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GROUP REF. : C2
PREF. SUBJECT : PS2
QUESTION N° : 2.3

Question 2.3:
While the control systems of power electronic interfaced resources can be highly flexible they may not be able to be adjusted to meet all of the power system technical performance requirements. In what circumstances are supporting technologies, such as battery energy storage systems or synchronous condensers, needed to complement the capabilities of the power electronic interfaced resources? How are control interactions between these technologies being managed to improve power system technical performance?

M-SSSC & Supporting Complementary Technologies

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 is currently utilized in different grids to manage congestion and reduce curtailment in real time. Using standard SCADA protocols, such as IEC 61850, IEC 60870-5-101/104, 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 into the control centers allows various real-time applications and interactions with other complementary technologies. Using algorithms at the EMS level, M-SSSC installed across different lines can receive dynamic setpoints based, e.g., on the wind intensity measured and made available at the EMS. Given the geographical dispersion of generation centers and 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. Other environmental variables available with the utilization of different technologies, e.g., DLR systems (Dynamic Line Rating), can allow complete utilization of the existing grid capacity, adding a new degree of freedom in real-time operation and transforming the transmission lines from rigid assets to intelligent and controllable variables.

The synergy between storage solutions (BESS) and M-SSSC have also been widely studied. While these two technologies are sometimes compared as competing solutions for grid congestion, hybrid solutions have shown greater technical and economic benefits. While BESS can operate synchronized as « virtual power lines » to avoid congestion scenarios, it has been proven that the installation of SSSC can optimize the charge and discharge cycles and can be used to inject and steer the stored energy to the areas of the grid where it is most needed. In addition, as most meshed networks have underutilized transmission capacity (due to the difference in line lengths and thermal ratings), M-SSSC can control the reactance to optimize utilization, leading to a smaller BESS capacity needed for the same congestion scenario. Additionally, the combination of BESS + M-SSSC can increase the safe operating scenarios by increasing overall system reliability and allowing for black-start capabilities. These combined benefits are currently studied in markets such as Chile and Colombia.

As the penetration of intermittent inverter-based renewable (IBR) generation sources increases globally, grid instability due to the lack of synchronous inertia becomes a more significant issue. This is particularly the case in relatively weaker networks where long lines and reduced network connectivity result in a higher system impedance being seen at the point of connection for IBR generators. Synchronous condensers have been utilized to improve SCR and system inertia, specifically in areas with high IBR energy sources penetration. The kinetic energy stored in the synchronous machines' rotor can help stabilize a power system during rapid system fluctuations. When synchronous condensers are used this way, instability issues can still arise for IBR generators whose connection point is electrically remote from the installed rotating machines. In addition, more traditional modal oscillations can occur between the different groups of installed rotating inertia. An M-SSSC installation can be used to bring two areas electrically closer together by injecting a capacitive voltage, thereby decreasing the effective line reactance between two nodes. In the case of a small IBR generator, this reduces the impedance between the IBR generator connection point and the location of the synchronous inertia, increasing the stability of the IBR generator and thereby increasing the maximum amount of IBR generation that can be produced at the connection point.

Thus, a complementary M-SSSC + Synchronous Condenser deployment can improve the network's system strength over a wider area, allowing the integration of a greater quantity of IBR generation as the impact of the synchronous Condenser at a given node can be extended to more remote parts of the network. It is important to note that since the M-SSSC predominantly only appears as series capacitance at the fundamental system frequency, employing an M-SSSC in this manner largely avoids the potential pitfalls of SSR and SSCI that can accompany traditional methods of series compensating a transmission line with capacitors.

The complete integration of the state-of-the-art M-SSSC also allows the deployments to participate in Smart Grid Wide Area Monitoring, Protection, and Control (WAMPAC) schemes with other complementary technologies, such as topology control software algorithms, allowing for a more intelligent, flexible, and optimized grid and solving planning issues by a systematic approach.

As grids become more flexible, intelligent, and with more synergistic technologies living harmoniously together, interaction studies have to be performed to avoid controller interactions at subsynchronous or supersynchronous frequencies. Control interaction studies investigate potential interactions between M-SSSC deployments and other surrounding active and passive devices and controllers, such as HVDC systems, series capacitors, SVCs, and AVRs.

The future grid will be intelligent, digital, and flexible to guarantee the delivery of clean and decarbonized energy. Instead of seeing different technologies as competitive, the new mindset should push for studying the symbiosis and interoperability between them, ensuring they can live together, enhance the technical benefits, and allow for an acceleration of the energy transition globally.

[1] V. Sood, “Capacitor Commutated Converters for HVDC Systems,” in *HVDC and FACTS Controllers: Applications of Static Converters in Power Systems*, Boston, MA: Springer US, 2004, pp. 117–138. doi: 10.1007/1-4020-7891-9_6.
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[3] S. Hincapie and C. Ordonez “Test Case: Modular SSSC and LCC-based HVDC Link Technical Synergies”, IET ACDC 2022 conference, Glasgow, UK.