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The challenges of High Penetration of Renewable Energy on Today's Power Grids and The Impact of Multilevel STATCOM and Grid Forming Control

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The changing power landscape

Many drivers – one common need

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Generation

- Increasing energy production
- Integration of renewables
- Deal with distributed generation

Need for good Power Quality

Consumers

- Increasing power consumption
- New grids in emerging markets
- Faster and stronger transportation systems

Transmission and Distribution

- Aging infrastructure
- Changing regulations grid code compliance
- Energy trading between regions
- Reversible power flow

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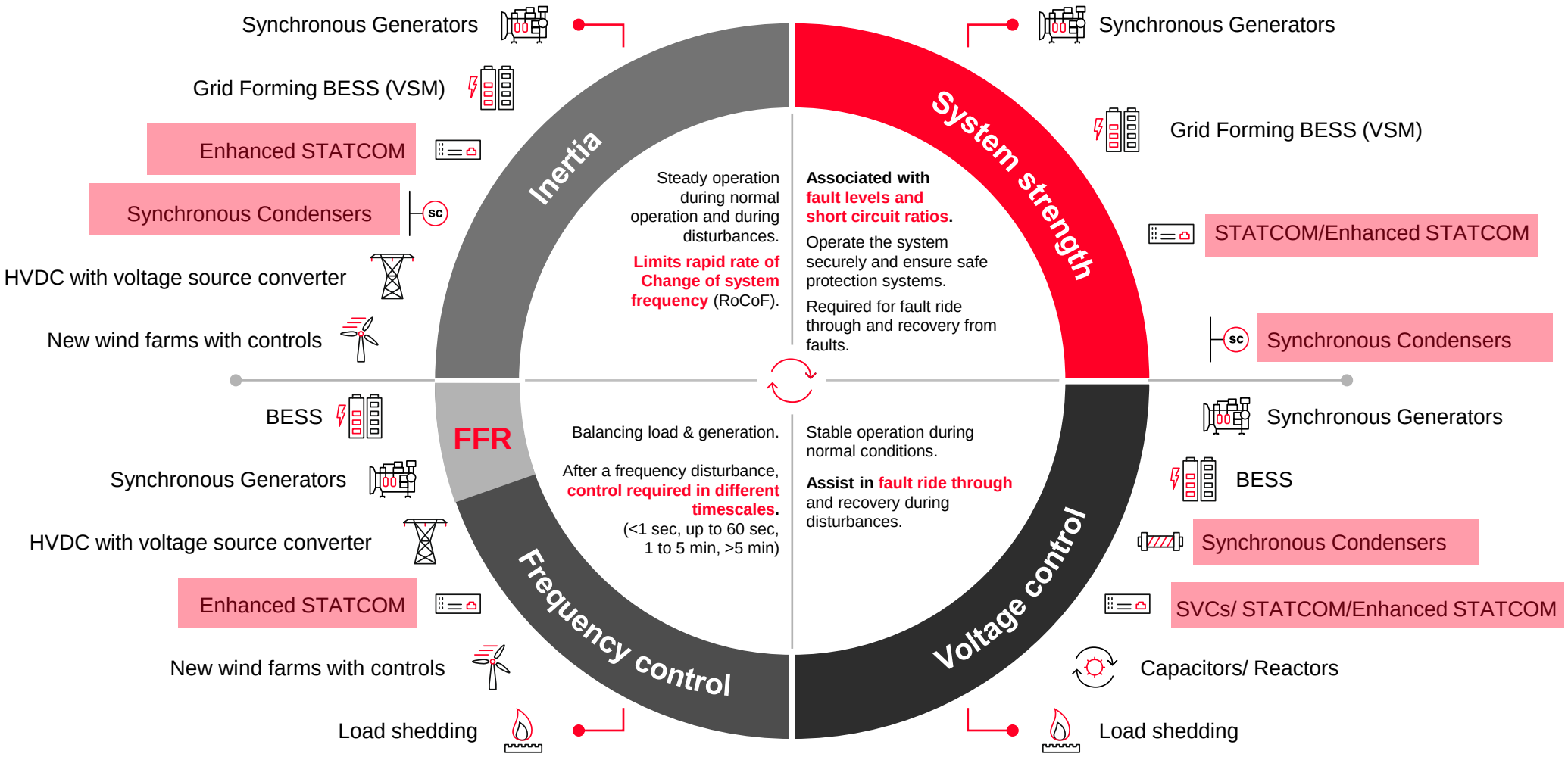
What services are required to operate a stable and secure grid?



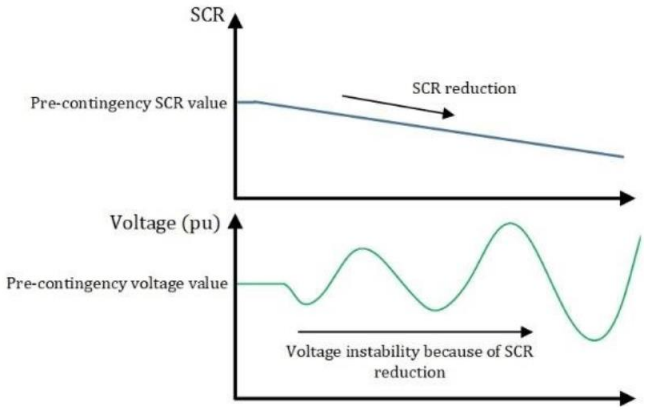
Challenges in today's grids – Transition into renewables

System strength (Short-circuit power)

System strength relates to the ability of a power system to manage minor fluctuations in supply or demand while maintaining a stable system voltage.

Reduction in system strength will have an impact on:

- Voltage control
- Relay protections
- Harmonics in the grid
- Voltage dips and post-fault voltage recovery profiles

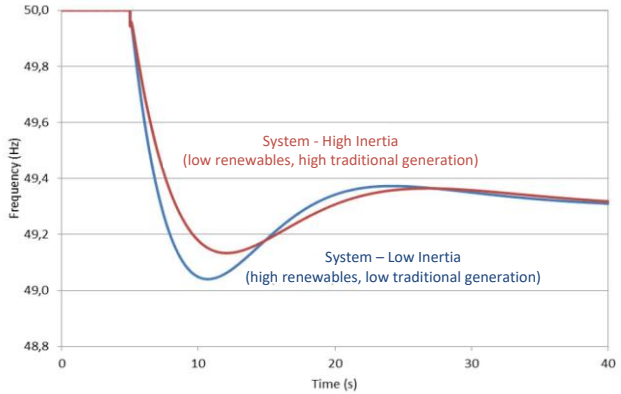


Inertia

Inertia relates to the ability of a power system to manage fluctuations in supply or demand while maintaining a stable system frequency.

