POWER

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What Does It Take to Bring Stability to a Renewable-Focused Grid?

As coal, gas, and nuclear plants are retired, and wind and solar resources are added to the power grid, stability can become a problem. Understanding the solutions that are available to help manage potential issues is important for decision-makers so they can select the best options for their system.

Grid stability and system strength have become major issues around the world. Whether it's in South America, Australia, UK, Europe, or North America, the subject of strengthening the grid is front and center. This is driven by the seismic shift from traditional power generation to renewables that has occurred over the past decade.

The more wind farms and solar PV that comes online, the cleaner becomes the energy mix. But there are repercussions, such as:

- Take too many coal and gas plants offline and the grid loses the built-in inertia provided by spinning turbines, generators and motors. They provide inertia as they rotate at the same frequency as the electricity grid. Thus, the presence of gas turbines and steam turbines acts as a buffer against power spikes and changes in frequency.
- Wind turbines don't replace this inertia as frequency converters are placed between the wind turbine and the electricity grid that prevent the kinetic energy of their rotating mass from providing inertia.

- The system loses reactive power, which needs to be replaced. While real power (or effective power) delivers energy from the generation source to the load, reactive power (measured in volt-ampere reactive or VARs) is a form of electricity that creates or is stored in the magnetic field surrounding a piece of equipment.
- Reactive power does not travel well, yet, wind and solar farms are often far from load centers. Long transmission lines operating at heavy loads consume VARs. Doubling the amount of power consumed quadruples the amount of reactive power needed.
- Failure to address reactive power on these lines can lead to conductor heating and voltage failure. If the voltage sinks too low, the consequences can be electric system instability or collapse, motor damage, and electronic equipment failure. If the voltage goes too high, it can exceed the equipment's insulation capabilities and lead to dangerous electric arcs.
- Sudden surges and drop-offs of supply due to wind or solar resources coming online and offline (as in the California Duck Curve) means that grid operators must scramble to ensure supply matches demand.
- Grid operators are tasked with maintaining voltage at a specific level to maintain grid stability. If voltage drops too much, system failures occur locally, which can require load shedding to prevent grid collapse. Taken to extremes, a cascading series of outages can lead to a major blackout. The Northeast U.S. experienced this in 2003 when 60 million people were left without power. On a smaller scale, New York City and London suffered from blackouts during 2019.
- Lack of short-circuit power (the ability to resist changes in the amplitude and/or phase of its voltage in the face of external events) as a safeguard against grid failures.

Technology exists to address these issues. These range from simple capacitors to static VAR compensators (SVCs, Figure 1) and from static synchronous compensators (STATCOMs) to advanced electrical systems. Some also utilize old generators by turning them into synchronous condensers (Figure 2).

1. Static volt-ampere reactive (VAR) compensators, or SVCs, are one of many solutions used to prevent outages during times of high demand and stabilize grids that are increasingly reliant on renewable energy. Courtesy: Oncor

2. The Commonwealth Chesapeake Power Plant near the Virginia-Maryland border provides standby power to the local grid as well as providing synchronous condensing services and offering spinning reserve availability to the region. This was done by adding SSS Clutches to several of its GE LM6000 aeroderivative gas turbines. Courtesy: SSS Clutch

“Instead of retiring a coal or gas plant, it often makes financial sense to use old turbines to provide much needed services and stability to the grid,” said Morgan Hendry, President of SSS Clutch Company, Inc.

Global Problem

As the world pushes for more and more renewables, the issues of grid stability and system strength are becoming more apparent. As a country’s percentage of renewables rises, these problems become sharply evident. Here are a couple of extreme examples from South America and Australia, though the same issues arise in North America and Europe.

Chile plans to close 28 coal plants and add 15 GW of renewable energy by 2025, according to BNamericas. And that is just the beginning. From 13% today, the country is fast tracking renewable energy to supply 70% of its total energy by 2030. This headlong charge is running into problems. Chile’s Coordinador Eléctrico Nacional (CEN) issued an international tender for complementary voltage control services via the installation of synchronous capacitors or the conversion of power plants into synchronous condensers.

As CEN said, “According to the studies that have been carried out, the exit of coal-fired power plants and the greater penetration of variable renewable energies can reduce the short-circuit power of the system, making it more fragile, especially in the north of the country where there is a greater presence of this type of generation. There, in the event of a failure in the system in a decarbonization scenario, some solar or wind farms may be disconnected due to the lower short-circuit power, which is insufficient to avoid this risk. In this way, it is concluded that the installation of synchronous capacitors, which are equipment capable of controlling the voltage in the system, is essential to maintain safe and economical operation.”

