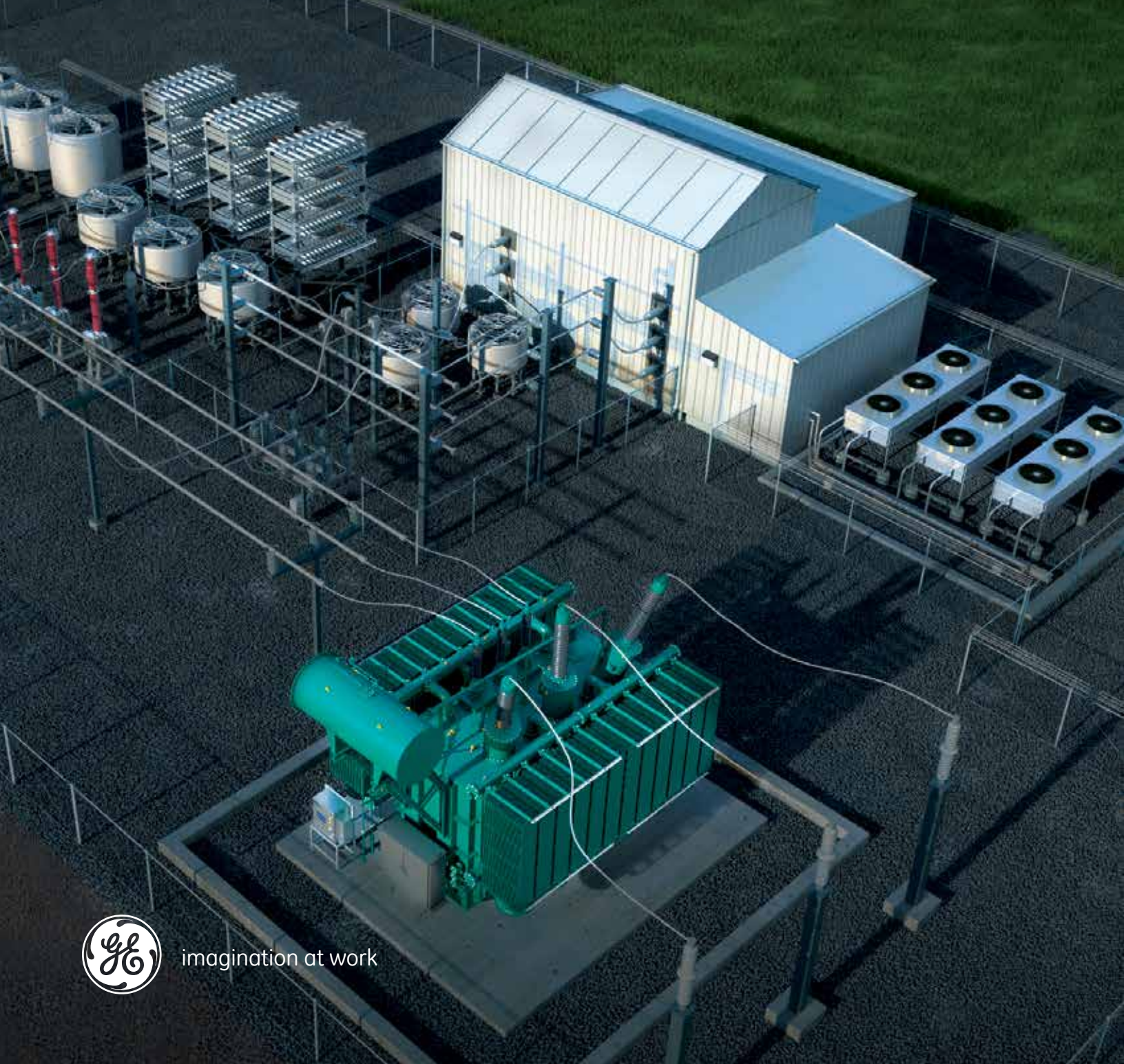


GE
Grid Solutions

Static Synchronous Compensator (STATCOM) Solutions



imagination at work

Today's Environment

Today's transmission grid is changing and becoming more complex to manage, utilities globally are experiencing grid 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 to manage with stability issues under fault clearing and post-fault conditions.

The increase in load demand and renewable integration combined with aging infrastructure can cause voltage on the grid to fluctuate. The grid is also experiencing other issues including harmonics, flicker phenomena, unbalanced loads and power oscillations which can impact power quality and power transfer capability.

