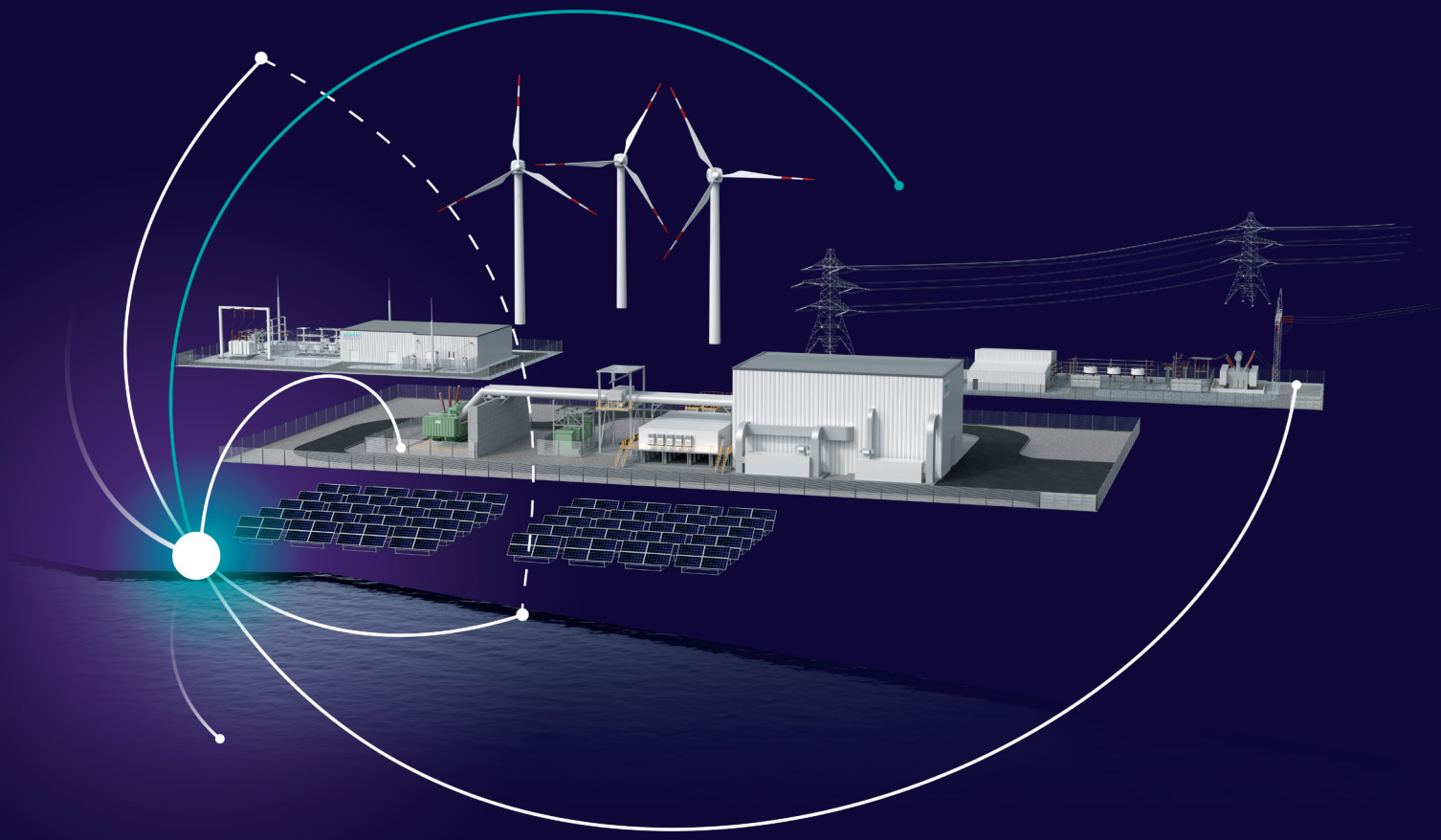
SIEMENS energy

Grid Stabilization

The power grid is the backbone of the energy system – and we're making it stronger

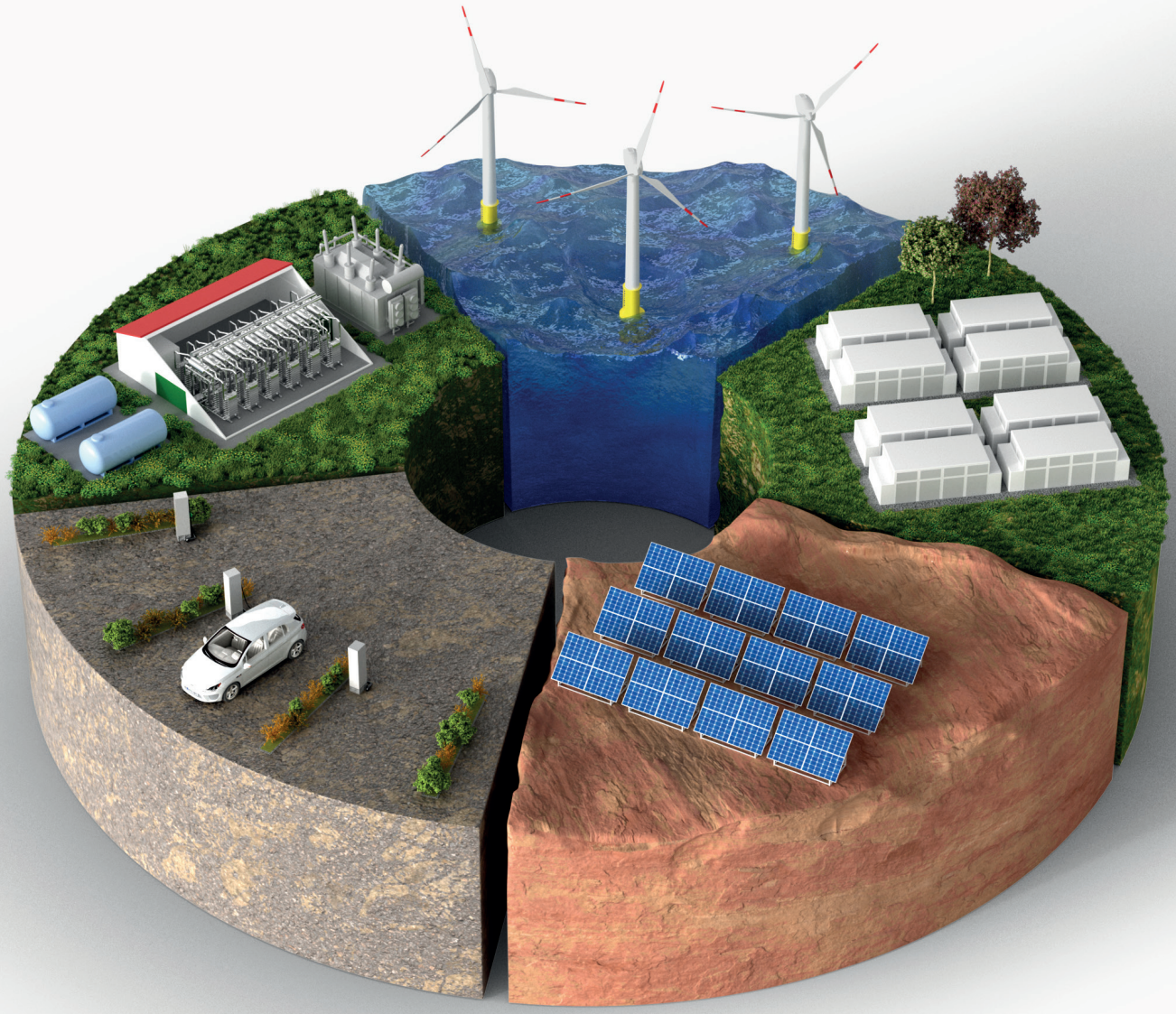


siemens-energy.com/facts

Wind turbines

Electrolysers

Batteries and
storage solutions



E-mobility

Solar panels

1 Challenges in changing grids
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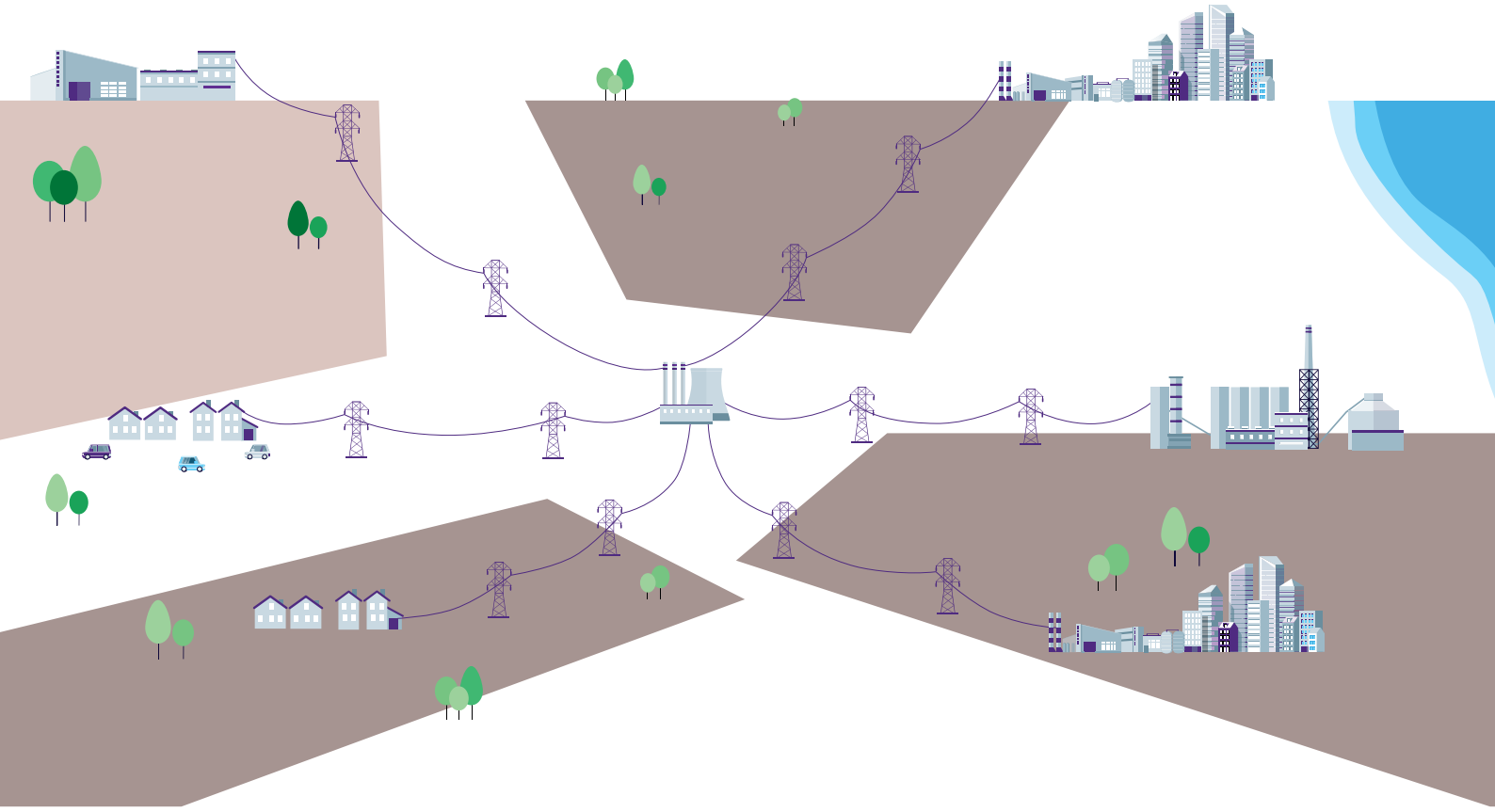
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Transforming HV-grids from conventional...

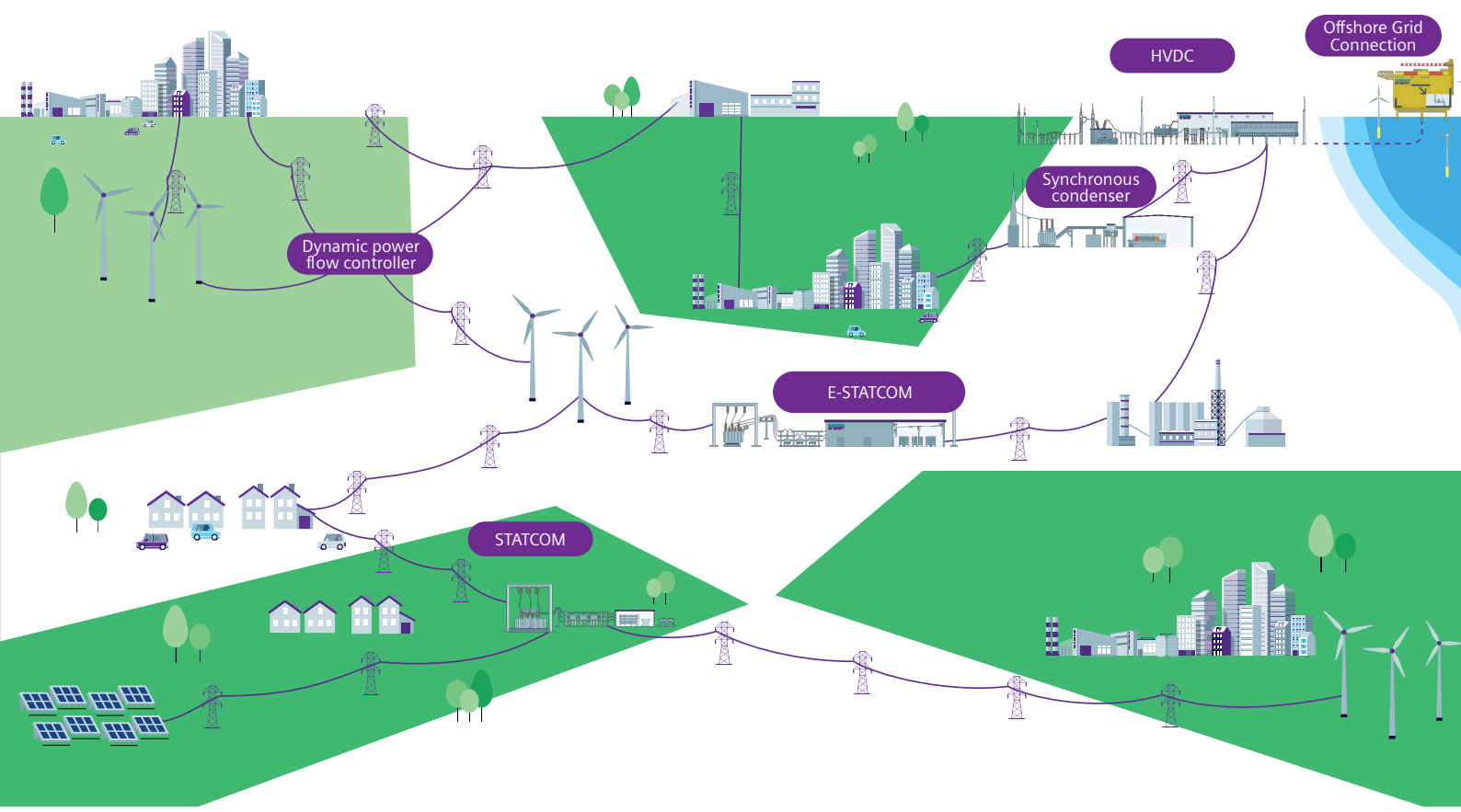
1. Challenges in changing grids

The worldwide power sector has witnessed significant disruption, growth, and change in recent years. Three components driving these developments include decarbonization, electrification, and the increasing liberalization of energy markets. On the generation side, integrating renewable energy sources, mainly photovoltaic and wind power, alters the operation of conventional power systems. One factor is the intermittent nature of renewable energy sources. In addition, associated technologies have power electronics at the grid interface, decreasing overall inertia due to a lack of rotating masses directly connected to the grid. This issue is exacerbated by the increasing demand for electricity and the need for stronger interconnections between power systems.

These factors pose new challenges for grid stability along three domains: voltage stability, frequency stability, and load flow management.

Voltage stability

The system voltage must be maintained within allowable voltage ranges to ensure stable power system operation and safeguard people, equipment, and consumer devices. A sufficient supply of reactive power is needed to maintain voltage stability and leverage the transmission capacity of existing transformers and lines. Both in transmission and distribution grids, voltage stability requirements increase in transmission and distribution grids, compared to a corresponding decrease in conventional power plants. Therefore, more grid services must be used.



