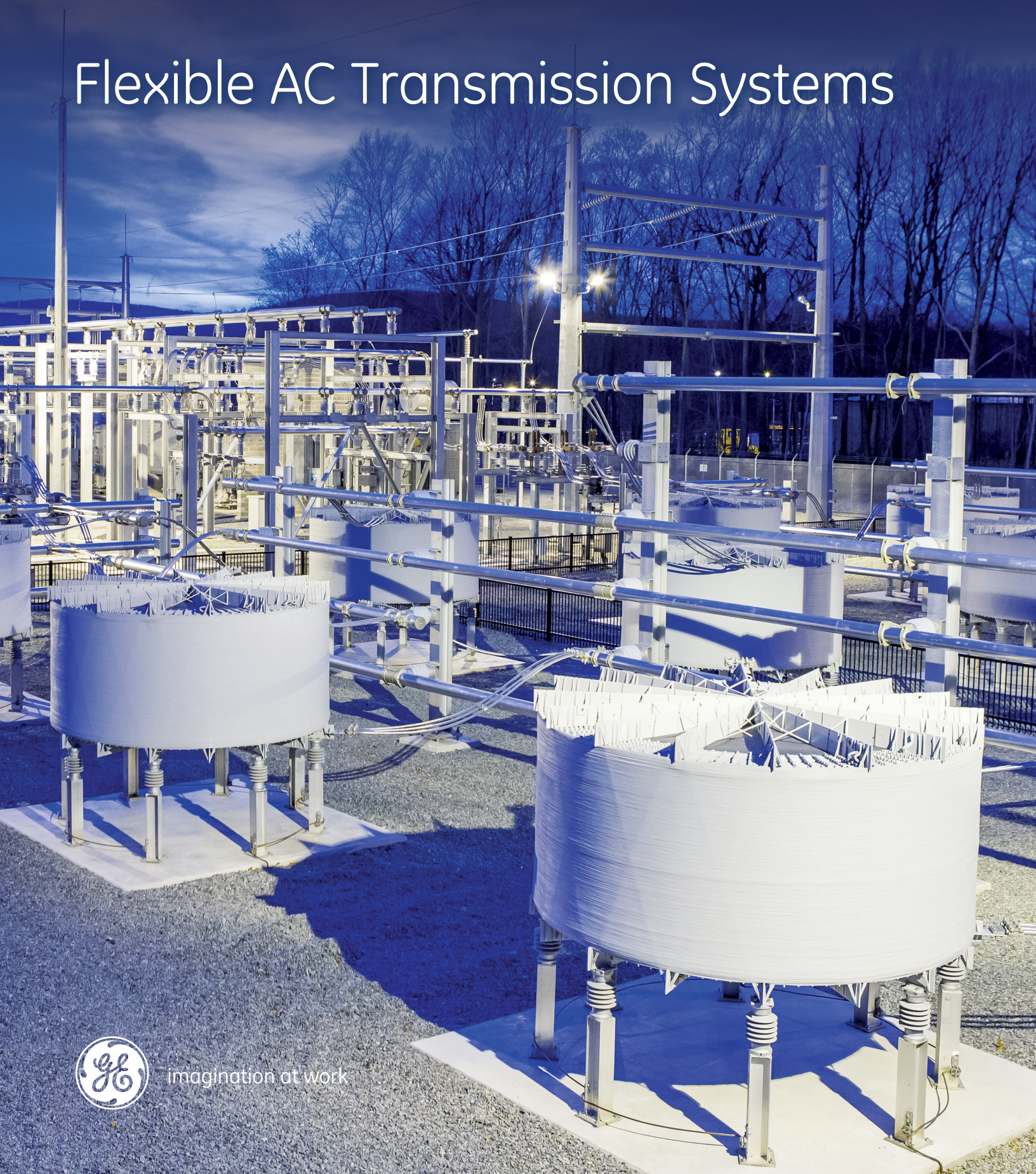


GE
Grid Solutions

Flexible AC Transmission Systems



imagination at work

Increasing Demands on Transmission Grids

Today's transmission grid is changing and becoming more complex to manage. Utilities globally are experiencing challenges such as:

- Increase in global demand for electricity
- Thermal plant retirements coupled with an increase in renewable generation, often remote from load centers
- Stringent requirements by regulatory authorities on power quality
- Interconnected grids
- Aging transmission infrastructure

These challenges can make power flow stability more complex for network operators as they manage stability issues under fault clearing and post-fault conditions.

The increase in demand and renewables combined with aging infrastructure can cause voltage on the grid to fluctuate, including harmonics, flicker phenomena, unbalanced loads and power oscillation which can impact power quality and power transfer capability.

The solutions that the utility customers are now looking for are more technically sophisticated than in the past, including networked solutions to wide area networks and hybrid Flexible AC Transmission Systems (FACTS) solutions. Today's grid challenges are complex and demand significant engineering analysis and studies to ensure the right solution is being put in place.

