Synchronous condensers rediscovered – a new way to strengthen grids

After decades out of favour, utilities and industrial operators around the world have started to place major orders for synchronous condensers to address grid stability issues associated with the increased penetration of renewables. Why has the technology found a new role in the 21st century?

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The world's power grids have been built for well over a century on a centralised basis. They provide a linear flow of electricity from large rotating, fossil fuelled generators through transmission and distribution lines to consumers. Utilities and network operators have a deep understanding of these systems, combined with the experience and know-how to control them to ensure continuity of supply.

The situation has started to change fast in recent years due to the need to decarbonise power production and increase the use of renewable sources. Networks are evolving in response to these changes. And the networks of the future, as shown on the right of Figure 1, will look very different in structure from the traditional model on the left.

The main driver for these changes is the rapid uptake of renewable energy, usually wind and solar power. At the same time, large fossil fuel power plants have been decommissioned, cutting the amount of spinning mass or kinetic reserve in the network, reducing frequency stability in the grid.

These renewable power plants tend to be geographically remote and are inherently unpredictable and intermittent due to their reliance on weather conditions. Almost without exception they generate "non-synchronous" or synthesised power. That means, between the generation source and the power system, are power electronic devices such as inverters or converters.

Inverters are power electronic devices that cannot effectively support the network in case of faults or other unfavourable network events. This is because these semiconductor devices operate like switches, with no inherent power reserve, and have limited overloadability.

These new networks require intelligent sensors for monitoring inertia, fault level, loadability, phase angle and other parameters. Additionally, the changes in network structure and the continuously changing power generation mix require more advanced control algorithms.

To address the new challenges, attention has turned to synchronous condensers (SCs). While these synchronous rotating machines were once widely used in the power industry, they have seen little use in recent times. This is because their former function – reactive power compensation – is now handled by modern semiconductor-based equipment. However, grid stabilisation issues are becoming more acute with the increased penetration of large-scale renewable energy resources. This is driving the return to rotating devices with physical inertia. These can provide instantaneous support to maintain stability irrespective of the upstream network voltage or frequency.

What is a synchronous condenser?

A synchronous condenser is a synchronous machine. But it is not a motor, since it does not drive anything. Neither is it a generator, as there is no prime mover. However, it is very similar to a generator in its design and behaviour. And it does produce reactive power. As a rotating electric machine, the SC is a very traditional device. In the past, SCs were deployed as compensators to produce reactive power, balancing out highly inductive loads, like electric motors.

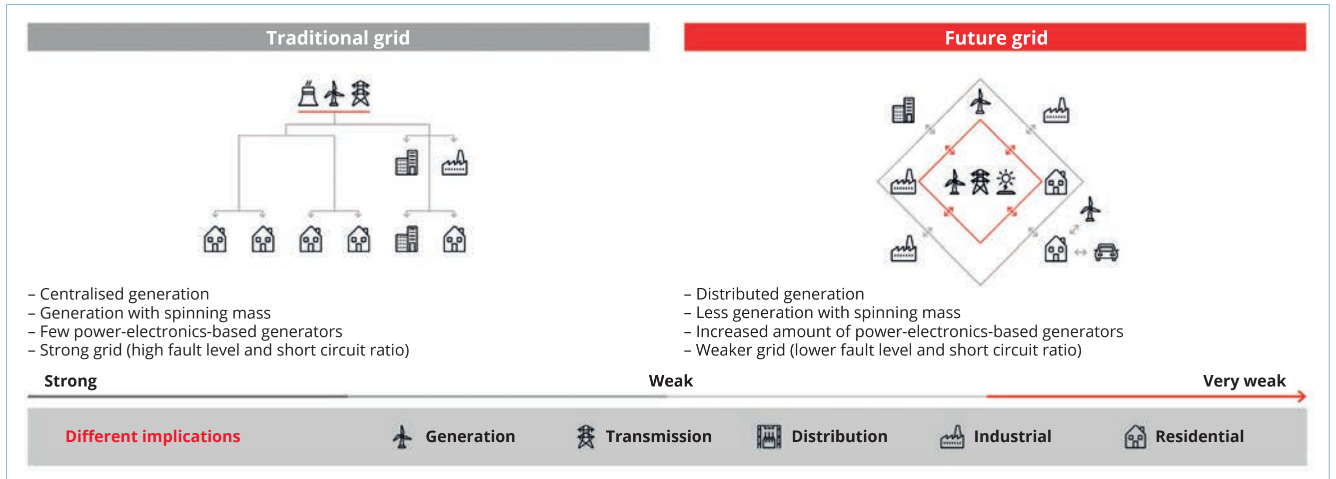
The typical users of SCs were electrical utilities and heavy industry enterprises operating transmission, distribution or industrial power grids. After many years when there was little interest, grid operators and utilities are turning back to SCs (see Figure 2). This is to handle the large-scale integration of wind and solar power generation as well as the introduction of smart grid technologies.

