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Roadmap for M-SSSC integration – Models and Tools

The adequate representation of the inherent dynamics of all elements that make up a Power System is a need that has existed since its inception. Models have been developed to represent synchronous machines, transformers, transmission lines, loads, compensation elements, protections, among others. In addition, it is possible to find studies that analyze their behavior, seeking to understand their complexity from the field of engineering and mathematics. One element that has been widely studied in the literature is transmission lines, where compensation systems play an important role in how they are operated and upgraded.

Modular Static Synchronous Series Compensators (M-SSSC) have been globally utilized mainly to actively control power flows in the existing grid by pushing power off congested lines and/or pulling power towards underutilized transmission corridors. This effect is achieved by injecting a series voltage in quadrature to the line current (90° leading or lagging), thereby changing the effective impedance on meshed networks and holistically optimizing transmission margins.

The representation of M-SSSC devices in commercial and open-source packages for power system simulation depends largely on whether they have standard models of such technology and on the ease of access to the solution engine. Some alternatives are presented below.

Load flow with access to solution engine

- Series voltage source:
  - VSCs performing voltage injection in quadrature with line current modeled as voltage sources.
  - The SSSC operating setpoints (voltage or reactance setpoint) are included as part of the load flow equations.
  - The network equations are extended to account for the change in power injection added by the voltage source.
  - The Jacobian matrix is extended to account for the effects on the M-SSSC response while numerically adjusting the system voltage phasors.
  - All voltage variables, including those of the source representing the M-SSSC are adjusted at each iteration of the solution method.

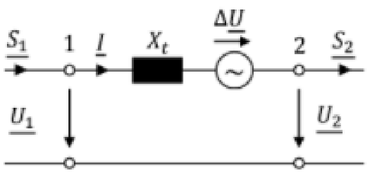
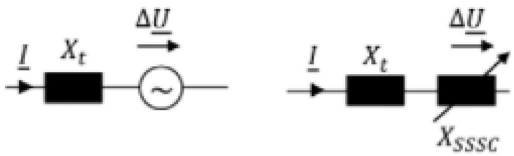


Figure 1, M-SSSC modelled as a voltage source

Load flow without access to solution engine

- Variable impedance:
  - The impact of M-SSSC voltage injection is modeled as a controllable impedance that obeys the operating characteristic of the M-SSSC.
  - Adjustments in the admittance matrix lead to a new Jacobian matrix.
  - The phase angle of the M-SSSC voltage depends on the voltages calculated by the load flow solution engine.

- Changes in the M-SSSC impedance also have an impact on the voltages calculated by the load flow solution engine.
    - Iterative adjustments to the M-SSSC impedance are necessary to reach the desired operating point.
    - For each change in the M-SSSC operating point, the admittance and Jacobian matrices need to be recalculated.



M-SSSC modelled as a variable reactance

Time domain simulations

Since the M-SSSC is a FACTS type device, whose implementation is based on VSCs made with power electronics equipment, it is of interest to perform time domain simulations (EMT) in which the performance of the control system and the power electronics can be accurately represented.
The EMT model of an M-SSSC in general should have the following components:

- Phase Locked Loop (PLL) to monitor and latch to line current.
- State machines to handle the transition between M-SSSC device states.
- Switchover logic of the IGBTs to generate the quasi-sinusoidal waveform.

The expected voltage waveform for a M-SSSC with MMC topology is based on the fact that VSC converters have the task of injecting a DC level which, in coordination with the other converters, makes it possible to achieve a quasi-sinusoidal waveform. The following figure illustrates the contribution of each converter for an M-SSSC device with 5 VSCs.

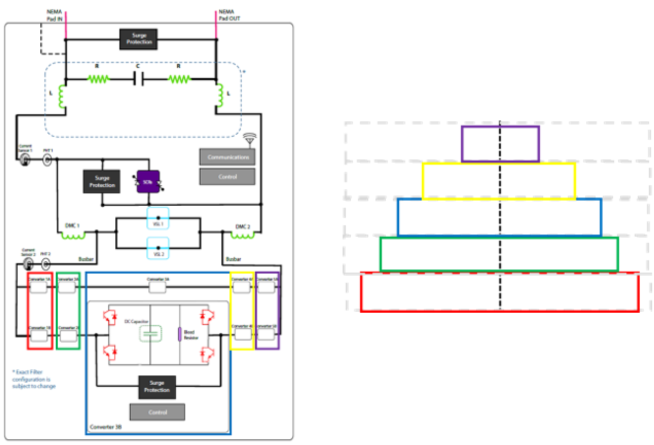


Figure3, voltage waveform construction by an M-SSSC

- Equivalent voltage source model.
    - A controllable voltage source is used to emulate the DC link response from the converters.
    - It facilitates the creation of black box models that can be shared by manufacturers to external users while preserving sensitive device information.

Considering M-SSSC is a technology with increasing adoption over the last decade, system integration assessment studies are the best tool provide technical assurance before deploying M-SSSC solutions in the power system.

The goal of the system integration assessment studies is to ensure that integration of M-SSSC technology does not have any adverse effects on the performance of the surrounding power system or on existing protection equipment. These studies also provide the means to evaluate the dynamic performance of M-SSSC technology and investigate any risks associated with harmonic distortion or interactions between its control and protection features and other equipment close to the installation area.

The extent of the scope of works for each study can vary and it is determined collaboratively between the technology vendor and the utility installing the solution. A comprehensive set of system integration studies typically includes the following:

- Steady-state and RMS planning studies
- Harmonic emissions
- Transient voltage stability
- Protection coordination studies
- Dynamic performance
- Control interaction (incl, sub-synchronous control interaction)
- Protection-In-the-Loop to validate protection coordination studies
- Sub-synchronous resonance (incl. sub-synchronous torsional interaction, induction generator effect and sub-synchronous transient torque)
- Transient recovery voltage
- Temporary overvoltage
- Insulation coordination (incl. lightning and switching impulses)
- Bypass filter performance
- RTDS validation tests with Control-HIL (focused on functional, harmonics, and dynamic performance)

Technology maturity and evolution of system integration assessment methodologies and models have led to successful execution of typical M-SSSC applications. This is simultaneously opening the path towards novel M-SSSC applications, where new control algorithms and synergies with other grid enhancing technologies are being studied. Advanced applications to highlight include:

- Oscillation damping, use M-SSSC to bring two areas electrically closer.
- Combine M-SSSC with Dynamic Line Rating to maximize grid utilization.
- Detection and mitigation of sub-synchronous resonance (SSR)
- Implementation of WAMPAC schemes where line reactance can be considered as a new control variable.
- Provide system support to other elements of the power grid (i.e. LCC- HVDC links)

Ultimately, the development and technical assurance process of new applications with M-SSSC will require the extension of existing or the creation of new system integration assessments. Evolution and proper integration of these novel solutions to the power grid will require a continuous interaction between utilities and developers of said solutions.