750GW

750GW OF WORLDWIDE COAL-FIRED CAPACITY RETIRING BY 2030

27GW

27GW OF U.S. COAL-FIRED GENERATION TO RETIRE OVER THE NEXT 5 YEARS

35,000TWh

BY 2035 WORLD ELECTRICITY DEMAND WILL INCREASE TO 35,000TWH

130,000Mvar

NEARLY 130,000MVAR OF SERIES COMPENSATION INSTALLED GLOBALLY

400

NEARLY 400 POWER ELECTRONICS SHUNT COMPENSATION SYSTEMS INSTALLED GLOBALLY

200+

200+ SYNCHRONOUS CONDENSER INSTALLATIONS WORLDWIDE



GE Flexible AC Transmission Solutions (FACTS)

GE provides solutions that offer grid operators the ability to provide reactive power support, enhance controllability, improve stability and increase power transfer capabilities of AC transmission systems. GE's portfolio includes power electronic based technology as well as more traditional electro-mechanical solutions, which utility operators have become increasingly interested in because of their grid friendly and reliable nature. Solution offerings include:



STATIC SYNCHRONOUS COMPENSATOR (STATCOM)

GE's utility grade Static Synchronous Compensator solution is a custom designed system for installations on transmission grids. It provides grid operators with reactive power compensation and improved range of operational voltage with faster response times and a reduced footprint.



STATIC VAR COMPENSATOR (SVC)

GE's Static Var Compensator solutions are a cost-effective and efficient means to provide dynamic voltage support and maintain the reliability and efficiency of the transmission grid. These solutions are highly reliable, easy to integrate into both existing and new infrastructures, and reduce the investment required for building new network extensions.



SERIES COMPENSATION SYSTEM

GE's Series Compensation System allows utilities to cost effectively increase the power transfer capabilities of their existing infrastructure and new transmission lines. GE's systems are the most installed series compensation solution in the world, which is a result of our advanced technology, our robust capacitor designs, the fastest protection system available and high reliability.



SYNCHRONOUS CONDENSER

GE's Synchronous Condenser Systems are engineered and designed to provide a highly reliable and efficient solution to address reactive compensation and voltage support requirements, providing transmission operators an optimized solution for cost, performance and operational flexibility.

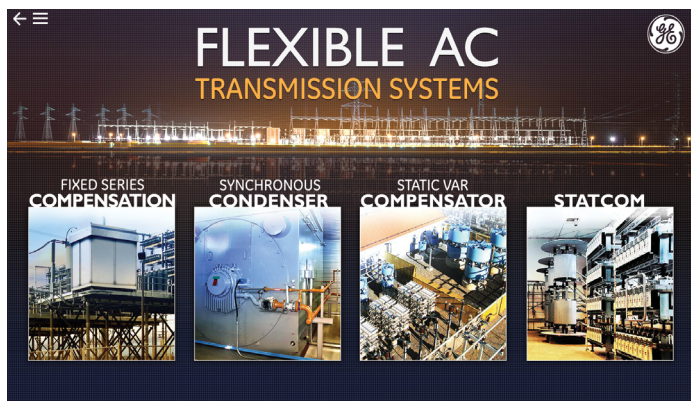
Identify the right problem ... Selecting the right technology

The transmission grid has become a very sophisticated network of sophisticated loads, distributed generation and intermittent renewables. Couple this with an ever changing mix of generation and de-commissioning of baseload coal generation facilities and these technical challenges of the transmission grid become very difficult to solve.

Transient conditions, voltage collapse, inertia, short circuit strength, oscillations and harmonics are just a few of the issues that utility planners must understand. Once these challenges are vetted out and identified, the next challenge is to determine which technology is best suited to solve the current problem, and to some extent, be flexible enough to handle anticipated future problems. This is a question that GE often gets asked - "Which Flexible AC Transmission Systems (FACTS) technology is the right solution for my problem?".

Given GE's broad solution portfolio, it puts GE in a unique position to be able to objectively evaluate the technical issues and recommend the technology solution that best solves the customers problem, as opposed to trying to make a suboptimal solution fit because it's the only solution available.

GE has developed a number of tools available for customers to assist them in evaluating their specific problems and to identify the right technical solution based on their needs. These tools range from a web-based application that allows a customer to input their prioritized technical and commercial constraints, to more sophisticated modeling exercises that GE's Energy Consulting group would perform while engaging with the customer. In either case, the solutions can be validated with actual machine models that can be downloaded and run in the customers simulation environment to confirm problem resolution.



Static Synchronous Compensator (STATCOM)

GE's STATCOM solution leverages Voltage-Source Converter (VSC) technology based on Modular Multilevel Converter (MMC) architecture, from GE's robust High Voltage Direct Current (HVDC) design. The solution is an open-rack structure, where the valve is located inside a building making the accessibility and any required maintenance significantly easier than containerized solutions.

The uniqueness of GE's solution is the larger DC capacitance, re-usable by-pass switch and the industry's leading Model-Based Design STATCOM control platform which is uniquely designed for our STATCOM and SVC platforms. Utilizing highly dynamic VSC based compensators, the STATCOM solution provides superior undervoltage performance and robust recovery support under severe system disturbances and provides a smaller footprint.