Additionally, the ability to implement a more flexible solution is highly desired as utilities today are facing a highly dynamic grid, which requires solutions that can accommodate more drastic changes than in the past.

GE's Solution

GE's utility grade Static Synchronous Compensator (STATCOM) solution is a custom designed system to be installed on transmission grids. It provides grid operators with reactive power compensation and improved range of operational voltage with a faster response time and a smaller footprint than traditional Static Var Compensator (SVC) solutions.

A shunt connected STATCOM system is able to generate capacitive or inductive output current independent of the AC system voltage. STATCOM solutions can help utilities achieve the following:

Increase system stability and power quality by providing:

- Voltage control and support
- Reactive power control
- Power oscillation damping
- Power transfer capacity increase

Grid code compliant renewable integration by providing:

- Fault ride through support
- Voltage control and support



Did you know 

GE introduced the world's first chain link power electronics technology in 1997 adopted by all suppliers

GE's STATCOM Solution

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.

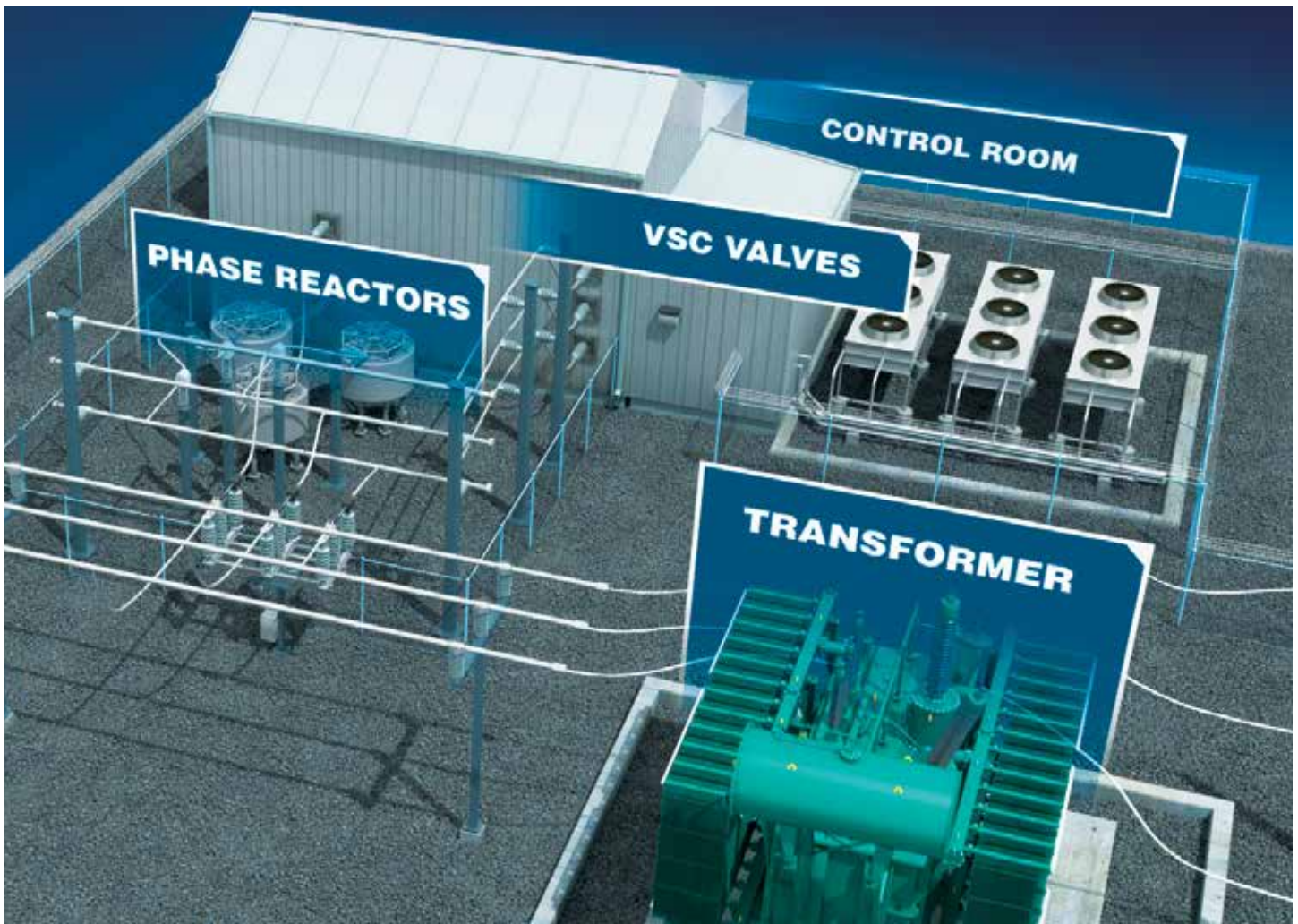
The uniqueness of GE's solution is the larger DC capacitance, a re-usable by-pass switch and industry leading Model-Based design STATCOM control platform.