Meanwhile, in Australia, 32% of the country’s total electricity generation came from renewable energy sources in 2022. By 2027, the International Energy Agency forecasts Australia’s renewable energy capacity will expand by 85% and reach 40 GW. Simultaneous efforts to phase out local diesel generators and coal plants as part of grid modernization initiatives are running into a variety of grid challenges.

The Australian Renewable Energy Agency (ARENA) published a report highlighting requirements for system strength and inertia services to manage power system security. It said: “Retirement of fossil-fuel generation, particularly large coal-fired power stations, is projected to reduce both system strength and inertia. The international energy transition and adoption of more inverter-based renewable generation is driving international demand for large synchronous condensers (SCs). One possible solution is to convert existing fossil-fueled generators, which are synchronous machines, into SCs. At face value, this should provide a cost-effective way of providing the required security services."

Grid Solutions

As mentioned previously, there are a series of traditional and advanced ways of dealing with grid stability and reactive power issues. Capacitor banks, SVCs, and STATCOMs have been used for these functions for decades, though the technology continues to evolve. Capacitor banks (or shunt capacitors) are low cost and widely used. They have a relatively large footprint and other limitations: they supply reactive power but can't absorb it and struggle when faced with major load or voltage drops. Meanwhile, GE Vernova's Grid Solutions business is supplying Power Grid Corp. of India (PGCIL) with a series of 765-kV shunt reactors (Figure 3) for its Rajasthan and Karnataka regions to help maintain voltage levels and improve grid stability.

3. 765-kV shunt reactors. Courtesy: GE Vernova

"This equipment plays a crucial role in enhancing grid stability and efficiency, especially in the context of integrating large-scale renewable energy projects," said Eric Chaussin, Power Transmission Business Leader of Grid Solutions, GE Vernova.

SVCs can be regarded as switches composed of shunt capacitors and other electrical equipment that are designed to provide a high level of voltage control and lower reactive current demand on the transmission system. While they can both absorb and supply reactive power, they sometimes struggle due to sudden changes in the grid. But the technology is growing in sophistication. The likes of Hitachi Energy and GE Vernova have developed SVCs that can be customized to grid condition and control external shunt banks.

STATCOMs take things to another level by leveraging power electronics. They cost more than SVCs but deliver response times of a few microseconds. American Superconductor's Dynamic VAR (D-VAR) system can scale from 2 MVAR and up, and has overload capabilities of three times their rated capacity for up to three seconds. Hybrids of SVCs and STATCOMs are also available. Hitachi Energy's SVC Light Enhanced combines power quality and grid stabilization technologies as well as reactive power support. It incorporates supercapacitors, which store hundreds of megawatt-seconds of energy and automatically release it within milliseconds when disturbances occur.

Synchronous Condensers

Synchronous condensers are large pieces of spinning machinery composed of a generator. They are often paired with a flywheel to provide rotating inertia without generating any power. These machines spin at grid frequency and contribute to system stability by dampening frequency fluctuations and providing voltage stability through reactive power.

"Synchronous condenser is the name given to a synchronous machine that is connected into an electrical network to help in maintaining the system voltage," said Dr. James F. Manwell, a professor and director of the Renewable Energy Research Laboratory at the University of Massachusetts. "The synchronous machine is essentially a motor to which no load is connected."

There are several approaches to synchronous condensing from the likes of GE Vernova, Siemens Energy, and Hitachi Energy. GE Vernova offers a synchronous condenser and flywheel combo that is air cooled and rated up to 300 MVAR to be used for reactive power compensation, voltage support, and system inertia.

Siemens Energy's horizontal synchronous generator connects to the high-voltage transmission network via a step-up transformer. It is started and stopped with a frequency-controlled electric motor (pony motor) or a starting frequency converter.

When the generator reaches synchronous speed, it provides reactive power to the transmission network, as well as inertia and active power injection or absorption during sudden load unbalance events.

4. This Siemens Energy synchronous condenser has been installed at a facility in Rassau in the UK. Courtesy: Siemens Energy

Quinbrook Infrastructure Partners is installing four synchronous condensers in Scotland as part of the UK National Grid's Stability Pathfinder Program. The sites chosen near Gretna, Neilston, Rothienorman, and Thurso are largely in remote or rural areas adjacent to substations where there is already a critical need for grid stability.