Reducing network risks with SCs

There are three main ways that synchronous condensers can help to reduce the risk associated with future networks:

• *Inertia support for frequency stability*

The balance between supply and demand is critical to maintaining a stable grid frequency.



Above: **Figure 1. Power grids are becoming decentralised**

Above: **Figures 2a and 2b. Synchronous condensers (left) installed at the Darlington Point solar farm (right) in New South Wales, the largest solar farm connected to Australia's grid**

Historically, this balance has been effectively self-regulated by the large spinning inertia provided by traditional rotating generators. But there is now a variety of non-synchronous resources on the grid such as wind, solar, tidal and battery energy storage (BESS). They are both intermittent and lacking any electro-mechanical connection to the grid. The result is an increased rate of change of frequency (RoCoF) that can result in systems tripping offline. The rotating mass in synchronous condensers can provide the instantaneous inertia that keeps the grid frequency within acceptable limits. They also help by damping the frequency excursions and providing more time for the operator to take suitable action to respond to frequency changes.

• *Fault level contribution*

When network faults occur, non-synchronous generators are unable to provide instantaneous support to avoid unnecessary tripping of loads. Their fault current capability is controlled to a level that is close to the nominal current. In contrast, the fault current response of the SC is uncontrolled and defined by its electrical parameters. This means that the fault current can be high in amplitude – possibly five times the nominal current or even higher.

There is a simple reason why fault current is so important. It is because the majority of the installed protection systems monitor the difference between a normal operating current and phenomena such as inrush currents and a fault current caused by a fault. This difference must be big enough to be detected easily, otherwise it is hard to protect critical assets such as transformers or switchgear.

Another important point is that measures of power quality such as voltage harmonics, unbalance and flicker relate to a defined fault level in the system. If this fault level is reduced by the introduction of significant levels of renewables then power quality issues will increase. This may result in overriding of power quality limits or could have a direct negative impact on the connected loads, such as overloading of rotating machines and transformers, or disturbing electronic devices.

• *Voltage regulation*

Synchronous condensers also deliver megavolt amperes reactive (MVArs) for voltage regulation. An SC cannot provide active power, it only provides reactive power. In an undervoltage condition, such as when there is a voltage dip, reactive power is produced to support the grid voltage. Equally, in an overvoltage condition, where the voltage is becoming too high, reactive power can be absorbed.

Where can synchronous condensers be deployed?

As shown in Figure 3, synchronous condensers can be deployed in many areas of the grid to support a variety of requirements:

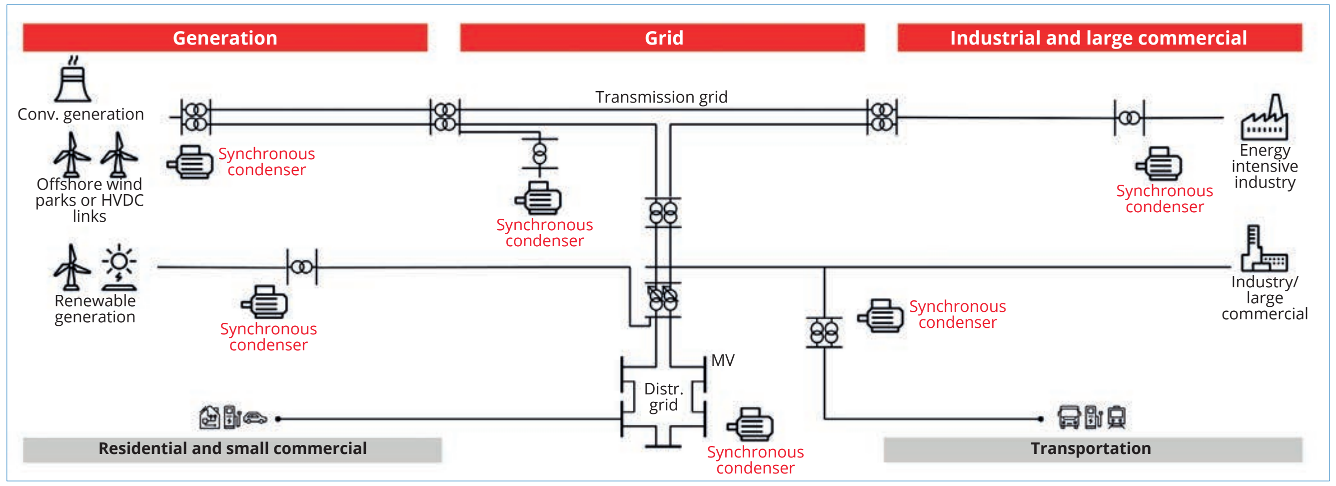
• *Renewables*

For renewable energy projects, SCs support grid code compliance. They support voltage stability and mitigate transient faults when integrating large wind farms. SCs can also combat phase-locked loop (PLL) synchronisation instability in converters, as well as limitations in the power infeed caused by low short circuit level (SCL). Solar farms can use SCs to increase revenue by boosting active power output as otherwise part of the total inverter power has to be assigned for reactive power compensation.

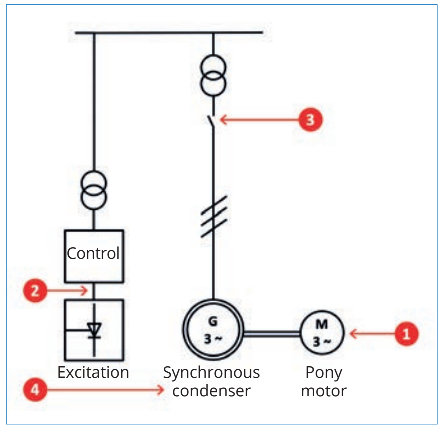
• *Conventional power generation*

In conventional power generation synchronous condensers mitigate frequency instability that occurs through the imbalance of peak demand and renewable power – they help prevent an increased RoCoF.

They also support the grid with inertia and offload reactive power from generators during peak or ramp times ("duck curve"). SCs can enable power generation operators to sell additional ancillary services such as higher



Above: **Figure 3. Synchronous condensers can be deployed in many different areas of the grid**



Above: **Figure 4. Starting a synchronous condenser**

inertia, additional fault current and reactive power.

- ***Transmission systems***

For transmission system operators (TSOs), synchronous condensers mitigate protection problems due to decreased SCL, PLL instability, rapid changes in power flow, system stability problems, power system splits due to different inertia levels, and other issues. They can facilitate inertia planning, provide additional short circuit capacity to strengthen the network and remedy voltage collapse during heavy load peaks.

SCs can also mitigate transient faults when integrating large wind farms and enable higher system availability through redundancy when multiple units are installed.

To reduce the risk of power oscillation, SCs can be remotely deployed in decentralised grids.

- ***Distribution systems***

For distribution system operators (DSOs), synchronous condensers mitigate large variations in SCL between day and night periods and manage deeper voltage dips caused by reduced SCL and general power quality problems. They can be configured to supply "switchable" fault current support during high/low load times. SCs also supply fault current and inertia during island operation, such as in microgrids.

- ***Industrial applications***

In industrial applications synchronous condensers resolve power quality issues in weak grids, counteracting voltage dips that cause variable speed drives (VSDs) to trip and interrupt production processes. They Increase fault current and reduce the transfer of power quality issues (flicker, harmonics, unbalance) to the grid.

Synchronous condensers can mitigate voltage stability issues associated with heavy industries like mining, especially when fossil fuel generators are phased out.

Other capabilities include supplying short circuit capacity to strengthen the network and prevent voltage collapse during heavy load peak. They also increase fault current and reduce problems with motor-starting and demanding loads like gearless mill drives and furnaces at mines.

Converting unused generators

It is entirely possible to convert an unused large generator into a synchronous condenser, and there are a number of these converted generators operating successfully. However, this should be approached with caution as the equipment to be converted will, by definition, be old technology and its actual condition unknown. Before starting a project, it is advisable to have the condition of the generator assessed thoroughly, such as by ABB's Lifetime Expectancy Analysis Program (LEAP) service.