Utilizing highly dynamic VSC based compensators, which when compared to SVC solutions, provides improved range of operational voltage, with higher reactive output at lower system voltage 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.

Key features of the STATCOM system include:

- Usually connected to High Voltage (HV) grid 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 compared to a classical SVC solution



Static Synchronous Compensator – 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

- 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



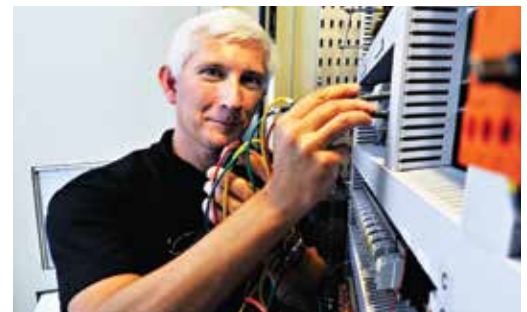
System flexibility to ensure optimized performance

- 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 is rated 2 to 3 times higher than competitive offerings, leading to much improved system performance during transient events and fault ride through capacity



Manufacturing excellence and deep domain technical expertise

- Over 50 years' experience with over 380 global shunt compensation installations, including 17 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



GE's Advanced Digital Control for STATCOM Systems

GE's approach to STATCOM control systems represent the latest in design methodology by utilizing a powerful Model-Based Design approach. With this approach the STATCOM control system software is built using a core library of complex control algorithms that represents over 50 years of FACTS experience within GE, key features include:

Graphical Interface

Model-Based Design utilizes a graphical interface for the design stage and translation of control models with automatic code generation for all testing and verification stages. With this approach, GE has enhanced the quality, reliability, and maintainability of the Advanced Digital Control system for STATCOMs.

Built-in Monitoring, Self Diagnostics & Event Logger

Extensive self diagnostic capabilities are built-in to maximize reliability, any degradation of performances or fault of components is pinpointed in real-time and can be easily replaced. When availability is at stake, the control system is configured in a dual lane redundancy concept which allows for the highest availability. A built-in event logger with automatic time stamping of 1 millisecond resolution and a synchronized transient fault recorder with up to 10µs sampling will allow for post event detailed analysis by experts.

Secure Remote Access

The control system can be remotely accessed via internet using secured protocol. It allows remote monitoring (using the built-in real-time monitoring function) and fault detection including diagnostic. To fulfill modern remote control interfacing requirements, the control platform supports an extensive set of industry standard protocols including IEC@ 61850, DNP3 and IEC 60870. Custom protocols can be implemented as an option.

Proven Technology

Based on commercial off-the-shelf (COTS) hardware, the control platform runs on VPX military technology and meets all the requirements of the Flexible AC Transmission System (FACTS) market. Depending on the application complexity, the control platform consists of single or multiple racks, interconnected by high speed serial fiber optic interfaces. The fiber optic interface enables the boards in different racks to communicate with each other as if they were installed in the same rack without any software change.

Control Software

The platform's software now leverages entirely new state-of-the-art features and technology. Using model-based design, real-time algorithms are deployed to speed up development and reduce software design errors in the early stages of development.



