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WHITE PAPER

# Deploying synchronous condensers to provide distributed power grid support





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**Front cover image:**

Synchronous condensers supporting the Darlington Point Solar Farm in New South Wales, Australia (image supplied by Edify Energy and Octopus Investments).

# Introduction – how is the structure of electricity networks changing?

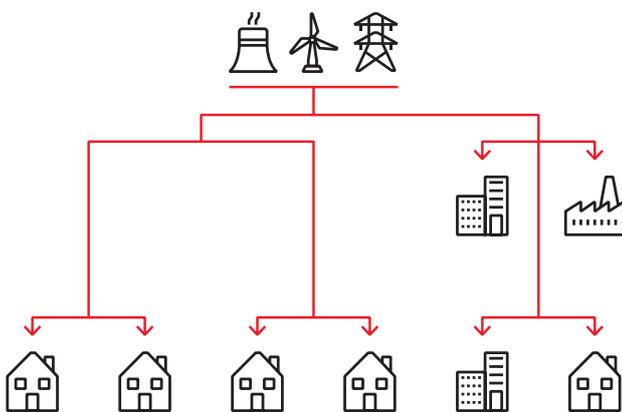
Traditional power grids are centralized, with linear relationships from the rotating generators through transmission and distribution lines to consumers. See Image 01. Generating companies and network operators fully understand the technology of these systems and have the experience and know-how to control and supervise them.

The need to decarbonize power production and increase the use of renewable sources has led to rapid changes in the way power is generated. Networks are evolving in line with these changes, and the networks of the future will be very different in structure from the traditional model. See Image 02. The main driver behind these changes in networks is the rapid uptake of weather-driven power generation, which generally consists of wind and solar power.

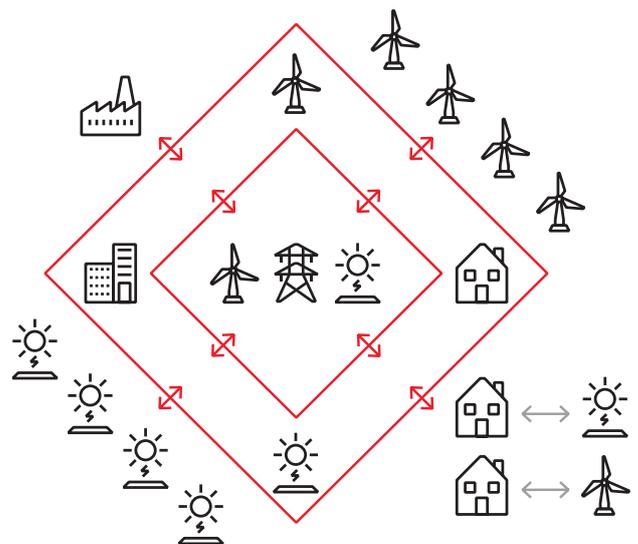
Weather-driven power plants are geographically decentralized and often operate on an intermittent basis. Almost without exception they generate 'non-synchronous' or synthesized power, i.e. they produce DC (direct current) that is converted by inverters into the AC (alternating current) required in the network.

Inverters are power electronic devices that cannot effectively support the network in case of faults or other unfavorable network events. This is because these semiconductor devices operate like switches with no inherent power reserve and limited overloadability. At the same time, large fossil fuel power plants have been decommissioned, cutting the amount of spinning mass or kinetic reserve in the network and thereby reducing fault ride-through capability.

01 Traditional network



02 Future network





03 Darlington Point Solar Farm is supported by two ABB synchronous condensers at the farm's 132 kV connection point (image supplied by Edify Energy and Octopus Investments).

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

In the context of efforts to mitigate the recurring challenges, attention has turned to synchronous compensators or condensers (SCs). These synchronous rotating machines are widely known in the power industry. They have seen little use in recent times, however, as their former function – reactive power compensation – is now handled by modern semiconductor-based equipment.