Siemens Energy transmission solution

...to decarbonized and renewable power supply

Frequency stability

Frequency control ensures that power fed into the grid corresponds with power consumption, as any deviations in the total balance can result in a change in frequency. The transmission system operator must quickly return the required frequency to the rated value and can do so with the help of grid service products. The rising fluctuation in generation capacity due to renewables has led to the increased demand for grid services.

Load flow management

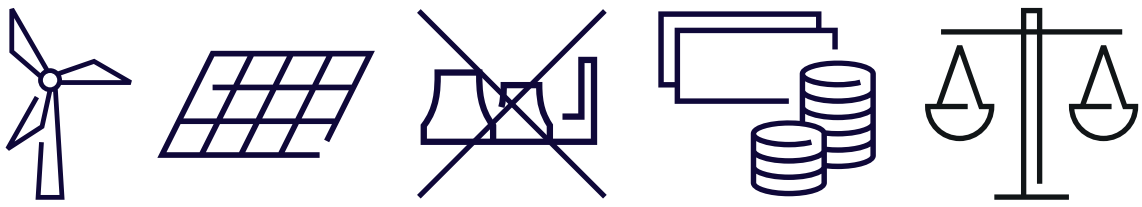
Power system supply and demand must be kept in balance. Thermal overloads in power transmission lines and a growing number of instances in which frequency and voltage approach critically acceptable range limits – or even exceed them – may require costly redispatch interventions to resolve current and voltage factors. System operators must optimize the utilization of transmission lines to get the most from existing grid capacity while maintaining maximum protection, reducing the risk of power failures, and minimizing redispatch costs.

Increasing complexity

To manage these interrelated factors, grid operators are looking for flexible, scalable solutions that fit within local requirements in terms of energy supply areas.

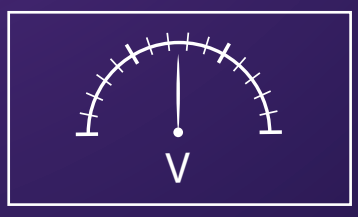
Trends in electric energy supply

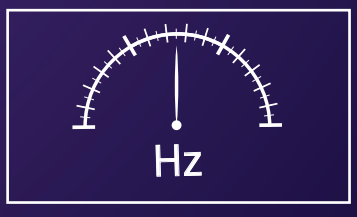
- **Shutdown of conventional fossil and nuclear power plants**
- **Large-scale integration of renewables**
- **Increasing power demand in existing grids**
- **Continuous evolution of power market rules and regulations**

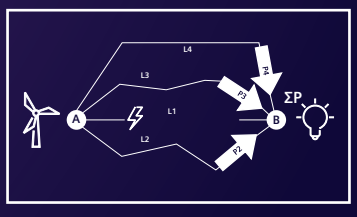


...cause grid stability risks

- Decreases grid strength and frequency stability
- Increases inverter-connected generation
- Decreases voltage stability
- Increases unbalanced load flows, congestion, and redispatch





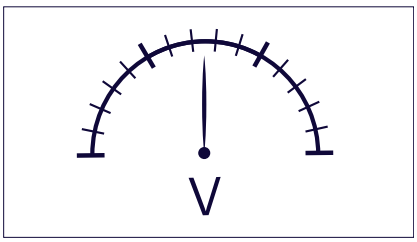


2. Complexity in grid stabilizing

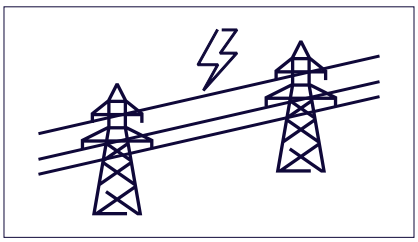
The challenges within frequency stability, voltage stability, and load flow management are highly complex. System services available to support reliable grid operation are detailed in the following table.

Voltage stability V	Frequency stability f	Load flow management P
Dynamic voltage control To ensure voltage stability at any time, reactive power output is controlled with a fast response time.	**Inertia contribution** When large rotating generators that previously provided inertia are replaced by non-synchronous generation, inertia must come from other sources.	**Dynamic load flow control** Volatile renewable generation may cause temporary overload of certain power lines and must be avoided.
Stationary voltage control To react to slow grid changes, the full output range will be provided, initiated by the control system or manually by the operator.	**Grid forming** Grid forming is not only for frequency stability but also for voltage control. Therefore under dynamic voltage control there should be mentioned grid forming as well.	**Stationary load flow control** Adding power generation into the grid can overload power lines, while freeing capacity for others.
Active filtering / active damping Modern semiconductors promote flexibility and utilization of the remaining capacity in the operating range to actively filter or damp existing background grid harmonics.	**Fast frequency response** If the frequency suddenly deviates from its nominal value, additional power is needed immediately.	**Power oscillation** If power oscillation is detected, the control system will automatically mitigate power swings.
	Short circuit contribution In case of a fault in the grid, short circuit power is needed to avert a system-wide voltage collapse and enable the protection equipment to detect the fault.	**Sub-synchronous resonance** To protect the large power generator shafts, torsional interaction should be avoided; if this occurs, additional measures must be taken.

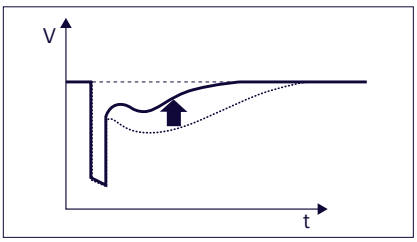
2.1 Voltage stability



Stable operation



Event



Restabilization

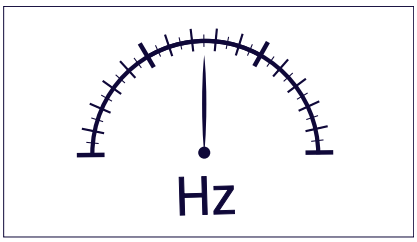
When talking about voltage stability, many aspects play a role. All consumer and electrical devices work at a specified voltage. Malfunction or damage to these devices can occur due to under or overvoltage. Keeping the voltage stable means keeping the voltage in the allowed bandwidth for which the devices in the electrical system are designed. Voltage stability is also essential for dynamic events in networks such as faults, where the voltage may collapse for a short time and recover after fault clearing. If the recovery takes too long or does not fully recover, there may be system brownouts or blackouts.

The topic of voltage stability is not new and has been prevalent since we have electrical systems. There were always measures to stabilize voltages, and electrical systems were optimized to avoid outages and increase system availability.

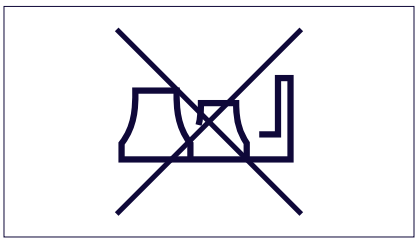
These measures were based on the system topologies we had in the past, where power generation was centralized and close to the big loads. Decarbonization goals lead to a shift in the way we generate power. There is a transition from known big centralized to smaller decentralized power generation, which is challenging to manage.

Changing how we generate power also changes the transmission systems and their physical topology. Decarbonization-based changes also impact voltage stability in the systems mainly because the system changes. We transmit power over longer distances, as renewable sources are not always close to large consumers. In addition, voltage stability is impacted by the volatility of renewable sources. Voltage stability in modern power system topologies is a considerable challenge – and dynamic reactive power compensation is the solution to tackle it and make decarbonization possible.

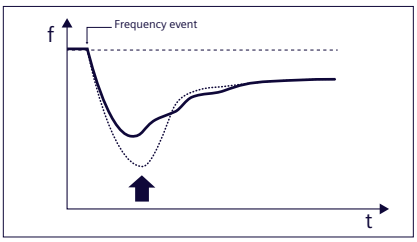
2.2 Frequency stability



Stable operation



Event



Restabilization

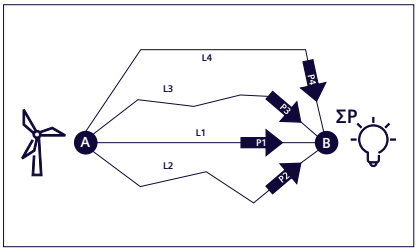
f Like voltage stability, it is critical to keep the frequency of a power system stable. Over- or under-frequency leads to malfunctions and can also cause system shutdowns. Conventional power plant generators control the frequency in power systems, where the sum of the rotating mass of generators and turbines measures the strength of the system frequency.

However, the frequency is not always constant due to minor mismatches between generation and consumption. These discrepancies happen continuously when loads are disconnected and generation needs to be reduced. The strength of the system frequency, called system inertia, measures the system's sensitivity to these mismatches.

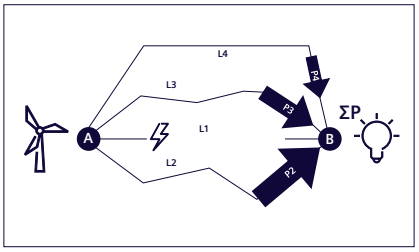
Today, we see a change in power generation where more power is generated based on power electronic converters than conventional power plants with large rotating masses. The reduction of rotating masses –and therefore system frequency strength – leads to higher deviations from the nominal frequency in generation and consumption mismatches.

Frequency stabilizing solutions are necessary to maintain the frequency within acceptable limits, especially during high converter based generation.

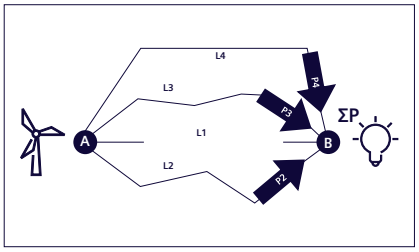
2.3 Load flow management



Stable operation



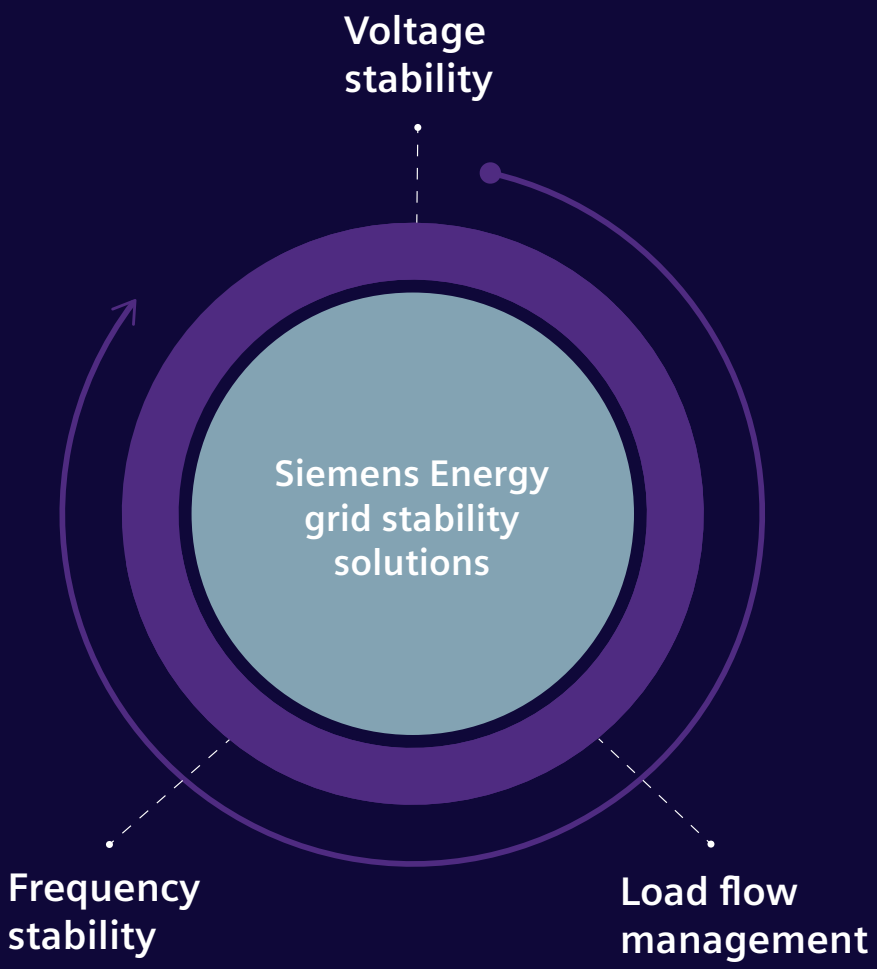
Event



Restabilization

An electric power system consists of interconnected transmission and distribution lines carrying energy from points of generation to consumption. It is crucial to perform load flow planning for all possible scenarios, as grid components can only withstand a certain amount of current. Transmission grid operation follows the N-1 criterion in which electrical components do not operate at maximum thermal capacity to withstand scenarios where one line is out of service, and other parts must assume power flow on top of their regular loading. Following this criterion ensures reliable and secure grid operation, especially for system faults.

As the load flow in power systems is becoming increasingly complex, we must account for even more scenarios. Volatile generation from renewable energy sources directly impacts line loading, but system underutilization remains a point of discussion. Due to the growth of renewables and increased energy needs, optimal utilization of all assets is imperative.



3. Pathways to solutions

Power generation now utilizes more efficient and environmentally friendly technologies. Given the changes in power consumption sites, HV grids must use state-of-the-art technologies to provide essential stability and reliability.

3.1 Our approach

As a leader in the power transmission industry, Siemens Energy has developed modern, flexible, high-capacity grid stabilizing solutions, including Flexible AC Transmission Systems (FACTS), to prevent high voltage fluctuations and power failures, optimize network asset utilization, and mitigate load-induced disturbances. Our solutions efficiently and reliably regulate voltage, impedance, and phase angle, providing inertia and short-circuit power.

Grid stabilizing solutions

At Siemens Energy, we provide grid stabilization solutions to address even the most complex problems and network instability. We are also developing new solutions to manage current and future grid challenges while improving transmission system stability and performance.

With our grid stabilizing solutions, power companies can better utilize their existing transmission networks, substantially increase the availability and reliability of their line networks, and improve dynamic and transient network stability while ensuring a better quality of supply. The table below highlights some solutions offered by Siemens Energy.

	Technology / System service	SVC PLUS® GFL *	SVC PLUS® GFM **	SVC PLUS FS®	SynCon	FSC
Voltage stability V	Dynamic voltage control	✓ ✓	✓ ✓	✓ ✓	✓	✗
	Stationary voltage control	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✗
	Active filtering of harmonics	✓	✓	✗	✗	✗
	Damping of harmonics	✗	✓	✓	✓	✗
	Damping of subsynchronous oscillations	✗	✓	✓	✗	✗
	Short circuit contribution	✗	✓	✓	✓ ✓	✗
Frequency stability f	Inertia contribution	✗	✗	✓ ✓	✓ ✓	✗
	Fast frequency response	✗	✗	✓	✗	✗
Load flow management P	Stationary load flow control	✗	✗	✗	✗	✓ ✓
	SSR damping / POD	✓	✓	✓	✗	✗

*GFL: Grid-following
**GFM: Grid-forming

3.2 Grid consulting – from grid challenge to the solution

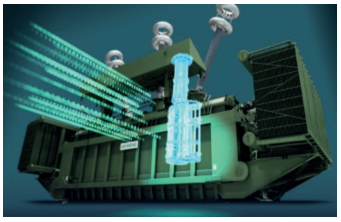
Moving from the identification of grid challenges to the optimal solution definition is not always trivial, as many questions arise:

- Which grid stabilizing devices are the best choice?
- How large should they be, and how many are needed?
- Which locations in the grid should they be installed?
- When are they required, and how do they fit into the long-term grid development plan?
- What will the future energy system connected to the grid look like (e.g., generation mix, load forecast)?
- What are the costs and benefits of specific stabilization solutions?

Applying simulation-based studies and using their grid expertise and extensive product knowledge, our highly experienced team of grid consultants can answer these questions and guide you toward a tailor-made solution.

These services range from initial optioneering and component selection to full-scale long-term grid development masterplans, as shown in the portfolio overview below.

Strategic grid planning
Data- and simulation-driven decision support

Study portfolio	Model development Digital representation of transmission and generation assets	Solution design Dimensions, selection, design, and verification of transmission and generation solutions	Grid integration Grid interconnection of transmission and generation technologies
			



Amprion's STATCOM substation in Kriftel to support the power supply for the greater Frankfurt area in Germany with its almost six million inhabitants.

What our customers say

„The ongoing energy transition leads to substantial new challenges for the safe operation of our transmission grid. This need is covered by the increased use of grid stabilizing solutions, such as synchronous condensers with additional flywheels, and STATCOMs with multiuse capabilities. For the future we see a further need for new solutions providing instantaneous reserve and for grid forming control concepts. With its technical expertise and innovative capabilities, Siemens Energy is an important partner for our journey towards a green future."

