Super Grid Increases System Stability

The 400-kV super grid interconnection of six Arabian countries is now fully operational.

By Ahmed Ali Ebrahim, Gulf Cooperation Council Interconnection Authority

The Gulf Cooperation Council Interconnection Authority has commissioned a 400-kV super grid that connects the electrical power networks of the Arabian Gulf Cooperation Council (GCC) countries of Bahrain, Kuwait, Qatar, Oman, United Arab Emirates (UAE) and Saudi Arabia. This interconnection enables electrical energy exchange and emergency support among these countries.

The 400-kV transmission system was constructed in three phases:

- Phase I included the 400-kV interconnection connecting the existing power systems of Bahrain, Saudi Arabia, Qatar and Kuwait, including a high-voltage direct-current (HVDC) back-to-back 1,200-MW installation between a 50-Hz, 400-kV system and a 60-Hz, 380-kV system.

- Phase II included the internal interconnection among the southern systems (UAE and Oman) to form the UAE national grid and the Oman northern grid.

- Phase III included two major projects, a double-circuit 400-kV transmission line from Salwa (Saudi Arabia) to a new 400-kV substation at Al-Silaa (UAE). The new substation connects to UAE Transco’s Shwaihat Substation as well as existing double- and single-circuit 220-kV transmission lines between the Al Fuhah Substation (UAE) and Mhadha Substation (Oman).

To control operations, the Gulf Cooperation Council Interconnection Authority (GCCIA) established a new interconnector control center equipped with supervisory control and data acquisition (SCADA) and energy management system (EMS) facilities in Ghunan, Saudi Arabia.

Operational Studies

In addition to conducting studies during the feasibility and planning stages of phase I, the GCCIA commissioned operational studies during the final construction stage of the GCC interconnection, prior to commissioning the interconnecting transmission lines. Undertaken by a consultant consortium consisting of RTE, Tractebel Engineering and Elia, the planning and operational studies were GCCIA’s final verification of safe energization, synchronization and stable operation regimes for the interconnected power systems.

These studies provided recommendations for implementation on the interconnected systems. The study work entailed various workshops, attended by GCCIA, the consultant consortium and representatives from the operations team, as well as visits to European control centers.

Operational Standards

The implementation of such an interconnection highlights the need for new operational standards to ensure the reliability of the interconnected systems is improved and the frequency-control reserves are shared among the power systems. This gives rise to a balancing reserve generation ca-
capacity and the harmonization of policies and practices.

The HVDC converter station ensures a large power reserve is available in case of a severe disturbance on either side of the 50-Hz and 60-Hz networks. Steady-state analysis and dynamic studies were conducted to identify the limits of such joint interconnected operation, and to give guidance to procedures and sequences that ensure safe and stable operations.

Operating Reserves

Operating reserves are crucial for reliable performance of the interconnection; the sharing of spinning reserves was foreseen as the first benefit of the interconnection. In addition, the support in case of a severe generation failure is improved by the mutual delivery of emergency reserves by the interconnected power systems.

The control of the frequency usually mobilizes different types of reserves, depending on availability and situation specifics. The size of the operational reserves is 664 MW, which is what the loss of the biggest generating unit would be. The acceptable transient frequency drop and the final frequency deviation agreed on for the interconnector were a maximum deviation of 500 MHz and a final deviation of 200 MHz.

Three different types of reserve responses were identified. The primary reserve aims to stabilize and halt any drop in frequency. The secondary reserve aims to reconstitute the volume of the primary reserve and restore the frequency to its nominal value. The tertiary reserve is used for restoring...
safe operating conditions, thus restoring enough secondary reserve margins.

The time allowed for cost-efficient decisions must be defined and agreed to by the interconnected power systems. The composition of these reserves depends on their origin. Short-term reserves, also called spinning reserves, include the power margin between the present setpoint of the turbine and the maximum output, or the limiter value. Secondary and tertiary reserves may use contractual fast load shedding, power exchange agreements or additional unit commitment according to availability and cost efficiency. Each interconnected power system is responsible for complying with the common reserve requirements while satisfying their technical and economical objectives.

Converter Station

The HVDC converter station was designed for two operational modes. The economic dispatch mode allows stable commercial exchanges with no frequency control. The dynamic reserve power sharing (DRPS) mode provides automatic fast power transfer and mitigates generation deficiencies by mobilizing DRPS between the 50-Hz and 60-Hz systems.