In Estonia, too, transmission system operator Elering AS is working with Siemens Energy to add three synchronous condenser plants. These Flexible Alternating Current Transmission System (FACTS) units are being installed to stabilize the grid and manage the ongoing integration of renewable energy generation. Each 330-kV synchronous condenser will be connected to the high-voltage transmission network via a step-up transformer. Each of the three plants will be able to provide the grid with reactive power of –50/+50 MVAR and up to 1,750 megawatt-seconds of inertia. They will have a short-circuit capability of more than 900 MVA.

“Without the inertia provided by this equipment, the hazard for the unexpected shutting off of the power system and leaving consumers without power would be very high,” said Taavi Veskimägi, chairman of the Management Board of Elering.

Repurposing Old and New Turbines

An alternative approach to a purpose-built synchronous condenser is to make use of existing steam and gas turbines. Instead of them being decommissioned and dumped, some are being converted into synchronous condensers by adding a synchronous self-shifting (SSS) clutch that can disengage the generator from the turbine. The turbine brings the generator up to grid synchronous speed, disconnects the turbine from the generator, and the turbine is shut down. From that point on, only the generator is spinning as a way to supply or absorb reactive power, provide grid support, and maintain inertia.

This approach is favored by ARENA in Australia. It said in its report, “Our analysis indicates that repurposing generators as SCs can provide a viable solution for delivering the required security services. This approach can be used in combination with new SC investments to mitigate the risk of insufficient services.” The agency believes re-purposing generators as synchronous condensers will:

- Stabilize the voltage and thus provide system strength.
- Contribute inertia.
- Provide a source of reactive power for voltage control.
- Contribute positively to fault levels.
- Lower costs compared to purchasing new synchronous condensers.

Some users only utilize an aging turbine to supply reactive power. Others are looking to gain more value from their aging assets. “Turbines can be easily converted to synchronous condensers,” said Hendry of SSS Clutch. “Many choose to have the option of using their machines for peaking power or backup power should the need emerge.”

With so many coal plants being mothballed, Hendry suggested that facilities consider converting old steam turbine generators to synchronous condensers by disconnecting the turbine and adding an acceleration drive with an SSS Clutch at the exciter end of the generator. The steam turbine could be reconnected if seasonal power generation is needed or in some emergency sometime in the future.

Similarly, gas turbine plants can add a clutch (Figure 5), so the machine is configured to both generate power when needed or provide grid support and ancillary services. Although the machine may mainly operate for synchronous condensing, the clutch can be reengaged to generate electric power if there is a sudden need for peaking power, as often happens in renewable-heavy grids.

5. The Sask Power Ermine plant in Canada is one of many adding SSS Clutches to GE LM6000 PF+ turbines to enable them to operate as synchronous condensers. Courtesy: SSS Clutch

Old Turbines, New Tricks

In recent years, many utilities have discarded rotating assets in favor of renewables. It appears that some are having a change of heart—at least concerning the potential value of aging rotating assets. Case in point: SSS Clutch has received orders for 35 clutches intended for GE LM6000 PF+ Sprint models in recent months.

The clutches are built into a load gear as the gas turbine operates at a higher speed than the generator at 3,600 rpm, which is needed for a 60-Hz grid. The gear is needed to create synchronization with the grid.

Many of these orders were from the Tennessee Valley Authority (TVA), which is now rolling out 1 GW of wind turbines and solar PV in Tennessee. While it intends to decommission a great many coal and other rotating assets, it is keeping many of them available for peaking power and grid support. To date, TVA has received 10 GE LM6000 PF+ gas turbine generators with SSS Clutches and has another 20 on order. These are being fitted on LM6000s for peaking power. “By enabling these LM6000s to run as synchronous condensers, the TVA is ensuring it has enough inertia, system stability, and reactive power support,” said Hendry.

TVA’s strategy is to retire coal assets while adding lots of wind, solar, and natural gas to the grid, and fitting some of its turbines to operate as synchronous condensers to support greater penetration of renewables. Accordingly, three new GE 7FA.05 natural gas units recently came only at the Paradise Combined Cycle Plant in Kentucky, adding 750 MW to TVA’s operating fleet. They joined three other combustion turbines that began operating in July at the Colbert site in Alabama (another 750 MW). That’s just the first part if a plan to add 3.8 GW of natural gas generation to the grid by 2028.

“Many of TVA’s new combustion turbines are replacing older, less-efficient units,” said Jamie Cook, TVA’s general manager of Major Projects. “Natural gas units are cleaner than coal-fired generation. We can also operate them when other sources of generation, like solar, aren’t available. They supplement those sources with reliable power when we need it most.” n

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