Dr. Daniel Eichhoff, Grid Projects, Senior Manager Substations, Amprion


After-sales services, condition spare parts & based maintenance
Consulting and feasibility studies
Financing
Project management
System design and engineering
Civil design and works
Procurement
Factory testing
Transport
Installation supervision and works
Commissioning & performance test



3.3 We'll be there for you – around all your needs

From the early phases throughout the lifecycle, Siemens Energy is your reliable partner and ensures no gaps in the full cycle. Our in-house capability minimizes risk across all phases of the project.

Siemens Energy offers a single source for all necessary grid stabilizing solutions and a comprehensive range of complementary services, including system design, modeling, network analyses, civil works, project management, functional performance tests, delivery, and installation. In addition, we assist with commissioning, onsite tests, and training of operating personnel.

Siemens Energy analyzes and calculates the power system requirements, develops customized solutions for complete system configurations and plants, and quickly implements them. Siemens Energy can deliver turnkey solutions and create new solutions, enabling timely grid stability improvements in rapidly changing energy systems. We provide innovative, proven grid stabilization solutions, including in-house components. Siemens Energy offers services for nearly all customer requirements, including design studies, financing support, project management, assembly, commissioning, and after-sales service.
We are your trusted partner for all project stages.

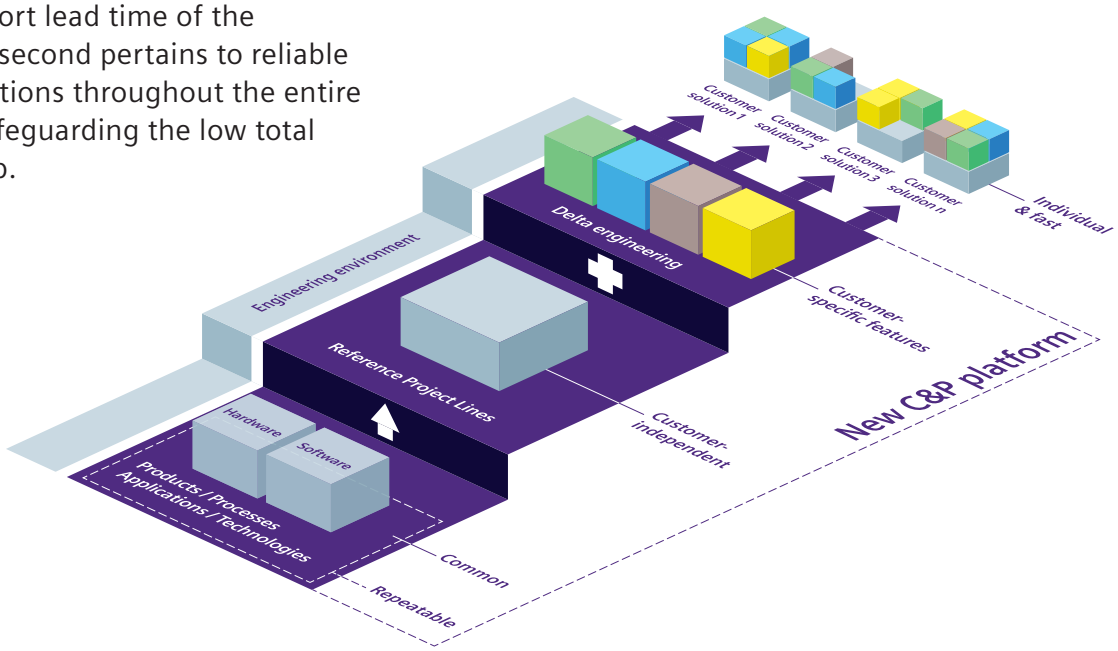
4. State-of-the-art approach

Siemens Energy is the world leader in state-of-the-art grid stabilizing solutions and pioneered modular multilevel converter technology as well as modern synchronous condenser and flywheel solutions. Our grid stabilization portfolio features decades of success in solving the most complex customer challenges. Siemens Energy succeeds through our combined engineering expertise and innovative capabilities. Most importantly, common hardware and software platforms enable us to stay ahead of the technological edge.

4.1 The new control and protection platform

Control and protection (C&P) systems are critical to managing power flows and protecting grid components in FACTS plants. Both are paramount in light of increasingly complex grid architectures and fluctuating power infeed from renewable energy sources. As a result, system operators must contend with three main challenges. The first involves a quick reaction to market needs and the short lead time of the C&P system. The second pertains to reliable and secure operations throughout the entire lifecycle while safeguarding the low total cost of ownership.

Lastly, the C&P system should allow for the easy expansion of new solutions and services. Addressing these challenges is crucial to managing the ongoing energy system transformation and leveraging future innovations.



Modularity meets reliability

With our new modular C&P platform, Siemens Energy is tackling these challenges head-on. Our platform approach provides a common, proven, reliable basis for applications, processes, products, and technologies. Our pre-integrated and ready-to-use reference projects – called reference project lines – allow us to configure customer-specific solutions following your performance requirements. Based on these configured reference projects, customer-specific delta engineering leads to significantly reduced engineering and lead times.

The platform philosophy is incorporated in all areas of the system:

- Software applications for control and protection, field, and operations levels
- Hardware for control and protection, communications, field, and operations levels
- An open and digitalized engineering ecosystem

Software applications

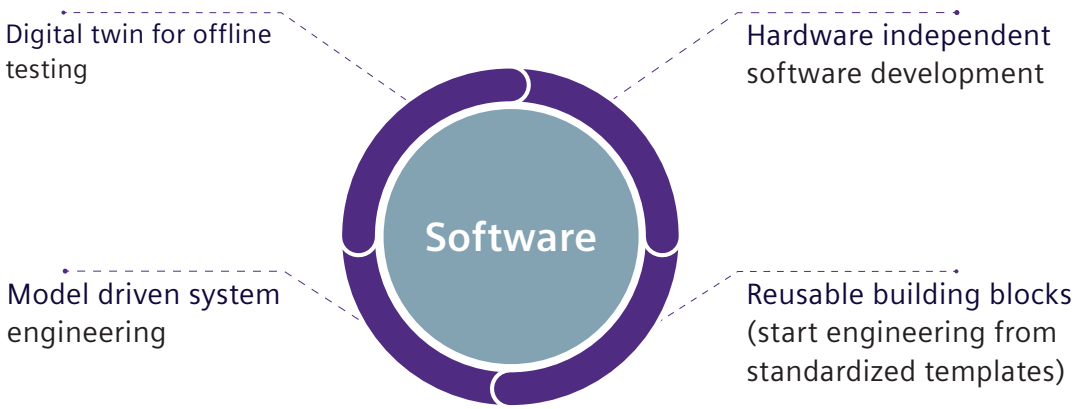
Our state-of-the-art methods and tools increase software development speed, efficiency, and accuracy. One such method is **model-driven system engineering** with MATLAB® and Simulink®,[1] which creates a single point of code transformation, including software development, simulation, and offline testing. Functionalities can be seamlessly integrated and simulated, facilitating the identification and correction of design errors from an early stage.

The same advantage applies to the **digital twin** – tests can be performed automatically and offline without impacting the physical process.

The digital twin escorts the system from the beginning, enhancing documentation and traceability.

Throughout the development process, we generate **building blocks and functions** for reuse in other projects. Engineering starts from standardized templates using reference project lines, significantly reducing the risk of errors and allowing for project implementation in parallel. We can also leverage the advantage of **hardware-independent software development** – even with hardware changes, software applications remain usable.

[1] MATLAB® und Simulink® are registered trademarks of Mathworks, Inc.



Control-level hardware

The hardware concept at the control level focuses on quick reaction, robustness, and secure functionality and data exchange.
In addition, scalable rail-mounted **PC technology** makes it easy to extend the system at any time in computing and processing power.

A wide range of internal **standard protocols**, from IEC61850 to EtherCAT, allows for fast and seamless communications. Short **bus cycle times** of up to 250µs enable closed-loop control tasks and deliver the performance to support new features.

With the ever-faster digital revolution, we've invested extensive expertise and diligence into **cyber security**. The primary hardware will run on an industrially proven open-source Unix operating system, creating a small footprint since every running service and configuration can be justified and explained. There are no dependencies on other operating systems. Thanks to open-source distribution, the functionality of the operating system and its applications can be verified, which is essential to comply with future security legislation initiatives. Continuous updates and life-long patch management complete the package.

Engineering environment

Digitalization offers unparalleled opportunities for collaboration, co-creation, and stakeholder involvement. With the new C&P platform, we are leveraging this potential to accelerate engineering and execution – for the benefit of all.

The **plant data digital twin** is a common data backbone for agile collaboration throughout the lifecycle. With the **cloud-based engineering portal**, all stakeholders in the engineering process gain full transparency and access to current and accurate data, enabling them to work in parallel. The underlying **common cloud infrastructure** enabled by a DevOps mindset and principles helps manage the build and release process and promotes fast deployment – a crucial aspect to react to and seize the potential of the energy transformation.

However, it is only not about engineering speed – equally important is operative reliability. With SensOTS, a **cloud-based operator training simulator**, staff can be trained in advance to operate the C&P system, "read" data if using the option for analytics, and manage condition-based maintenance.

Integrated controls for synchronous condensers

When it comes to grid control and the operation of a synchronous condenser, its control functions are of utmost importance.
Synchronous condensers must fulfill multiple tasks in grid management, and it is therefore essential that they are equipped with control capabilities for a variety of control modes such as:

- Voltage control
- Reactive power control
- Inertia response
- Fault current capacity

To handle all these tasks in an efficient and reliable way, a control system must meet multiple requirements:

- Fast and failsafe operation of rotating equipment
- Integration of electrical controls including excitation system and substation automation
- Remote operation
- Compliance with cybersecurity regulation and standards
- Maintenance approach covering the entire life cycle of the main equipment
- Remote maintenance and system diagnostics

The Omnivise T3000 control system is at the core of the Omnivise family of solutions. This integrated control solution offers the possibility to simultaneously manage electrical equipment and fast control loops.

The T3000's system architecture, remote access, service concept, and cybersecurity features are among the factors that make it the perfect fit for synchronous condenser operation, now and in the future.

Integrated system architecture

For the different technical areas covered by the T3000, there are typically numerous subsystems in place. The coordination of rotating, switchgear, metering, and protection equipment, which may be divided among various manufacturers, is a challenge. The interfaces frequently are the weak points– data synchronization between systems is always an issue.

Omnivise T3000 overcomes these challenges by providing an integrated architecture. It supports various communication protocols, like IEC 61850, 60870-104, and DNP3. This enables seamless integration into the overall grid system.



4.2 Grid-forming control

For converter-based FACTS and HVDC applications grid-forming controls are becoming the state-of-the-art-solution.

With the major shift towards renewable energy sources, there are growing concerns over the stability of future power systems around the globe. Conventional power plants are traditionally the main contributor to the stability of the grid, in terms of voltage and frequency. Therefore, a higher share of renewables in the power supply can potentially bring major challenges to power systems.

This has led to an increasing demand for grid-forming capabilities from converter-interfaced systems, as a promising solution for enhancing grid stability.

To address this demand, Siemens Energy has equipped three of its main power electronics-based grid solutions with advanced grid-forming capabilities.

These solutions include:

- STATCOM (SVC PLUS®)
- E-STATCOM (SVC PLUS FS®)
- HVDC systems (HVDC PLUS®).

By providing a constant voltage source, grid-forming control allows a stabilizing current contribution, counteracting AC grid transients, such as angle or amplitude changes in the grid voltage.

The ideal transient behavior of a grid-forming converter at its terminals is similar to that of a rotating machine generator, providing instantaneous reactive power support for changes in the grid voltage magnitude and instantaneous active power support for changes in the grid voltage angle or frequency (inertial support), while being able to facilitate a controllable steady-state active and reactive power operation point.

The main grid-forming functionalities can be summarized as follows:

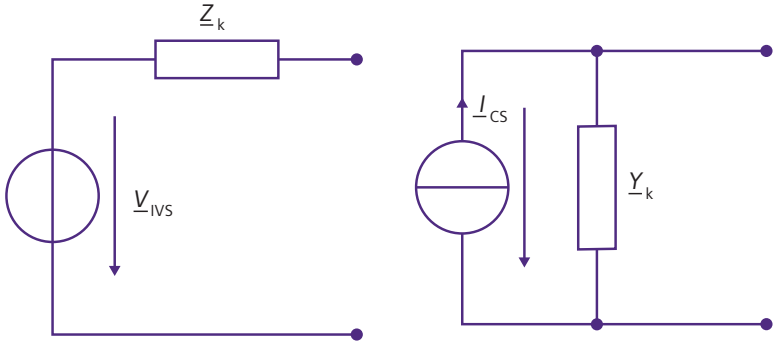
- Inherent reaction counteracting grid disturbances (voltage and frequency)
- Provide inertia for frequency stability (E-STATCOM and HVDC)
- Inherent damping of system oscillations
- Operating in all grid conditions, including weak grids and islanding scenarios
- Support grid recovery
- Contribute short circuit power

Detailed information can be taken from our white paper “Grid-forming converters”.

The following table shows an overview of these solutions and what they can offer in terms of grid-forming capabilities.

Characteristics	HVDC PLUS®	SVC PLUS FS®	SVC PLUS®
Grid-forming control	✓	✓	✓
Inherent active power support, e.g., inertia response	✓	✓	✗*
Inherent reactive power support	✓	✓	✓
Primary energy source	Remote AC grid	Supercapacitors	✗
Topology of the converter arms	Y (Star)	Y (Star)	A (Delta)

* SVC PLUS® does have inherent short-term active power exchange with the grid. However, it does not have an additional storage to provide a notable active power support.



Equivalent circuit diagram for a grid-forming control (left) compared to a grid-following control (right). Note that $\underline{Z}_k$ is not equal to $1/\underline{Y}_k$

4.3 Digital engineering and execution platform

Our state-of-the-art approach is common processes with a high degree of engineering digitalization and project execution.

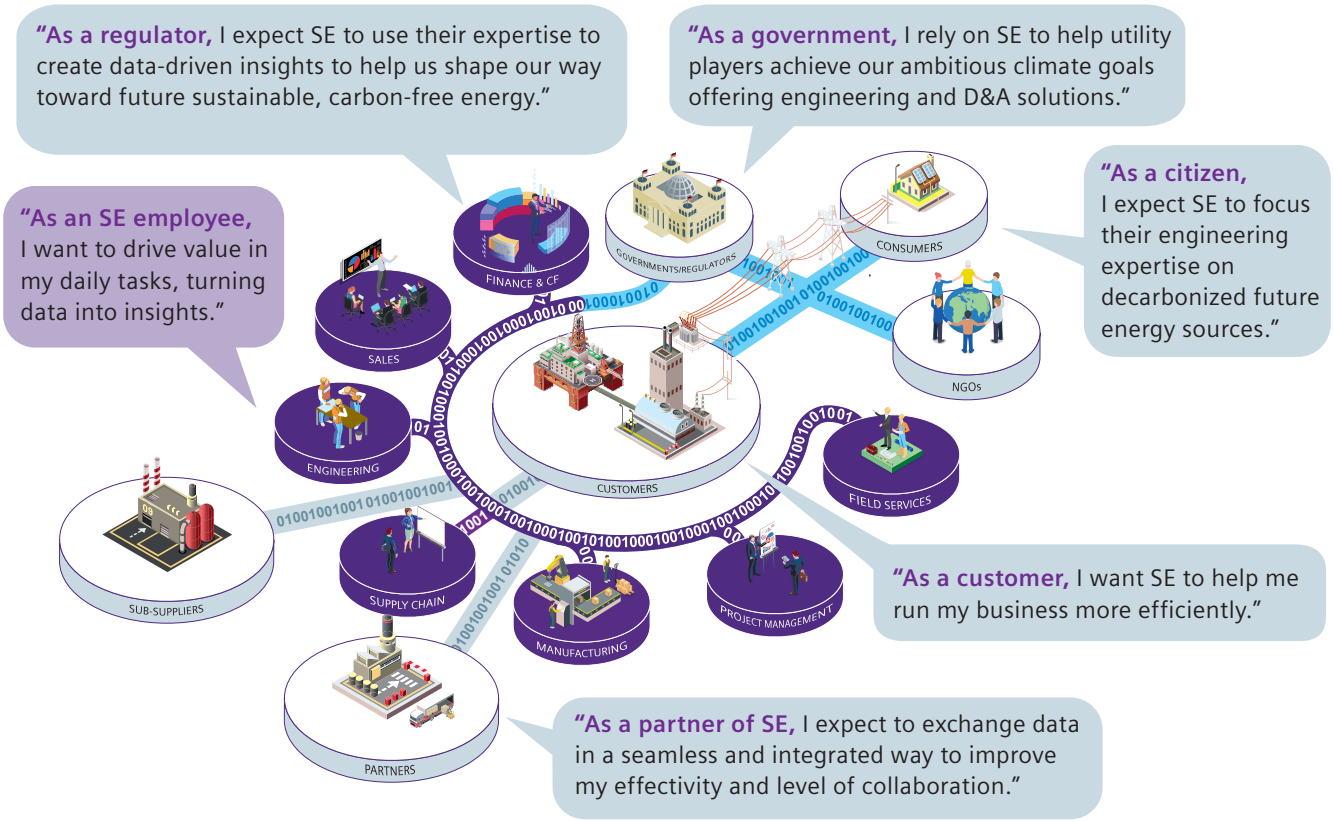
Digitalization has a profound impact on the way we can deliver projects. Siemens Energy offers the complete package, including project management and engineering. Using the latest digital management and engineering methods, we provide endless flexibility in collaboration and communication, ensuring a seamless and successful experience for our customers and partners.