As renewables replaces synchronous generation, system inertia will reduce:

- Impacting frequency management as renewables come with smaller rotating masses as well as decoupling between mechanical and electrical systems
- Increased rate of change of frequency (RoCoF), particularly at low demand periods
- Requirement for additional energy to contain the frequency within the limits and a reduction in the overall dynamic stability of the grid



STATCOM Technology - Continuous Technological Development

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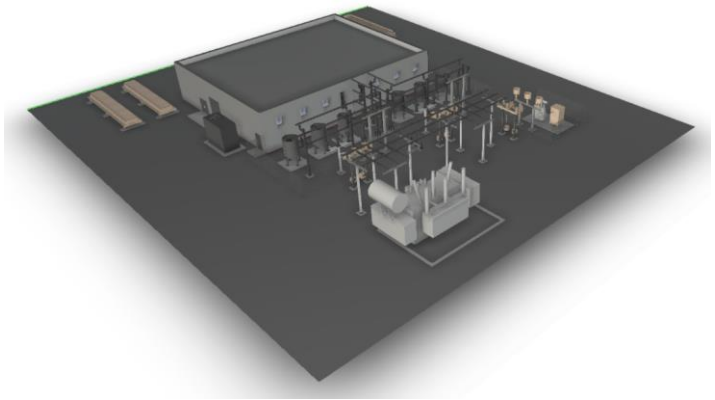
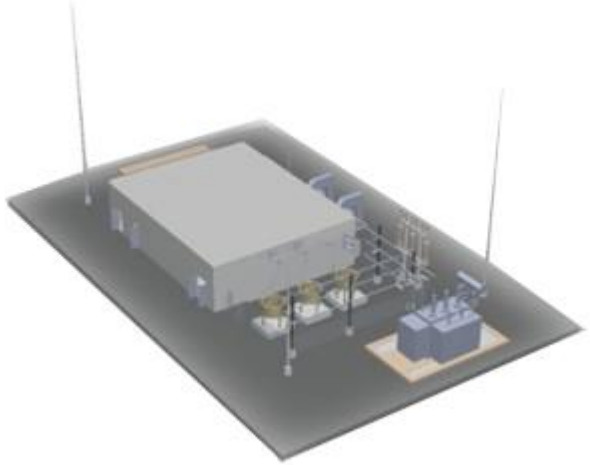
Yesterday

– Traditional STATCOM
  - Multiple VSC Branches over 150 MVAR
  - Grid Following, STATCOM typically connected in delta



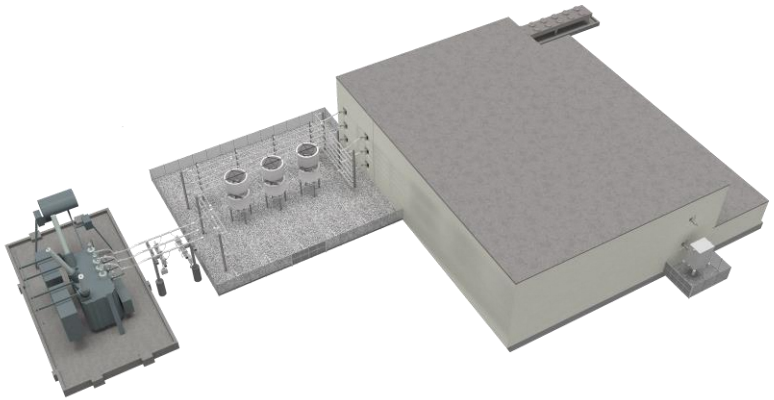
Today

– Traditional STATCOM
  - Single branch up to 425 MVAr
  - Grid Forming (Short Circuit Current), Multiple topologies



Tomorrow

– Enhanced STATCOM Technologies
  - Active and Reactive Power Capability
  - STATCOM connected in double wye topology
  - Grid Forming (Short Circuit Current, Inertia, Fast Frequency Response),



Larger Capacity → Reduced Footprint → Increased Functionality

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Grid Forming (GFM) control

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Grid Forming STATCOM

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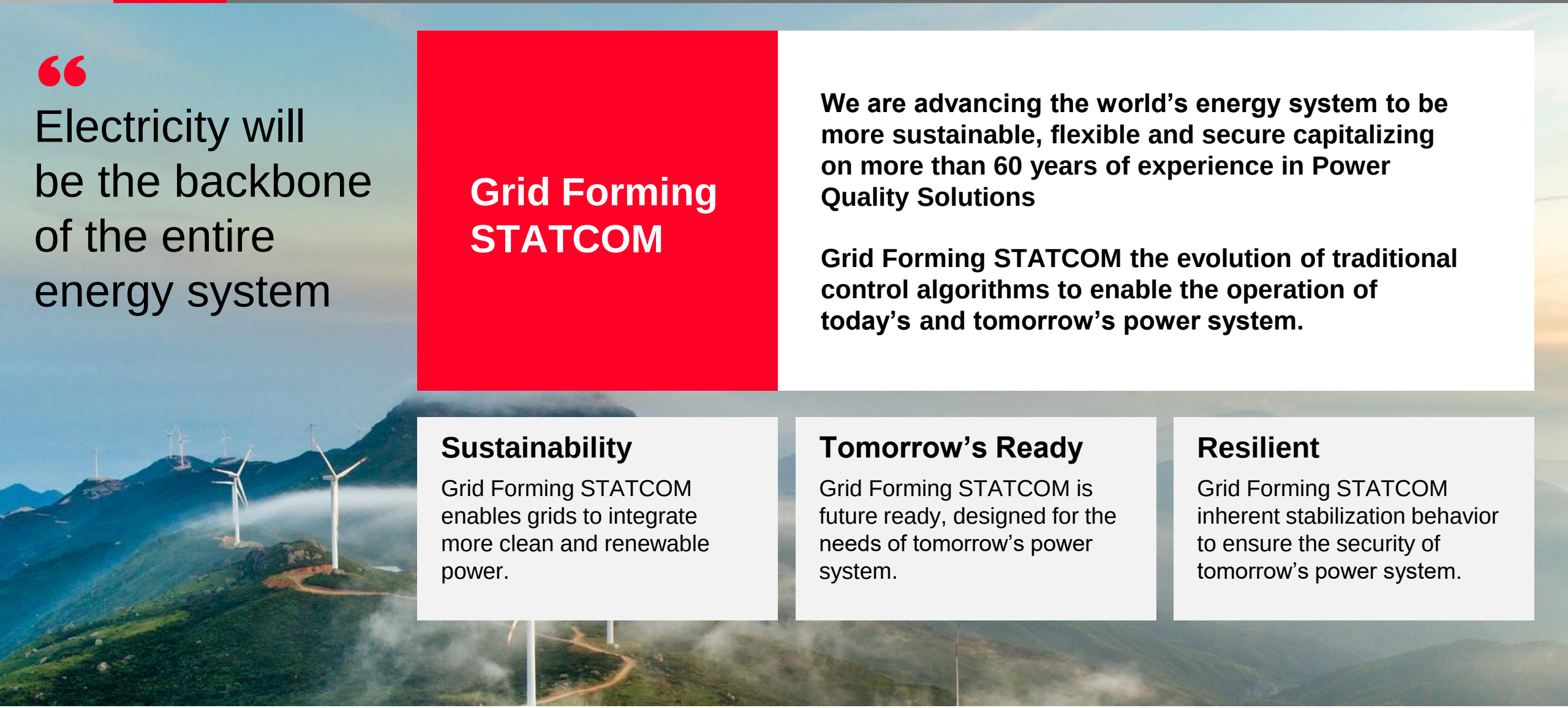

