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Combining Synchronous Condenser and Battery Energy Storage System Technology to Boost Grid Stability

by **Christian Payerl**

Photo: ABB, Shutterstock

Electric power grids around the world are facing a major challenge due to the steady loss of the spinning inertia, otherwise known as kinetic reserve, that is vital for their stable operation. The main reason for this decline in inertia is that the transition to decarbonized energy is driving the decommissioning of traditional large-scale, centralized power plant based largely on rotating synchronous generators. Increasingly, power is being produced by inverter-based non-synchronous resources such as wind and solar that are not able to contribute inertia to the grid.

Historically, power systems have relied on the inertia inherent in large, centralized generation plant to keep them stable. Inertia acts rather like a car's shock absorbers smooth the way over bumps in the road. It helps the grid to react to sudden changes in frequency, such as when a generator trips offline, by providing time to respond. This keeps the system frequency within controlled limits around 50 or 60 Hz (depending on the country). In an intact and stable system, the frequency of electricity across the grid network is the same and the system can react to any loss of load or generation and is robust against disturbances.

The impact that reduced system inertia can have on grids in terms of lower stability and resilience is generally well known. It is perhaps less well recognized that the loss of synchronous generation can also cause a decrease in the available fault current, with a consequent impact on existing relay protection systems.

A further way that the increased penetration of renewables can affect grid stability is by potentially introducing new phenomena such as oscillations. These also have a negative impact on power quality.

The need to mitigate grid stability challenges is driving substantial R&D activity focused on the development of new algorithms and control schemes. There is however an alternative approach that shows considerable promise – this uses a hybrid solution that combines well-proven SC technology for fault current contribution and real inertia with a

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A hybrid combination of a Synchronous Condenser (SC) with a Battery Energy Storage System (BESS) offers a range of grid-supporting functions, including black-start capability.

BESS for active power and frequency support.

Why have Synchronous Condensers made a comeback?

A Synchronous Condenser is a large rotating electric machine. It is not a motor – it does not drive anything. Equally, it is not a generator – there is no prime mover. There was a time when SCs were ubiquitous in power grids where they were used to provide reactive power to balance out highly inductive loads, like electric motors.

However, over the past 50 years there was a decline in the use of SCs as their reactive power role has been replaced by power electronic equipment.