Digital engineering and execution mean working with all stakeholders on a common data platform for agile project collaboration and efficient operation, enabling the reduction of execution time and steps, data exchange and access in the cloud, and improved efficiency.

Digital engineering and execution also facilitate collaboration between different project stakeholders, reduce project lead time and risk, and increase data safety.

Examples of digital engineering and execution platform use include building information modeling (BIM) applications for planning, design, and construction (e.g., 4D time scheduling, 3D modeling, design, collaboration) and modeling tools for simulation (e.g., plant noise simulations).

The following figure presents an overview of the complex global digital cooperation for state-of-the-art digital operations. The use of digital tools for engineering accelerates project delivery and establishes maximum transparency for all stakeholders involved in the project.



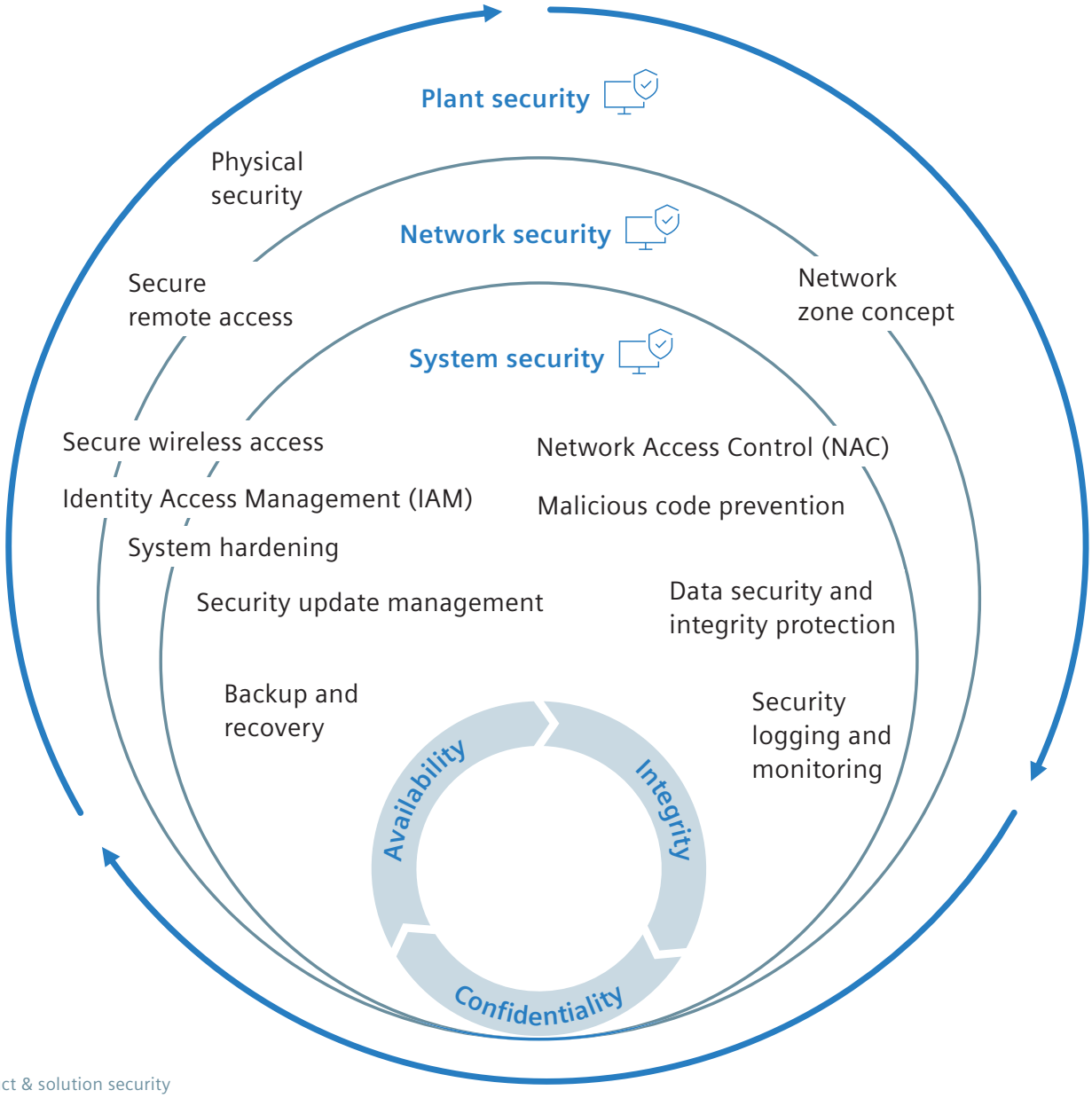
4.4 Cyber security approach

Secure your energy future with Siemens Energy transmission

Siemens Energy transmission offers a comprehensive security approach that safeguards your plants, networks, and systems.
Our grid stabilization solution integrates a wide array of security functions as standard.

Based on the “onion” principle, the concept of “defense in depth” entails multiple complementary security layers.

Holistic security approach of Siemens Energy transmission



Siemens Energy transmission security functions
01 | Network zone concept
02 | Identity Access Management (IAM)
03 | Data security and integrity protection
04 | System hardening
05 | Malicious code prevention and malware protection
06 | Security update management
07 | Network Access Control (NAC)
08 | Security logging and monitoring
09 | Secure wireless access
10 | Secure remote access
11 | Backup and recovery
12 | Physical security

Product & solution security

A holistic security approach:

- **Plant security:** We offer a comprehensive range of services to enhance the security of the IT infrastructure. This includes access control, system hardening, reliable backup and recovery solutions.
- **Network security:** Our approach encompasses the network zone concept, identity access management, and secure remote access.
- **System security:** We implement network access control, malicious code prevention, data security and integrity protection by using state-of-the-art protocols, security logging and monitoring, backup and recovery, and security update management.

All the measures listed ensure the three basic pillars of cybersecurity: availability, integrity, and confidentiality. Every element of cybersecurity and every security control put in place by an entity, should be designed to achieve and support these principles.

01. Network zone concept:
Our network zone concept segregates the networks into distinct segments protected by firewall rules, ensuring maximum security and control over data traffic. All unnecessary services and ports are blocked by default.

02. Identity Access Management (IAM):
Our IAM solution defines complex passwords and utilizes passphrases by creation, which are documented only in encrypted formats. This effectively protects the access credentials and ensures that only authorized users have access.

03. Data security and integrity protection:
Using state-of-the-art secure protocols and securing communication to the station and off the station. Public and private keys provide strong authentication and periodic synchronization.

04. System hardening:
By setting the boot order in BIOS, establishing BIOS passwords, and disabling unnecessary services, we enhance the security of the systems. Group Policy Objects (GPOs) enforced according to the Center for Internet Security (CIS) benchmark further strengthen protection.

05. Malicious code prevention and malware protection:
Our whitelisting based on application control ensures that only authorized applications can be executed. The system is scanned during the initial run, and all existing executables are whitelisted while others are blocked.

06. Security update management:
Windows-based systems utilize offline updates to install security updates and address known vulnerabilities. Vulnerabilities are continuously monitored and tracked.

07. Network Access Control (NAC):
NAC deals with controls and measures required for prevention of non-authorized access to a network zone by unauthorized devices. Additionally, all switch ports which are not needed are closed by default.

08. Security logging and monitoring:
A central logging solution captures and monitors all security-related events. The management console is installed on a station PC, and agents are deployed to Windows-based machines. Heartbeat agent checks the availability of remote hosts. The Syslog-server receives events from network devices. Events can be viewed in a local browser and forwarded to a remote Syslog-server.

09. Secure wireless access:
For our solutions the use of wireless technology is not recommended and in general not foreseen.

10. Secure remote access:
Using state-of-the-art secure protocols such as TLS and VPN, we enable secure access to the customer network from anywhere. The SSL VPN tunnel ensures that remote access is protected, and only authorized traffic is permitted.

11. Backup and recovery:
Our solutions provide reliable backups and quick recovery options, both online and offline. Static configuration backups for embedded devices and full backups during runtime ensure the security of your data.

12. Physical security:
Physical security encompasses all the measures and controls required to protect our solutions, including data and data processing systems.

Trust Siemens Energy transmission to navigate the challenges of the modern energy world and secure the energy future.



5. Grid stabilizing technology

The accelerating global energy transition, driven by the increasing integration of decentralized renewable energy sources, presents significant challenges in maintaining reliable and stable grid operations. Flexible AC transmission systems (FACTS) are crucial in modernizing and stabilizing power grids, offering comprehensive solutions to enhance grid reliability, stability, and transmission efficiency.

Siemens Energy, a global leader in power transmission, operates across all continents and possesses extensive experience in addressing global environmental challenges. With a proven track record of executing FACTS projects across its entire portfolio and at the highest voltage levels, the company is recognized as a world market and technology leader in both the industry and utility sectors. Committed to innovation and improvement, Siemens Energy continuously adapts its FACTS portfolio to meet the evolving needs of energy networks, enhancing grid resilience.



5.1 SVC PLUS® (STATCOM)

Static synchronous compensator (STATCOM) technology is a dynamic solution for voltage control in the power grid by injecting and absorbing reactive power. Our well proven modular multilevel STATCOM, SVC PLUS®, offers optimal performance to our customers.

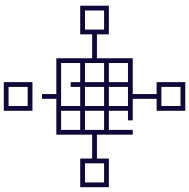
IGBT based multilevel converter technology with outstanding performance and features

SVC PLUS® is the leading technology in reactive power compensation and is based on VSC technology, using high-performance transistors (IGBTs) as the primary semiconductor device. This modular multilevel system has several advantages compared to previous STATCOM configurations.

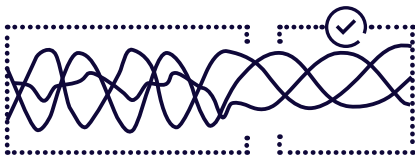
For mining and metal specialized industry solutions of SVC PLUS® are available.

SVC PLUS® control delivers:

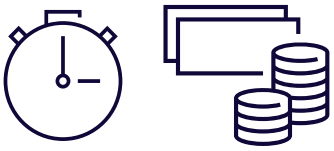
- **Voltage control** with superior under-voltage performance and voltage recovery after grid faults
- **Grid-forming** converter control, offering inherent voltage support in both strong and weak grid conditions as well as provision of harmonic damping.
- **Power oscillation damping**, for increasing the transmission capability of the power system
- Several additional **control features**, e.g.
  - **Active filtering** reducing the need of passive filters, filtering is adaptable to future grid changes
  - **External device control**
  - **Unbalance control**, e.g. negative phase sequence control
- **Cyber security compliance** being continuously improved



Optimal stability and quality



In harmony with harmonics – grid forming capability

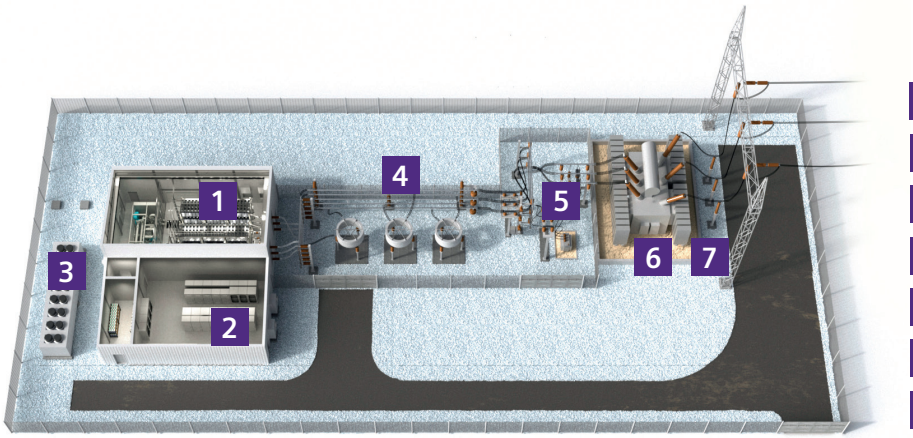


Fastest response – efficient solution

Benefits

Wide range of reactive power

- Reactive power range scalable from 50 Mvar **up to 425 Mvar per branch**
- Possibility of converter branches in parallel
- Full turnkey project realization including all civil works
- Prefabricated containerized, modular variants available
- Mobile STATCOM solution, realized on truck trailers for quick relocation



1 SVC PLUS converter
2 Control room
3 Cooling
4 Phase reactor yard
5 MV switchyard
6 Power HV/MV transformer
7 Connection to the HV switchyard

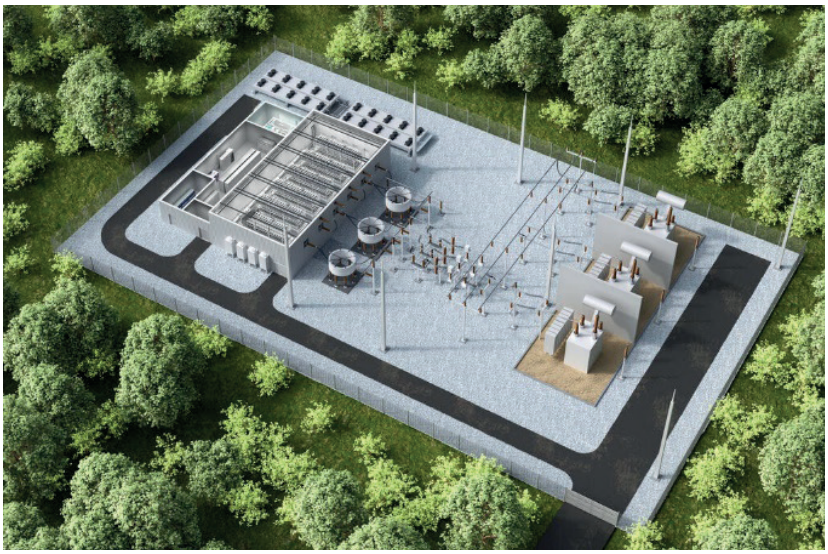
SVC PLUS Overview

Siemens Energy introduced SVC PLUS® over 10 years ago, and the technology has since garnered tremendous attention and appreciation across the industry.

With more than 150 installations on all continents and many years of extensive experience, SVC PLUS® is a proven and trusted technology.

