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M-SSSC Novel Applications Worldwide

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 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**.

M-SSSC utilizes a set of Voltage Source Converters (based on IGBT full-bridge topology) that allow for fast DC link control and makes this technology **unable to stimulate new subsynchronous resonances (SSR)** in the AC grids. SSR events are becoming more relevant with the international interconnection of AC systems and due to the presence of thermal power plants (e.g., Peru, where in 2016, an SSR event led to damage to the generator shafts in Puerto Bravo). With this unique characteristic, M-SSSC technology has been adopted as an alternative to FSC (fixed series compensators) in systems where long lines are to be **compensated without the risk of inducing a new SSR**.

Utilizing standard SCADA protocols, such as IEC 61850, IEC 60870-5-104/101, or DNP3, the operation of the M-SSSC can be integrated into upper control layers for supervision and control. Upper control layers include local S.A.S. and centralized Energy Management Systems (EMS). This complete integration of the M-SSSC to the control centers allows for various **real-time applications**. In Australia, an M-SSSC deployment is currently utilized to manage congestion and reduce curtailment in real-time. Using an algorithm at the EMS level, the fleet of installed M-SSSC across four lines receives dynamic setpoints based on the wind intensity measured and made available at the EMS. Given the geographical dispersion of the wind farms, and the generation peaks occurring at different times of the day, real-time optimal reactance setpoints can be sent based on the measured wind intensity to control the power flows in the available lines. This dynamic operation allows a complete utilization of the existing grid capacity, adding a new degree of freedom in real-time operation, transforming the transmission lines from rigid assets to intelligent and controllable variables, and introducing the **«dispatchable lines »** concept.

Besides the example mentioned above, the full integration of the state-of-the-art M-SSSC allows the deployments to participate in any Smart Grid scheme, together with complementary technologies, such as **Dynamic Line Rating monitoring systems, topology control software algorithms, and wide-area control** strategies, allowing for a more intelligent, flexible and optimized grid and solving planning issues by a systematic approach.

While series-installed FACTS (such as M-SSSC) are mainly utilized to control the active power (P) by controlling the effective impedance of an existing transmission line (X_{eff}) and thereby bringing two nodes electrically closer, the power angle difference ($\delta_1 - \delta_2$) does also change, per the following equation :

$$P = \frac{V_1 V_2}{X_{eff}} . \sin(\delta_1 - \delta_2)$$

This impact on the power angle difference, and the reduction of the voltage drop between two nodes, also implies an indirect effect on the reactive power flows and the receiving end voltage V_2.

$$Q = \frac{V_1 V_2}{X_{eff}} \left\{ cos(\delta_1 - \delta_2) - \frac{V_1}{V_2} \right\}$$

A set of new use cases have been studied worldwide to assess the efficiency of series-installed FACTS on voltage regulation and reactive power control. While shunt devices are better suited to actively control the node voltage (by injecting or absorbing reactive power), **M-SSSC can help solve voltage support issues, in which power flow control and series compensation can bring two nodes electrically closer**.

Inter-area oscillation phenomena have become more relevant as isolated grids are interconnected for synchronous operation, in which long transmission lines connect different generation centers. **Low-frequency power oscillation**s Modi have been identified (usually below 3Hz), in which generator' state variables from one area oscillate against the generators from another. As M-SSSC can bring two areas electrically closer, a **deployment can contribute to improving these detrimental phenomena**. In addition, state-of-the-art M-SSSC can operate in fixed voltage injection mode, in which the VSC modules inject a fixed set voltage (capacitive or inductive) independent of the circulating current (line current). This voltage drop independence leads to a « passive » damping effect that has been demonstrated in RMS studies for very slow frequency interactions, in which the M-SSSC injects a fixed negative (capacitive) voltage. Active filters POD, similar to the ones available in VSC-HVDC systems, are yet to be implemented for an « active » and more-effective damping effect.

Academic research has lately addressed the technical and economic contributions of an M-SSSC deployment to **help solve the challenges related to the operation of LCC-HVDC links in very weak networks (with low SCR).** These challenges include but are not limited to interactions stimulated by the AC-side filters, commutation failures of thyristor valves due to voltage fluctuations at nodes with low short circuit ratio (SCR), additional AAC voltage regulation needs, and reactive power consumption. M-SSSC can help provide reactive power for the converter stations and voltage regulation support, thereby mitigating LCC converter stations' commutation failures by increasing the SCR. Furthermore, this technology can also avoid the risk of ferroresonance with transformers related to large AC filters, passive shunt compensators, or fixed series capacitors in the electrical vicinity. The installation of M-SSSC in series with the converter stations could potentially reduce the need for passive shunt compensation on the rectifier and inverter sides, as it has been studied for TCSC and other controlled series compensation in the literature. The modular nature of these solutions allows adjusting injection at a granular level in real-time to provide power flow control and voltage support.