Figure 1: SC installation at Darlington Point solar farm in Australia

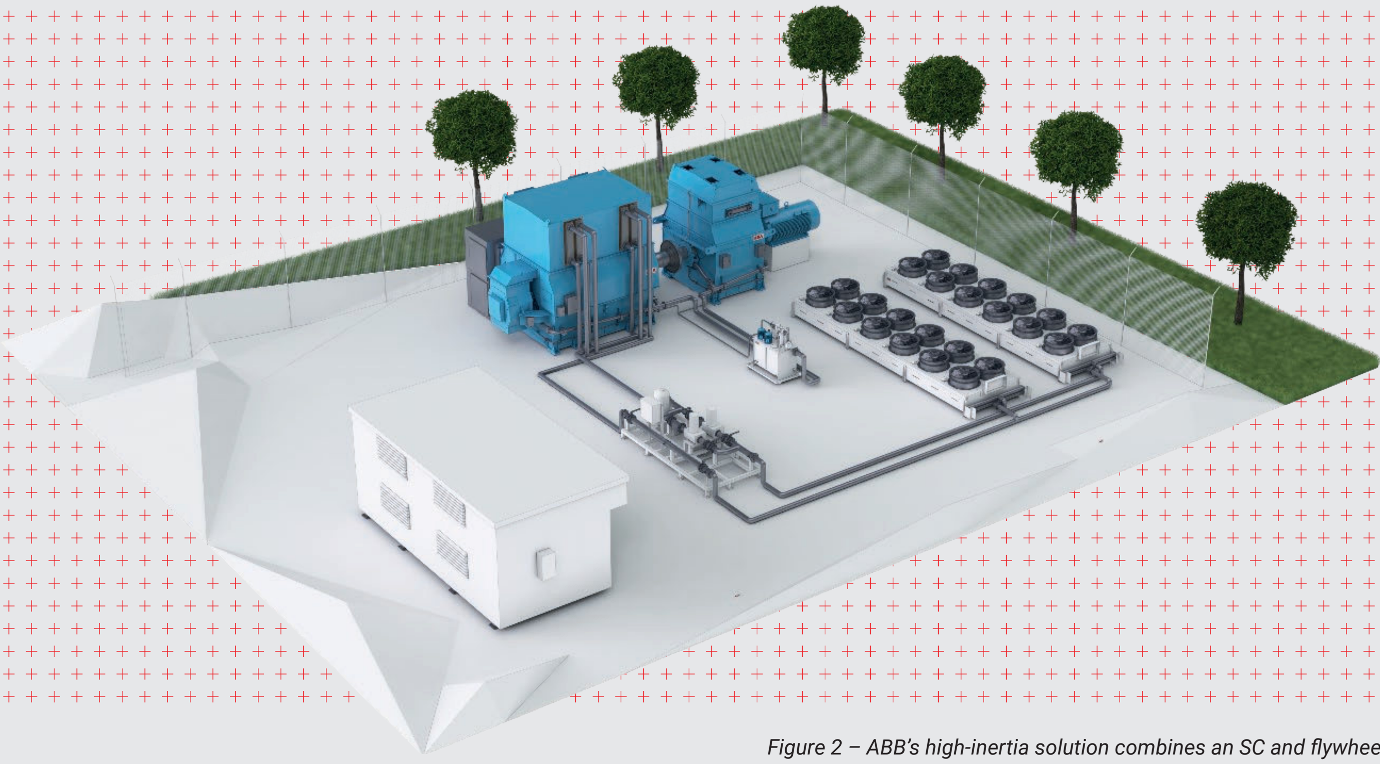

Figure 2 – ABB's high-inertia solution combines an SC and flywheel

They are now making a comeback as the changing nature of grids, and concerns over the loss of inertia, have stimulated new interest. The reason is that SCs can mimic the operation of large generating plant by providing an alternative source of spinning inertia. Because they are large rotating machines, SCs can both supply and absorb reactive power, delivering voltage support and dynamic regulation.

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One advantage of SCs is that they are a very cost-effective, scalable and reliable way to maintain power quality. This includes the capability to provide the level of fault current protection essential to strengthen a weak grid. SCs are therefore a key enabling technology that facilitates the increased grid penetration of renewable energy.

SCs are typically supplied in ratings up to 80 megavolt amperes of reactive power (MVAr) and 3 to 15 kilovolt (kV) system voltage to provide a decentralized solution to increase grid strength and stability. It is possible to combine several modules to achieve a higher output, with the added advantage of better redundancy and availability compared to one large unit.

A particularly interesting deployment of SCs is at the Lister Drive Greener Grid project at Liverpool, England. In early 2023, ABB completed a contract for Statkraft, Europe's largest renewable energy producer, to design, manufacture and install two high-inertia SC systems. This innovative project is now playing a key role in stabilizing the local grid to handle more wind and solar power so that National Grid can meet its target of operating a zero-carbon electricity system by 2025.

Lister Drive is the world's first project to feature ABB's high-inertia SC configuration. It couples a 67 MVAr SC with a 40-tonne flywheel that increases the instantaneously available inertia by 3.5 times.

Combining a mid-size SC with a flywheel multiplies the available inertia several times, with much lower losses than installing the whole inertia as SC. It is also a cost-effective way of using up to two mid-sized SCs coupled together with the benefits of a high level of redundancy, increased inertia and greater controllability.

A notable feature of the Lister Drive project is that safety has been a priority in the design, installation and operation of the large flywheels. This includes satisfying safety requirements during abnormal events, including containment of a loose but mainly intact flywheel rotor. To achieve this an integrated safety enclosure has been designed to manage the flywheel and provide protection in a single unit.

Combining an SC and BESS

Older, well-established BESS installations feature grid-following inverter technology. This is also a common approach for new installations, especially on a smaller scale. The challenge is that it relies on a stable grid as too much variation in the voltage phasor can cause control problems for the inverter. Therefore, this type of inverter cannot connect to an unstable grid or be used for a black-start.

Photo: ABB

Figure 3 – Lister Drive is the world's first application of ABB's high-inertia SC configuration – housed in the two gray buildings.

There is an alternative solution in the grid-forming inverters that are relatively new and less common, although they are being deployed in larger scale BESS installations.
This type of inverter has the advantage that it can stabilize a grid and provide black-start capability.

One potential issue with using inverter-based technologies is that they can cause problems such as power oscillations and opposing control.
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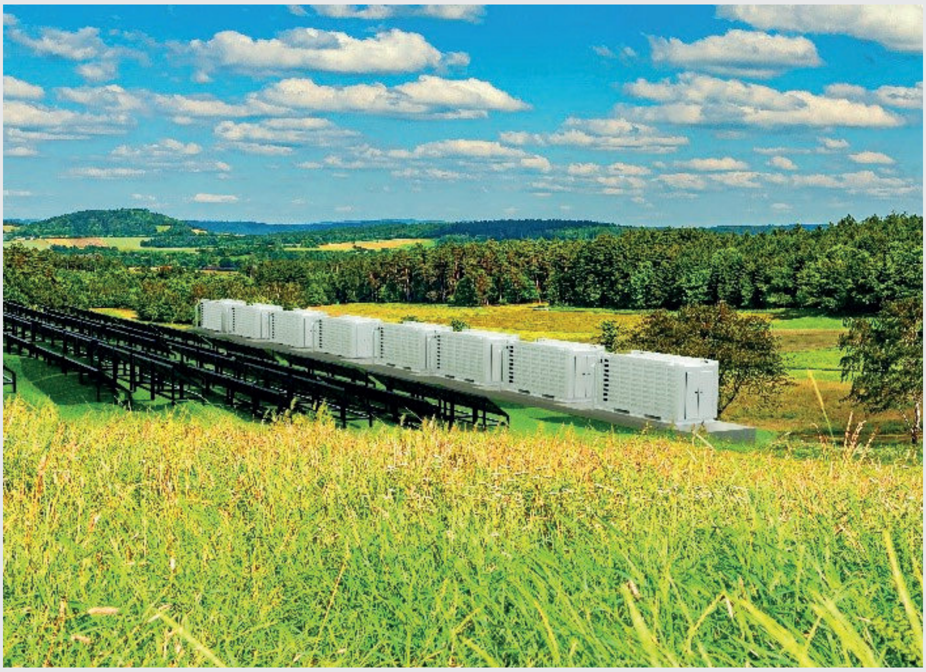