Network stabilization issues are becoming more acute with the arrival of larger scale weather-driven power generation and synthesized power. This has required a return to rotating (physical inertia) devices that can inherently provide instantaneous support by maintaining voltage generation irrespective of the upstream network voltage or frequency. This can be easily achieved by a stand-alone (not coupled) rotating SC equipped with a fast-acting, programmable excitation system. See Image 03.

This document explores recent experience of network issues and shows how SCs provide an effective solution to a range of undesirable network behaviors.

# Risk factors in future networks

**Increased rate of change of frequency (RoCoF).** The higher RoCoF associated with new networks risks large generators tripping. This may necessitate re-setting of protection parameters to allow operation over a wider frequency band.

**Weather-based fluctuations.** Changes in generation due to changes in weather patterns require substantial investments in readily available rotating generation, which is generally provided by stand-by gas turbines.

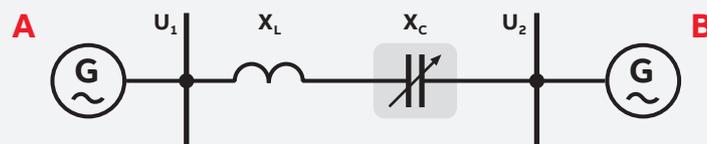
**Voltage stability.** When network faults occur, 'non-synchronous' generators are unable to maintain voltage stability, and they cannot provide instantaneous fault support to avoid unnecessary tripping of loads. In other words, they trip because they have no inherent instantaneous capacity or energy reserve. Spinning devices, by contrast, can maintain

voltage provided that their excitation is stable. In fact, the field forcing feature even enables SCs to maintain voltage generation at a higher level, helping the network to return to its pre-fault state and equipment to remain connected.

**Changing power generation mix.** As the power generation mix changes both with weather conditions and load conditions, the strength of the grid (fault level as well as inertia) also changes continuously.

**Inter-area oscillations.** These oscillations, which occur when generating plants are interconnected with weaker areas, represent one of the most imminent problems with decentralized generation. Power oscillates between stronger and weaker areas at low frequencies, in the range 0.1-0.8 Hz. This results in sub-optimal power flows, ineffective operation and the risk of instability.

04 Inter-area connections between strong and weak areas are prone to stability issues unless additional support is provided.



Referring to Image 04, if area A is the power center with strong power generation and inertia support, then remote area B will have a weak network with limited reserves as a consequence of being remote from area A. This may be acceptable if area B is characterized by non-critical passive consumption and little or no power generation. However, if significant inverter-based power generation is added in area B then the overall system will become vulnerable and unstable. This is because synthesized power generation has very limited instantaneous support capability and inertia reserve, which are needed to counteract undesirable network events.

Network operators cannot rely on inverter-based generators to damp inter-area oscillations when large traditional coal based generators are

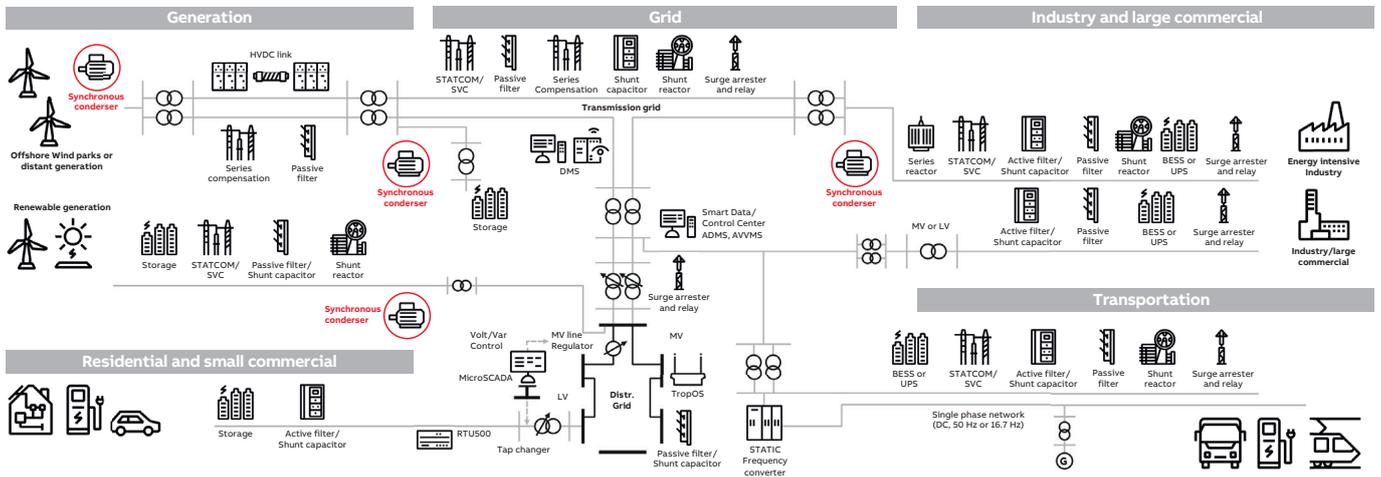
being gradually removed from the generation mix. Rotating generators are able to damp oscillations in their local area by means of their Power System Stabilizer (PSS). The PSS forms part of the excitation control system, and it detects oscillations through phase angle measurements. However, the PSS is not effective against inter-area oscillations.