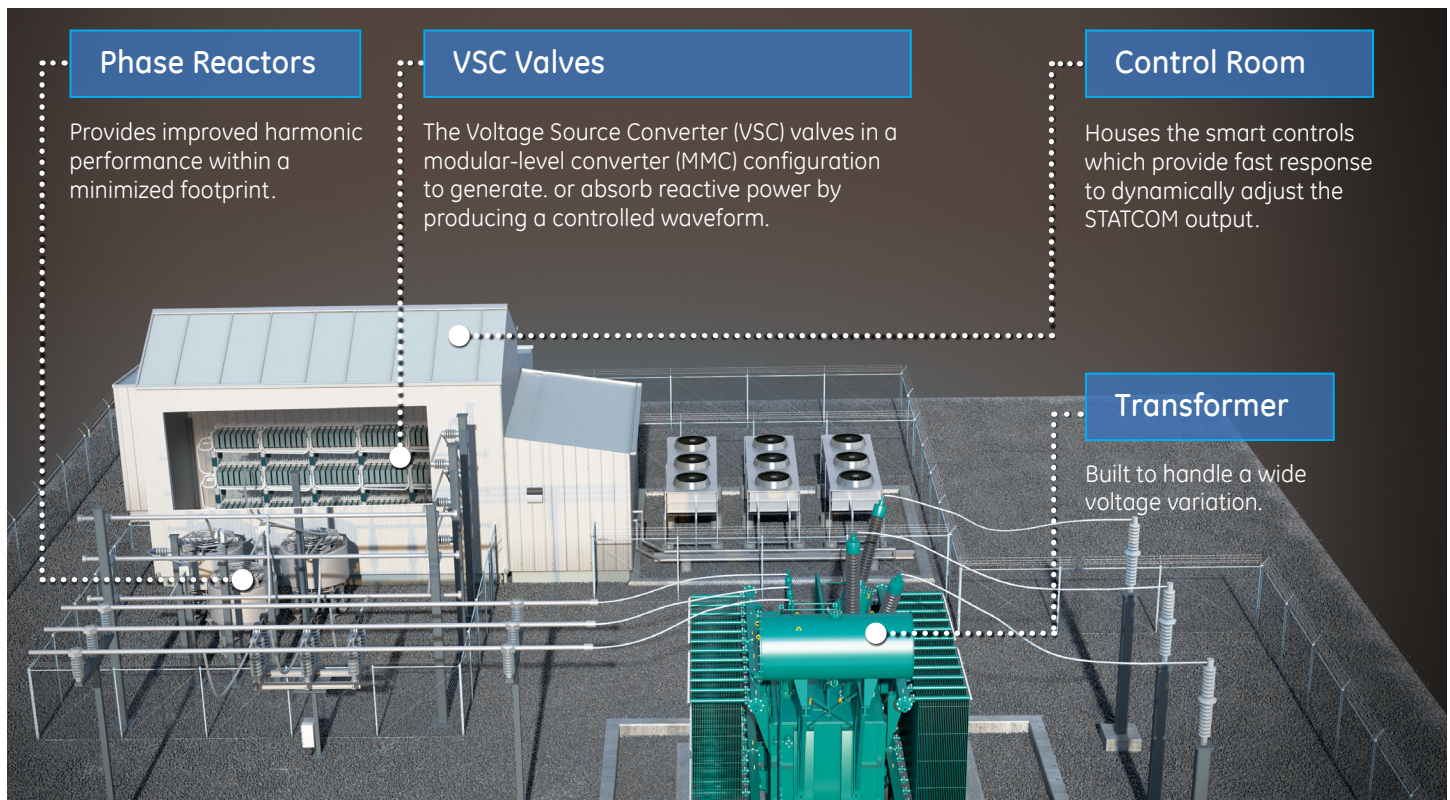
The relatively low frequency switching of the Insulated Gate Bipolar Transistor (IGBT) provides the performance of high frequency switching when used in a modular multi-level configuration, while maintaining low power losses. This switching may result in distortion at the switching frequency which can be mitigated with a High Frequency (HF) Filter. The amount of distortion is not always significant, which means the HF Filter is an optional configuration.

Strong support exists in the marketplace for GE's technology and our project execution capability. Reinforcing this point, GE has recently been awarded the largest STATCOM project in Europe. The project involves 3 different substations which act in a coordinated fashion to support a critical HVDC link.

Key Benefits

- Most commonly connected to High Voltage (HV) grids via a step down power transformer
- Always a symmetrical power rating in the inductive and capacitive operating regions
- Hybrid STATCOM solutions available for increased power rating including:
 - Thyristor Switched Components,
 - Mechanically Switched components or Static Var Compensator (SVC)
- Reduced footprint

Typical STATCOM System and Main Components



The GE Advantage

GE's latest STATCOM solution leverages and builds upon GE's global history of voltage-sourced converter technology and robust HVDC valve design. GE provides an extensive portfolio of feasibility and network studies, project management skills, engineering capabilities, equipment, installation services and long term maintenance contracts, delivering an integrated and robust system providing utilities with the following competitive advantages:

Industry's only Model-Based Design Control System minimizes project risk and ensures optimal and accurate performance by direct deployment into the system software

- Model based design provides rapid technical responsiveness to the customer, from planning support and project execution to commissioning.
- Intuitive graphical interface provides fast, automatic, and error free code generation from control models, ensuring a greater level of confidence to the customer.
- Ease of integration to Control System software with Power System modelling tools such as PSCAD, providing the most accurate representation of system performance for planning and troubleshooting analysis.
- Advanced Digital Control based on open VPX offers future-proof higher control execution speed with higher controller-internal (backplane) data rates, and scale up without sacrificing speed.
- Supported components/technologies are the same state-of-the art used in commercial applications – with wider knowledge community, support, documentation. The physical size of VPX rack is half the size of the VME.

System Flexibility to Ensure Optimized Performance

- Open rack structure including unique modular valve design that facilitates a safe and clean maintenance environment, including individual access to control cards, DC capacitors and rechargeable bypass switch providing easier access and higher availability than containerized solutions.
- Based on large scale HVDC VSC valve design principles and standards, utilizing the most advanced MMC architecture with system redundancy through the valve, cooling system, P&C and passive optical network communication system.
- DC capacitor, which includes both a pressure switch and relief valve for safety, is rated 2 to 3 times more than competitive offerings, leading to much improved system performance during transient events and fault ride through capacity.

