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MITSUBISHI ELECTRIC POWER PRODUCTS, INC.

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ADVANCED HVDC TECHNOLOGY FROM MITSUBISHI ELECTRIC

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A LEADER IN HIGH-VOLTAGE DIRECT CURRENT (HVDC) SOLUTIONS

MITSUBISHI ELECTRIC POWER PRODUCTS, INC.



For more than 40 years, Mitsubishi Electric Corporation (MELCO) has been a leader in the development, design and production of high performance power electronics-based systems. These solutions enable delivery of reliable high quality power. Mitsubishi Electric is pleased to announce a new key technology to add to its history of innovation: Voltage Source Converter (VSC)-based HVDC-Diamond®

Mitsubishi Electric's HVDC-Diamond® technology features the company's proven Insulated Gate Bipolar Transistor (IGBT) technology and apply a Modular Multilevel Converter (MMC) topology for power conversion of high voltage AC to DC. Mitsubishi Electric's HVDC-Diamond® solutions feature power transfer ratings in excess of 1000MW with a DC voltage level up to +/- 500kV DC.

The high reliability of MELCO's IGBT devices, protection & control, cooling systems, bypass systems and transformers has made them the components of choice for numerous utilities that build power transmission and distribution infrastructure.

HVDC APPLICATIONS IN ELECTRIC POWER TRANSMISSION

The emergence of renewable energy sources to meet society's energy demands while being more environmentally sustainable has created new challenges for utilities. It's becoming more common that electricity is generated by renewable energy sources located far away from load centers and requires advanced transmission technologies to deliver the power efficiently and reliably. HVDC is perfectly suited for these situations of integrating bulk power renewable energy over long distances.

HVDC-Diamond® systems offer additional performance benefits such as the ability to interconnect asynchronous AC systems, improve reliability and controllability of power flow, as well as replace aging back-to-back HVDC installations.

Aside from facilitating delivery of power, HVDC-Diamond® systems can help regulate system voltage by simultaneously supplying reactive power independent the amount of active power being transmitted. Specifically, HVDC-Diamond® systems can supply capacitive and inductive reactive power, often eliminating the need for a mechanicallyswitched capacitor, reactor banks, and harmonic filters that were commonly applied to HVDC systems.

THE SYSTEM

HVDC-DIAMOND®

The development of Voltage Source Converter (VSC) based technology represents a key breakthrough for the electric power industry. Compared to classical Line Commutated Converter (LCC) HVDC technology, VSC-based HVDC systems have faster responsiveness, independent control of active and reactive power, and a more compact physical footprint. These advantages have expanded the market for HVDC technology into new applications, such as integrating offshore wind farms, black starting islanded loads, and supplying passive networks.

CHARACTERISTICS & BENEFITS

- Ability to Transmit and Control Real Power from Terminal to Terminal
- Independent Supply and Control of Real and Reactive Power
- High Reliability by Adopting High Speed Control and Protection
- Fast Power Flow Reversal
- Improved Fault Ride-Through Capability
- Improved Renewable Resource Integration
- Low System Losses Compared to Conventional AC Transmission
- Small Footprint

THE FUNDAMENTAL COMPONENT

- Compatibility with Multi-Terminal Systems
- Increased Grid Accessibility for Weak Systems with Low Short Circuit Strength
- Ability to Feed into Passive Networks
- Black Start Capability
- Improved Renewable Resource Integration
- Inteconnection with Offshore Wind Resources



TECHNOLOGY OVERVIEW

THE HVDC CONVERTER STRUCTURE & RATINGS

Each phase is comprised of upper and lower arms that consist of numerous sub-modules connected in series. The number of series sub-modules required is determined by DC voltage. Through switching combinations of the upper and lower sub-modules by PWM (Pulse Width Modulation), the output waveform is "built" through a large number of precise, small switching steps. This process results in the formation of a near perfect sine wave at the AC side and smooth voltage at the DC side. The resulting configuration has the ability to create an AC waveform without an AC grid connection for reference.

Typical converter ratings vary from 50 to 1500MW and will use up to the optimized number of sub-modules per branch arm for a voltage of up to +/-500kV DC. A coupling transformer is used to connect the converter to the AC transmission system, allowing connection to any voltage level. Because a coupling transformer is used, the converter can be connected to a transmission system with any AC voltage. The AC sine waves produced by the HVDC system have low harmonic currents, allowing the use of a standard AC Coupling Transformer. By connecting the sub-modules in series within the converter, the IGBT's operate at low switching frequencies, resulting in converter losses of less than 1%.



VSC-Based HVDC MMC: Simplified Output Voltage.

IGBT IS THE PROVEN CHOICE FOR CONVERTER DESIGN

The heart of an HVDC-Diamond is the Insulated Gate Bipolar Transistor (IBGT). These power electronic devices have a proven track record of superior performance and high reliability, making them the right choice for critical applications like HVDC systems. By utilizing its internally sourced power electronics, Mitsubishi Electric has developed a fully optimized HVDC design that considers all aspects of component performance and construction.

