eLumina™
Control System for HVDC Schemes
TODAY’S ENVIRONMENT

Today’s transmission grid is changing and becoming more complex to manage as utilities globally are experiencing grid challenges such as an increase in demand, renewable generation, more stringent power requirements and more frequent extreme weather events, cyber and physical attacks.
These challenges can make power flow more complex for network operators to manage, particularly stability issues under fault clearing and post-fault conditions. These issues, as well as additional issues such as aging infrastructure, harmonics, unbalanced loads and power oscillations will impact power quality levels on the grid and power transfer capability.

High Voltage Direct Current (HVDC) technology is one of the key solutions utilities are investing in to address these modern grid challenges. Modern technology developments such as ultrafast, high performance and compact computing & digital communication systems are improving HVDC’s ability to address grid challenges. Increasingly complex HVDC schemes, such as Smart Modular Multi-level Converters and multi-terminal configurations require more advanced digital control systems features such as:

• High levels of controllability, reliability, availability and safety
• Strong fault tolerance & recovery
• Advanced control and protection algorithms
• Faster dynamic response to grid condition changes
• Seamless integration and secure communications between substation and remote control centers
• Short deployment times
• Smart diagnostics enhanced by Digital Twin technologies
• Compact Footprint

MARKETS DEMAND SMARTER, FASTER CONTROL SYSTEMS
GE SOLUTION

eLumina™, GE’s Most Advanced HVDC Control System

GE’s latest fully-digital industrial HVDC Control System is designed to enable utilities to efficiently move more power further with a higher degree of controllability, thus improving power quality and maximizing overall grid performance. Built using GE’s proven technology, with fully redundant systems and state-of-the-art software, eLumina delivers a reliable, high-performance platform consisting of:

- Core Computing Units (CCU)
- System monitoring and protection
- Real-time digital measurements & IO
- Fully redundant optical networking
- HMI & diagnostic interfaces
- Advanced fault recording
- Valve control module
- Replica systems

Outcomes

GE’s eLumina was designed and built with strong focus on delivering better customer outcomes. Extensive customer interviews, through GE’s “voice of customer” process, highlighted those areas that were most important and valuable to how our customers use HVDC systems. These highlights combined with industry-leading technologies enabled the creation of a solution that best suits today’s and future customer needs.

Utilizing nearly 60 years of HVDC expertise along with a powerful Model-Based Design methodology, GE has combined cutting-edge computing technology with standardized application software to provide:

- Optimized system performance
- Enhanced reliability
- Reduced system complexity
- Compact footprint
- Rapid installation and commissioning
- Extended operational lifetime (25+ years)
Maximized Performance and Reliability

- High-performance computing and communications platform with real-time multitasking application software and absolute determinism
- Enhanced engineering interface tool integrated with advanced analytics engines provides best-in-class operation & maintenance performance
- Incorporates GE’s Digital Substation solution, utilizing duplicated high-speed IEC 61850 and IEC 61869 fiber optic communication networks, resulting in a substantial reduction in total length of cables
- Improved system resiliency through simplified, fully-redundant control and triplicated protection systems, that are tolerant to multiple points of failure with no degradation in system availability

Rapid Project Delivery Cycle with Faster Return on Investment

- More than 30% reduction in project delivery cycle resulting from standard project approach that utilizes modular hardware platform and proven application software
- Robust, predictable factory acceptance tests and reduced field commissioning times resulting from standardized and configurable HVDC applications, built from 150+ proven software components
- Reduced installation time, faster diagnostics, and improved safety resulting from fiber optic networking and advanced digital tools that eliminates over 80% of hard-wired connections
- Optimal performance, accurate documentation and streamlined deployment of error free code, reducing design and testing iterations by as much as 70% by utilizing GE’s Model-Based Design approach

Modular Platform, Compact Footprint with Proven Technology

- 50% reduction in footprint, 40% reduction in number of cabinets resulting in reduced complexity, lower power usage and measurable reduction in audible noise
- Modular control system platform utilizes widely-available avionics-grade components and international and industry standards, to provide a long in-service life, extensive scalability and maintainability, resulting in simplified life-cycle management
Modern, Standardized Software
Developed following the latest best practices from the software industry, eLumina™ application software is fully standardized and configurable. Built from over 150 proven software components available in GE’s HVDC reference libraries, which provides robust, predictable factory acceptance testing and reduced field commissioning times.

Graphical Interface
GE’s industry leading HVDC application tool chain provides an unified graphical user interface for the design of control application models and automatic deployment of efficient error-free code. This approach enables the realization of a fully-automated regression testing framework for all verification stages which enhances the quality, reliability, and maintainability of the control system.