Manufacturing Excellence and Deep Domain Technical Expertise providing full system lifecycle support resulting in simplified and streamlined commercial offerings

- Over 50 years' experience with over 380 global shunt compensation installations, including 20 STATCOM references, ranging from small industrial to large utility projects, in diverse applications and extreme environmental conditions.
- GE supports the entire value chain with a full range of competencies, eliminating project and logistical complexities of multiple vendor projects.
- Valves are produced in our state-of-the-art HVDC facility that is specifically designed for manufacturing and testing of VSC technology.
- All major STATCOM components are vertically integrated within advanced manufacturing facilities, certified to ISO 9001:2015 Environmental Standards, ISO 4001 and OHSAS 18001.

Hybrid STATCOM Solution



Static Var Compensator (SVC)

GE's Static Var Compensator (SVC) solution allows grid operators to gain accurate control of reactive network power, increase power transfer capabilities and improve steady-state and dynamic stability of the grid.

SVC's control transmission line voltage to compensate for reactive power balance by absorbing inductive reactive power when voltage is too high and generating capacitive reactive power when voltage is too low. SVC systems are particularly effective in solving applications where overvoltages occur due to transients and recovering from faults.

Compared to the investment required for additional transmission networks, SVC provides customers with a flexible solution that has minimal infrastructure investment, low environmental impact, rapid implementation time and improved return on investment.

Leveraging design best practices with the GE Store, GE's power electronics scope is one of the largest in the industry serving both utility and industrial customers. The fundamental building blocks in GE's SVC solution, such as thyristor valves, cooling schemes and control systems, are jointly developed and shared with GE's High Voltage Direct Current (HVDC) designs so that all of the solutions benefit from the best practices that have been generated from over 50 years of experience in these technologies.

GE provides a broad range of SVC configurations, including classic design and Patented Main Reactor design which are customized based on the utility's key requirements for system performance. Every system is tested extensively during factory acceptance testing and site commissioning to guaranteed performance.

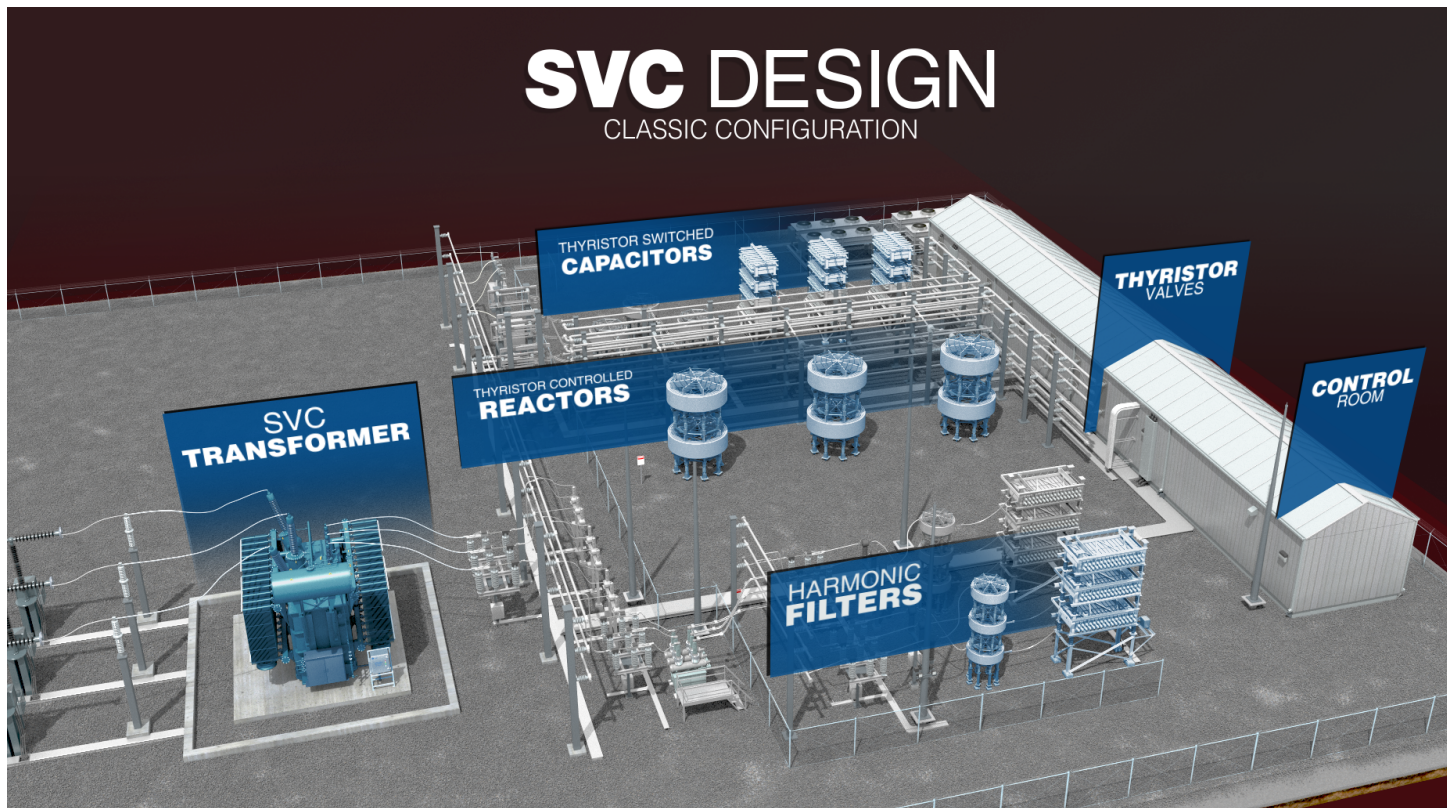
Benefits of the classic SVC design include:

- Allows grid operators to gain accurate control of network reactive power and voltage
- Increases power transfer capability
- Improves steady-state and dynamic stability of the grid

Traditionally, the SVC medium voltage bus is connected directly to the SVC coupling transformer, but with the main reactor configuration there is a reactor connected between SVC bus and coupling transformer. The Main Reactor concept efficiently isolates harmonics, even in demanding network conditions. This design requires fewer harmonic filters enabling a compact, optimized SVC layout. The Main Reactor has many other inherent benefits for improved harmonics, simpler design and cost savings, including:

- Main Reactor blocks harmonics generated by the SVC
- Lower amount of filtering is needed
- Improved harmonic distortion at the Point of Common Coupling
- Less harmonic stress on the SVC coupling transformer
- Lower voltage stress on all components
- Minimized requirement for Thyristor Switched Capacitors (TSC), potentially eliminated
- Thyristor Controlled Reactors (TCR) has smaller coils, lower losses and reduced number of thyristor valve levels
- Only low order filters are needed (reactor blocks high order), wide filtering band can be used

Typical SVC System and Main Components



The GE Advantage

GE's SVC solutions are customized based on the utility's technical and economic requirements for their network such as fault level and load parameters. GE provides one of the broadest range of SVC configurations with two types of SVC design - Classic and Patented Main Reactor. GE provides an extensive services portfolio comprised of feasibility and network studies, project management, engineering capabilities, equipment, installation services and long term maintenance contracts, delivering an integrated and robust system that provides utilities with the following competitive advantages.

Model Based Design Control System Ensures Optimal and Accurate Performance of the SVC by Direct Deployment into the System Software

- Rapid technical responsiveness to the customer, from planning support and project execution to commissioning.
- Intuitive graphical interface provides fast, automatic, and error free code generation from control models, ensuring a greater level of confidence to the customer.
- Ease of integration into control system software with power system modelling tools such as PSCAD provides an accurate representation of system performance for planning and transients analysis.
- Modular hardware design based on commercial off-the-shelf components which provide extensive scalability to any project rating, while maintaining quick system delivery time and simple life-cycle management.

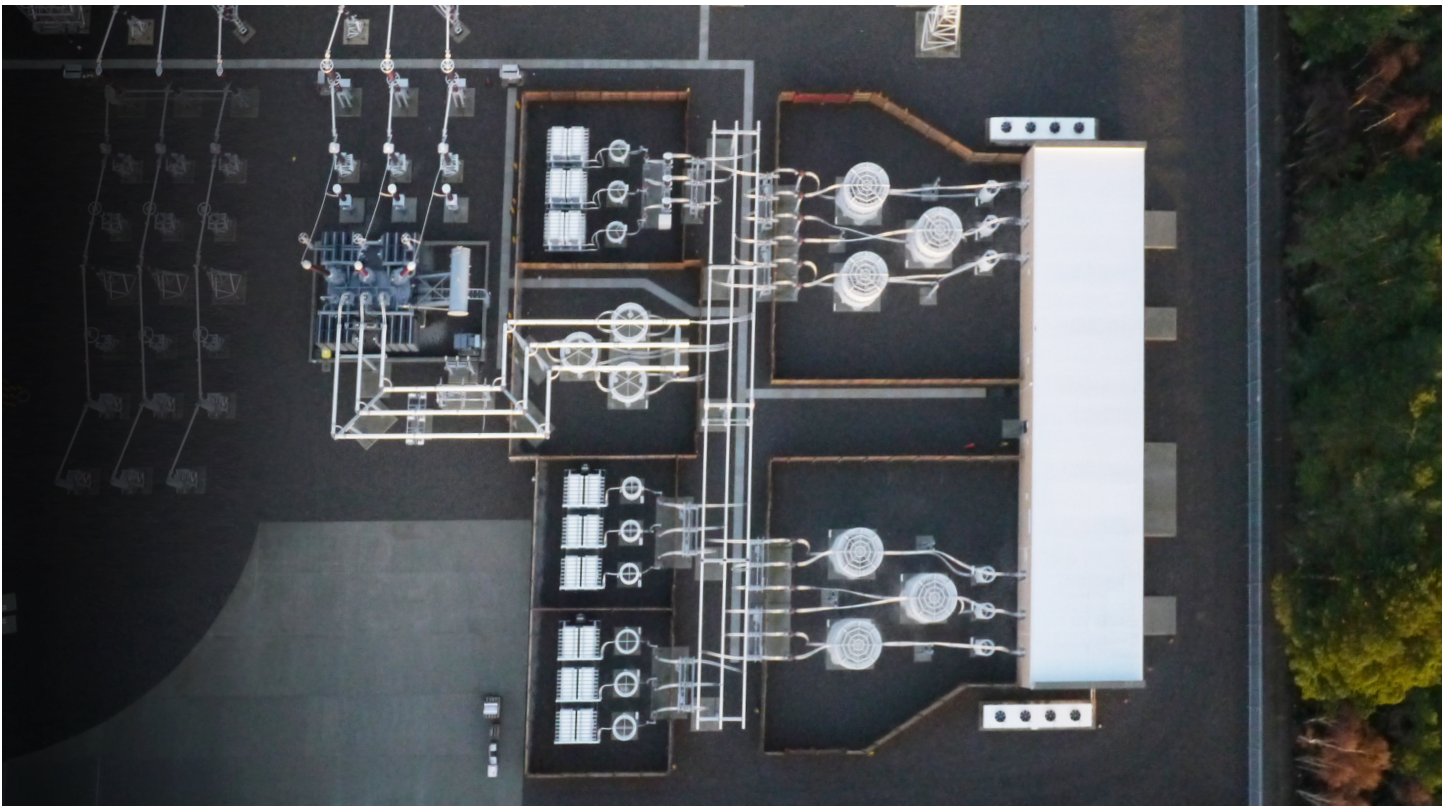
Classic SVC and GE's Patented Main Reactor SVC Provides More Design Flexibility to Ensure Optimized System Performance

