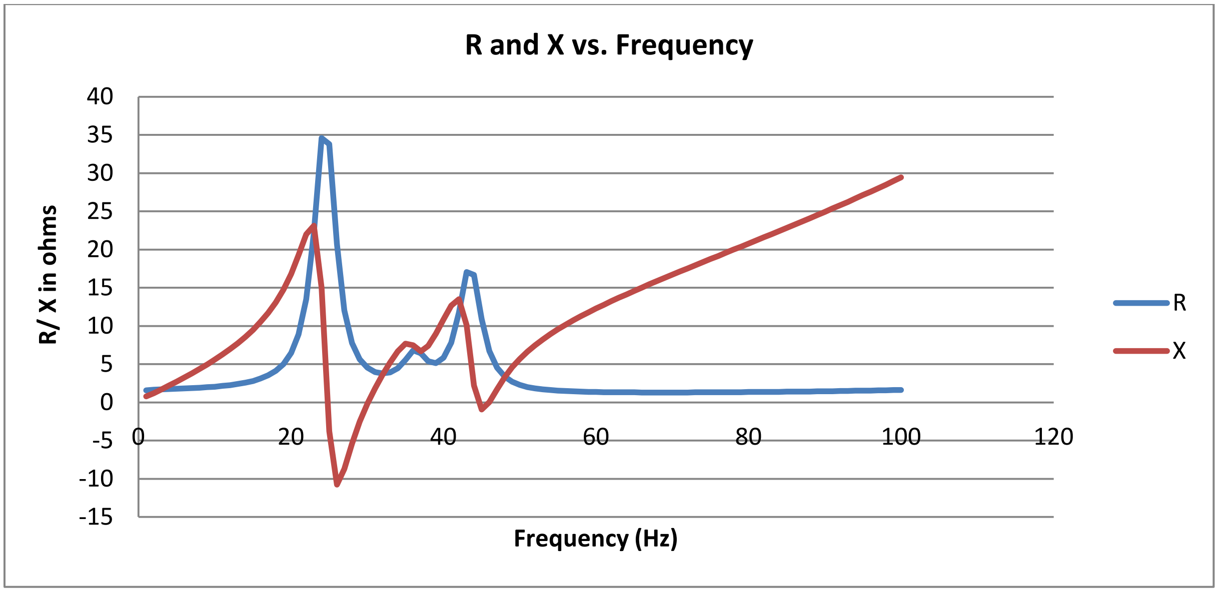

Figure 2 Frequency scan results of a near radial case to a series capacitor

1.3 Dynamic frequency scans for SSCI studies

In order to approximate an "effective impedance" of each converter with consideration of the potential variation in impedance with frequency, a simple and approximate analytical test is used. Small magnitude voltage harmonics are injected to the fundamental waveform at the POI of a wind farm at a range of sub-synchronous frequencies. Sub-synchronous currents flowing into the wind plant are measured and a DFT algorithm is used to extract all sub-synchronous voltages and current magnitudes and phases. Using the known voltage harmonic perturbations and the measured currents, the R and X values are calculated at the wind plant terminal for each sub-synchronous frequency. The resistance component may be used to approximate damping provided by the inverter. Example active frequency scan results of a wind turbine with and without a special sub-synchronous damping controller are shown in Figure 3. In order to capture a range of controller and plant operating conditions, the following operating modes are often used for dynamic frequency scanning:

a. 100% and 10% generating with 100% turbines in operation
b. 100% generation with 10% and 20% turbines are in operation
c. Unity, capacitive and inductive reactive power generation
d. Low, medium and high perturbation magnitudes