Figure 4 – Typical BESS installation supporting a solar farm

The advantage of using a synchronous condenser is that its operation is determined by simple physics, making it a stable and reliable method for grid support.

However, it is not so much a case of making a choice between a BESS incorporating power electronics and an SC. Using the two as a hybrid combination is the best solution for the multiple applications we outline here.

Voltage and reactive power control

Using an SC will add high overload capability to the grid through its inherent properties as a large rotating machine. It provides instantaneous support during a fault, lifting the voltage and reducing the impact of voltage dip.

When the fault is cleared the SC can create a slight overvoltage since it cannot respond quickly to reduce the excitation current. That is where the quick absorption of reactive power by a power electronic device such as a BESS or STATCOM is useful to reduce this over-swing in voltage. This ensures a faster return to the steady state.

Inertia and frequency control

The SC supplies inertia and frequency control as "real" inertia. This is complemented by fast frequency control, sometimes called "virtual" inertia, by the BESS. Using this hybrid system has been shown to give better system performance and a lower rate of change of frequency (ROCOF).

Short circuit capacity

A vital aspect of a power grid is its short circuit capacity (short circuit ratio – SCR) and its relay protection functions. The SC can provide very high short-circuit currents of several times the rated current. Using an SC in combination with a BESS can therefore provide a large fault current contribution, but without the need to over-dimension the BESS inverter to handle the large current that occurs in fault scenarios.

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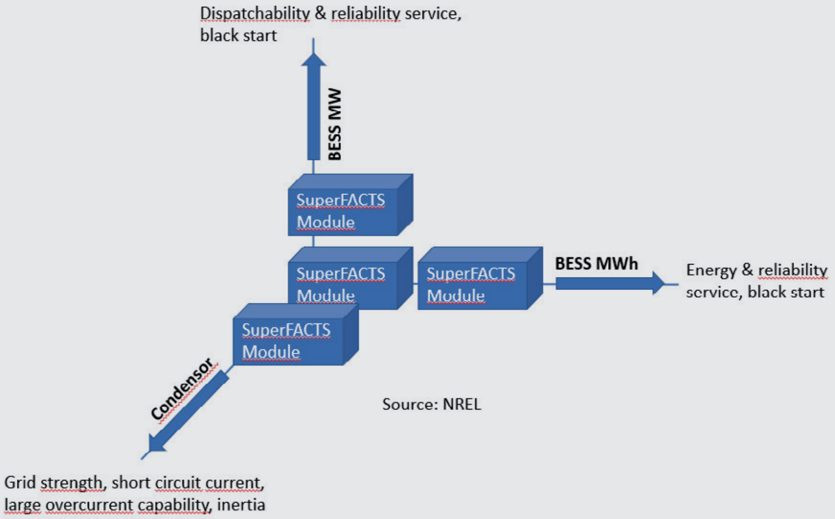

Figure 5 – Combining a BESS and SC is the best solution for multiple applications

Black-start capability

A BESS with a grid-forming inverter can provide black-start capability. First, it establishes the local grid to which the SC is synchronized. The SC then adds fault current capability and voltage and frequency stability as the larger grid is restarted and built up by adding additional power generation and loads.

Oscillation damping

To improve oscillation damping an SC can be connected to the grid in combination with BESS units. Or a power oscillation damping function (POD) can be added as part of the SC's automatic voltage regulator (AVR) system.

Conclusion - A new powerful combination for stable grids

While SCs and BESS have their individual merits combining them will offer clear benefits in providing grid-supporting functions. These include stabilizing the grid through increased short-circuit current, increased frequency support and system inertia, decreasing ROCOF, and reactive power control. An added benefit is that a hybrid SC and BESS installation can provide black-start capability.

A hybrid SC and BESS installation can provide black-start capability.

Photo: ABB