- Broad range of SVC configurations including: classic, hybrid, Main Reactor, fixed, modular, relocatable, low noise, and reduced footprint designs
- Ground level power to the thyristor valves provide system voltage independency and benefits operation at very low voltages, increasing SVC readiness during severe system events
- Unique Main Reactor configuration improves harmonic performance, reduces operational losses and design footprint, and ensures regulatory compliance at the point of interconnection

Manufacturing Excellence and Deep Domain Technical Expertise Providing Full System Lifecycle Support Resulting in Simplified and Streamlined Commercial Offerings

- More than 50 years' experience on more than 360 global installations ranging from small industrial to large utility projects, in diverse applications and extreme environmental conditions
- Full range of lifecycle support competencies including network analysis, system design, engineering, procurement, civil works, installation, testing and commissioning and asset management, eliminating project and logistical complexities of multiple vendor projects
- SVC main components are vertically integrated within GE's advanced manufacturing facilities, which are certified to ISO 9001, ISO 14001 Environmental Standards and OHSAS 18001

Main Reactor SVC design



Series Compensation

GE installs Series Compensation Systems in existing and new substations. They may be installed where transmission lines end or at mid-line locations within the established right-of-way boundaries.

Included in GE's Series Compensation System are the following components:

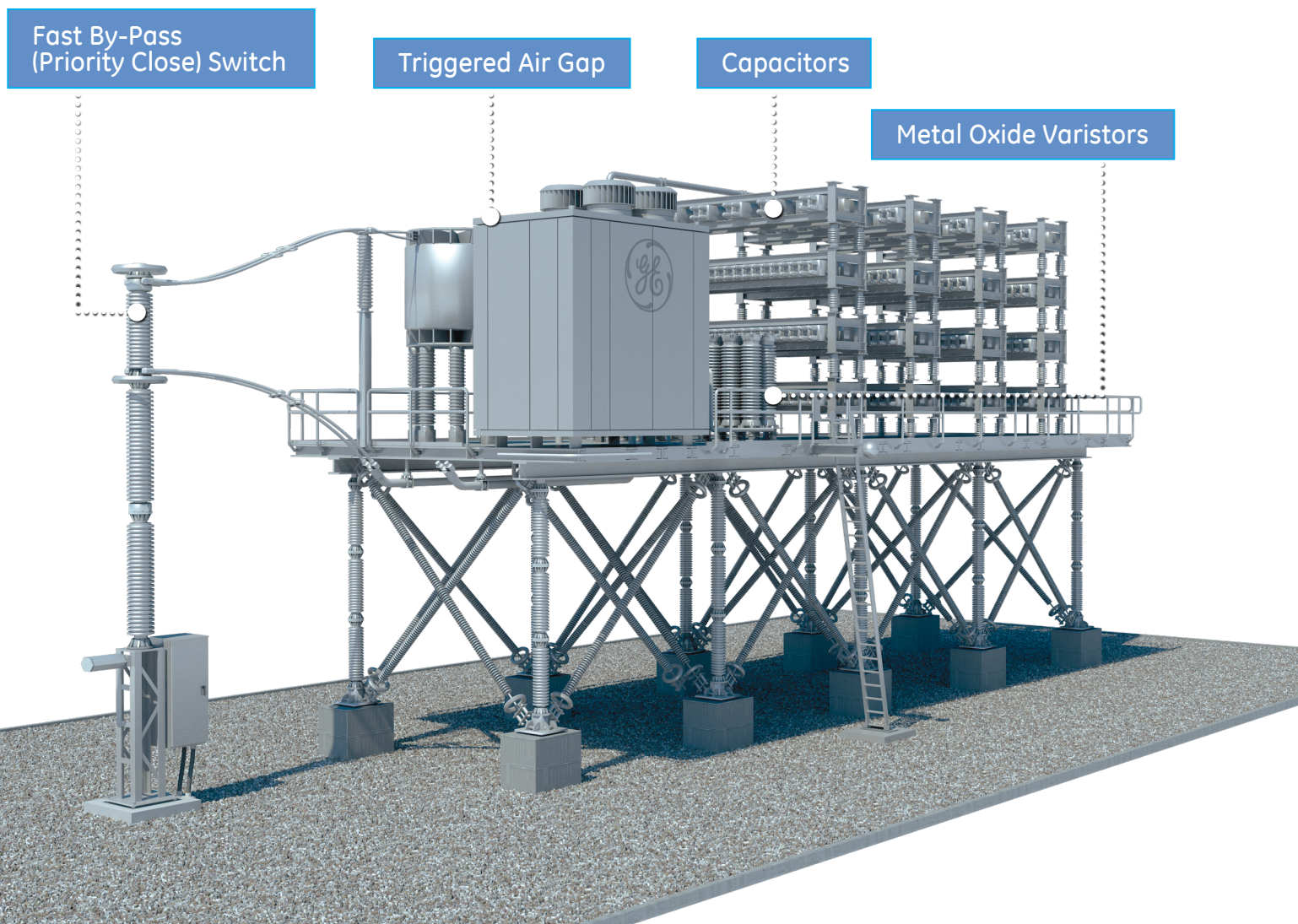
- **Capacitors:** May be fuseless, internally fused or externally fused.
- **Metal Oxide Varistor (MOV):** The MOV is connected in parallel with the capacitors and are used to limit capacitor voltage (the Protective Level Voltage) to protect the capacitors from overvoltage during system faults.
- **Triggered Air Gap (TAG):** If used, the TAG conducts to limit the energy absorbed by the MOV.
- **Discharge Damping Circuit:** Most commonly consists of a reactor only, but may also include non-linear resistors, and is used to limit capacitor discharge current.
- **Fast By-Pass Switch:** This switch closes rapidly to limit both MOV and TAG energy, removing the series capacitors from service. This switch is also used for normal switching to insert the series capacitors or bypass them. External motor operated switches are used to isolate the series capacitor bank.