Advantages of Model-Based Design

- Programming and customization of control functions is simplified by the use of a graphical programming interface
- Testing and verification of the control system at the design stage starts early using real-time control models in closed loop with the STATCOM power electronics and the power grid
- Simulation environment uses real-time control models providing the most accurate representation of control performance. The control models can be easily exported to PSCAD™ or similar tools with one-to-one representation for further testing and simulations
- Automatic code generation allows direct conversion of graphical control models into real-time control software, eliminating the manual "coding stage", resulting in improved quality and reliability
- Complete traceability of customer requirements throughout the control model provides easy and efficient way for software modifications and new feature implementation at any stage of the project
- Model-Based Design approach adopted by GE has already revolutionized the development approach for critical control software in aviation, space and automotive industries, resulting in significant improvement in software quality for critical and life-supporting applications

Modular Multilevel Converter Valves

Static Synchronous Compensators (STATCOM) consist of a voltage source converter (VSC) connected to the grid by phase reactors and a step-up transformer. STATCOMs use Insulated Gate Bipolar Transistors (IGBT) in a modular multi-level converter (MMC) configuration. The STATCOM generates or absorbs reactive power by producing a controlled voltage waveform.

Basic Principles of Operation

The STATCOM system is shunt connected to the transmission grid. There are voltage transformers (VTs) in the STATCOM that measure the voltage of the grid. The Advanced Digital Control (ADC) takes the VT input and controls the individual sub-modules, so that they produce a voltage waveform that is either:

- The same as the system, when there are no grid issues
- Lower in magnitude than the system, making the STATCOM act as an inductive device and absorbing reactive power from the grid
- Higher in magnitude than the system, making the STATCOM act as a capacitive device and generating reactive power to the grid

Ultimately the STATCOM continually monitors the grid voltage and constantly adjusts its reactive power output in response to system disturbances and thus improves grid stability.

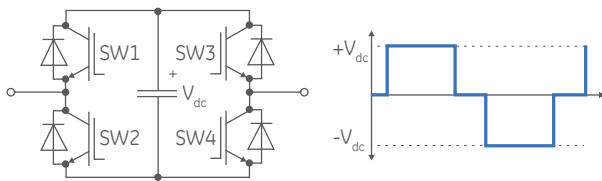


Fig. 1 - Typical full bridge valve sub-module and its output waveform

Figure 1 above illustrates how the controlled switching of the IGBT valves in a single sub-module creates the basic three-level waveform that the STATCOM uses to control the reactive power contribution to the grid. When multiple such sub-modules are connected in series, as shown in Fig. 2, you can see how the voltage waveform can be built up with better resolution to deliver improved performance, higher rating and enhanced controllability of the STATCOM.

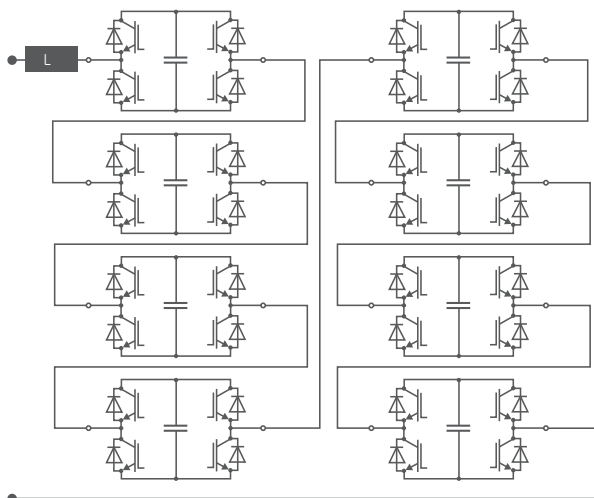


Fig. 2 - Multiple sub-module operation and resulting waveform

By controlling the magnitude of the voltage waveform produced by the voltage sourced converter, and by maintaining synchronism with system voltage, the reactive power output of the STATCOM can be either zero, inductive, or capacitive as shown below:

V_s

 $I=0$

$V_L = 0$

V_c

$I = 0$
If $V_c = V_s$, then $I = 0$

STATCOM in standby mode with zero current output. When VSC voltage equal in magnitude to system voltage

V_s

 I

V_L

V_c

If $V_c < V_s$, then I is inductive

STATCOM in Inductive mode with lagging current output. When VSC voltage smaller in magnitude than system voltage