Optimized System Performance
The performance of each HVDC application is characterized and qualified utilizing an automatic regression test engine. Easier integration of control system software with power system modelling tools such as PSCAD provides an accurate representation of the power system performance, and streamlined planning and troubleshooting analysis.

Model-Based Design
GE’s Model-Based Design approach provides rapid technical responsiveness and support to the customer throughout the project life. This approach has allowed GE to create an inherently modular architecture that provides the high degree of flexibility required to deliver all types of HVDC applications, and the ability to easily make future upgrades. This, combined with GE’s next generation real-time platform software, provides the independence between the software and hardware required to ensure portability of proven application software, reducing delivery times and simplifying the software life-cycle management.

Secure Remote Access
The control system provides the high level of cybersecurity required for secured remote access. This allows for real-time monitoring, fault detection and diagnostics. To fulfill modern remote control interfacing requirements, the control system supports an extensive set of industry standard protocols including IEC® 61850, DNP3 and IEC 60870.
FULLY DIGITAL, MODULAR COMPUTING PLATFORM WITH STATE-OF-THE-ART COMMUNICATIONS

REDUCE CAPEX
- Quicker installation (~40% faster)
- Over 80% copper cable reduction
- ~30 tons less material to transport

REDUCE OPEX
- ~50% reduction in outage time
- Reduced maintenance
- Maximized asset utilization

IMPROVE SAFETY
- Fiber optic communications
- Minimal wired connections
- Reduced footprint (50%)

World-Class Digital Measurement System
eLumina™ features a best-in-class, real-time digital measurement system that seamlessly integrates all the voltage and current sensors in the HVDC converter station. The Reason MU640 merging units, which exceed the latest industry standard IEC 61869 for performance, are strategically placed in the switchyard close to the primary equipment and sensors to improve the measurement accuracy and reliability of the overall system. The merging units transmit data to the control system via a dedicated high-speed optical network using the IEC 61850 protocol, which virtually eliminates copper wiring and creates a safer work environment. Configured for very high sampling rates and very low latency, this measurement system is designed to optimize the performance of HVDC applications.

GE’s Digital Substation
The eLumina HVDC Control System aligns with GE’s digital industrial strategy, utilizing state-of-the-art Digital Substation technology to meet the changing and increasingly complex demands on the electrical grid. The compact, fully digital core computing unit utilizes purely industry-standard communication protocols over high-speed optical fibers to interface with HV sensors, power electronics, and the other equipment in the converter station.

Reduced System Complexity and Compact Footprint
The modular approach used with the controls platform combined with cutting-edge computing technology reduces the form factor and footprint by nearly 50%.

Remote Interface Cabinet
As part of the HVDC digital substation solution, outdoor cabinets are strategically placed in the switchyard to communicate with and provide advanced monitoring of the primary equipment.

Fiber Optic Communication Systems
Communication with the valve components is done exclusively via high-speed standard optical communication technology. Unlike most systems used in this industry, GE’s latest solution is made of a dual-redundant and bi-directional point-to-multipoint optical network. This allows each power module to be controlled and monitored in tightly-synchronized, time-critical and reliable manner while minimizing the number of fibers needed without compromising redundancy.

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CONTROLS PLATFORM

The eLumina™ control system provides a fully-digital, highly-redundant control platform for both Voltage Source Converter and Line Commutated Converter HVDC schemes. It is compact, flexible and designed with standard building blocks that are easily configured for point-to-point, multi-terminal, or back-to-back converter arrangements with most functions remaining common.

The control system footprint has been minimized to suit both onshore and offshore converter station applications without compromising the important physical and electrical segregation required to ensure redundancy or the ability to safely maintain the control system without needing a transmission outage.

The control platform consists of core control cabinets in a compact, centrally-located control room as well as small remote interface cabinets which are strategically placed in the switchyard close to the primary equipment and sensors to keep the installation and electrical cabling to a minimum and thus substantially increasing reliability and safety in the converter station.

HVDC Converter Control & Protection

The Converter Control and Protection cabinets are the “brain” of the HVDC system and utilizes advanced control and protection algorithms to deliver power safely and efficiently.

Key features include:
- Dual-redundant converter control
- Triplicated converter protection
- Seamless transition between hot and standby controls with built-in manual changeover facility
- Maximized availability, increased reliability and serviceability
- Line replaceable Core Control Units (CCU) interconnected via industry standard high-density fiber optic cables
- Two identical, physically and electrically independent CCUs, used to execute the advanced control and protection algorithms
- Built-in touch screen displays cabinet health and self-diagnostics
- Dual power supply feeds with self-monitoring function
Core Computing Units

Physically-identical, software-definable application execution units that perform all software functions

GE’s HVDC control system use one type of standard Core Computing Units (CCU) sub-rack that contain high power processing modules to execute all software functions. High speed optical communication ports digitally interface the CCUs with the sub-station equipment, the high-voltage measurement sensors, the valve interface system, and the local I/O system. Key features include:

• Fully enclosed, self-contained, EMC-proof 19" sub-racks
• Complies with OpenVPX Standard (ANSI/VITA 65-2017) used for aerospace and other high reliability applications
• 64-Bit multicore (4-Core) general purpose processor with 2.8GHz speed single-board computer
• 8 core digital signal processor with up to 180 Gflops
• Latest Virtex 7 field-programable gate array unit
• Duplicated power supply for high reliability
• Thorough type-testing of all populated sub-racks
• CCU are designed as line replaceable units for simplified maintenance

Network Interface Cabinets

The digital hub coordinating all communications between the HVDC system elements

Fully-duplicated, IEC 61850 compliant Network Interface Cabinets (NIC) contain industrial and ruggedized optical gigabit ethernet network switches, a satellite clock unit, an optical patch panel and HMI and archives servers.

Fiber Connections

The Core Computing Units within the Control and Protection cabinets are all connected to the NIC by high speed optical fiber cables. Each fiber within these cables is connected via simple passive optical breakout patch panels to the optical ports of the ethernet switches, which are in turn connected to the HVDC station networks or other HVDC control system connections.

Monitoring

The status of each active device within the cabinet is monitored via the Simple Network Management Protocol. The status of the door switch is also monitored to provide support to cybersecurity policies.

Fully Redundant Design

The NICs are fully duplicated to ensure fully independent redundant communication paths are provided.

Power Supply

Dual power supply feeds with self-monitoring function.
Valve Base Electronics

Interfacing the converter control system to the thousands of individual power electronics modules within the HVDC power converter

The Valve Base Electronics (VBE) system communicates with the large number of power electronics modules using an industry standard passive optical communication technology which allows each module to be controlled and monitored in a tightly-synchronized, time-critical and reliable manner while minimizing the number of fibers needed without compromising redundancy.

Advantages of Valve Base Electronics
- Low fiber count makes it much easier to install and maintain than traditionally used point to point systems
- Provides a very fast update rate and low overhead communication
- Provides the electrical isolation required to communicate between devices at ground level and 800kV

Performance Optimization and Predictive Maintenance
The optical communication system provides essential operational and valuable diagnostic data to be collected from every sub-module, enabling performance optimization and predictive maintenance. Data includes: sub-module status, communication light level, serial numbers, firmware version numbers, physical location of the sub-module within the valve hall, detailed failure codes, transceiver temperatures.
VBE Function

Line Commutated Converter (LCC) Systems

In LCC systems the phase control defines the instantaneous point-on-wave firing angle which applies to the whole converter. This is then passed down to valve control, which converts it into a switching sequence for each of the valves in the 12-pulse converter.

This valve sequence is passed down to VBE, which then distributes individual signals to turn on each of the thyristors in the valves at the appropriate time.

Voltage Source Converter (VSC) Systems

In VSC converters, the switching commands for the Insulated Gate Bipolar Transistor (IGBT) valves are selected in such a way as to simultaneously balance the individual sub-module capacitor voltages, and to define the sub-module switching instant and thereby create the phase and amplitude of the synthetic waveform.

The valve control functionality provides the average capacitor voltage of each valve to the phase controls via a fast optical link. This average value is used by the control algorithms to:

i. balance the capacitor voltages across all valves
ii. manage power flow into and out of the convertor
iii. maintain the average capacitor voltages at their target values

Status Information

Status information from every valve sub-module or thyristor level is collated by the VBE system in the form of databack information.

This databack information includes the module capacitor voltage and status information in the case of VSC converters, and thyristor level status information in the case of LCC systems, which is required by the higher levels of the HVDC control and protection systems.

This databack information contains specific and summary data of the converter status, and is transmitted through multiplexed, full duplex, and redundant optical fiber links to the HVDC control and protection systems.

This mechanism is used, for example, to report the present valve redundancy levels to the operator workstation and to provide the “converter valve ready for service” information to the HVDC control system’s start-up interlocks and sequencing functions.
INDUSTRY LEADING HVDC APPLICATION SOFTWARE

GE’s eLumina™ control system uses a Model-Based Design approach, integrating standardized and configurable HVDC application software. The software is built from a proven library of building blocks and validated control and protection algorithms. This approach has significantly improved the quality and reduced the cycle time for software design and validation into the customer’s specific requirements.
Demonstrated and Proven

The Model-Based Design approach is widely adopted within GE and has revolutionized the development approach for critical control software in GE’s Aviation, Healthcare and Power business units, resulting in significant improvement in software quality for critical and life-supporting applications.

Quantifiable process improvements on customer deliverables within the project, such as testing and design iterations have been reduced by as much as 75%, with corresponding design documentation being available almost immediately.