The activation of the DRPS mode is dependent primarily on two criteria, namely, the rate at which the frequency changes or the rate at which load is lost. These events are governed by the load on the interconnector and the time or season at which these events occur. Thus, the HVDC converter station offers a significant capability of emergency reserve sharing between the 50-Hz and 60-Hz systems, thus contributing to the stabilization of the systems after large disturbances.

Load Shedding

Harmonization of under-frequency load shedding (UFLS) is concerned with the high imbalance in active power as a result of sudden loss of generation, leading to a drop in frequency. This frequency drop can be corrected by suitable automatic load-shedding schemes. All member states had such schemes in place, but the interconnection of separate power systems required a harmonization of the existing UFLS schemes and the definition of common rules to be followed by each member state.

When different power systems are interconnected, the solidarity principle automatically becomes the rule: The load is shed not only in the area where the imbalance occurs but also in the interconnected systems. This harmonization is required to minimize the shed load and fairly share the contribution of each member state.

Two rules were recommended for the UFLS harmonization of the GCC system:

- The first UFLS threshold for the 50-Hz side (Qatar, Bahrain and Kuwait) is 49.3 Hz.
- The first UFLS threshold of the 60-Hz side (Saudi Arabia) is set to 59.2 Hz to keep a similar frequency range for the primary frequency control on both sides of the HVDC connections.

The distribution of the UFLS stages in the frequency range and the load shedding amount per threshold should be harmonized. A range similar to the Union for the Coordination of Transmission of Electricity practices was recommended:

- No more than 200 MHz between two UFLS stages.
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Recommended global load shedding amount between 40% and 45% for each country. It is left to the discretion of each country to exceed this global amount by activating additional UFLS stages under 48.3 Hz (the frequency threshold to disconnect the interconnections).

The shed load has to be evenly distributed geographically, and the percentage of load per threshold should remain constant as much as possible throughout the year (peak and light load conditions).

Stability Studies

The interconnected system of GCC is characterized by several sections connected together by relatively long alternating-current lines. This type of structure is likely to face problems with inter-area oscillations. This is another class of power system stability, namely, small-signal stability, which is concerned with the ability of the system to remain stable following small disturbances.

Extensive analysis was conducted to identify any such modes of operation that would cause small-signal-stability problems. Small-signal-stability analysis also allows the identification of the different inter-area oscillation modes of the GCC interconnected system. In accordance with international practice, a mode is judged to be critical if damping is lower than 5%.

Synchronization

Among the three member states with 50-Hz synchronous systems, Kuwait has the strongest network. Therefore, studies showed the preferred scenario was to energize the interconnector progressively from Al-Zour (Kuwait).

First, the systems of Kuwait and Qatar were interconnected and synchronized, and then Bahrain was interconnected later. The studies highlighted that it is preferable to perform the synchronization with conditions leading to limited voltage and frequency difference, and to the lowest impedance between the two systems.

The voltage at the connection points is controlled by adjusting the transformer taps. For frequency difference, the recommended setting of the synchro-coupling devices in asynchronous mode was set at 200 MHz. This requires the member states to maintain a frequency in a range of about 0.1 Hz around the nominal value. The GCCIA’s interconnector control center orchestrates synchronizing operations, as it has a view of both system frequencies and, therefore, is able to remotely trigger the synchro-coupling schemes.

The Future

During the first two years in operation, the GCC interconnection contributed significantly to the continuity of power flow to the power systems of the member states. Between July 2009 and the end of 2010, there were some 250 incidents of sudden loss of generation units connected to the networks in various member states, but because of the GCC interconnection, the systems managed to avoid supply interruptions. Also, the need to program customer shutdowns has been avoided as there have been no incidents of low frequency in the member states since the GCC interconnection became operational.

The GCCIA aims to promote power trading to optimize the use of fuel resources. To achieve even more power exchanges and trade, the GCCIA is conducting interactive seminars and workshops to establish common grounds among the GCC power authorities.

Interconnection of the GCC grid to other grids such as the Egypt, Jordan, Iraq, Lebanon, Syria and Turkey (EJILST) grid or the Maghreb Arab grid will offer the opportunity to export surplus power to other regions (for example, to export surplus power from the GCC region during the winter period when demand is low to Europe where winter power demand is high). This market also would encourage energy interchange during seasonal diversity with the peak demand during the hot summer seasons in the GCC region being supplied by regions where demand is low. Therefore, the development of a regional market through the GCC grid can provide alternative solutions to exportation of power by energy wheeling as an alternative to exporting energy through natural gas or oil.