Broad spectrum of variants and applications

- Full turnkey project realization including all civil works
- Prefabricated modular variants available for medium reactive power ratings, no building required
- Compact prefabricated modular variants available for small reactive power ratings
- Relocatable Mobile STATCOM solution, realized on truck trailers



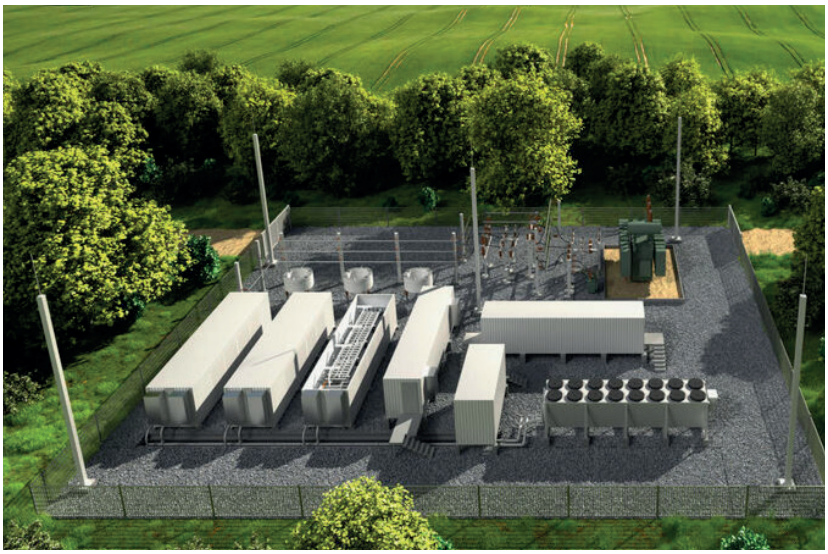
SVC PLUS® for highest reactive power ratings
(up to 425 Mvar per branch)



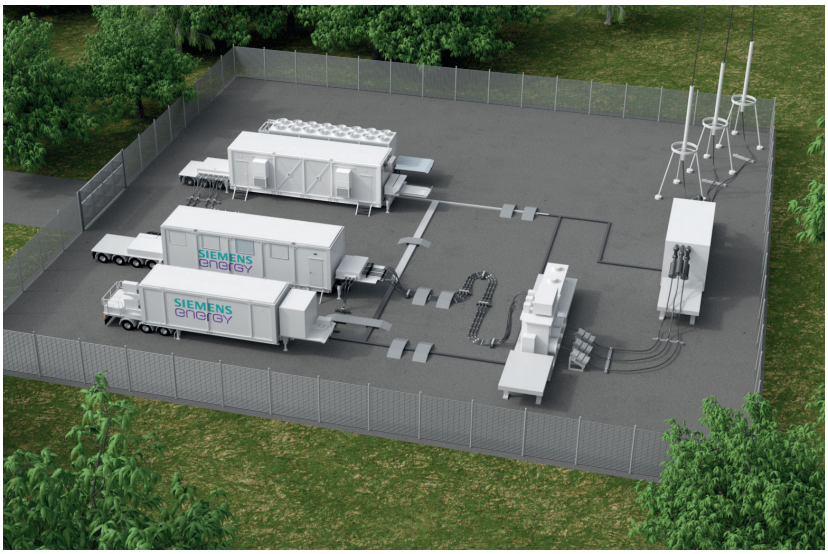
SVC PLUS® prefabricated modules for small reactive power ratings

Realization even for demanding constraints

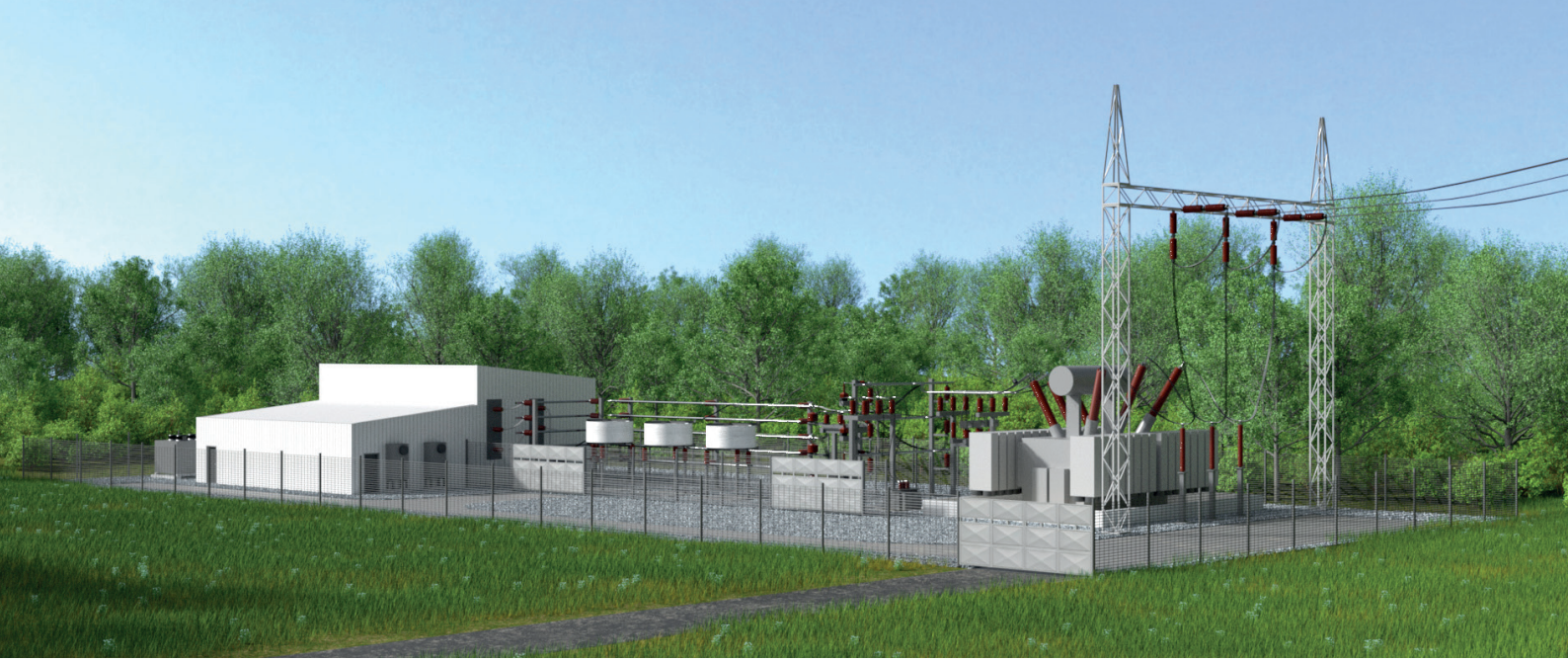
- Very high system availability
- Seismic-compliant station design
- Noise-compliant realization
- Even applicable under severe conditions (e.g., coastal conditions, high or low temperature sites, pollution, altitude)
- Electromagnetic compatibility: Immunity of SVC PLUS® equipment, low radio frequency emissions



SVC PLUS® prefabricated modules for medium reactive power ratings, no building required



SVC PLUS® Mobile STATCOM for small reactive power ratings



5.2 SVC PLUS FS® (E-STATCOM)

Extended STATCOM (E-STATCOM) solution with voltage and frequency control in one unit.

The challenge

While grids are undergoing fundamental changes in power generation, renewable infeed, and ever-increasing demand, power quality and dynamic grid stability are at risk due to less synchronous power generation.

As the power infeed from inverter-based resources continues to replace conventional synchronous power generation, the grid frequency is becoming more sensitive due to the reduced amount of rotating machines. Grid operators face the challenge of providing sufficient system inertia with rotating equipment to stabilize the grid. Because inverter-based resources have minimal inertia and cannot be used for frequency stabilization, new solutions are needed.

SVC PLUS FS® (Frequency Stabilizer): An E-STATCOM solution providing active and reactive power

Using a bulk number of supercapacitors, the new SVC PLUS frequency stabilizer® (FS) is a cost-efficient, compact solution supporting voltage and frequency grid stability.

- Grid-forming converter: Voltage source behavior provides phase-correct instantaneous response to voltage magnitude or phase angle changes
- Energy reserves: A bulk number of super-capacitors provide grid-scale active power output, up from milliseconds to several seconds

Technical data	Configuration scalable
Active power	up to +/- 300 MW
Reactive power	up to +/- 300 Mvar
Available energy	Active power out-/input for 1... 5 s depending on super-capacitor unit

Blackout prevention

Dynamic voltage and frequency support combined in one unit for optimal power quality.

Cost-effective solution

Low lifetime expenditures through compact, space-saving installation with high power density, low losses, and easy maintenance.

Grid forming

Inherent response time with high active power output over several seconds.

High flexibility

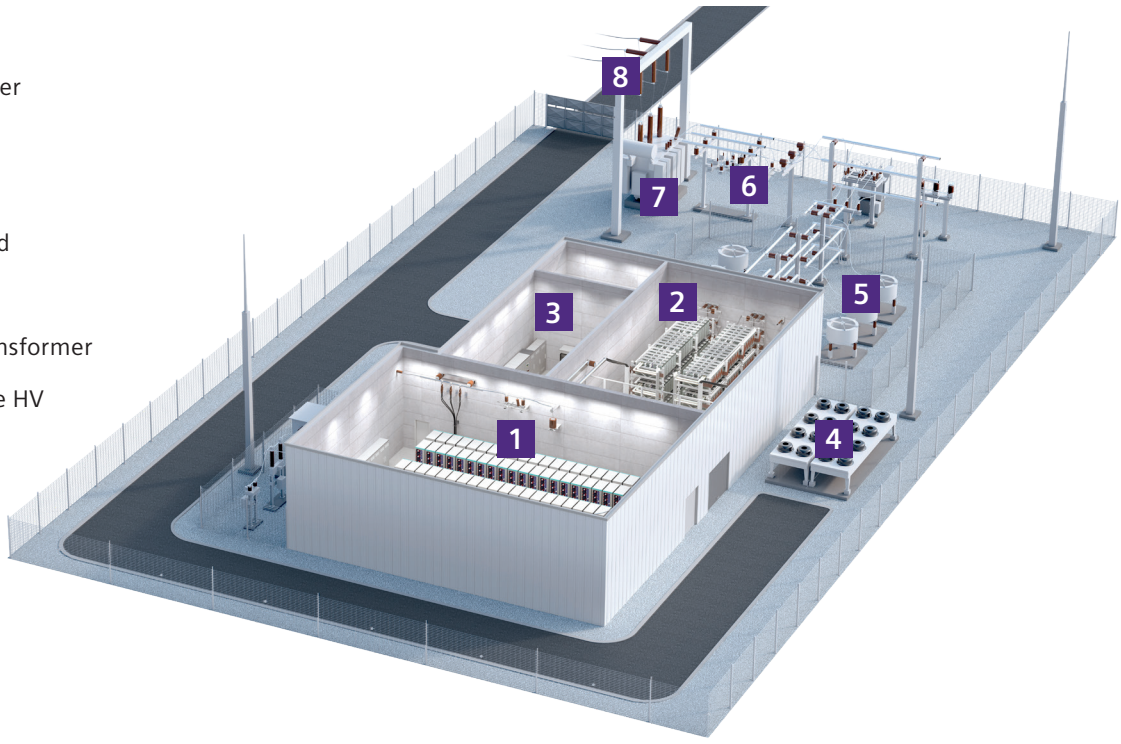
The highly adaptable solution is suitable for various applications through the flexible adjustment of control parameters.

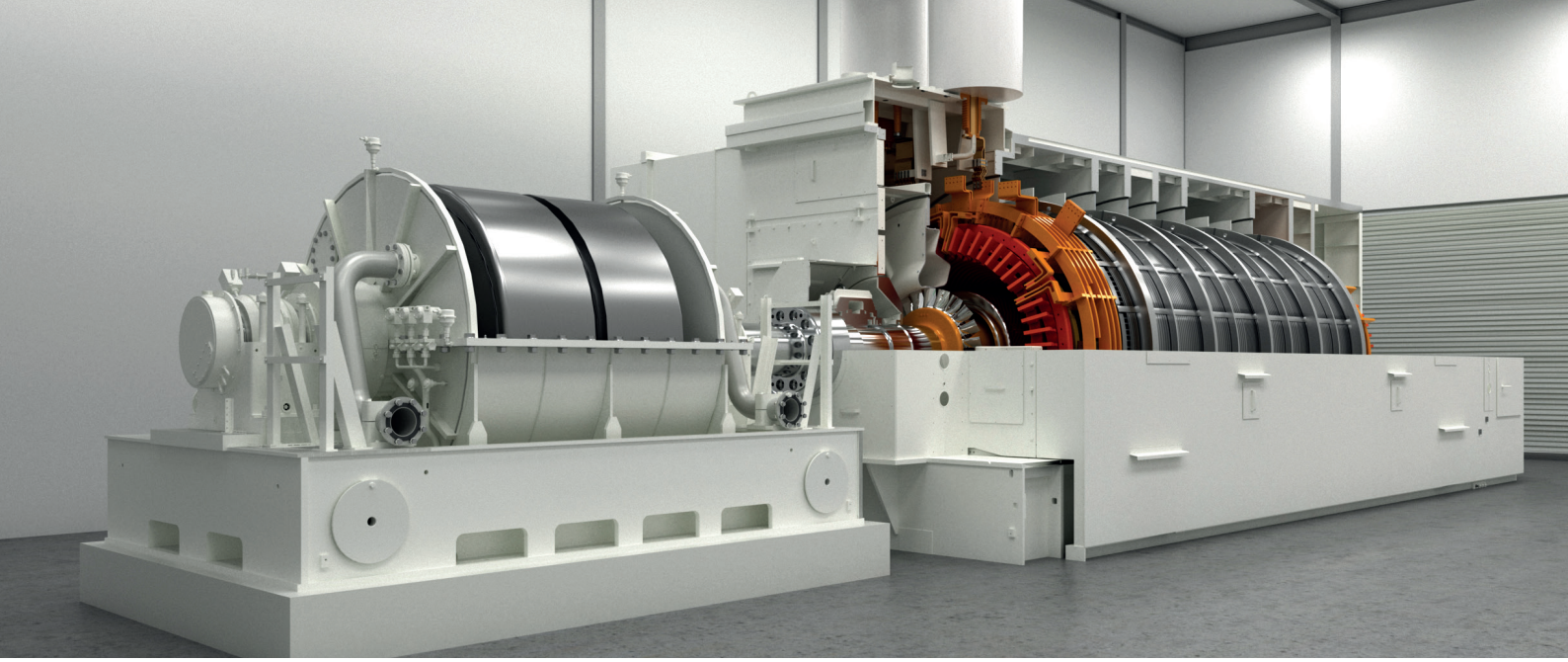
Benefits

The SVC PLUS FS® provides the following features:

- Steady-state and dynamic voltage control through reactive current provision
- Frequency control using active current provision at frequency deviation
- Virtual synchronous machine with natural inertial response through active power injection due to a phase-angle step of frequency gradient
- Stabilization of weak grids through voltage source behavior

1 Supercapacitors
2 SVC PLUS converter
3 Control room
4 Cooling
5 Phase reactor yard
6 MV switchyard
7 Power HV/MV transformer
8 Connection to the HV switchyard





5.3 Synchronous condenser

With an increasing share of renewable power generation and the shutdown of large conventional and nuclear power plants for environmental, economic, social, and political reasons, most power grids are experiencing a decreasing level of inertia and short-circuit power.

Inertia and short circuit power are integral factors for a capable system. Inertia reduces oscillation on grid frequency and prevents system blackouts, while short circuit power ensures reliable system protection.

Our synchronous condenser solution uses a generator to supply the necessary inertia with its rotating mass while also providing or absorbing reactive power. The generator is connected to the transmission network by a transformer and is started by a static frequency converter. Once the operating speed is achieved, the generator is synchronized with the network, behaving like a synchronous motor with no load and providing reactive power, short-circuit power, and inertia to the transmission network.

Major driving forces requiring synchronous condensers are e.g., the replacement of synchronous generation machines with renewable energy sources like wind power and solar plants and increasing distances between generation and demand.

Contribution of short-circuit power

Voltage support

Short-term overload capability

Inertia to the transmission system

Benefits

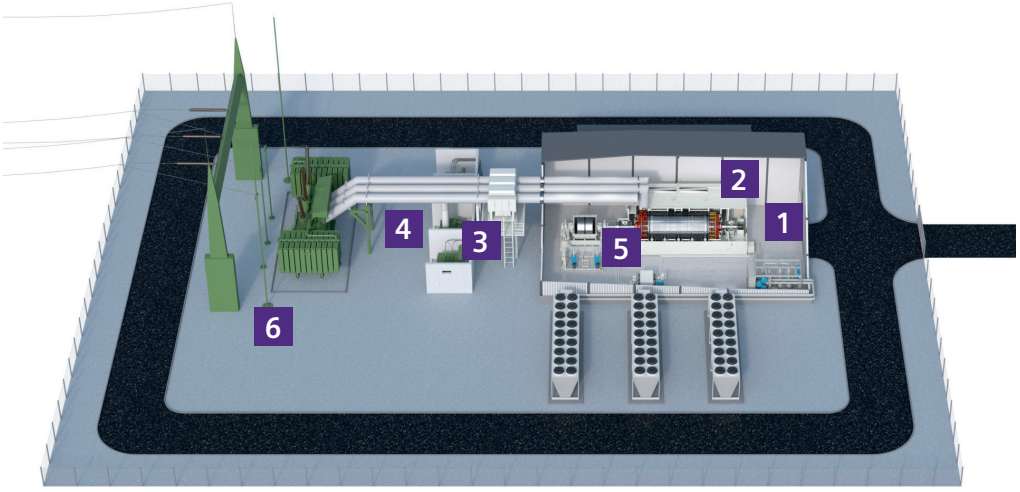
Maximum inertia with additional masses provided by flywheel solution

To provide maximum inertia, Siemens Energy has extended the synchronous condenser solution with additional rotating mass from a flywheel. This extension is a highly effective method to maintain the required level of inertia and rate of change of frequency (RoCoF) of the system.

Rotating mass provides an inherent synchronous inertial response, counteracting grid frequency fluctuations with active power injection or absorption during sudden load unbalance events.

Siemens Energy's flywheels operate in a partial vacuum to minimize air friction losses and reduce the cooling efforts to maintain required temperature levels in all operational and emergency modes. This design enables a safe emergency rundown in case of total power loss (grid blackout).