“Electricity will be the backbone of the entire energy system

Grid Forming STATCOM

We are advancing the world’s energy system to be more sustainable, flexible and secure capitalizing on more than 60 years of experience in Power Quality Solutions

Grid Forming STATCOM the evolution of traditional control algorithms to enable the operation of today’s and tomorrow’s power system.

Sustainability

Grid Forming STATCOM enables grids to integrate more clean and renewable power.

Tomorrow’s Ready

Grid Forming STATCOM is future ready, designed for the needs of tomorrow’s power system.

Resilient

Grid Forming STATCOM inherent stabilization behavior to ensure the security of tomorrow’s power system.

Grid Forming – Common objective

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- **The term ”Grid Forming” does not yet have a universally accepted definition**
- All requirements share one common objective:
  instantaneously react to any change on the grid system and contributing to maintain its stability.
- Behaving as a voltage source behind an impedance is generally considered a way to achieve the objective.
- The Grid Forming behavior shall have the following characteristics:

❑ Creating (forming) system voltage
❑ Robust operation in grids with very low system strength
❑ Provision of positive- and negative-sequence current during faults, i.e. boost of the positive-sequence grid
❑ voltage and decrease the negative-sequence grid voltage
❑ Behavior as L-R circuit for harmonics, similarly to a generator but with higher damping
❑ Contribution to fault level (short-circuit power)
❑ Provision of positive damping of oscillations
❑ Prevent adverse control system interactions

STATCOM with Grid Following (GFL) vs. Grid Forming (GFM)

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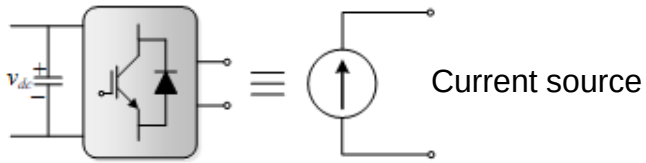
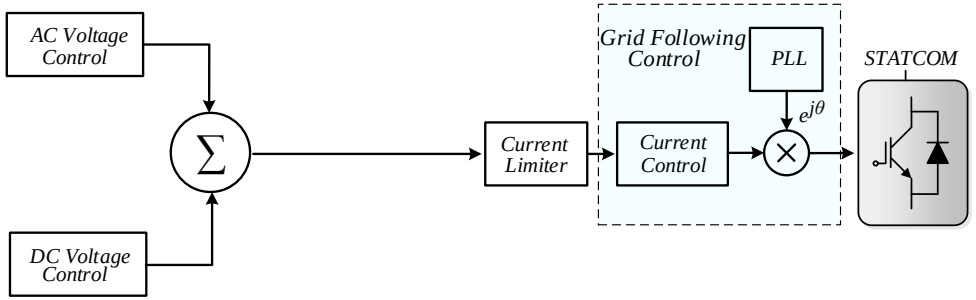
Grid Following (GFL) Control

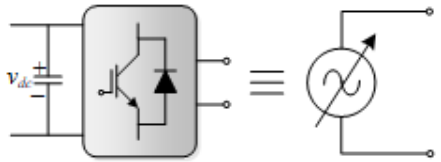


Current source

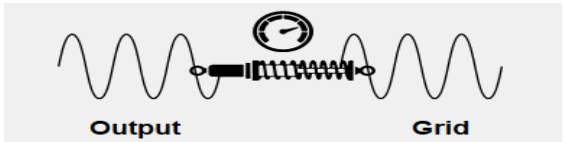


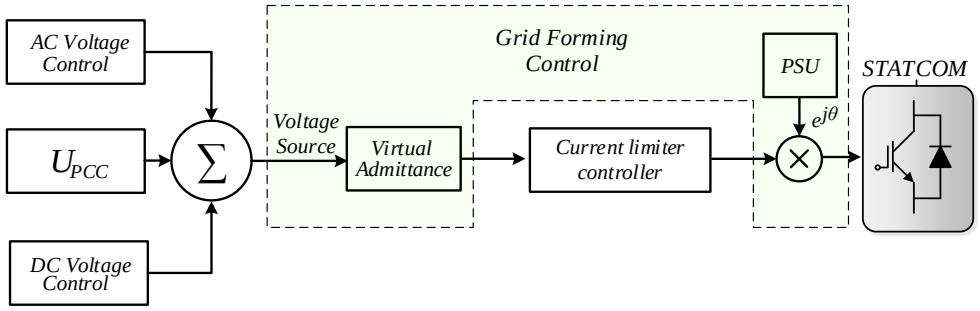
- **Synchronism** relies on **firm** voltage available from the **Grid**
- **No instantaneous support** for voltage and frequency stability
- **Less** robust **stability** for **weak Grid** conditions

Grid Forming (GFM) Control



Controllable voltage source





- **Create** and **maintains** its own voltage, keeping synchronism
- **Instantaneous support** for voltage and frequency
- **Improved stability robustness**, especially relevant for **weak grids**

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Grid Forming STATCOMs are Here...Today!

Grid Forming to support global networks

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Large number of Grid Forming STATCOMs worldwide (13 projects in service and 8 to be commissioned in 2024)

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Grid Forming STATCOMs – A Proven Technology