In any case, modern SCs will be smaller and simpler, enabling them to be installed in any location. They also come with the benefits of modern control and communication technology. Maintenance requirements are very low, as they are simpler and smaller than traditional power generators. Furthermore, SCs are usually applied as two or more smaller units for redundancy.

Synchronous condenser configuration

ABB supplies synchronous condensers in ratings up to 80 MVAr and 3 to 15 kV system voltage. The preferred voltage is a matter of optimisation, since the network voltage is usually much higher, so a step-up transformer is used. Higher outputs are reached by using several units in a standardised module concept. This configuration offers better redundancy and availability compared to one large unit.

The construction of the SC is not substantially different to a synchronous generator as it features a salient pole rotor, brushless excitation and epoxy resin insulated stator windings. The machine is usually water cooled, as this is one of the most effective ways to dissipate the heat losses and it is designed to be used both indoors and outdoors in different ambient conditions. However, other cooling options, such as air-to-air cooling, are also possible.

For starting, a small pony motor of about 200-300 kW is coupled to the SC (see Figure 4). It is controlled by a drive which ramps up over a few minutes to bring the speed of the SC into synchronous operation, usually at 1500 rpm.

The excitation system is then started and at the right moment the synchronization procedure will switch the machine online, ready to support the network

Examples of synchronous condenser applications

Synchronous condensers are being deployed in grid support applications around the world including:

- ***Darlington Point solar farm***

Two ABB synchronous condensers have been installed as an integral part of the Darlington Point solar farm (see Figures 2a and 2b). They help stabilise the local power grid as the penetration of renewable energy increases in a critical area of New South Wales. The facility started operation in August 2020, and with a projected annual output of 685 000 MWh, it is currently the largest solar farm connected to Australia's grid.

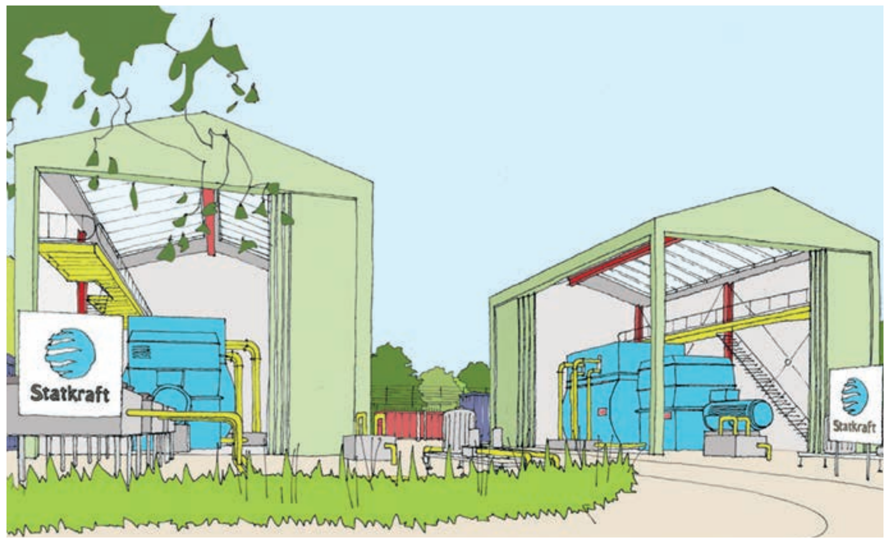
The synchronous condensers contribute to short circuit capacity so that the network can easily ride through any fault conditions and avoid loss of power in the region. This is especially important as the solar farm is located in an area where it is challenging for new projects to meet the stringent connection requirements.

- ***Antapaccay copper mine***

In 2013, ABB completed the commissioning of two synchronous condensers and harmonic filters for Xstrata Copper's Antapaccay project in southern Peru. The project is located in a remote area and is connected by a long power transmission line. The synchronous condensers ensure accurate and dynamic power factor compensation for safe and reliable operation at the remote mine. By integrating SCs and harmonic filters, the harmonics are mitigated and short circuit levels improved, optimising Antapaccay's productivity and energy efficiency.