The flywheel is designed for plug-and-play installation delivered to the site with the rotor installed, allowing for a minimal footprint and low supervision and maintenance effort.



1 Generator hall
2 Synchronous generator
3 Generator circuit breaker
4 Auxiliary transformer
5 Flywheel
6 Power Transformer

Technical data	
Reactive power range	Up to + 500/ -260 Mvar (@Generator terminal)
Terminal voltage	Up to 20 kV
Short circuit power range	Up to 2000 MVA
Inertia (kinetic energy)	Up to 4000 MWs

Flywheel technology

Inertia and short circuit power are the key factors for a strong system. Inertia reduces oscillation on grid frequency and prevents system black-outs. Short circuit power guarantees a reliable system protection.

To help provide maximum inertia, generators can be extended with an additional flywheel with a scalable and customized design. This approach is intended to preserve the inherent inertia that was originally provided by the turbines.
In order to help minimize friction losses and reduce cooling efforts, flywheels are operated in a partial vacuum and equipped with a dedicated cooling system.




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5.4 Fixed Series Capacitor

The ongoing energy system transformation requires effective means to address challenges in reliable power transmission. Instead of building new lines, our FACTS technology can increase transmission capacity. Series compensation technology provides higher transmission capacities for existing long-distance AC transmission lines and increased grid stability – without the costs and time requirements of building new lines.

How to increase transmission system capacity and stability

The increasing energy demand can only be met when grids provide sufficient transmission capacity. Building new lines is not only expensive, but also complex due to changing regulations, public acceptance, and environmental concerns. Fixed series capacitor (FSC) technology provides an alternative solution by increasing the transmission capacity of existing lines.

Proven fixed series capacitor technology for cost-effective capacity expansion

Power transfer with long overhead transmission lines is limited by the impedance that can lead to voltage drops. For decades, fixed series compensation has been the proven solution to maintain a minimum voltage profile and maximum utilization of transmission lines. This technology works by connecting a capacitor bank in series with the transmission line to partially compensate for inductive impedance while increasing the

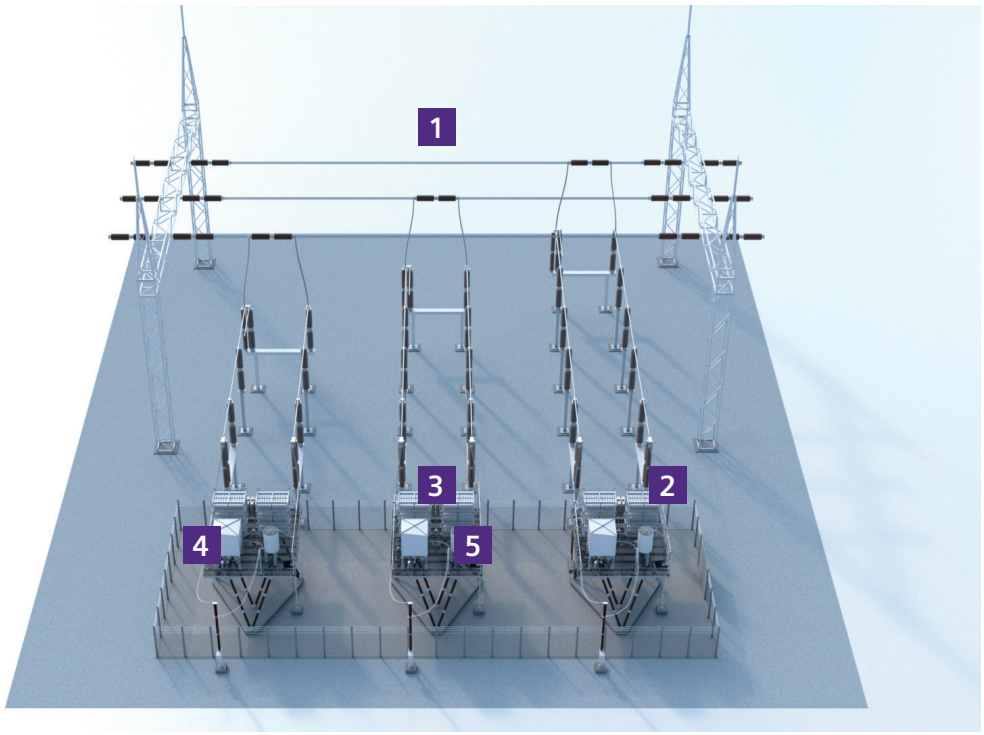
Increased maximum capacity

Increased grid stability

Economical solution

Benefits

voltage at the point of connection. The capacitors are protected by metal oxide varistors (MOVs) and – in case of a severe fault – by a breaker which bypasses the FSC. For instant protection, a triggered spark gap bypasses capacitors and MOVs within less than 1 ms. Gapless solutions are also possible, provided that local requirements match. Due to this complexity, Siemens Energy offers individually designed solutions with FSCs.

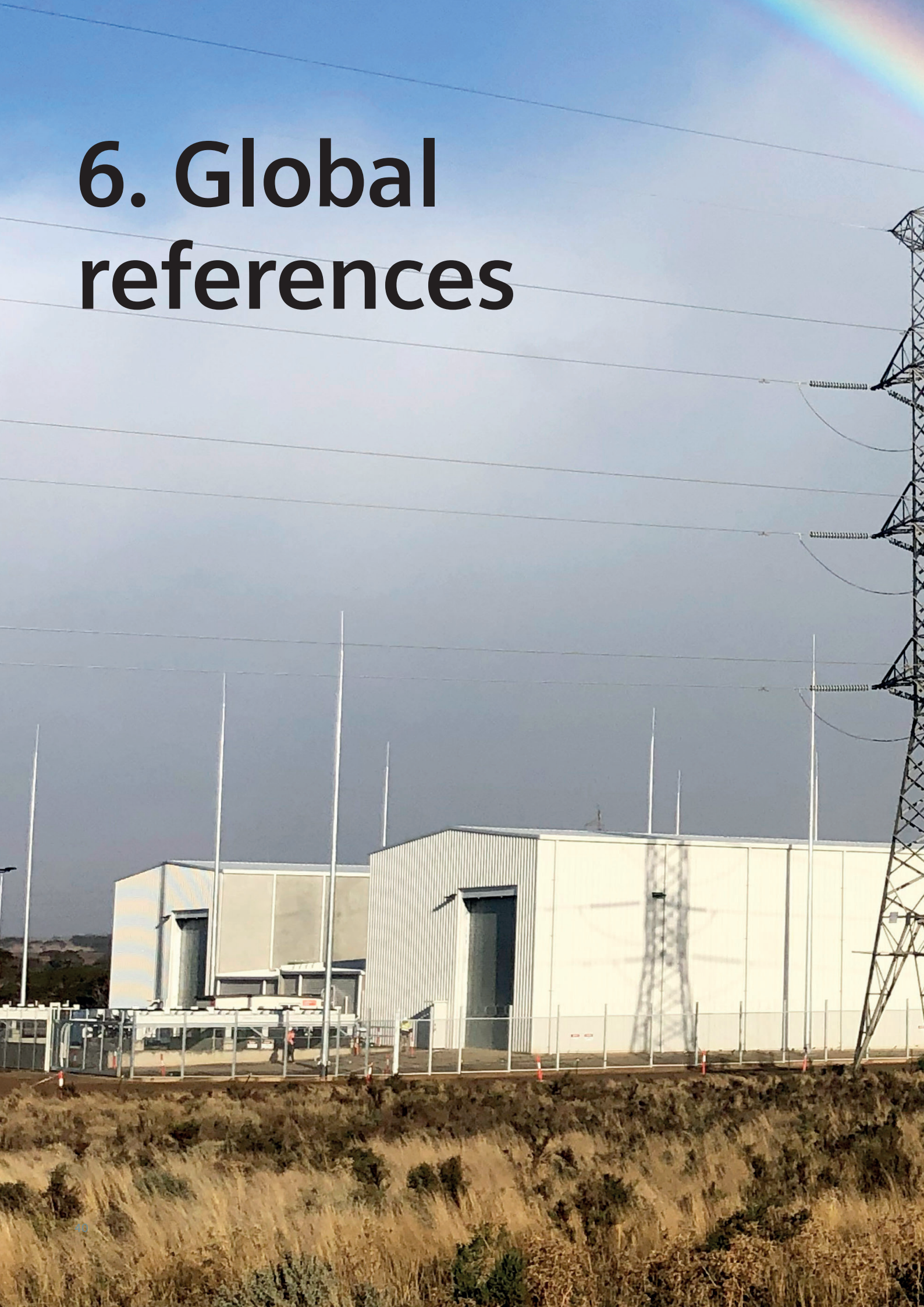


1 Transmission line
2 Capacitor bank
3 Metal oxide varistor
4 Spark gap
5 Damping circuit

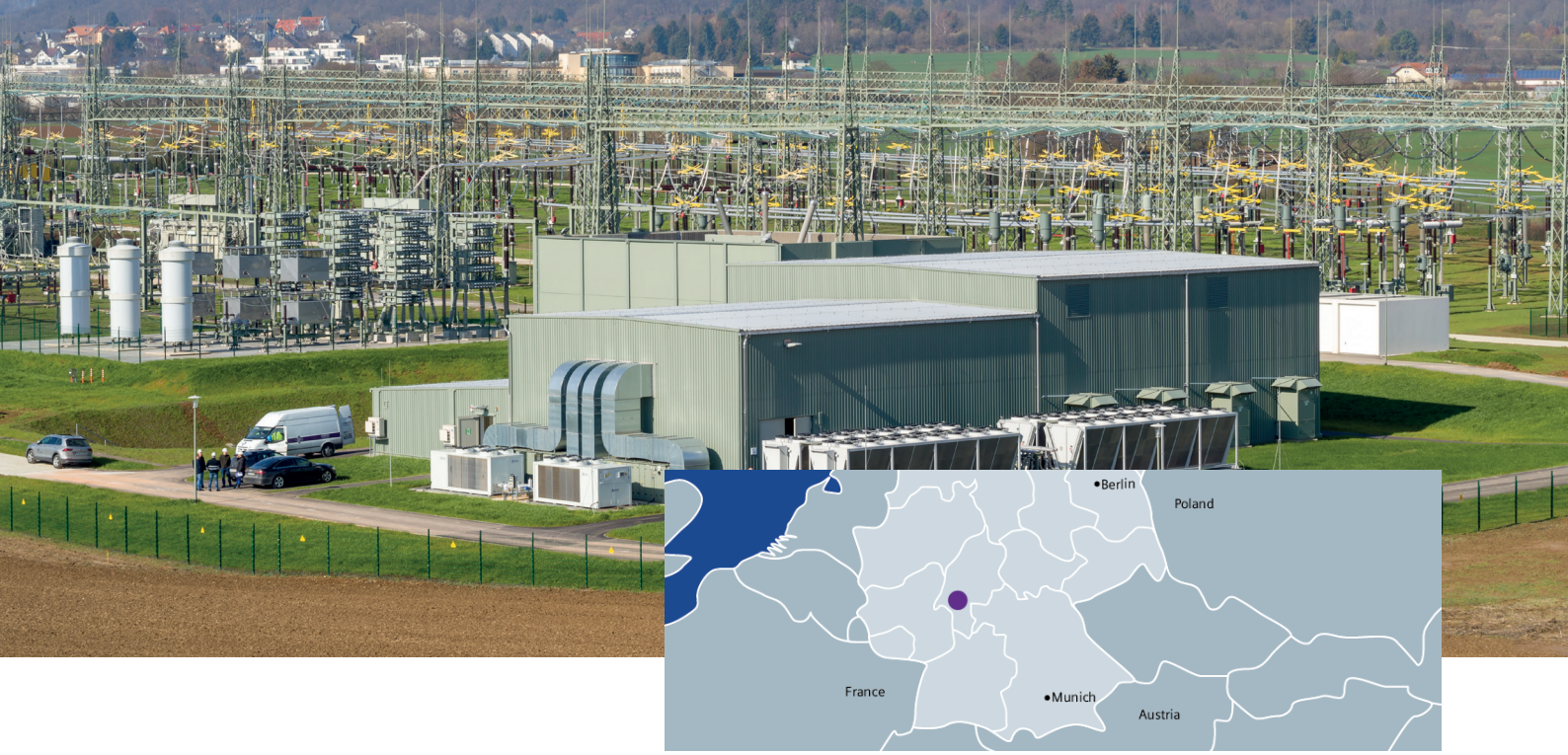
Siemens Energy's advanced power delivery solution translates into many benefits:

- Increases power transfer capability
- Reduces line voltage drops
- Limits load-dependent voltage drops
- Influences load flow in parallel transmission lines
- Reduces transmission angle, increasing stability
- Reduces transmission systems footprint
- Cost-effective
- Reliable and robust design even in seismic areas

6. Global references







6.1 SVC PLUS® – Kriftel, Germany

Reliable energy transmission by stabilizing the grid node in Rhine-Main

Commissioned by grid operator Amprion, the transmission systems by Siemens Energy support the power supply for the industrial city of Frankfurt in the Rhine-Main area. The reactive power compensation systems have been successfully running since 2018 for nearly 6 million inhabitants. Additionally, this power grid node supplies wind power from northern Germany to the industrial south.

Due to the energy transition in Germany, renewable and distributed energy sources increase power fluctuations. Amprion is responding by installing an SVC PLUS® system to stabilize grid voltage during long-distance large-scale power transmission. Combined with a mechanically switched capacitor with damping network (MSCDN), these systems will help prevent gaps in supply due to large power plant shutdowns.

The SVC PLUS® system does not generate power but instead modulates and manages electricity that flows from sources hundreds of miles away. It can dynamically, rapidly, and flexibly increase or decrease grid voltage demand and effectively transmit electricity. At the core of SVC PLUS® is multilevel converter technology. Compared to other self-commutated converter topologies, the required space is reduced, and the system is ideal for flicker compensation, integration of wind power plants, and railway electrification.

Technical data	
Customer	Amprion GmbH
Project name	Kriftel
Location	Germany
Scope	1x SVC PLUS®, 400 kV, ±300 Mvar
Special features	Voltage support Power transformer with DC compensation system
In service date	2019



6.2 SVC PLUS® – Rheinau, Germany

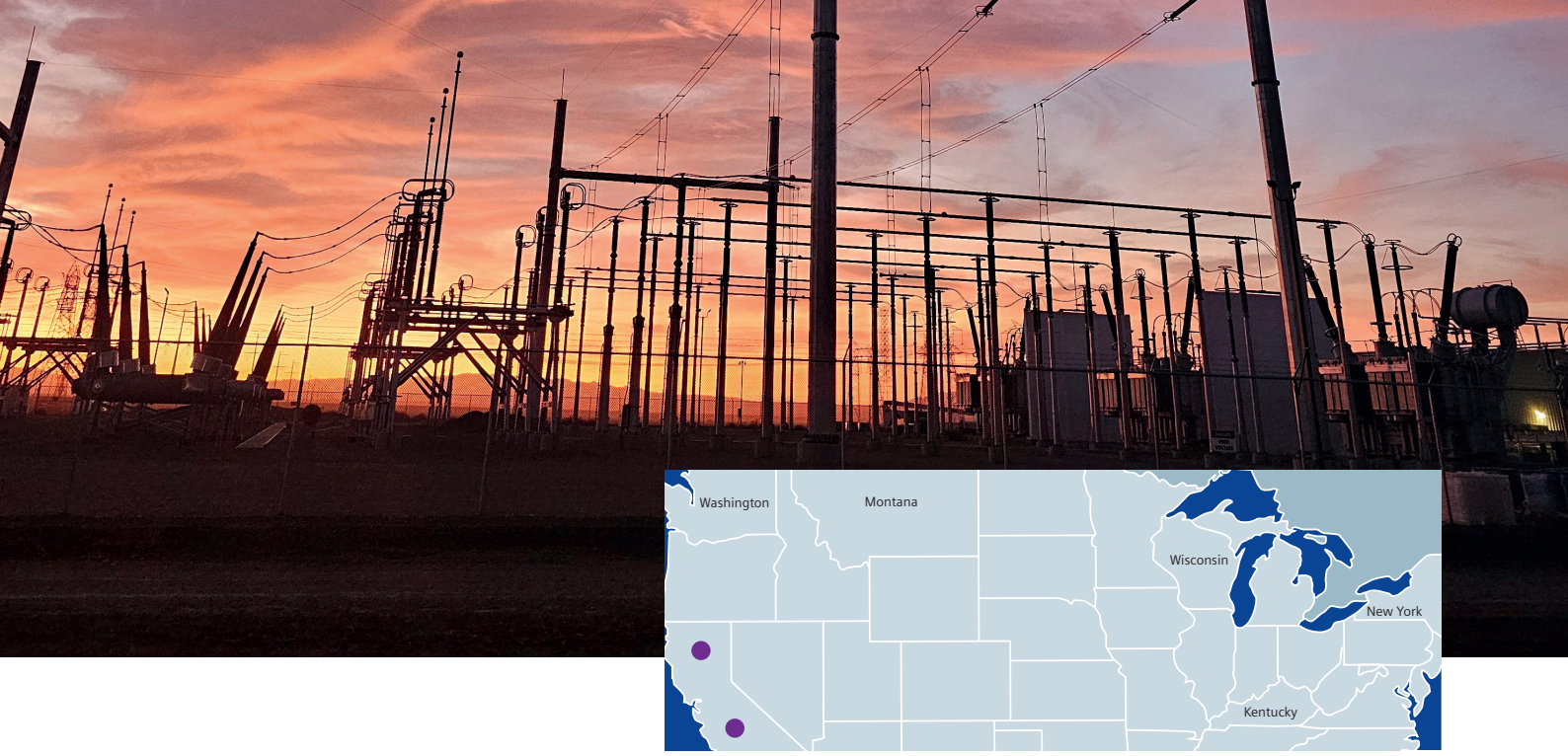
Strengthening the German power grid with grid-forming controlled STATCOM

German transmission system operator Amprion has commissioned Siemens Energy with the construction of SVC PLUS® installation to further stabilize the German transmission power grid, located in Rheinau (Baden-Württemberg). The system is designed for a reactive power range of +/- 600 Mvar making it among the most powerful system in the world.