Plays a vital role in todays and future's electricity systems

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By 2025 in digits

➢ 20 large-scale* installations

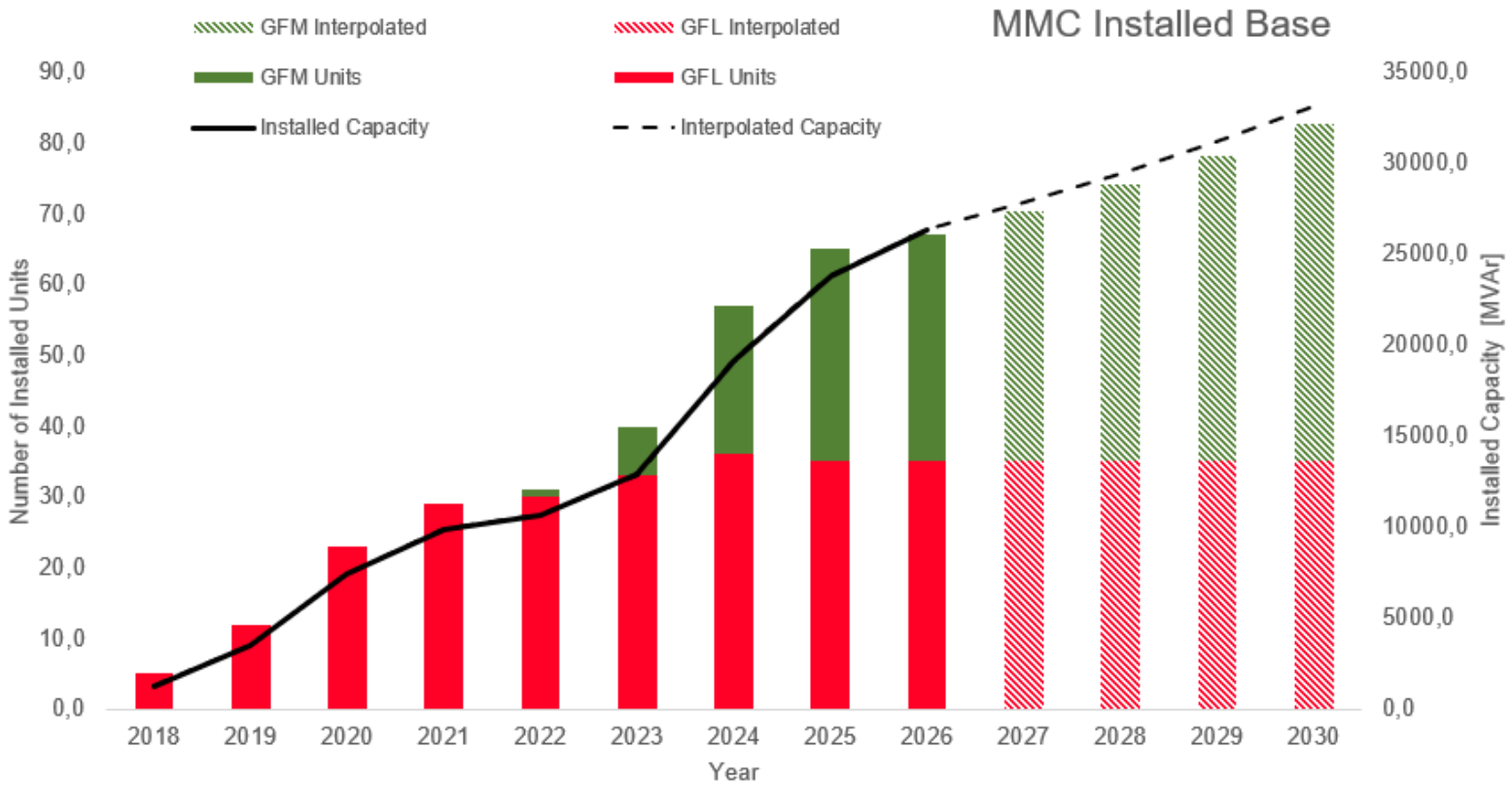
> 8000 Mvar of Grid Forming installed

> 200 months of accumulated operational experience

– Experience in traditional Utility applications, Renewable applications, and Electrical Arc Furnaces.

… and there is more to capture

*: > 50 Mvar



Market trend towards more VSC based solutions due to fast growing networks and challenging networks

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References
STATCOM, Germany

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Amprion

Amprion, which operates one of the largest of Germany's four power transmission grids, commissioned Hitachi Energy to build a series of SVC Light® stations.

Opladen STATCOM

The first of which was installed in early 2023: the world's first grid-forming high-power STATCOM for utility applications in the Opladen substation in the north of Cologne.

Single VSC, ±300 MVAR

Main objective dynamic reactive power support independently from the short-circuit level at PCC, which under certain grid scenarios, can reach extremely low level.

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STATCOM, US

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±120 Mvar Lookout STATCOM – Garland Power and Light, Texas

- In Texas, large integration of RES and the electricity network has experienced a decrease in grid strength, reduced inertia, and low resilience to heavy disturbances.
- Substantial blackouts in the last couple of years, causing high costs for the utilities and industries, serve as a reminder of the necessity of continued deployment of stability-improving measures.
- The Lookout STATCOM with GFM provides dynamic support with the purpose of improving the post-contingency recovery and mitigating Fault-Induced Delayed Voltage Recovery (FIDVR) related voltage variations caused by high penetration of induction motor load in the area. The way to prevent motor stalling is to reduce voltage drop during the fault and reaccelerate the motors by injecting reactive power.
- An interesting observation with regards to the GFM discussion relating to the Lookout case is the improved effectiveness in FIDVR performance compared to GFL. This is explained by the dynamic negative sequence performance that improves performance during unsymmetrical faults. The STATCOM is a ±120 Mvar unit connected to 138kV, designed to emphasize the dynamic reactive negative sequence performance of the single converter.

2

Installation: Lookout
Customer: Garland Power & Light
Application: Transmission
Size: ± 120 Mvar
Year of installation: 2023

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References
STATCOM, US

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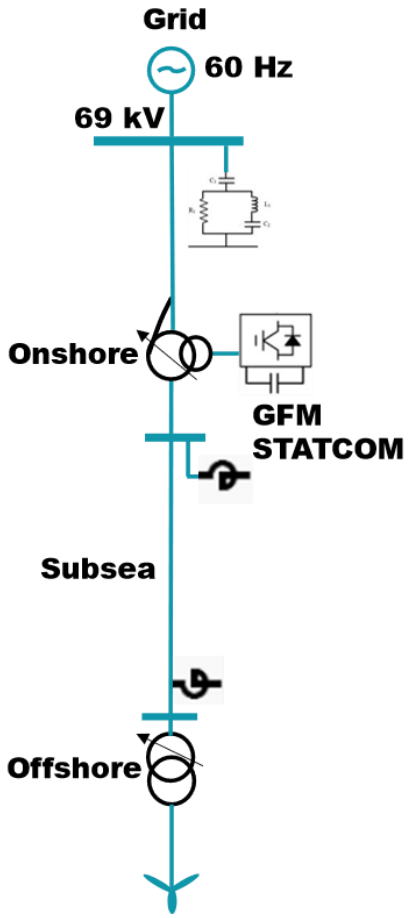
± 75 Mvar South Fork Wind STATCOM – Eversource, New York

- South Fork Wind is New York's first offshore wind farm, The wind farm, rated at 132 MW, is expected to yield the annual energy demand of 70 000 average households
- The wind farm connection's low SCR imposes operational challenges. The STATCOM is expected to support the connection during heavy voltage disturbances during weak system conditions.
  - A conventional GFL STATCOM find difficulties in achieving this capability while maintaining stability, The GFM STATCOM, on the other hand, is synchronized by the active power angle.
- The ±75 Mvar STATCOM is a MMC-converter connected to the main auto transformer tertiary, where the primary winding connects to the 69 kV.. This topology is seen in wind farm applications to gain footprint and cost efficiencies.
- The South Fork Wind STATCOM is the first transmission STATCOM with GFM capabilities for offshore wind applications in the US.