As a result, the only means available for network operators to tackle inter-area oscillations is to strengthen weak networks in remote areas. This can be achieved by deploying synchronous condensers (SCs) to generate short-circuit current (SCC) and thereby provide local fault support capacity. SCs also strengthen synchronizing torque, reducing phase angle differences and acting as a sink for low frequency harmonics.

# Benefits of synchronous condensers in weak areas

As shown above, there are important advantages to deploying smaller SCs in weak areas rather than using a large, centrally located SC or synchronous generator (SG). This is due to the significant impact of transmission and distribution lines on

transient events in inter-area power flows. Long power line impedances reduce the SCC capability of centrally located SCs and SGs, making them less effective in remote areas. As a result, local, smaller units are needed to provide local SCC and inertia. See Image 05.



05 Distributed network optimization.

## Advantages of installing synchronous condensers in weak network areas

- Provide reactive power and synchronizing torque
- Provide effective support for grid restoration
- Provide significant short-circuit current (SCC)
- Contribute to small signal and transient stability; act as a ‘sink’ to correct low order system harmonics and phase unbalance
- Provide instantaneous inertia (kinetic energy) up to 100 – 460 MWs
- Provide voltage support and dynamic regulation by generating/absorbing reactive power (MVar)
- Can conveniently be integrated with fast dynamic MVar providers like Statcoms, SVCs, HVDC links, wind/solar inverters, as well as storage converters

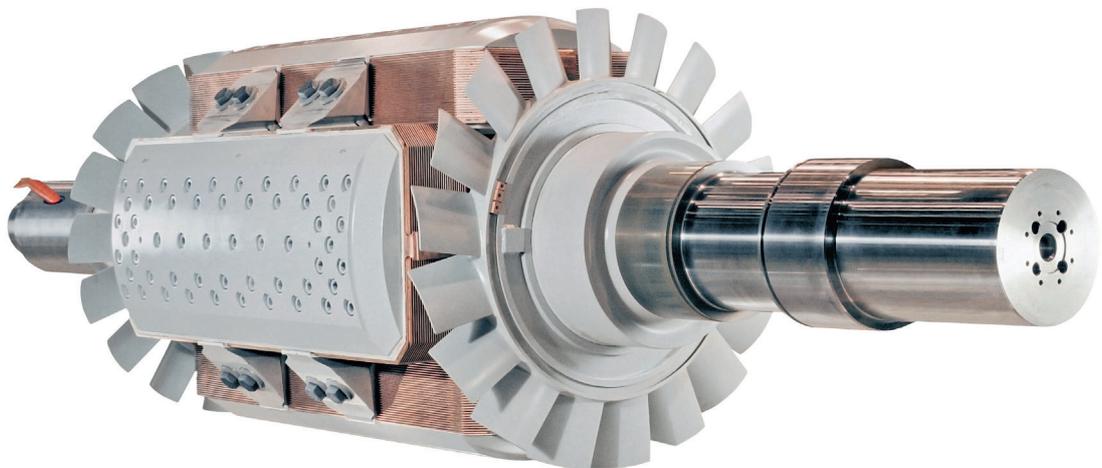
# Tailored synchronous condensers for maximized grid support

Synchronous condensers supplied by ABB are made to order on the basis of network studies for the location where grid support is required. They therefore provide a tailored solution that can be strategically installed to achieve maximal grid support impact in a particular network node.