The STATCOM system compensates for the voltage fluctuations by regulating the reactive power as required, keeping the grid voltage in a stable range. The expansion of renewable energy generation adds more stress on powerlines, reinforcing the need for increased reactive power compensation.

In addition, the STATCOM features the innovative control mechanism, grid-forming, allowing the system to efficiently compensate for increasing voltage fluctuations in the electrical transmission network. These feature leads to control behavior of the converter similar to rotating synchronous generators, such as those used in conventional power plants. Like generators, a STATCOM can keep the voltage in the network constantly stable by itself. The new turnkey STATCOM built in Rheinau possesses these new grid-forming control system.

Technical data	
Customer	Amprion
Project name	Rheinau
Location	Rheinau, Baden-Württemberg, Germany
Scope	Full turnkey, two SVC PLUS® stations, ±600 Mvar at 400 kV at each station Development and first-time application of grid forming control for SVC PLUS® delta
Special features	Innovative control design allowing effective reactive power compensation during periods of low short-circuit ratios due to grid forming capability, support during reconstruction of network, active filter functionality, two stations with four SVC PLUS® systems – possibility of selective take out of VSC during operation, possibility of external device control
In service date	2025



6.3 SVC PLUS® – Gates & Round Mountain, USA

Strengthen grid stability and support increased renewable energy generation in California

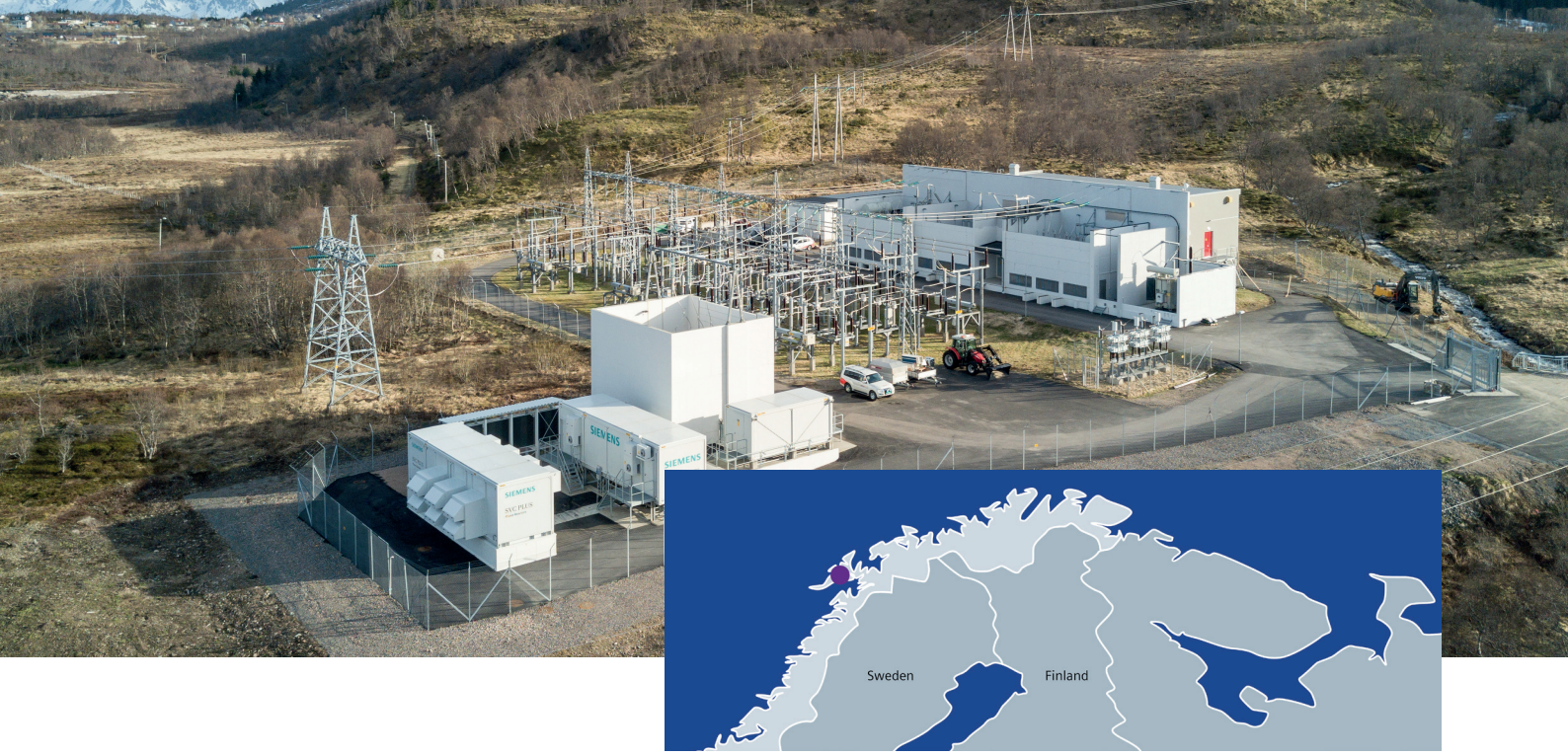
Siemens Energy has provided four static synchronous compensator (STATCOM) installations for LS Power Grid California substation projects in California. These STATCOMs are the key to ensuring the reliability of the power grid as renewable energy sources are brought online, enabling further decarbonization of California's energy mix.

With the retirement of Pacific Gas and Electric Co.'s (PG&E) Diablo Canyon nuclear power plant in 2025, it comes to greater sensitivity to voltage instability, especially as PG&E integrates more renewable generation onto the grid.

Two of the STATCOM systems have been installed at LS Power's Orchard substation connecting to the existing PG&E Gates 500 kilovolt (kV) substation in Fresno County and provide 848 megavolt-ampere (MVA) of dynamic reactive power support. Under the light-load conditions, this support is mitigating high voltages during extreme contingencies on the Bulk Power System.

The other two STATCOMs have been installed at LS Power's new Fern Road substation connecting the Round Mountain to Table Mountain 500 kV transmission lines. The purpose of these systems is for voltage control and voltage support in case of system events and transmission outages.

Technical data	
Customer	LS Power Grid California, LCC
Project name	Gates & Round Mountain
Location	California, USA
Scope	Design, supply, installation and commissioning of 4 SVC PLUS®. Long-term service agreement.
Special features	2 SVC PLUS® with 500 kV, ±264.5 Mvar each 2 SVC PLUS® with 500 kV, ±424 Mvar each
In service date	2023



6.4 SVC PLUS® – Sortland, Norway

Dealing with the harsh environment to stabilize transmission in Norway

To improve the Norwegian power system and provide a reliable power supply, Statnett installed the SVC PLUS® by Siemens Energy.

The remoteness of the Lofoten Islands caused voltage instabilities on the existing HV line. Therefore, a fast compensation device was required close to the town of Sortland. Siemens Energy was awarded the SVC PLUS® contract since this solution featured several benefits for this case. Reducing local construction and installation activities to a minimum and finishing the work before the early start of winter were the driving forces behind prefabricating as many system parts as possible. Also, the solution needed to deal with the harsh environment.

Accordingly, all electrical equipment was placed inside the SVC PLUS® containers, including the coupling reactors interconnected by cables. No active air-insulated parts were installed in the yard, which provided optimal protection, including vermin attacks. This solution also eliminated the need for an expensive and resource-consuming building.

Technical data	
Customer	Statnett
Project name	Sortland
Location	Norway
Scope	1x SVC PLUS®, 132 kV, ±50 Mvar
Special features	Increase of power line transfer capabiliy Voltage support Containerized phase reactors
In service date	2015



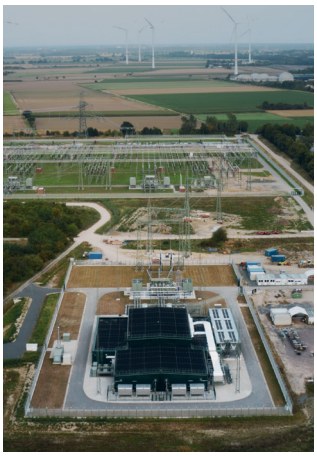
6.5 SVC PLUS FS® – Mehrum, Germany

At the pulse of the energy transition: Grid stabilization in Germany

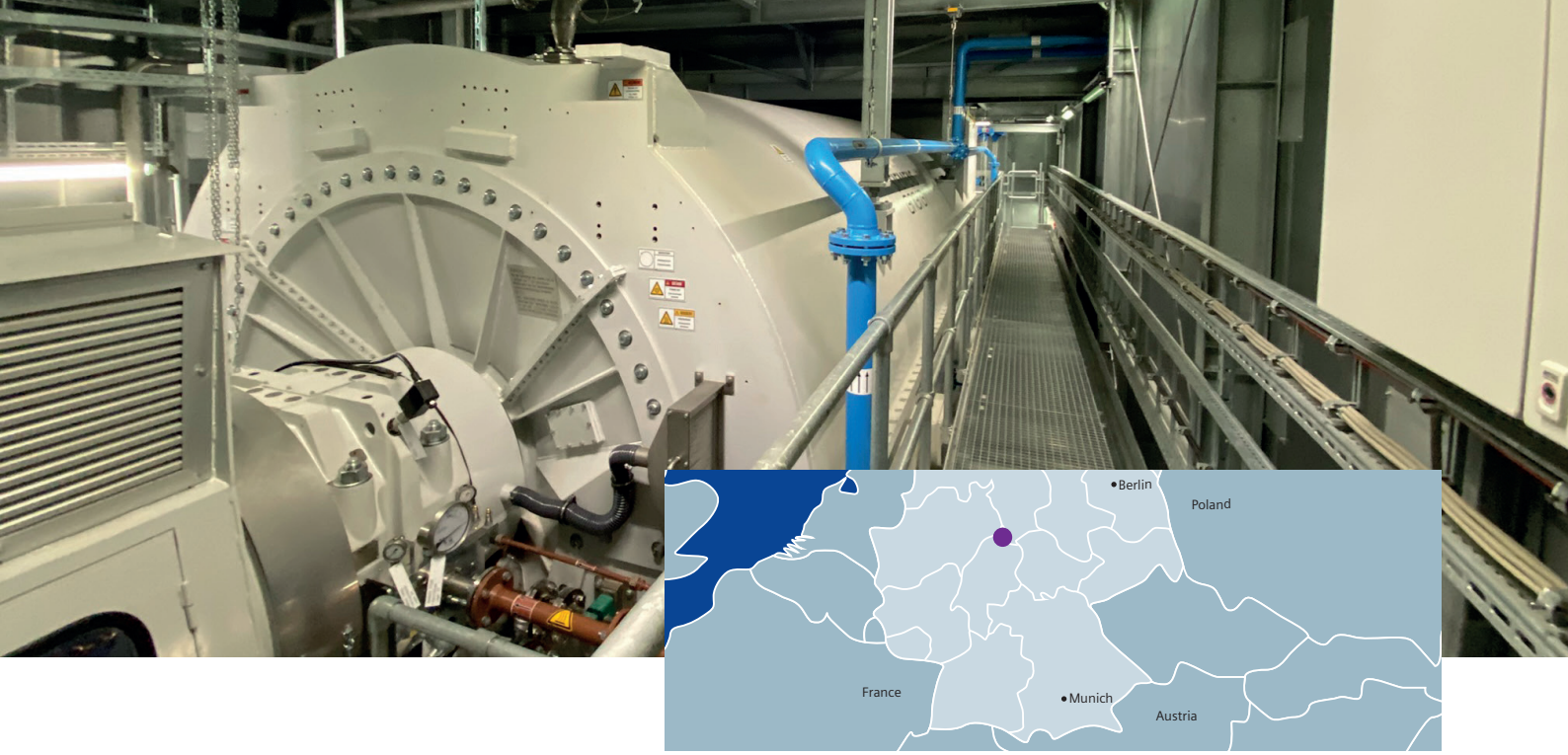
The German-Dutch transmission system operator TenneT has awarded Siemens Energy to install the world's first E-STATCOM with power supply system via supercapacitors. If more and more conventional power plants are taken off the grid and replaced by electricity from renewable energy sources, such plants are necessary.

By far the most onshore wind energy is produced in this location (Lower Saxony). Grid expansion is an important prerequisite for a reliable power supply. The project is scheduled to go into operation in 2025. The required energy is stored in supercapacitors in very compact space, in a way that fluctuations of the grid frequency can be stabilized by charging or discharging of the stored 200 MW capacity.

Tim Holt, Member of the Managing Board at Siemens Energy: "The great strength of the European power grid is its resilience - it guarantees security of supply and thus also prosperity. To ensure that this remains the case in the future, investments in grid stability are extremely important. There is no time to lose, because energy transition does not just mean simply replacing fossil fuels with renewable energies. In the end, the electricity must also reach the consumers' sockets reliably. This is our drive for this project."