3

Installation: South Fork Wind
Customer: Orsted/Eversource
Application: Offshore Wind
Size: ± 75 Mvar
Year of installation: 2023

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Enhanced STATCOM (SVC Light® Enhanced)

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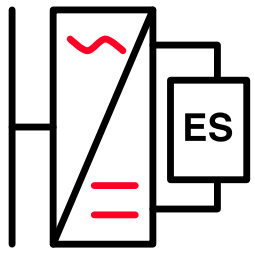
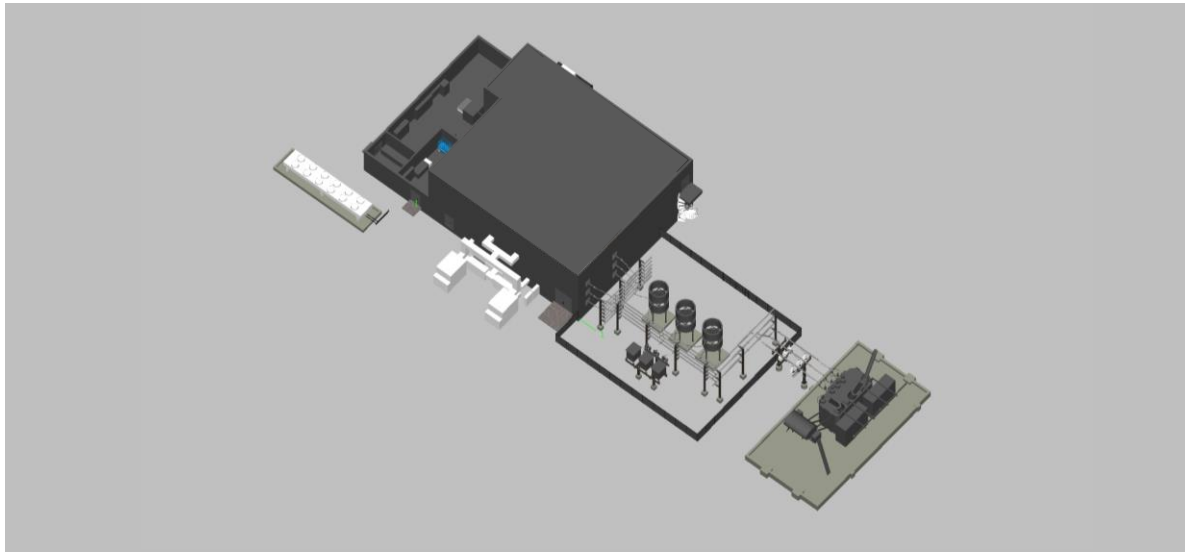
SVC Light® Enhanced

- Building on Hitachi Energy's proven STATCOM technology, SVC Light®
- Integrating supercapacitors for energy storage – contributing with active power
- Combining the advantages of two grid-stabilizing technologies into one solution – providing both active and reactive power
- Offer multiple grid-stabilizing services – in a single solution
- Reducing the risk that unexpected system events will be causing more severe frequency disturbances than we are seeing today

Main circuit



STATCOM + Energy Storage = Reactive + Active Power



Features

- Fast voltage/ frequency support
- Synthetic inertia
- Fault current generation
- System strength support

Capabilities

- Up to over 400 Mvar in a single system
- Grid-forming (GFM) control
- Scalable energy storage capacity in the hundreds of MWs

SVC Light® Enhanced – Concept

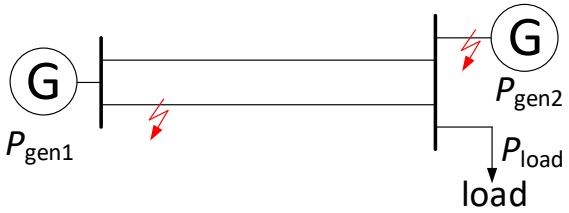
Challenges with more renewables?

Lower short-circuit power

- Deeper and widespread voltage dips for grid faults
- Lower power quality (larger voltage variations)

Lower inertia

- Grid fault resulting in reduced generated power (power plant or line)



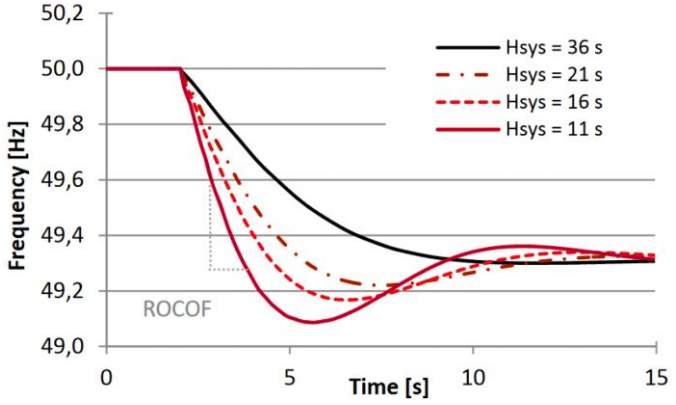
Power imbalance results in reduced frequency:

- Frequency change (slope)
- Frequency deviation

At too high frequency change and too low frequency, loads and generators are disconnected from the power system

Frequency variations

Lower inertia results in quicker frequency variations



Potential solutions to add inertia to increase stability:

Synchronous condenser

STATCOM

Enhanced STATCOM:

- STATCOM (SVC Light®)
- Energy storage
- Advanced controller

Comparison

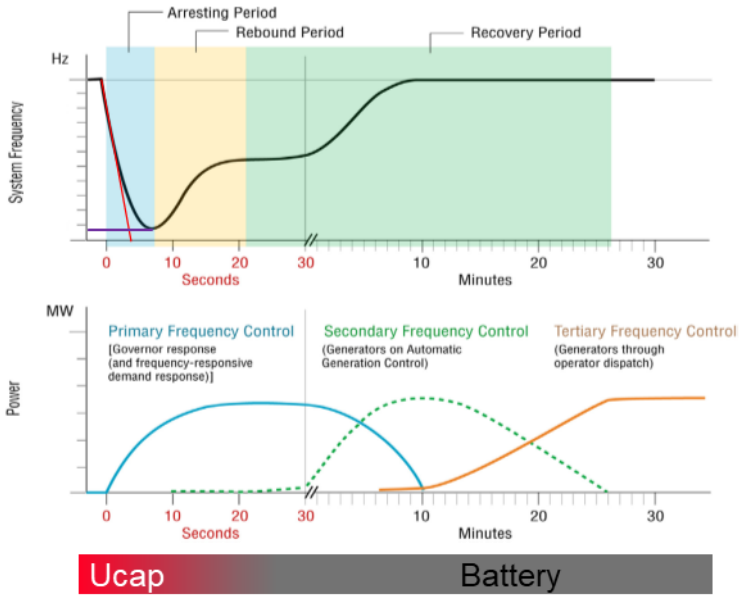
Grid-stabilizing services	STATCOM (with GFM)	Synchronous condenser	SVC Light® Enhanced
Voltage regulation	● ● ●	● ●	● ● ●
Inertia		● ●	● ● ●
Short-circuit current contribution	●	● ● ●	● ●
Flexibility/ modularity	● ● ●		● ● ●
Controllability	● ●	●	● ● ●