- **Digital Protection and Control System:** Each three-phase bank is equipped with a fully redundant protection and control system with Human Machine Interface (HMI) and Digital Fault Recorder (DFR) capabilities per project requirements. The protection & control system is a critical component of the fast protective system and also monitors the health of all components.

Key Benefits

- Improves voltage profile and provides voltage support for long HVAC transmission lines by introducing capacitance in the line
- Reduces transmission bottlenecks, increases power flow and improves power system stability by reducing the line impedance
- As power system stability is improved, additional power transfer capability is available during a transient event, when needed the most
- Minimizes land requirements needed for system installation resulting in a lower cost solution
- Lowers environmental impact by eliminating the need for new infrastructure
- Increases short-circuit strength on the receiving end

Components of a Series Capacitor Bank



The GE Advantage

GE's Series Compensation System allows utilities to cost effectively increase power transfer capabilities of their existing infrastructure and new transmission lines. GE offers an extensive portfolio of project management skills, engineering capabilities, equipment, and installation services, delivering an integrated and robust system. GE's scope of work can be tailored to match the project requirements and may vary from a simple Engineered Equipment Package (EEP) through an extensive Engineer, Procure, and Construct (EPC) project, often including work beyond the series compensation system.

Extensive Global and Unmatched Technical Experience, GE is a Worldwide Leader in Executing and Delivering Series Compensation Projects in a Broad Range of Utility Environments Resulting in Reduced Implementation risk

- More than a century of experience designing transmission networks, including the first series compensation project in 1928
- Leading the industry by delivering nearly 40,000Mvars of series compensation systems since 2012
- 350+ systems installed globally, more than any other competitor

Providing Superior Systems Enabled by GE's Innovate Products Results in Project Cost Savings and Increased Quality and Reliability

- Fastest Triggered Air Gap (TAG) available in the industry
- Newly patented TAG and Platform Damping Technologies
- Pioneered the use of SSR filter technology in a series capacitor system

Best-in-Class Quality and Process Standards Utilizing GE's Industry Leading and Well-Established Set of Project Management Processes and Procedures, Certified to ISO® 9001 Standards, Resulting in On-Time and On-Budget Execution

- 99% record of on-time project completion
- Greater than 98% on-budget execution

Three Phase Series Compensation with TAG



Synchronous Condenser

GE offers transmission utilities a simple and reliable solution to address reactive compensation and voltage support requirements. GE's newly re-designed motor based Synchronous Condensers are custom designed to provide transmission operators with a proven, robust and reliable solution. GE's Synchronous Condensers are modular and rated for any range up to 100Mvar per machine. The solution can provide both steady state and dynamic support to the power system efficiently. GE machines can be easily combined in two (2) or three (3) unit systems to offer utilities reliability benefits, ease of maintenance and operational flexibility.

GE's Synchronous Condenser systems are tailored to meet the specific requirements of each application. GE's project engineering team has a broad spectrum of design disciplines and depth of experience, and works to ensure that each system design fully meets the specific requirements of the application.

Provided either as an Engineered Equipment Package (EEP) or an Engineer Procure Construct (EPC) solution that includes the system studies, design and engineering, installation, commissioning and services, each synchronous condenser project is assigned an experienced and dedicated project team. This team is identified and involved from the project kick-off through commissioning to ensure project execution excellence.