Advantages of GE’s Design Approach

**Rapid configuration of control and protection functions**
The use of a graphical programming interface and a proven standard library of thoroughly tested control function blocks enable simplified and accelerated delivery of the control system application software while ensuring consistent performance.

**Rapid integration with power system simulation software**
Through reuse of our existing proven models, the PSCAD/EMTDC environment can be used directly for dynamic performance and transient analysis studies. The ability to consistently demonstrate how the system will perform early in the project cycle, accounting for real world delays and constraints, contributes to additional customer value.

**Accelerated testing and verification**
The performance of each HVDC application is characterized and qualified using an automatic regression test engine. Because the application software is standard and fully configurable, real-time simulation, testing and verification of the control system can start very early in the project, to ensure the solution is robust and meets or exceeds the customer’s requirements.

**Automatic code generation and deployment**
GE’s HVDC application software has been designed in a way that is fully independent from the underlaying controls computing platform. This, combined with GE’s industry-leading tool chain, allows seamless and efficient conversion of graphical control models into real-time control software, resulting in improved quality and reliability.
Control Hierarchy

The HVDC Control System provides all of the functionality needed to control and protect the HVDC equipment and ensures safe, stable control of both real and reactive power flow through the converter.

The control system controls the converter switching, tap changer operation (if required), converter cooling plant operation and higher level sequencing. It also provides protection for the power converter valves and other related DC equipment including the HVDC transmission lines and/or cables.

The control & protection of a HVDC scheme is split into three main functional levels:

- AC/DC System Level
- Station Level
- Converter Unit Level

AC/DC System Level - Dispatch Centre System Control/Link Control

This level provides a supervisory level of control largely concerned with managing power flow through the DC link. The top level of control of both converter stations is the dispatch center.

At any one point in time during normal operation, the DC link is controlled from one location only - normally located at some distance from the HVDC station (either at one of the two converters stations or a remote dispatch center).

The remote dispatch center typically communicates with Station Control using an established internationally standardized or well-established protocol such as IEC 61850.

Station Level – Station/Bipole/DC Yard Control

The station control function implements the highest-level functions that determine the influence of the scheme on the connected AC networks, including control of real and reactive power exchange.

The controls use AC bus information, inputs provided by the operators and power level information from the lower level controls to optimize the reactive exchange at different power transmission levels.

The power flow through the link is shared between poles, in a bi-pole scheme, or allocated to a single pole, in the case of a monopole scheme.
Converter Unit Level

This level contains higher level converter control functions and derives voltage and current orders for each of the valves. Typically the following functions are included:

- **Active Power Control** - Controls the power transfer to meet the value and direction demanded by the operator.
- **DC Voltage Control** - At least one converter unit in a HVDC scheme has the role to control the DC Voltage.
- **AC Voltage Control** - Each converter unit in the HVDC scheme can control the voltage at the point of connection (POC) to a defined target.
- **Reactive Power Control** - Control of the reactive power exchange with the AC system. In a VSC system this is achieved by modifying the amplitude of the output voltage waveform to make the converter either absorb or provide reactive power. In LCC systems rudimentary RPC is possible by appropriate switching of shunt filter banks.
- **Power Demand Override (PDO)** - A PDO is a predefined response to certain specified stimuli, such as protection relay operation, breaker status change or bus voltage measurement. Each PDO action is triggered by either an external signal provided to the HVDC control system or by internal system condition recognizers.
- **Automatic Frequency Control** - Frequency control can be enabled if the HVDC link connects at least two asynchronous AC systems. When this function is activated the frequency of one system can be controlled within the power capacity of the HVDC link by variation of the transmitted power.
- **Power Oscillation Damping Control** - When activated, modulates the HVDC link power transmission to provide damping of low frequency power oscillations with frequency typically less than 1Hz. The Power Modulation Function detects power oscillations through changes in the absolute phase angle of the converter station AC busbar voltages.
- **Sub-Synchronous Damping Controller (SSDC)** - Modulates the power order to damp unstable, sub-synchronous modes of generators close to the converter station. Typical frequency range of operation is 15Hz to 45Hz.
- **Power Limits** - The operator may be provided with facilities to impose power limits on the system. The power order will be subjected to minimum and maximum power limits for the converter.
- **Converter Sequencing** - Provides automatic sequences for starting and stopping the converter in a safe and orderly manner.
- **Overload Control** - Calculates the continuous and time-limited temporary overload for the key converter station equipment. The overload controller also acts to reduce the DC current whenever a thermal limit is approached and to allow appropriate recovery time.
- **Depending of VSC or LCC system requirements, lower-level control functions such as Phase Control and Tap-changer Control are also included at this level.
Imagination at work

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For more information about GE’s eLumina Control System visit www.GEGridSolutions.com/HVDC