V_s

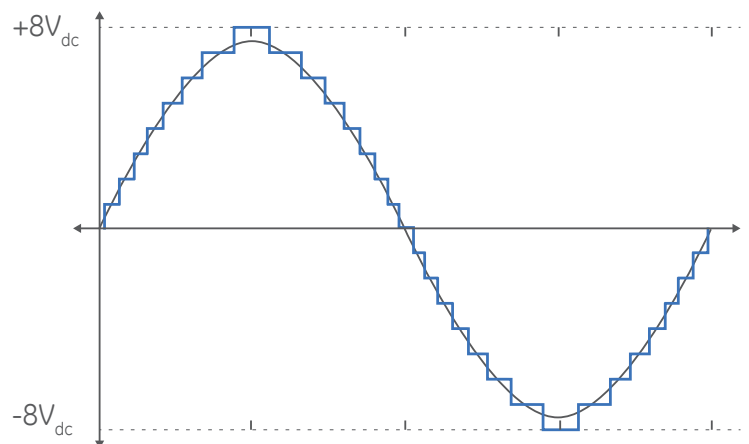
 I

V_L

V_c

If $V_c > V_s$, then I is capacitive

GE's STATCOM configuration uses 8 sub-modules within each module, which are the basic building blocks of the STATCOM design. As shown below, this configuration produces a nearly ideal sinusoidal-shaped waveform. The relatively low switching frequencies of the valve provides lower system losses and little or no high frequency filtering is required.



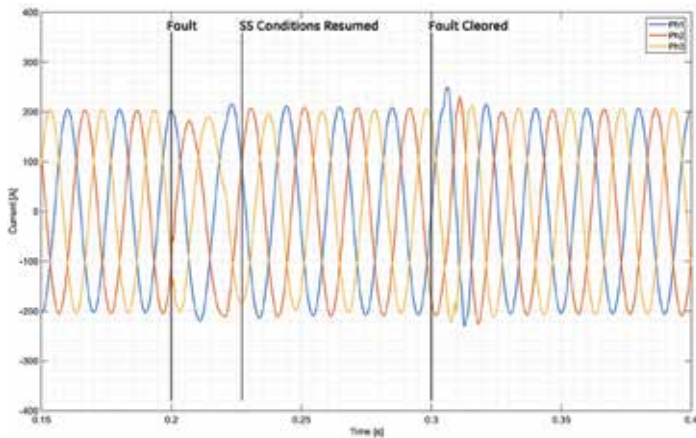
An unrivaled DC voltage source for a better STATCOM

The function of a STATCOM system is to provide reactive compensation to the grid when it is needed most, during fault and transient conditions. GE's STATCOM solution is the only commercial solution that uses a 7mF capacitor as its DC voltage source for stabilizing the grid, nearly 2 to 3 times larger than competing solutions.

Operational Advantage of the GE STATCOM Solution

The operational advantages of this design decision can be clearly seen in the two figures below. When a three phase fault is introduced just after 0.2 seconds, the STATCOM current contribution with the larger, 7mF capacitor is nearly perfect, resuming its steady state current profile within 25ms of fault inception.

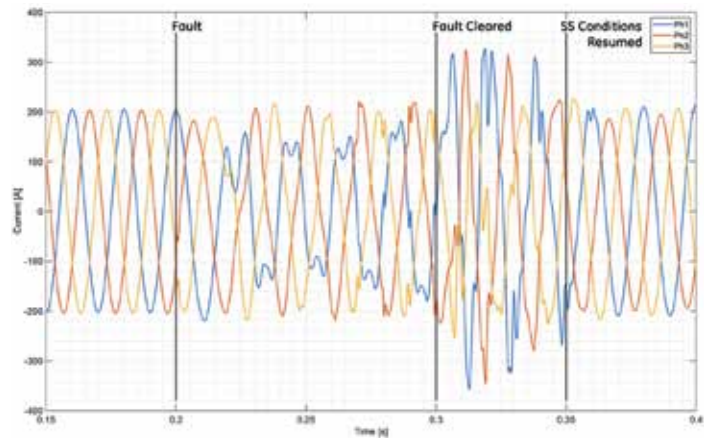
Using a larger capacitance provides more stored energy, delivering better fault ride through capability by delivering stable full current for a longer time duration.



Behaviour of GE's STATCOM Solution with 7mF capacitor

Typical STATCOM Solution

By contrast, the performance as modelled on a smaller, 3.5mF capacitor is substantially less stable. The STATCOM current contribution is significantly impacted and never stabilizes during the entire duration of the fault (100ms), and then goes through another 50ms of undesirable transient overshoots. Such transients, contrary to the objective of the STATCOM, produces more instability during and after the fault conditions.