- ***High-inertia solution, Lister Drive***

In February 2021, ABB was awarded a contract by Statkraft to design, manufacture and install two high-inertia SC systems for the Lister Drive Greener Grid project at Liverpool, England (see Figure 5). The innovative project will play a key role in stabilising the local grid to handle more wind and solar power. This will help National Grid meet its target of operating a zero-carbon electricity system by 2025.



Above: **Figure 5. Artist's impression of the Lister Drive Greener Grid project**

This project will be the first anywhere in the world to feature an ABB High-Inertia configuration. This couples a 67 MVAr synchronous condenser with a 40 tonne flywheel that increases the instantaneously available inertia by 3.5 times.

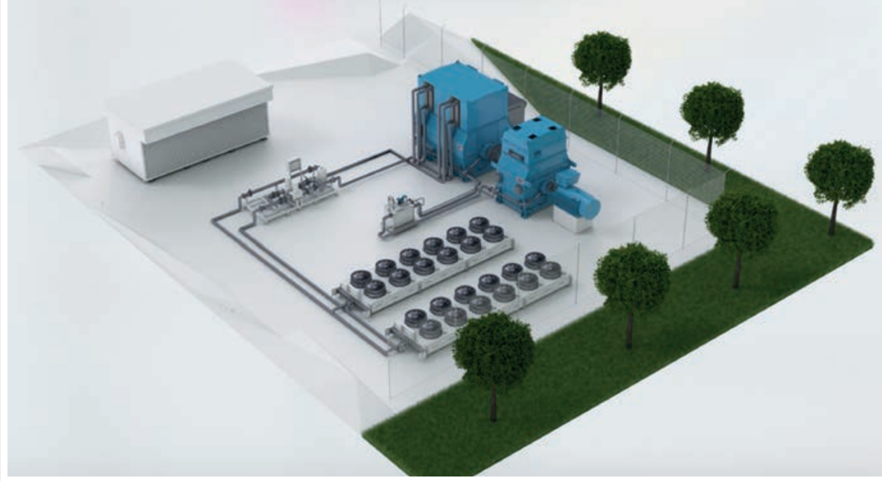
The advantage of combining a mid-size SC with a flywheel (see Figure 6) is that the inertia available is increased several times, while the losses will be much lower compared to having all the inertia provided by SC. This approach is also a cost-effective way of using up to four mid-size synchronous condensers coupled together with the benefits of a high level of redundancy, increased inertia and greater controllability.

- ***Phoenix hybrid SC system***

In an innovative four year project (Phoenix), SP Energy Networks is working with the University of Strathclyde and the Technical University of Denmark to deliver the world's first hybrid-synchronous condenser (H-SC).

The H-SC's two main physical components are a traditional ABB synchronous condenser and a power electronic static compensator (STATCOM).

The STATCOM's role in the H-SC is to absorb or inject fast reactive power, which helps during transient stability issues or for active filtering. Together, the SC and STATCOM provide inertia, fault current support and MVArs (from the SC) and the "fast" MVArs (from the STATCOM), which provide a good fit for power system stability.



Above: **Figure 6. The ABB High-Inertia concept combines a mid-size synchronous condenser with a flywheel**

The H-SC was installed in 2019 at Neilston 275 kV substation near Glasgow (see Figure 7). It is undergoing trials to evaluate how it can inject or absorb energy into the network to maintain the voltage within the required limits. In effect, it will provide spinning reserve over a few seconds until other resources such as a battery energy storage system (BESS) or a reserve generator can be brought online.

Decentralised generation demands decentralised solutions

In summary, there is an increasing grid penetration of renewables and fossil fuel power plants are being decommissioned.

Together, these developments are bringing about profound changes in the structure of electricity networks.

Future networks with decentralised power generation will require decentralised solutions to ensure grid stability and resilience. Synchronous condensers can be deployed to strengthen weak networks in remote areas. Their advantages include inertia support for frequency stability, fault level contribution and voltage regulation – all functions that are challenging to achieve with power electronic systems on their own.

The need for grid operators to address network quality issues and ensure reliability and continuity of supply will continue to grow, especially as they face the new challenges presented by renewables. That means that synchronous condensers, either on their own or in combination with static devices, will continue to enjoy a rebirth that could see several hundreds of units deployed worldwide over the next decade. ●

Above: **Figure 7. Hybrid synchronous condenser installed at Neilston substation (the Phoenix project)**

For further information: https://new.abb.com/motors-generators/synchronous-condensers