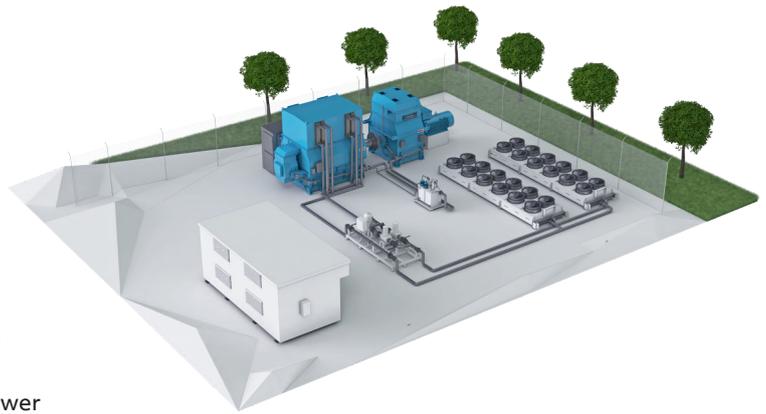
This approach is generally a good fit with regulatory approval processes. In Australia, for example, the AEMO (Australian Energy Market Operator) requires power generation applicants to supply a full study based on PSS/E® (Power System Simulator for Engineering) and PSCAD (Power System Computer Aided Design) modelling in order to ensure compliance. ABB supports this procedure by providing PSS/E® and PSCAD models for the SC and AVR (automatic voltage regulator), as well as recommended settings for the protection relay. This helps the applicant to obtain a measured, verifiable solution for the authorities.

ABB's SCs are compact units in the 10-70 MVar capacity range. They can be easily deployed for optimized effect. These small and medium sized SCs compare favorably with the very large 100-200 MVA SCs derived from turbine generators. Such large units tend to be feasible only at the 3000 rpm operating speed, which requires a cylindrical rotor construction and involves a number of mechanical challenges as well as project related challenges (i.e. logistics and installation for large units). The smaller, modular units supplied by ABB operate at 1500 rpm and feature a salient, solid pole rotor design. See Image 06. The dedicated pole pieces give a stronger and more focused magnetic field which results in better angular stability and higher overloadability. The superior diameter/length ratio, compared to 3000 rpm units, provides a more effective and more economical way to obtain the desired inertia.

06 Salient, solid pole rotor design provides greater stability.



# Conclusion



The increasing penetration of renewables, particularly wind and solar, in the energy mix, and the decommissioning of fossil fuel power plants are together bringing about changes in the structure of electricity networks.