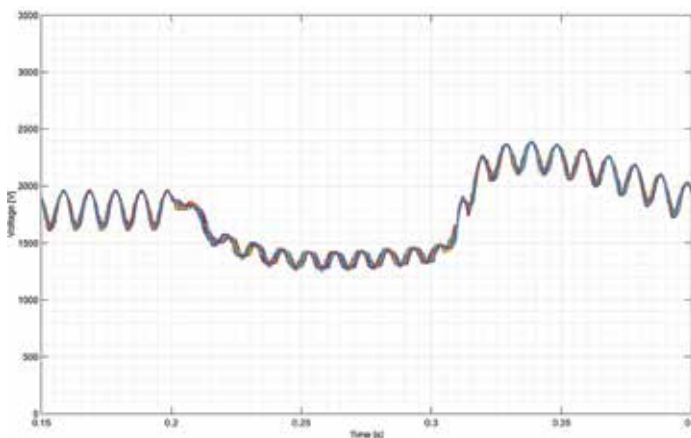
Behaviour of Typical STATCOM Solution with 3.5mF capacitor

Impact on DC Voltage

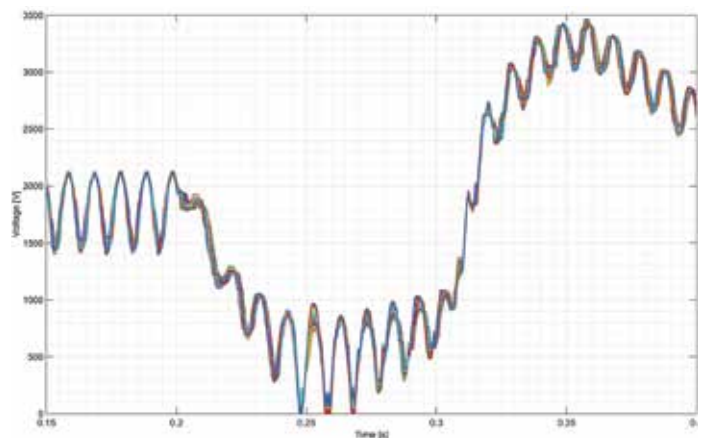
Significant improvements in transient performance of the DC voltage can also be achieved with the larger capacitor. Having a bigger capacitance provides more inertia in the DC bus, accepting greater phase difference between the valve and the grid system voltage. This enables the ability to absorb or deliver some active power due to this phase difference without significantly sagging the DC voltage, thus improving the performance in transient conditions.

The design decision also provides benefits in the long-term operational performance, and life-cycle cost, of the STATCOM.

As can be seen in the DC voltage ripple below, the larger capacitor provides a smaller ripple, meaning the GE system can work at higher nominal voltage, in some cases up to 10% more than competitive solutions. The smaller capacitor solutions will experience increased voltage swings, potentially causing capacitor insulation damage and shortened operational life as compared to the larger capacitor.



Impact on voltage with GE's STATCOM Solution with 7mF capacitor



Impact on voltage with Typical STATCOM Solution with 3.5mF capacitor

Flexible Hybrid STATCOMs

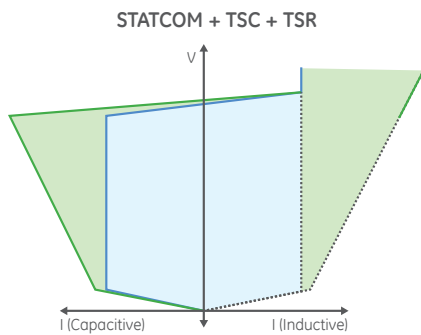
Hybrid STATCOM with additional dynamic capacity

The GE STATCOM system is modular in design and can be dynamically scaled by adding additional STATCOM units or by adding thyristor switched components to increase the capacitive or inductive dynamic rating of the system.

Full Dynamic Rating

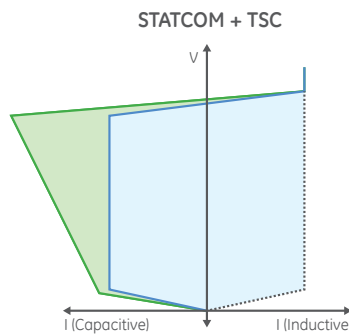
Applications where dynamic performance is required across the full system rating can be achieved either by installing a pure STATCOM solution, which is symmetric in rating, or through a hybrid design with thyristor switched elements, which allow non-symmetric dynamic ratings.