Technical data	
Customer	Tennet TSO GmbH
Project name	Mehrum Nord
Location	Germany
Scope	1x SVC PLUS Frequency Stabilizier® 400 kV -300/300 Mvar
Special features	First pilot worldwide, frequency stabilization and voltage support, active power by supercapacitors, emulates inertia very fast, active power input/ output, high power density, reactive power compensation
In service date	2025

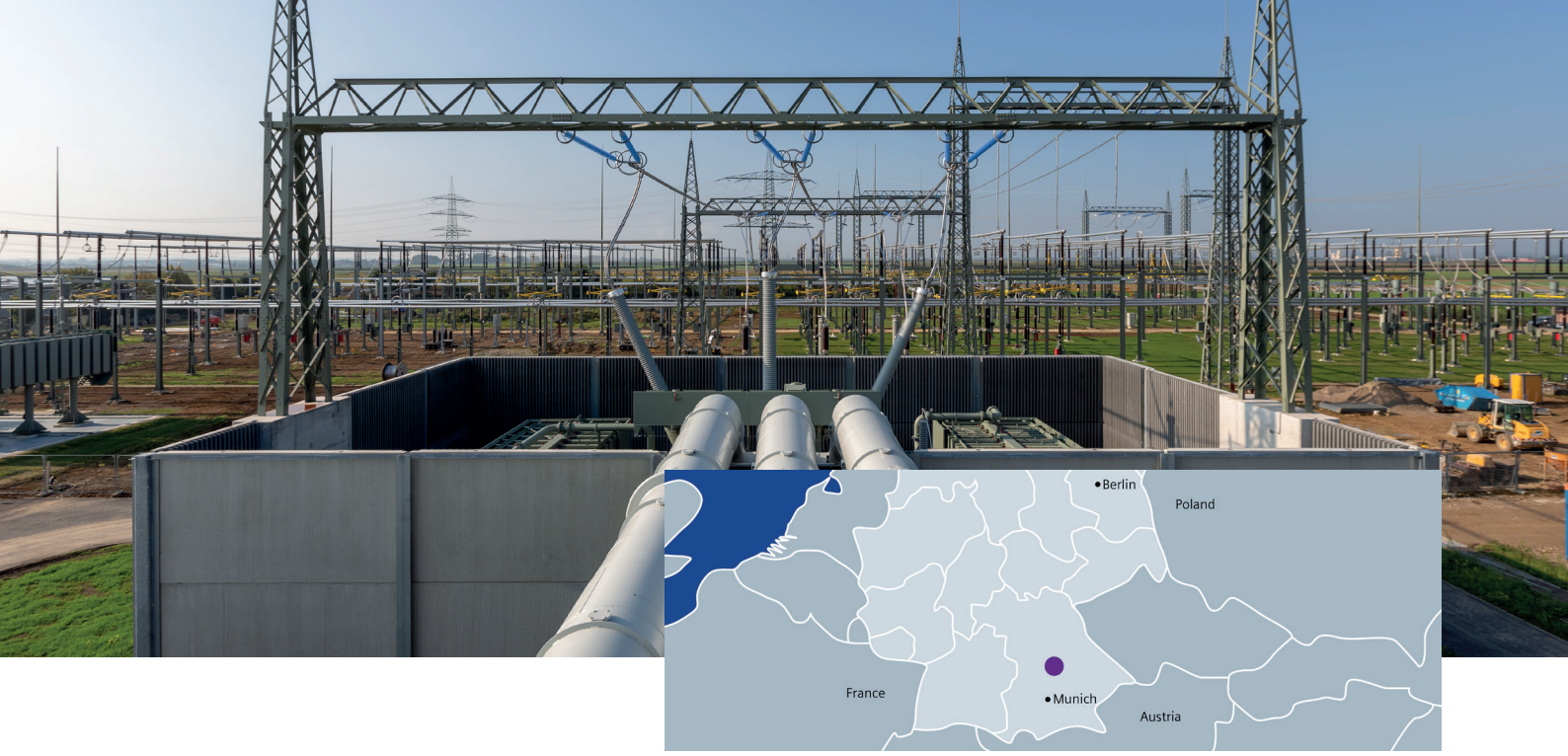


6.6 SynCon – Würgassen, Germany

Keeping its finger on the pulse of the energy transition: Siemens Energy stabilizes German power grid

The German-Dutch grid operator TenneT has placed an order with Siemens Energy to supply three grid stabilization systems for the German power grid. Such plants are necessary because conventional power plants not only generate electricity, but also automatically stabilize the grid (via their physical behavior). As more and more conventional power plants are taken off the grid and replaced by electricity from renewable energy sources as part of the energy transition, transmission system operators will have to find alternative solutions to keep the power grids stable and at the same time transport more electricity. Two of the three systems are synchronous condenser (SynCon): A SynCon essentially consists of a generator and a flywheel. The generator sets the flywheel in rotation. This stores kinetic energy, which can be fed into the grid for stabilization if necessary. TenneT is currently modernizing the substation in Würgassen (North Rhine-Westphalia) in order to make them fit for the energy transition as important grid hubs. Siemens Energy build the rotating phase shifters there.

Technical data	
Customer	TenneT TSO GmbH - DEU
Project name	Rotierende Phasenschieberanlage - RPSA WUER
Location	Würgassen, Germany
Scope	1x SynCon - SGen 5-2000P, 16,5kV / 400 kV, +399 / -261 Mvar
Special features	Largest flywheel connected to generator for additional inertia and short circuit power for system strength
In service date	2025



6.7 SynCon – Oberottmarshausen, Germany

Stabilizing the power grid with reliable rotating phase shifters at Amprion

A central energy hub, the Oberottmarshausen substation distributes electricity to the south of Augsburg. The Dortmund transmission system operator, Amprion, commissioned a synchronous condenser by Siemens Energy for regional voltage maintenance in the power grid. As former large power generators are increasingly taken off the grid, Amprion is building reactive power compensation facilities such as the Rotating Phase Shifter in Oberottmarshausen as primary nodes in the power grid.

Siemens Energy (formerly Siemens AG) was awarded the construction contract for the rotating phase shifter and ancillary equipment at this substation. The shift in the power grid toward decentralized generators predominantly focuses on wind and solar plants. These changes present increasing challenges for long-term grid stability.

The rotating phase shifter can flexibly raise or lower grid voltage, allowing for precise regulation of future voltage in the transmission grid and the subordinate distribution grids. The valuable contribution of large thermal power plants to ongoing grid stabilization will increasingly switch to new technologies such as the rotating phase shifter from Siemens Energy.

Technical data	
Customer	Amprion GmbH
Project name	Oberottmarshausen
Location	Germany
Scope	1x SynCon, -200/+300 Mvar@400 kV
Special features	Provides short circuit power Condition based monitoring Implementation of SGen5-2000P generator
In service date	2018



6.8 SynCon – Moneypoint, Ireland

The biggest flywheel in the world for a stable grid in the era of renewables

The progressive climate targets and the phase out coal put Ireland in a similar situation like other countries. The integration of additional renewable energy needs to be enabled. ESB, the leading Irish utility and owner of the Moneypoint powerplant, is currently working on transforming the site into a green energy hub.

The newly installed Synchronous condenser including the flywheel is designed to use the existing grid connection. If conventional power generation is needed, block 2 of the powerplant will be connected. If additional renewables are available, the synchronous condenser plant will be connected to stabilize the grid instead. Grid Stabilization is needed because the Irish Transmission System Operator Eirgrid is planning to use large wind farms to generate energy.

Since the turbines aren't connected directly to the grid, additional rotating mass is needed to keep the frequency stable. The installed flywheel at Moneypoint is the world's largest flywheel and the solution has a profound increased inertia capability. This allows more renewables to be fed into the Irish grid, because it supplies the same amount of rotation mass, inertia and short-circuit power as a coal turbine.

Technical data	
Customer	ESB generation and trading
Project name	Moneypoint
Location	Ireland
Scope	1x SynCon with flywheel -111/245 Mvar@400 kV, 4000 MWs
Special features	Biggest flywheel in the world
In service date	2023



6.9 SynCon – Püssi, Viru, Kiisa, Estonia

Ensuring voltage and frequency stability in Estonia's grid

The Baltic region is undergoing an energy transition, increasing investments in wind and solar power while integrating with the European grid. To achieve frequency and voltage stability synchronized condensers are used – massive rotors, providing inertia and thus stability to the grid.

Siemens Energy is responsible for design, supply and installation of the three 330 kV synchronous condenser plants, that are located at Püssi, Viru and Kiisa in the north of Estonia. By means of its rotating mass the synchronous condensers provide short-circuit power and inertia for stable operation of the Estonian grid while also providing or absorbing reactive power.
Due to the intermittency and volatile nature of renewable energies grid stabilization technologies play an increasingly important role for a successful energy transition.

SynCons to stabilize the grid are not only necessary for Estonia. In total, six SynCon facilities of this kind are being implemented in Estonia's neighboring countries: Latvia and Luthuania. Siemens Energy is responsible for delivering all the SynCons to these projects.

Technical data	
Customer	Elering
Project name	Püssi, Viru, Kiisa
Location	Ida-Viru & Harju, Estonia
Scope	3x SynCon incl. Flywheel, -50 / 50 Mvar@SynCon Terminal, Turnkey
Special features	Short Circuit Power (900 MVA) and Inertia (1100 MWs) for system strength Flywheel connected to generator, Long Term Service Agreement
In service date	2025



6.10 SynCon – Shannonbridge, Ireland

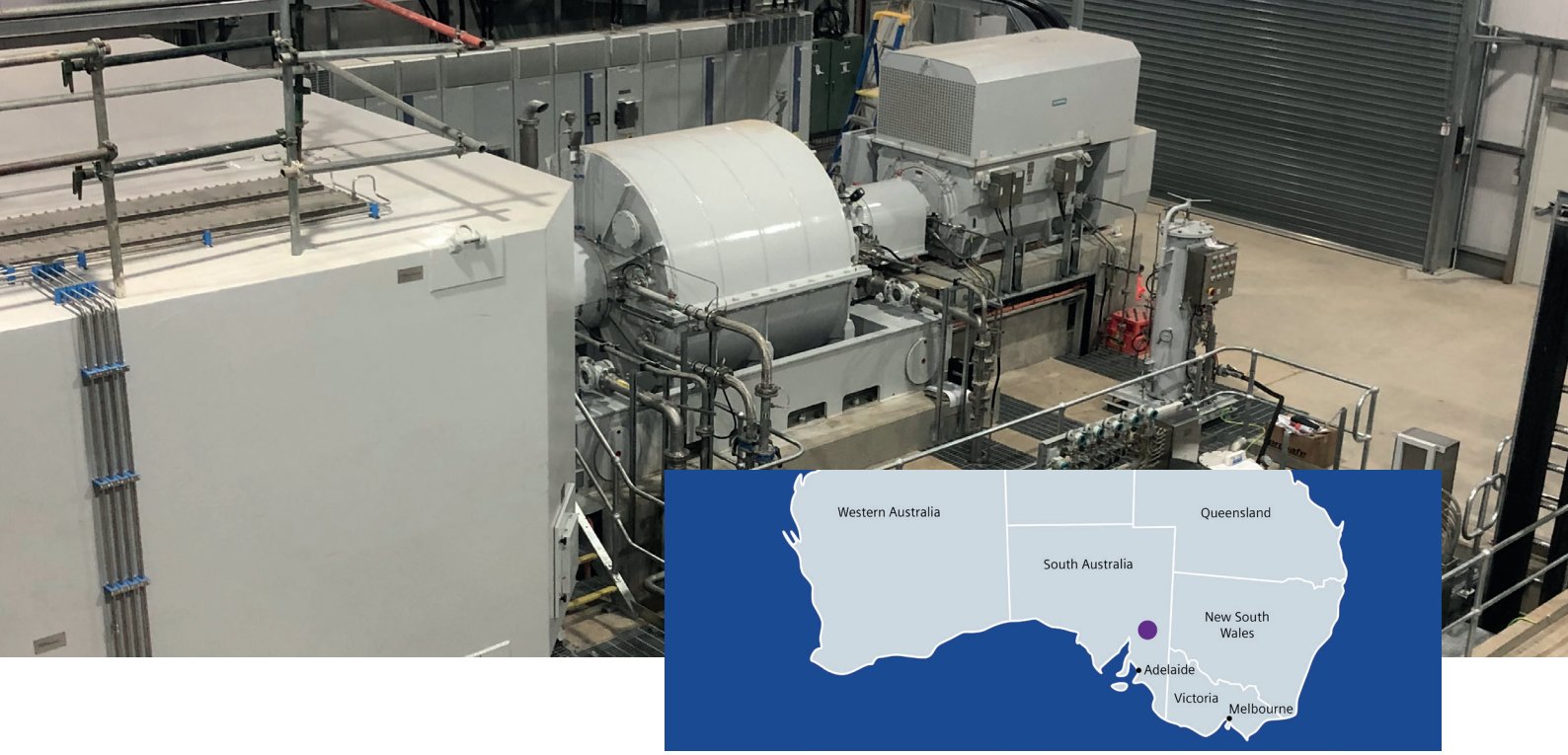
SynCon + BESS: a world premiere for hybrid operation

At Shannonbridge in central Ireland, on a green-field site near the River Shannon and a closed peat-fired power station, a new energy facility is taking shape. 'Shannonbridge B' will combine a large battery energy storage system (BESS) by Siemens Energy with a spinning synchronous condenser unit. For the first time at utility scale, a long-duration battery and a flywheel-based synchronous condenser will work together here, combining fast-reacting energy storage with heavy rotating inertia in one plant.

During operation, if there is a sudden drop in generation, the synchronous condenser's inertia will immediately slow the rate of frequency decline. At the same time, the BESS can quickly discharge to offset the power shortage – the inertial response and battery response together effectively prevent the frequency from dropping further.

This hybrid approach allows the installation to absorb excess wind or solar power and immediately stabilize the grid during sudden drops or spikes in supply, effectively acting as a safety net for Ireland's renewable-heavy power system. As Ireland's grid incorporates more renewables and phases out peat and coal, the 'Shannonbridge B' project illustrates how combining BESS with traditional grid stabilizers can enhance energy security and stability during the transition to clean energy.

Technical data	
Customer	Shannonbridge B Ltd.
Project name	Shannonbridge B
Location	Shannonbridge, Ireland
Scope	1x SynCon, +/-63 Mvar@220 kV, kin. energy 4000 MWs, short circuit contribution: 520 MVA
Special features	Inertia and short circuit power for system strength, hybrid project with 160 MWh BESS at a single grid connection
In service date	2025



6.11 SynCon – Robertstown, Australia

The right momentum for grid stability

South Australian grid operator ElectraNet must deal with over 50% renewable energy in its grid – a formidable challenge for grid stability. The lack of inertia by heavy power turbines can instantaneously bridge sudden frequency drops. To avert the risk of blackouts, ElectraNet equipped its Robertstown substation with two generators with high-tech flywheels.

Synchronous condensers have long stabilized AC grids. Although they do not generate active current, they help balance reactive current, representing a characteristic of AC grids. Due to their large rotating masses, synchronous condensers contribute a reasonable amount of inertia, but many grids need more. The flywheels also multiply the inertia and restore lost inertia in the Australian grid.

Although flywheels mean that synchronous condensers need to draw more current from the grid to remain in rotation, Siemens Energy developers have ensured that power losses for operating flywheels are as low as possible. The flywheels used in Robertstown rotate in a negative pressure close to a perfect vacuum. This innovation reduces frictional heat and energy losses – both would occur even if a surface as smooth as a mirror were turning in the air – by 90 %.

Technical data	
Customer	ElectraNet Ltd.
Project name	Robertstown Substation
Location	Australia, South Australia
Scope	2x Turnkey SynCon incl. Flywheel at 275 kV
Special features	Short circuit power and inertia for system strength Flywheel connected to generator Condition based monitoring
In service date	2021



6.12 FSC – Castanhal, Brazil

Optimizing the transmission line in the Brazilian grid

With a dynamic increase in power generation in the north of Brazil and the need for increased transmission capacity, Siemens Energy was awarded the FSC contract in Castanhal.

The installation of this equipment on the transmission line presented several benefits to the system, customer TPE, and the citizens. Installing the FSC reduced the used space in the substation. Additionally, the project lead time was optimized compared to duplicating the existing transmission line. Lastly, the environmental impact was decreased.

The FSC banks consist of capacitors and their protection devices are installed on the same potential of the transmission line voltage. Therefore, they must be isolated from the ground. For this, the equipment is mounted on a metal platform containing iron, steel, and aluminum structures, supported by insulators dimensioned for the voltage level of the transmission line. Another protection device for the FSC bank is the bypass circuit breaker – the only high-voltage equipment not installed on the platform.

Technical data	
Customer	TPE
Project name	Castanhal
Location	Brazil
Scope	1x FSC, 230 kV, 151 Mvar
Special features	70 % compensation degree
In service date	2012



6.13 FSC – Hirvisuo, Finland

Flexibility in the grid by using fixed series compensation

A significant amount of Finland's power is generated in the north by hydropower plants and wind power. The Finish grid is connected to Sweden and Norway by AC interconnectors in the north. The main challenge of Finland's grid operator, Fingrid, is to transport a large amount of energy from the north to the south, where most of the power is consumed.

To tackle this challenge, Fingrid upgraded their Rannikkolinja line (coastal line) from Turku to Oulu from 220 kV to 400 kV. Since studies show that system limits are defined by voltage stability and not thermal overload, fixed series compensation is the optimal solution. This technology applies capacitive reactive power and compensates for the inductive portion of transmission losses. The alternative would be a newly built line, but the investment cost, environmental impact, project complexity, and feasibility are all considerably lower in fixed series compensation.

Technical data	
Customer	Fingrid Oyi
Project name	Hirvisuo
Location	Finland
Scope	2x Turnkey FSC, 400 kV, 160 Mvar, and 232 Mvar
Special features	Tailored to ambitioned climate conditions
In service date	2016



6.14 FSC – Polpaico, Chile

Reliability in a high seismic area

Chile's energy transition strategy has evolved in recent years. Their goal is to convert 70 % of their total energy consumption to renewables by 2030 and pledged to become carbon neutral by 2050. In Polpacio, Siemens Energy Fixed Series Capacitors (FSC) help to improve their transmission capacity and system transient stability. Instead of building new lines to provide sufficient transmission capacity, it's often better to use our Flexible AC Transmission Systems (FACTS) technology.

Since the FSC is connected in series to the transmission line, all the equipment is installed at a steel platform at the same voltage level of the grid – in this case, 500 kV. For safety reasons, the platform needed to be isolated from the ground level with post insulators of the corresponding voltage level, which withstands the weight of all equipment.

The solution has a specific design called V-Shape, which reduces the number of foundations and insulators needed. Additionally, the project is located in a high seismic area. Due to these conditions, it became even more of a challenge by increasing the design complexity and site works requirements to assure that the steel platform would withstand the strongest force and influence conditions of this

Technical data	
Customer	ISA Interchile
Project name	DS422 Project
Location	Polpaico
Scope	2x FSC 550 kV 336,4 Mvar
Special features	High seismic design, Industry application
In service date	2020

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