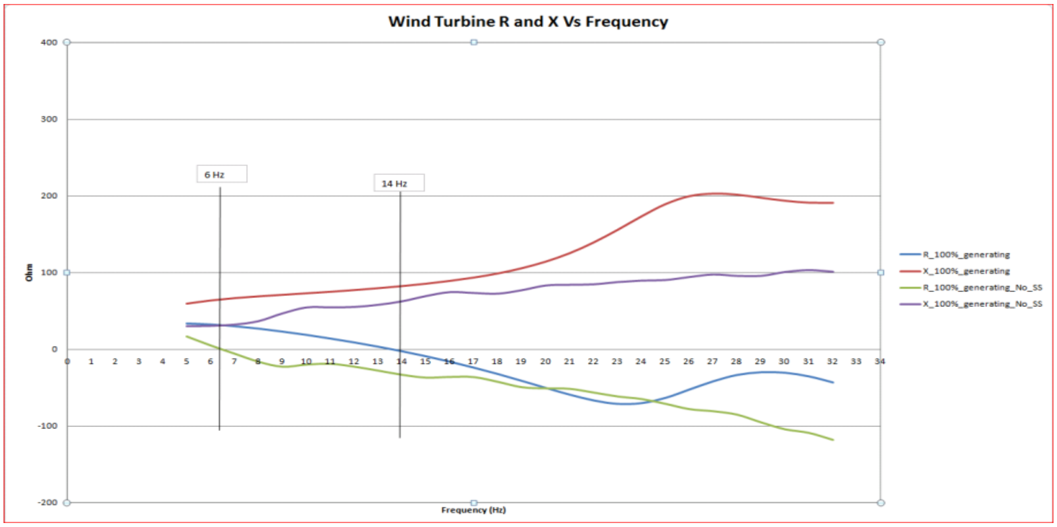

Figure 3 Active frequency scan results with and without SS damping controller

In addition, dynamic impedance scans of the inverters and system impedances can be added together to estimate the overall damping and resonant frequencies for critical contingencies. (Caution is required, there are approximations built into this!). It is important to note that these are screening techniques. All final conclusions must be based on fully detailed time domain simulations of critical contingencies.

1.4 Limitations and assumptions

1.4.1 Passive frequency scans

- Representation of nearby power electronic devices such as SVC, STATCOM and HVDC are approximate and relatively inaccurate.
- Representation of other nearby wind farms in the model are fixed at an assumed 60Hz impedance (generally inaccurate)
- Generator and transformer saturation is not considered with passive scanning.
- Response of exciters, governor and power system stabilizers cannot be represented in frequency scans.
- Frequency dependence of conventional generators are not represented.

1.4.2 Active frequency scans

- Results depend on perturbation magnitude in most of the cases.
- Results depend on internal control system design such as limiters and non-linearities. These must be modeled extremely accurately.
- Results depend on active and reactive power generation levels.
- Some wind turbines may not be stable for harmonic voltage injection and not be able to produce stable impedance curves.

- Dynamic scans are mostly done with positive sequence harmonic injection and some detailed models show completely different results with negative sequence harmonic injection as well as d-q domain harmonic injection.

1.5 Modeling requirement for frequency scanning and time domain simulations

1.5.1 Passive frequency scanning

- An EMT case is created to represent frequency dependency of the system. Cases must be quite extensive if using passive equivalents. It is important to increase the size of the modelled network until no change in the frequency scanning results is observed.
- Representation of transmission lines should use frequency dependant line models. A frequency dependant line has low damping compared to the Bergeron line models due to the reduced skin effect at sub synchronous frequencies.
- The impedance of generators needs to be checked in the system to ensure realistic impedances.
- Negative loads in the system need to be unidentified. A negative load (e.g. GNET translation) may be represented as infinite buses in EMT which introduces error.

1.5.2 Additional detailed modeling requirements and checks in time domain simulations

- Transformers should have saturation enabled (time domain simulations). Transformer saturation effects can impact post fault recovery and instigate resonant issues.
- Detailed models of nearby wind, solar, SVCs, STATCOM and HVDC etc are required (both side of the series capacitor).
- Series capacitors with MOVs and bypass logics should be modeled in detail.
- Sensitivities studies may be necessary with nearby switched shunts on and off.
- Sensitivities studies may be necessary with nearby conventional generators turned on and off. These machines change system resonant conditions.
- Sensitivities studies with peak and light load conditions may be required.
- A check is required for close in and remote 1ph and 3ph faults. The nature of the fault transient can cause inverter controls to behave in different ways.
- A check is required for line opening conditions with no fault. Some wind turbines have different control schemes for large signal disturbances compared to normal operation.
- A check is required for 100% and 10% generating cases with 100% turbines in operation
- A check is required for 100% generation with a reduced number (e.g. 10% and 20%) of turbines in operation.
- A check is required at unity, capacitive and inductive reactive power generation operating conditions.
- It is useful to check performance when only the plant of interest is in operation, as well as when all the nearby generation is in operation. More generation in the system may shift the sub-synchronous frequency to higher frequencies. Most wind turbines show higher negative damping at higher frequencies.
- The detailed wind turbine (or solar) model needs to satisfy "*Recommended PSCAD model requirements Rev. 5 by* Isaacs, A. & Irwin, G. (2018, February 15)*"*

References:

Isaacs, A. & Irwin, G. (2018, February 15). *Recommended PSCAD model requirements Rev. 5*. Retrieved from http://www.electranix.com/wp-content/uploads/2018/02/Technical-memo-PSCAD-requirements-V5.pdf