For conditions where fast and dynamic response is necessary but the grid requirements are highly non-symmetric, a hybrid solution with a STATCOM and thyristor switched components proves to be most efficient. Additional Thyristor Switched Capacitors (TSC) or Thyristor Switched Reactors (TSR) can be added to GE's STATCOM system with seamless and unified control systems. This solution provides a loss optimized and cost-effective solution for any type of reactive power needs.



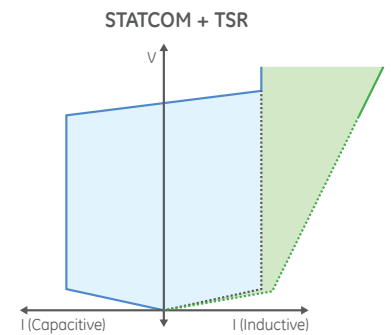
V-I Curve of Hybrid STATCOM

A combination of Thyristor Switched Capacitors (TSC) and Reactors (TSR) can add additional dynamic capacity (green) to the STATCOM (blue)



V-I Curve of Hybrid STATCOM

Thyristor Switched Capacitors can add non-symmetric capacitive dynamic capacity (green) to the STATCOM (blue)



V-I Curve of Hybrid STATCOM

Thyristor Switched Reactors can add non-symmetric inductive dynamic capacity (green) to the STATCOM (blue)

Hybrid STATCOM solution with TSC and TSR



Using thyristor switched devices to increase the inductive or capacitive rating of the STATCOM is a cost effective approach for adding additional dynamic capacity, or for increasing the non-symmetric rating of the STATCOM to support the grid requirements.

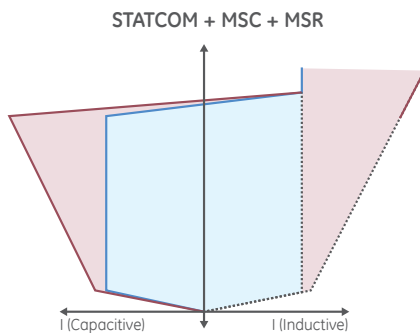
Hybrid STATCOM with additional steady-state capacity

With the GE STATCOM, a combination of dynamic and steady-state ratings can be achieved with one or more STATCOM units and mechanically switched reactive elements as needed. This type of configuration is suitable when a dynamic reserve is desired as part of the STATCOM solution, but additional reactive capacity is needed for slow response compensation such as load flow changes and can be served by mechanically switched elements.

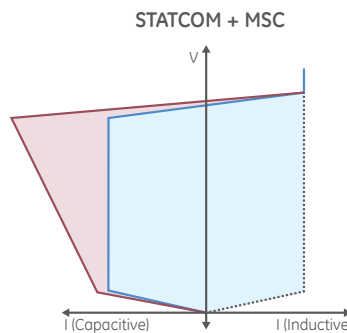
Dynamic and Steady-State Rating

With GE's Hybrid STATCOM solution, theoretical unlimited scalability can be achieved with additional mechanically switched elements that are located local or remote to the STATCOM substation. This solution allows unsymmetrical ratings of the hybrid solution allowing flexibility to configure the system according to grid requirements. Control coordination of the hybrid solution is robust with accurate control of reactive power and load flows in the transmission grid.

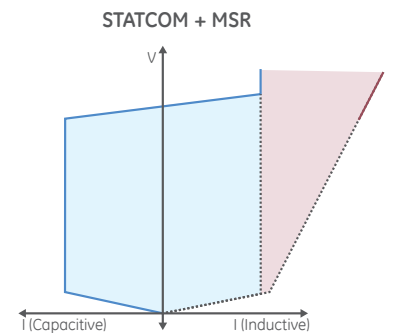
Using mechanically switched devices to increase the inductive or capacitive rating of the STATCOM is a cost effective approach for adding additional steady-state capacity, or for increasing the non-symmetric rating of the STATCOM to support the grid requirements.



V-I Curve of Hybrid STATCOM
A combination of Mechanically Switched Capacitors (MSC) and Reactors (MCR) can add additional steady-state capacity (red) to the STATCOM (blue)



V-I Curve of Hybrid STATCOM
Mechanically Switched Capacitors (MSC) can add capacitive steady-state capacity (red) to the STATCOM (blue)



V-I Curve of Hybrid STATCOM
Mechanically Switched Reactors (MCR) can add inductive steady-state capacity (red) to the STATCOM (blue)

Hybrid STATCOM solution with MSC and MSR



Using mechanically switched devices to increase the inductive or capacitive rating of the STATCOM is a cost effective approach for adding additional steady-state capacity or for increasing non-symmetric rating of the STATCOM to support the grid requirements.