ROCOF = Rate OF Change Of Frequency

SVC Light® Enhanced – Concept

The Need

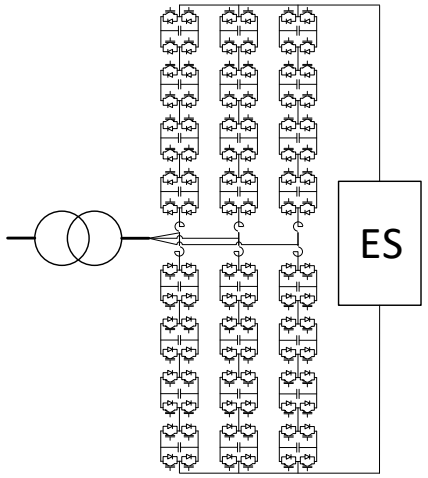
Networks with a high degree of power electronic interfaced renewable generation will face problems with low inertia and will require new types of services.



Enhanced STATCOM

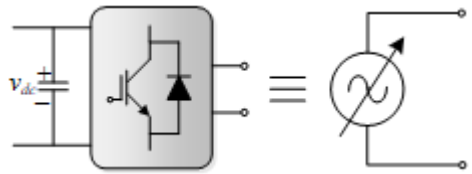
STATCOM with active power capability for synthetic inertia, fast frequency regulation and grid support

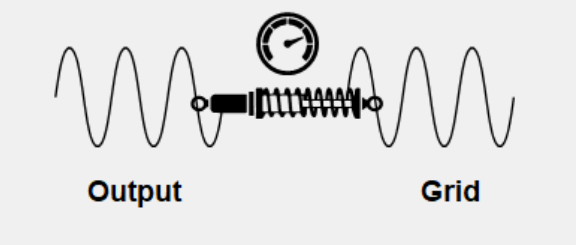
Choice of storage medium depends on power and energy requirements



Grid Forming Control

- STATCOM control emulates the machine
- Behaviour is similar to a conventional rotating machine
- Inherently provides synthetic inertia, fault current, harmonic passivity, stable behavior





Germany

Wendlingen and Oberjettingen Enhanced STATCOM

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Customer: TransnetBW, Germany

Customer's need

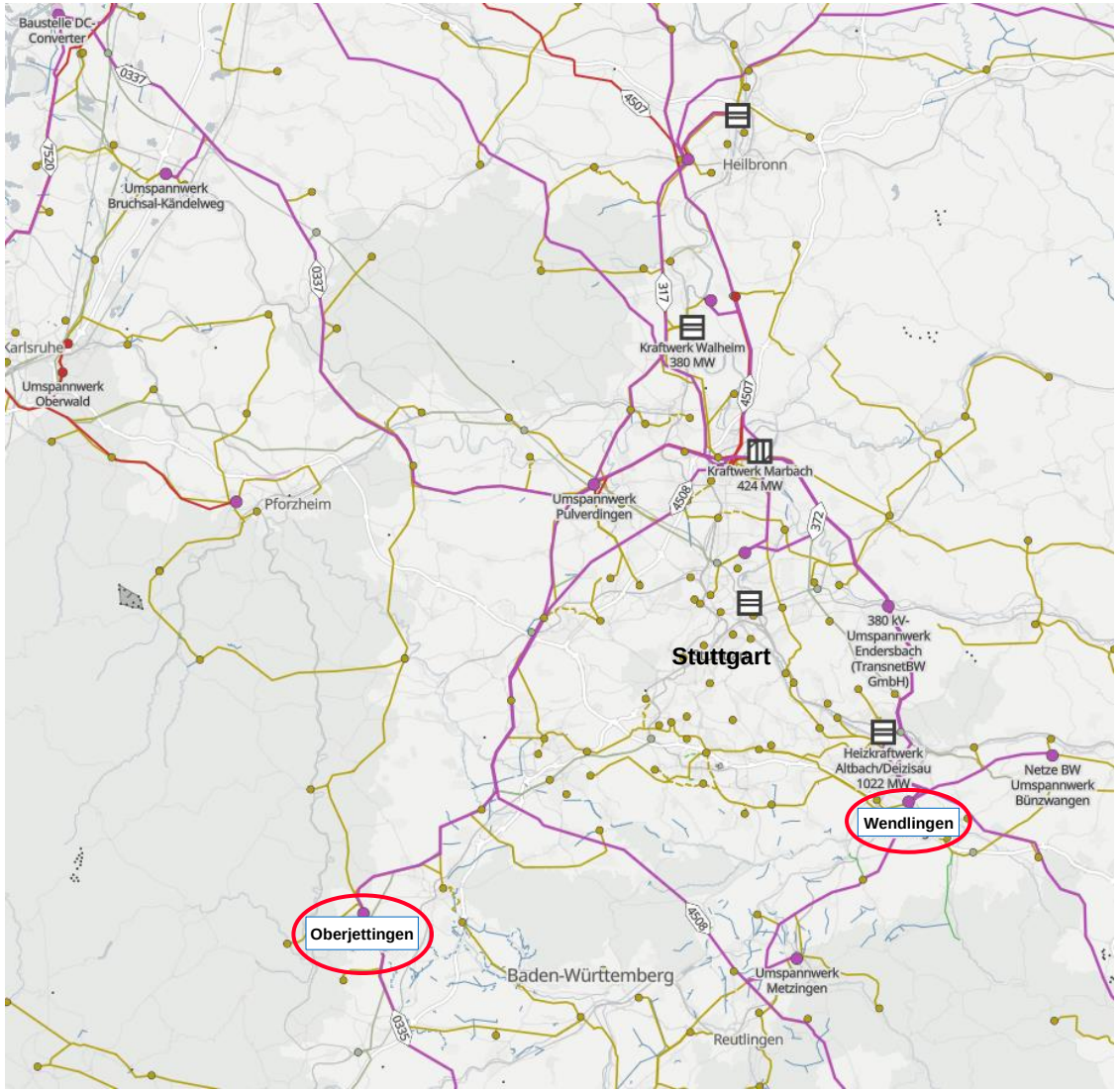
- TransnetBW is preparing for a future grid with less inertia, as generation will rely more on power electronics-based plants such as wind and solar.
- Based on the latest information available from BNetzA[1], a total provision for 34 GWs of inertial reserve is foreseen to be developed by the four German TSO.
- As of October 2023, the TSOs informed they are discussing with BNetzA to increase the provision for inertial reserve earlier approved.