The new generation, high capacity X-Series IGBT (6.5kV, 1.0kA) has highly desirable features & benefits, including:

- Compactness
- Optimum Current Rating
- Lower Device Loss (35%)
- High Reliability
- Above-Average Temperature Capabilities

A GLOBAL LEADER IN IGBT TECHNOLOGY

Mitsubishi Electric is a recognized leader in IGBT development and manufacturing. By serving a global, diverse customer base, Mitsubishi Electric's state of the art manufacturing facilities innovate through a culture of continual refinement and improvement while adhering to a numerous international standards.

Mitsubishi Electric's IGBTs are also used in many other applications including:

- Traction Motor Control
- Uninterruptable Power Supplies
- Induction Heating
- Solar Inverters
- Electric Vehicle Motor Drives



Mitsubishi Electric manufactures its own IGBTs (up to 6.5 kV). Mitsubishi Electric's reliable and proven IGBTs are being used in many FACTS and HVDC, and other heavy industrial/utility applications today.







Half bridge construction with a parallel IGBT connection per pair.



Each sub-module contains a capacitor, a pair of IGBTs and a diode. When one pair is turned on, the capacitor is placed in series with the arm circuit. When the other pair is turned on, the submodule is shortcircuited by a bypass switch, applying no voltage to the arm.

MODULAR MULTI-LEVEL CONVERTER (MMC) TECHNOLOGY OVERVIEW

Over the past 40 years, Mitsubishi Electric has made numerous technological advancements in the development of high performance power electronics based systems. These innovations include converter development, valve design, power semiconductor technology and optimal control techniques. All of these improvements have resulted in:

- Higher Operating Efficiencies
- Lower Transmission Losses
- Compact System Sizes
- Lower Operating Costs

Mitsubishi Electric's technology includes next generation Voltage Sourced Converter (VSC)-based HVDC systems that use the latest Modular Multi-Level Converter (MMC) topology which includes the industry's most reliable IGBTs.

Key components for VSC-based HVDC systems are designed, manufactured and tested at Mitsubishi Electric facilities in Japan. These robust devices are reliable, efficient and cost-effective. IGBTs are then assembled into sub-modules and subsequently into valves that are tested to meet IEC 62501 and other appropriate standards.

Along with manufacturing IGBTs used in power electronics system design, Mitsubishi Electric also designs and manufactures the cooling system, DC capacitors, and control system used in its HVDC systems, further ensuring system quality.

HVDC VERIFICATION FACILITY ESTABLISHES MELCO AS A VSC-HVDC TECHNOLOGY LEADER

MITSUBISHI ELECTRIC POWER PRODUCTS, INC.



Mitsubishi Electric successfully constructed and commissioned a fully functional back-to-back HVDC facility at its Itami Works campus near Osaka, Japan. The station was put into service in November 2018, and is available for customer visits.

The station serves as a true demonstration facility because it can be used to perform a series of performance tests on the HVDC system and results can be recorded and verified. Examples of these tests include AC and DC fault tests, heat runs, and harmonics and loss measurements. The converter's DC bus has additional impedance components that can be inserted to emulate a DC line characteristic for point-to-point HVDC applications as well.



One-Line Diagram of HVDC Verification Facility



Visitors will receive a full tour of the facility and get a firsthand look at Mitsubishi Electric's state of the art HVDC power electronics in addition to the other critical components that make up the HVDC system.

The tour agenda can be tailored toward the customer's interests and priorities, such as technology education or discussing power system needs and concept projects.





ITAMI HVDC VERIFICATION FACILITY KEY STATS

RATING	VALUE
Active Power	50 MW
Nominal DC Voltage	+/- 21 kV
DC Current	1190 A
Comissioned	November 2018

TURNKEY SOLUTIONS FOR ELECTRIC POWER TRANSMISSION

MITSUBISHI ELECTRIC POWER PRODUCTS, INC.



Mitsubishi Electric Corporation designs, manufactures, installs and maintains a full range of reliable and efficient substation systems and equipment for electric utilities worldwide. The company also supplies primary components and spare parts from its manufacturing facilities worldwide.

The company's quality assurance and continuous improvement program offers detailed guidance related to engineering procedures, materials handling, tool calibration, assembly, workmanship evaluation, testing and reporting.

For more than 40 years, Mitsubishi Electric has been a leader in the development, design and production of high-performance power electronics-based systems. The company's Voltage-Sourced Converter (VSC)-based High-Voltage Direct Current (HVDC) systems use the latest Modular Multi-Level Converter (MMC) configurations. These systems also feature the most reliable Insulated-Gate Bipolar Transistors (IGBTs). Mitsubishi Electric manufactures those components, assembles them into sub-modules and converter towers, and tests them to meet IEC 62501 and other requirements.

Mitsubishi Electric's value-added services include:

- 24/7 Telephone Support
- Aftermarket Service
- Diagnostics & Monitoring
- Equipment Testing
- Health & Safety Management
- Logistics
- Planning/Studies
- Project Management
- Site Management
- Systems Integration

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for a greener tomorrow

