As the generation mix evolves to a higher penetration of renewables and less traditional thermal generation, there are places in the power grid where stability becomes a challenge. It’s one that can be overcome by an unexpected technology—the synchronous condenser. Adding synchronous condensers can help with reactive power needs, increase short-circuit strength and thus system inertia, and assure better dynamic voltage recovery after severe system faults.
If you thought that the synchronous condenser was an antiquated relic of the past, think again! Synchronous condensers are considered as motors without any connected load or generators without prime movers. They produce or absorb reactive power. It is true that synchronous condensers were used at the dawn of electricity grids as the primary plant to regulate voltage, and hundreds of them were built and installed. “But then, around 40 years ago,” explains Arthur Depoian, Grid Solutions Commercial Manager who also doubles up as synchronous condenser application engineer, “new, power electronics technology emerged such that Static VAR Compensators (SVCs) and STATCOMs, with their lower costs, replaced synchronous condensers in the networks. However, even today, synchronous condensers offer other significant benefits.” Hence their more recent renaissance.
Synchronous condenser system up to 100 MVAr per machine

One of those benefits is based on the additional short-circuit strength they can provide. As further renewables penetration results in an increasing share of the world’s power generation, the power sources are frequently at considerable distances from the load centers, which has traditionally not been the case. This can in some cases cause a drop in the network’s short-circuit strength. Depoian adds, “This is what we term a ‘weak grid.’ And those remote sources, for instance wind farms, will be increasingly connected to the grid via high voltage AC and DC links.”

1 Dynamic voltage recovery and inertia

When a fault occurs on the grid the voltage is temporarily depressed, which requires an immediate and significant injection
of vars to recover the voltage and prevent a collapse of the grid. In less severe fault situations or on a strong grid, an SVC is likely to be adequate. However, if there is a risk of more severe faults or the grid is weak, a synchronous condenser is the most secure solution. “The decision is based on a set of fault case assumptions that the utilities make for the grid and associated simulations,” adds Depoian. “But they know that if the voltage does not recover quickly, they violate grid standards and face the risk of a widespread blackout. Opting for a synchronous condenser may be the only solution or a much stronger solution.” While costs of synchronous condenser installations do vary, overall capital investment appears to be comparable to both SVC and STATCOM.

Inertia\(^1\) may also become an important concern in the not-too-distant future. The spinning mass in the grid—generally turbines and generators at the production end of the network—creates the system’s inertia. As conventional generation (nuclear, thermal) is retired, it is often replaced by wind or solar sources, which provide less inertia. As a result, frequency stabilization becomes more challenging. FACTS-based equipment cannot provide the necessary inertia. “The question of inertia and frequency stabilization is not yet critical,” Depoian points out, “though it is already a problem in some specific island-based grids. This is an instance where synchronous condensers with their spinning mass could help resolve the problem.”

\(^1\): Inertia is basically resistance to change in motion. Inertia of a power network helps limit frequency fluctuations when a power imbalance occurs.

2 __The challenge of losses__

Opting for synchronous condensers implies optimizing the specifications and design to fit the operator’s requirements.
Parameters to be considered range from available substation footprint to long-term operating costs. The largest operating cost for synchronous condensers is electrical power losses, but certain choices can be made to reduce these:

- optimization of the machine design to match the expected operating conditions;
- use of slower speed salient pole machines that have lower losses at low Mvar output;
- if the system needs to vary considerably throughout the year, installing several smaller machines rather than one large one may allow part of the installation to be turned off when not needed, thus eliminating the associated losses.

3. **Old concept, new technology**

As in many other technology domains, synchronous condensers have been constantly improved and upgraded over the years. Gone are the analog control systems and rheostats of the past that could not deliver adequate response to dynamic events. Today’s synchronous condenser comes complete with state-of-the-art digital controls and relays. Modern machines are available with either full static or brushless excitation. Full static excitation has faster response: however, many utilities prefer the lower initial cost and lower maintenance costs of brushless excitation systems. Brushless excitation uses a rotating exciter built into the shaft that is controlled by a digital automatic voltage regulator. The speed and precision of these devices allow the performance of the latest generation of synchronous condensers to exceed their SVC counterparts in some applications. Maintenance needs are also considerably reduced. Depoian comments: “They still fulfill the same function, but their technology, quality and reliability have progressed almost beyond recognition.”
Synchronous condenser system up to 200 MVAr based on Topair or Topack generator combined with a FKG generator circuit breaker

4. **Synchronous condenser stabilizing the German network**

The German transmission network is in a very particular situation. The country has closed down eight of its 17 nuclear power reactors and will retire the rest by 2022. At the same time it has set very ambitious renewable energy targets; the country has been called “the world’s first major renewable energy economy.” It is worth noting that over 65% of 2015 worldwide offshore wind farm capacity
was installed in Germany. However, much of this will be transmitted via HVDC to the North and Baltic Sea shores where there are few major loads. The resulting highly variable load flow within the grid leads to voltage fluctuations and the need for enhanced reactive power control. It also reduces the inertia for the entire grid, making the need to improve short-circuit strength and frequency stability more critical.

German TSO TenneT called on GE Grid Solutions to adapt and install a two-pole synchronous condenser. “We needed it for high-speed dynamic voltage support and short-circuit power in case of failure on our grid,” says TenneT System Technology Engineer Dr. Simon Konzelmann. It was installed at their Bergrheinfeld substation in Bavaria, where the nearby Grafenrheinfeld nuclear power plant was recently closed down.

*Synchronous condenser installed with GCB and busduct*
The solution is based on the “Topair” range generator. This large rotating machine is normally part of a power plant. “Here, for the first time, it is installed by a TSO at one of its substations,” says Dr. Gert Hentschel, Grid Solutions Technical Solutions Manager. “The challenge was to build a standardized, yet
A novel hybrid solution consisting of the association of synchronous condenser with a static compensator can be envisaged to enhance the possibilities that a FACTS solution can offer. “Each technology (rotating versus static) will compensate the weakness of the other and all their strengths will be added,” says Guillaume de Préville, FACTS Senior Engineer at Grid Solutions. With such a solution, a STATCOM would offer the possibility of controlling the negative sequence voltage and therefore rebalance the grid system voltage, which could not be achieved by the synchronous condenser alone. With the addition of the static compensator, the hybrid solution would bring reinforced control of the sequence voltage, positive as well as negative.

This hybrid solution would therefore have the following features:

- load balancing associated with voltage control on a weak network;
• improvement of the time response of the complete Static VAR Compensation solution;
• reinforcement of the short-circuit capability mainly brought about by the presence of the synchronous condenser;
• reinforcement of grid inertia;
• Sub-Synchronous Resonance (SSR) mitigation with the rapidity of the STATCOM response.

The power electronic-based STATCOM can bring more added functions such as grid damping or harmonic filtering by injecting current or voltage at the correct frequency.
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