Hitachi Energy's response

- Turnkey delivery of two SVC Light® Enhanced connected to 400 kV.
- Each one is rated ±250 Mvar and 150 MW simultaneously and is built as a single VSC (Voltage Source Converter) with double wye configuration
- Centralized energy storage by means of supercapacitors.
- The STATCOMs are located in Wendlingen and Oberjettingen.
- Each STATCOM is equipped with state-of-the-art GFM (Grid Forming) capability, compliant with FNN guideline and customer requirements.

Customer's benefits

- Enabling integration of clean and reliable renewable power, by inertial and voltage support.
- Increased transfer capability by providing required dynamic reactive power.
- Grid Forming STATCOM provides improved network stability and response to grid changes.



1. BNetzA, Bedarfsermittlung 2021-2035 Bestätigung Netzentwicklungsplan Strom, 2022, Online: https://data.netzausbau.de/2035-2021/NEP2035_Bestaetigung.pdf

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Synchronous Condenser Systems (SCS) and Hybrid-SCS

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Hybrid-Synchronous Condenser System

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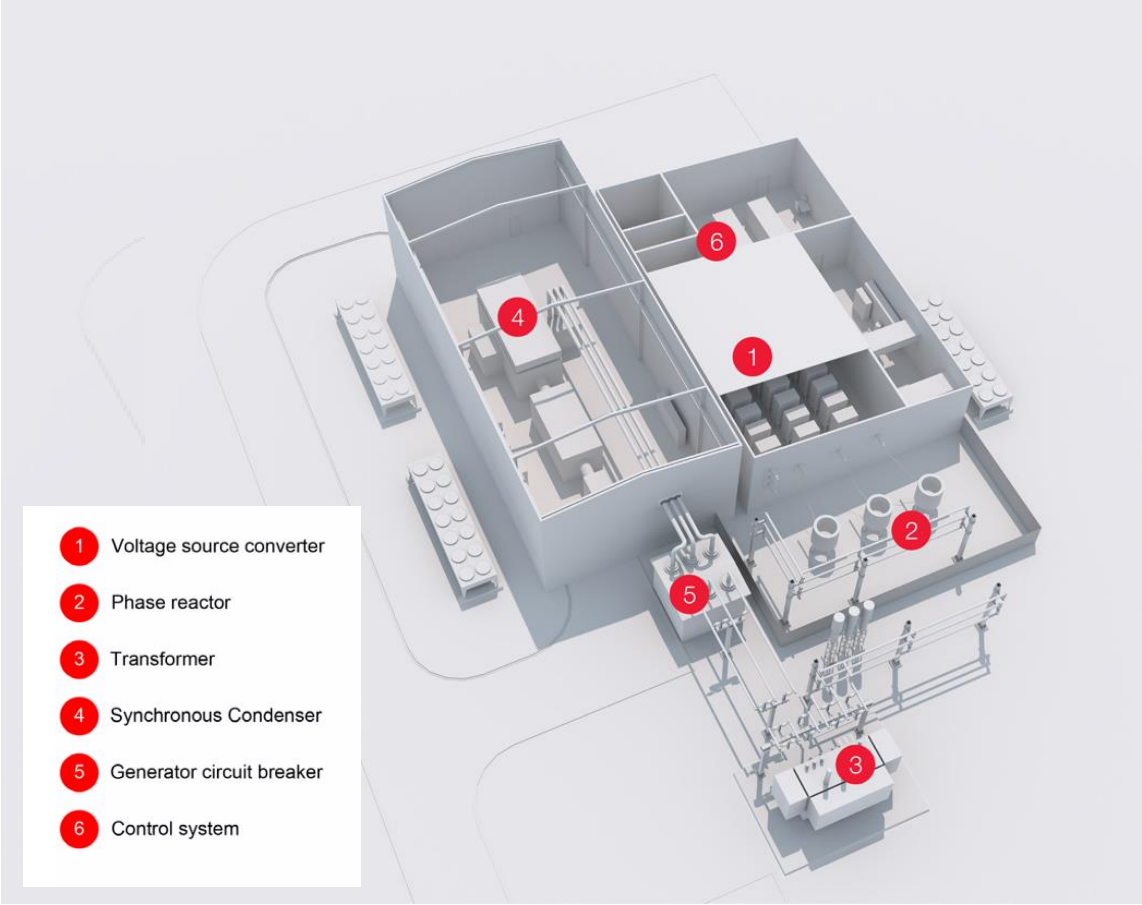
Benefits

- Boost system inertia.
- Provide fast fault current infeed and increase system total strength.
- Provide reactive power injection support in steady state to alleviate voltage dip conditions.
- Provide dynamic voltage regulation.
- Provide reactive power absorption to potential over-voltage scenario in light load conditions.
- Control as one system or on branch level
  - Two branches with different modes make it possible to have several combined operating modes
  - STATCOM & SCS can be on/off and run in either voltage or Q control independently



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References

Great Britain, Phoenix H-SCS (Hybrid-Synchronous Condenser System)

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Customer: Scottish Power Energy Network, GB

Customer's need

- Enable integration of renewables generation while retiring synchronous generation.
- Meet the United Kingdom's grid code requirements.
- Test the combination of static and rotating solutions (as that will be more common in future grids)