Project Management and Execution

The GE project team represents unsurpassed worldwide power system engineering capabilities, comprehensive system design expertise, and unequalled project management experience. GE delivers highly reliable solutions that fully meet the customers power system requirements. With each reactive compensation project GE undertakes, this team is committed to delivering 100% satisfaction.

Expertise

GE's experienced project managers have access to industry leading project tools and processes to execute projects on-time and on budget. GE's engineering teams have advanced internal design tools that provide customers with the most robust and proven designs to ensure a fully executed system with the highest level of quality and reliability.

GE's Energy Consulting works with customers to understand the overall system and project objectives. Through comprehensive analysis and studies the team develops the optimal, most cost effective technology solution based on customers requirements.

Global Capabilities

GE provides engineering excellence to design and deliver complete reactive compensation projects tailored to each customer's requirements and needs.

Providing dedicated engineering teams that are located in regions around the world, GE's subject matter experts bring a wealth of international experience to every project. Customers benefit from GE's local systems subject matter experts who are able to drive and comply with regional/local requirements ensuring the customers business and technical objectives are met.

Post Installation Service

GE's commitment to customer satisfaction is a primary goal – just because the project is complete, our job is not done. A primary responsibility is continued support of the implemented system throughout its lifecycle.

Offering an extensive network of field engineering locations and service centers around the world, GE is uniquely capable of responding immediately to urgent situations that may arise once the equipment is placed in service. Customers are provided with 24/7 field and application call center support.

Project Process and Key Activities

GE's project management approach follows a well-established set of processes and procedures that have resulted in the highest on-time delivery in the industry. GE has the people, process and rigor that customers require for the planning and execution of complex projects, including defined processes for the definition, analysis, design, implementation and post service support that is required for successful projects.



Energy Consulting

GE has a dedicated staff of consultants that provide engineering, technical support and expertise to the electrical power industry to support Flexible AC Transmission Systems (FACTS) projects worldwide. Below are details of the support and services GE provides its customers.

Electric Power Industry Support Activities

GE's technical subject matter experts, contribute towards advancements in the electric power industry through supporting the following activities:

- Deliver industry-leading technology webinars answering the most pressing challenges related to reactive power
- Specialized instruction through its Power Systems & Energy Course (PSEC) including:
 - Surge Analysis and Equipment Application
 - Reactive Power Compensation and Voltage Control
 - Power System Dynamics
 - Power Electronic Applications in Transmission
- Participation in standards committees such as IEEE® and IEC®
- Authoring of technical papers that are published and presented at numerous industry conferences



Preliminary System Analysis and Solution Definition (Pre-RFP Support)

GE works with customers to understand the overall system and project objectives through comprehensive analysis and studies developing the optimal, most cost effective technology solution. Examples of the types of studies include:

- Load Flow Study
- Transient Stability Study
- Voltage Profile
- Auto-Reclosing Requirements
- Overload Requirements
- Swing Current Analysis
- Transient Recovery Voltage (TRV) Analysis
- Equipment Sizing (Amps, Ohms, MJ, Mvar)
- Development of Project Specification Document
- Harmonic analysis
- Feasibility study



Final System Design (Post Award)

GE's subject matter experts work seamlessly with customers to finalize the system and equipment design to meet the customer's system requirements. In this stage we:

- Finalize system studies
- Develop protective relays settings,
- Specify control and operation coordination for integration into existing systems
- Finalize equipment design and sizing studies
- Generate equipment specifications



Implementation and Testing

During the project implementation phase, GE is focused on executing on the agreed design with the customer to meet the project requirements. Activities include:

- Integration of new equipment with existing equipment
- Definition of, and participation in, type testing, factory acceptance testing and field testing
- Commissioning support including highly trained field engineer and site technical advisory support
- On-site and off-site specialized system training



Project Support

GE's commitment to customer satisfaction is a primary goal – just because the project is complete, the job is not. A primary responsibility is continued support of the implemented system throughout its lifecycle. GE provides:

- Incident analysis and troubleshooting support
- System recovery services
- Equipment upgrades and retrofits to meet changing system needs



For more information about
GE's STATCOM Systems visit
GEGridSolutions.com/facts.htm



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