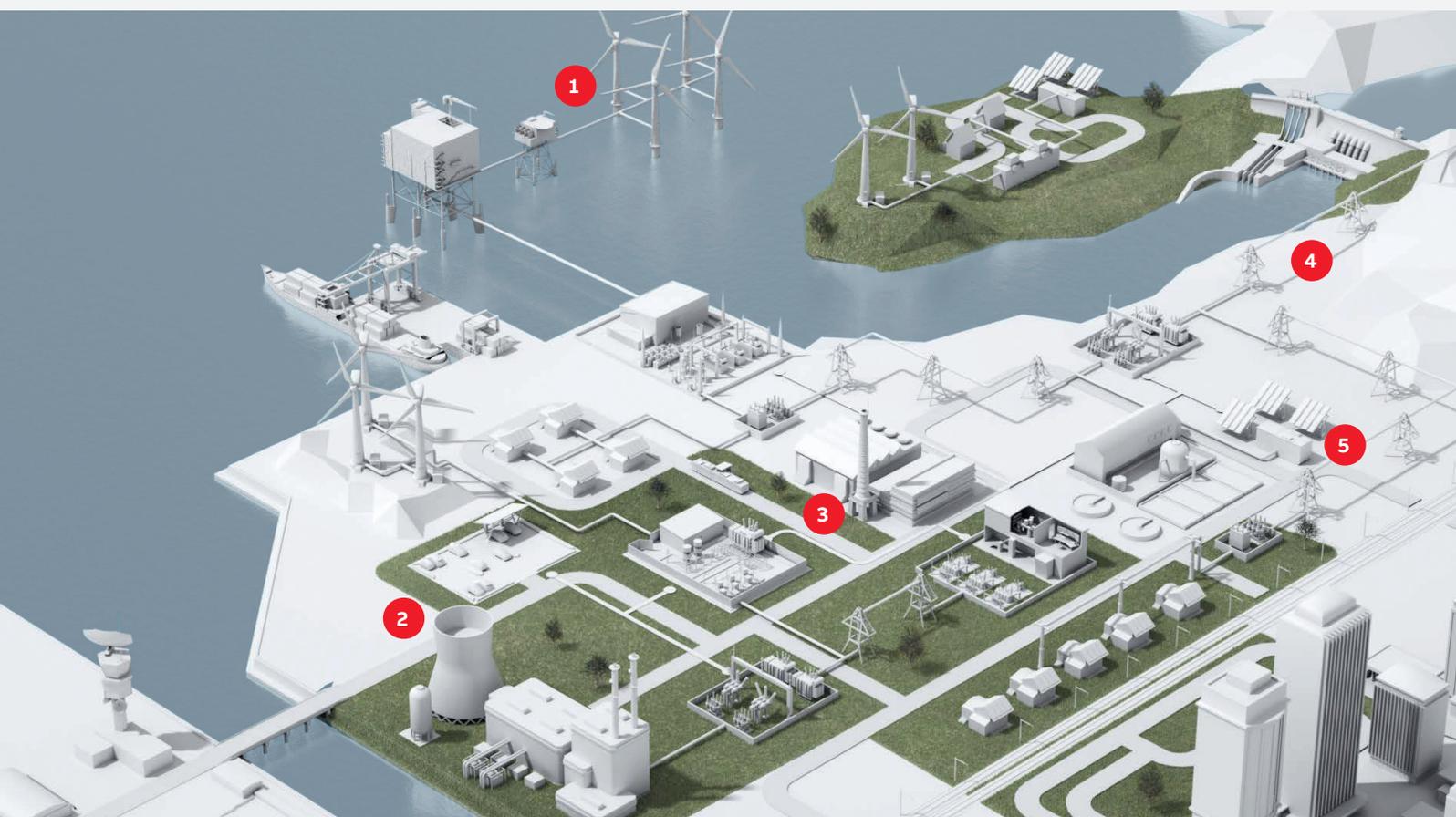
07 A complete system with small footprint can provide up to 460 MWs kinetic energy.

Future networks with decentralized power generation will require decentralized solutions to ensure grid stability and resilience. Synchronous condensers can be deployed to strengthen weak networks in remote areas. Advantages include the provision of reactive power and synchronizing torque, generation of short-circuit current and damping of low order system harmonics, as well as provision of instantaneous inertia up to 460 MWs.

Synchronous condensers supplied by ABB are compact units up to 70 MVAR that can be deployed exactly where grid support is needed. See Images 07 and 08. They are designed on the basis of network studies and therefore tailored to provide maximized grid support. Compared to larger units derived from turbine generators they provide better angular stability and higher overloadability.

08 Compact SCs are suitable for any location and can be deployed exactly where grid support is needed.

- 1 Wind power generation
- 2 Phase out fossil power generation
- 3 Industry, mining heavy peak loads
- 4 Long weak power distribution lines
- 5 Solar and geothermal power generation







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