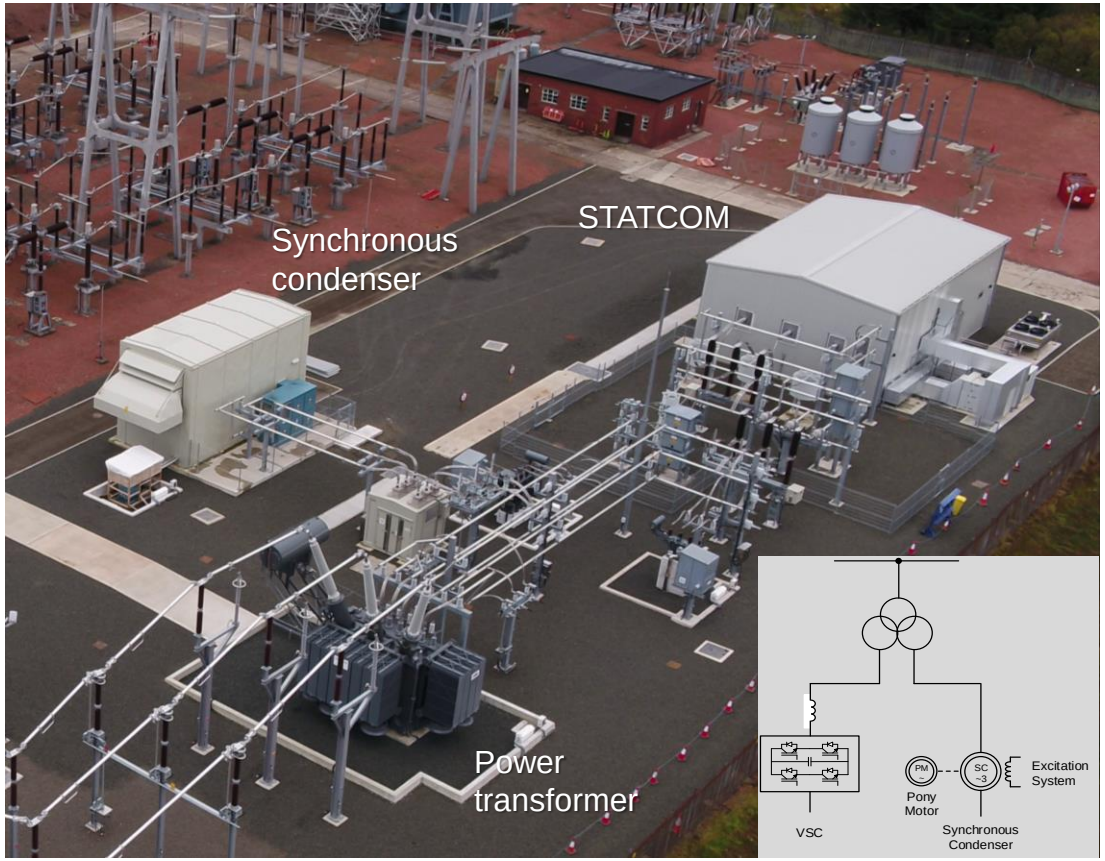
Hitachi Energy's response

- One 275 kV H-SCS rated -105/+140 Mvar, consisting of:
  - One STATCOM rated -70/+70 Mvar
  - One synchronous condenser rated -35/+70 Mvar

Customer's benefits

Optimized solution based on actual needs for voltage control, short-circuit current contribution and inertia contribution:

- Both the STATCOM and the synchronous condenser provide steady-state and dynamic reactive power support, that improves the voltage profile and voltage stability of the system
- The short-circuit current contribution from the synchronous condenser increases the overall system fault-current level, e.g. improves operation of PLL controllers and performance of HVDC converters
- The inertia contribution from the synchronous condenser increases the overall system inertia, improving system stability and frequency response
- Customer's estimated benefits in excess of $900M by year 2035.



https://www.spenergynetworks.co.uk/pages/phoenix.aspx

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References

Great Britain, Eccles H-SCS (Hybrid-Synchronous Condenser System)

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Customer: Scottish Power Energy Network, GB

Customer's need

- To meet the higher amount of renewable energy in the network. Various power quality issues must be mitigated to ensure stable grid operation during different conditions.

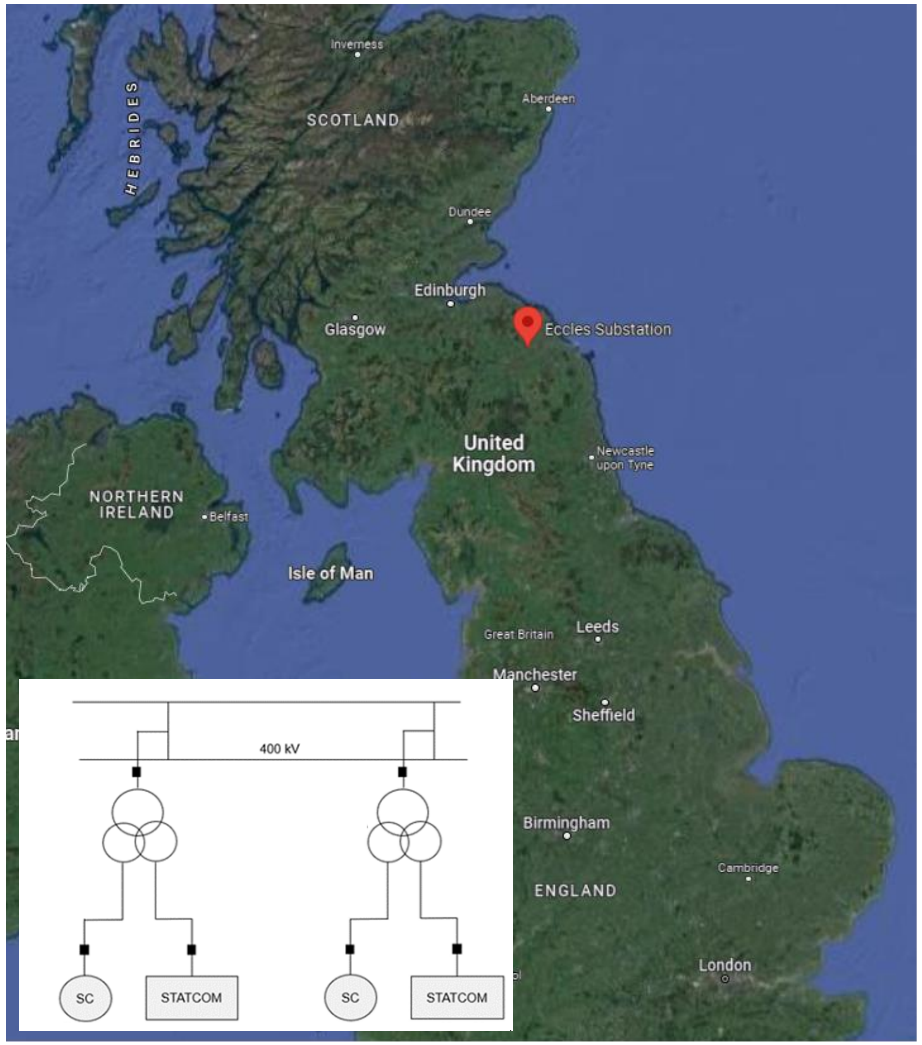
Hitachi Energy's response

- Two 400 kV H-SCS in independent or parallel operation,
  - One STATCOM
  - One synchronous condenser with flywheel
- Turnkey delivery; contract awarded September 2023.

Customer's benefits

Optimized solution based on actual needs for voltage control, short-circuit current contribution and inertia contribution:

- Both the STATCOM and the synchronous condenser parts provide steady-state and dynamic reactive power support, that improves the voltage profile and voltage stability of the system
- The short-circuit current contribution from each H-SCS increases the overall system fault-circuit power.
- The inertia contribution from each H-SCS increases the overall system inertia, improving system stability and frequency response



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