GE Synchronous Condenser Overview

Ratings: Range from 10 to 100Mvar per machine

Rotor: Solid Salient

Pole: Poles 4 or 6

Excitation: Static or Brushless

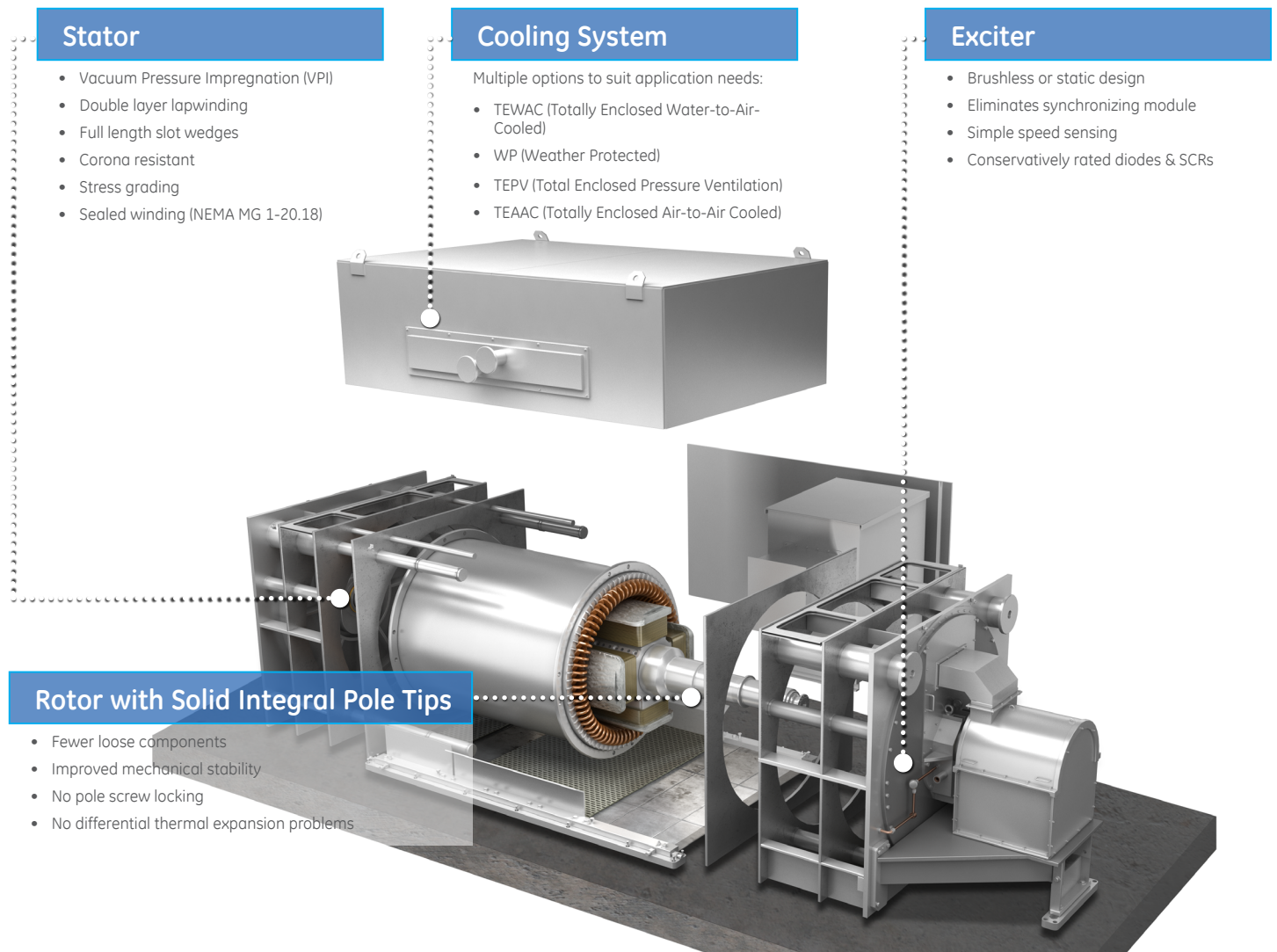
Starting: Full Voltage, Reduced Voltage, Reactor start, Pony Motor

Cooling: TEWAC, TEAAC, WP, TEPV

Synchronous Condenser Machine Main Components

Innovative Design

GE's Synchronous Condenser system consists of components commonly used in electric utilities and industrial facilities, with proven robustness and reliability.



The GE Advantage

GE's Synchronous Condenser Systems are engineered and designed to provide a highly reliable and efficient solution, providing an optimized solution for cost, performance and operational flexibility.

Modular Design Resulting in Operational Flexibility and Decreased Down Time

- GE has combined multiple synchronous condenser machines into systems that allow for reduced overall footprint, customize Mvar ratings and maintenance flexibility for utilities to reduce operational downtime.
- Robust design with extended life resulting in minimal maintenance, GE's synchronous condensers have superior construction, resulting in high efficiency, reliability, and provide easy access for routine maintenance and low vibration for a long life.

Robust Design with Extended Life Resulting in Minimal Maintenance

- GE's synchronous condensers have superior construction, resulting in high efficiency, reliability, and provide easy access for routine maintenance and low vibration for a long life.

Customized Design and Use of Innovative Technology Resulting in Increased Reliability and Reduced Risk of Failure

- Unique forged integral pole tip design well suited to high load inertia applications. Low mechanical stress is achieved through:
 - Fewer loose components
 - Improved mechanical stability
 - Reduced hot spots during starting
 - No pole screw locking concerns
 - No differential thermal expansion problems
 - Proven experience including the world's largest 1,800rpm motor

Extensive Experience Resulting in Seamless Integration into the Utility Transmission Grid

- GE leads the industry with more than 100 years of experience and the proven synchronous condenser design has been applied in over 200 applications.

Typical Multiple Machine Configuration



For more information about
GE's FACTS solution, visit
GEGridSolutions.com/facts.htm



GE
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