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SPECIAL REPORT FOR SC B4

C.WINTER J.DORN S.XU V.PATHIRANA

Special Reporters

J.HU – Chair
R.OSTASH – Secretary

Cigre Study Committee (SC) B4 is responsible for advancing and applying the technologies of DC and Power electronics in both transmission and distribution systems as well as DC Converters for the integration of distributed renewable (PVs) and energy storage, to provide the reliable power integration, transfer, operation and quality.

A total of ninety-nine (99) papers including five (5) NGN papers were selected based on the preferential subjects chosen by the SC B4 for the 2024 session as listed below. In some cases, the preferential subjects have been further broken down into subcategories to identify common themes. These papers represent the latest information on many aspects of DC and FACTS technologies, applications, and operations.

PS 1 DC Equipment and Systems

- PS1.1: Planning, design, performance, testing and commissioning of DC equipment and systems including point to point, multiterminal and DC grids, especially offshore DC systems.
  - PS1.1-1: LCC & Hybrid HVDC
  - PS1.1-2: VSC HVDC
  - PS1.1-3: Offshore HVDC
  - PS1.1-4: Multi-Terminal & DC Grids
- PS1.2: Refurbishment and upgrade of existing DC systems.
- PS1.3: Service and operating experience of DC converter stations and systems, especially VSC based DC systems and offshore DC systems.

PS 2 FACTS and Power Electronics

- PS2.1: Planning, design, performance, testing and commissioning of FACTS and other PE devices including inverter-based generation.
  - PS2.1-2: STATCOM & SVC
  - PS2.1-2: Other Power Electronic Devices
- PS2.2: Refurbishment and upgrade of existing FACTS and other PE devices.
- PS2.3: Service and operating experience.

PS 3 New Technologies and Concepts of DC and FACTS Enabling Energy Transition

- PS3.1: New technologies/concepts to address network issues associated with green energy transition such as application of grid-forming converters, multi-vendor interoperability.
  - PS3.1-1: Modeling & Analysis
  - PS3.1-2: Network Integration & Application
- PS3.2: New Concepts, Technologies and design of DC converters and PE devices for both transmission and distribution systems including interfacing generation and storage to the network, energy hubs/islands, etc.

cwinter@mnpower.com joerg.dorn@siemens-energy.com 9231711@qq.com vajira.pathirana@patternenergy.com

PARIS GROUP DISCUSSION MEETING (GDM)

You are invited to participate in discussing this Special Report at the Study Committee B4 Group Discussion Meeting (GDM) on ***August 29th, 2024, from 9 AM to 6 PM, in the Grand Amphithéâtre*** **(Level 1)** at the Palais de Congress de Paris.

Contributors are encouraged to submit proposed presentation material by *Saturday 3rd August 2024* at the latest. The prepared contributions should consist of a PowerPoint presentation with a maximum of 3 slides and a written contribution in Word format of a maximum of 1000 words per contribution. A guide for contributors as well as templates and sample pages will be available on the CIGRE 2024 Session website. Proposed contributions should be uploaded on the Registrations platform – "Contributions to Group Discussion Meetings" section - via the user's existing account and credentials.

It is important to note that:

- *Access to the uploading of contributions is given only to duly registered delegates.*
- *As a consequence, registration to the CIGRE 2024 Session should be finalized before uploading contribution(s) online.*
- *The system will be open for uploading contributions from **early June 2024**.*

The Special Reporters will review contributions for readability, technical/scientific content (no commercial information is allowed) and relevance to the questions posed in this Special Report. Any recommendations or changes to the contributions will be provided to the contributors by the Special Reporters between ***3rd of August and 16th of August 2024.*** Contributors are encouraged to visit their account on the Registration Platform to see the result of this review. **Final versions of the contributions must be submitted by *Sunday 18th August 2024***. Contributions received after the deadline will not be considered for presentation at the GDM.

On ***Wednesday, August 28, 2024, from 10AM-Noon and 2PM-4PM,*** all accepted contributors must meet with the Special Reporters in ***Room 233 (Level 2) at the Palais de Congress de Paris*** to finalize presentation arrangements including the final details of their contribution and the latest instructions (such as schedule).

There will be the opportunity for spontaneous contributions during the session, which will only be verbal with no slides. Attendees who provide a spontaneous contribution are encouraged to summarize their contribution as a short written response for the Proceedings. This text is required to be forwarded within two weeks after the SC B4 Session by ***Thursday, September 13th, 2024*** to be considered in the proceedings, this should be sent to cwinter@mnpower.com and joerg.dorn@siemens-energy.com.

POSTER SESSION

Authors of SC B4 Session papers are required to present their papers during the **SC B4 Poster Session scheduled for Wednesday 28th August (16:00 to 18:00)** in Halle Ternes on level 1. Template and instructions on poster preparation are available on the CIGRE 2024 Session website. Posters will be displayed on digital screens. **A draft copy of the poster must be uploaded to the ConfTool platform by Wednesday 31st July** for review by the poster session conveners. A final version, incorporating any requested changes, must be uploaded by **Friday 16th August 2024**. It should be noted that authors will **not** have the possibility to upload their own file on the day of the Poster Session. If the author(s) cannot attend the Poster Session he/she or the relevant National Committee is requested to send a substitute.

PS 1 – DC Equipment and Systems

PS1.1-1 – LCC & Hybrid HVDC planning, design, performance, testing and commissioning

Paper B4-10191 "Development and Engineering Application of Controllable-Line-Commutated Converter for HVDC"

The paper presents the technology development and a practical application of a novel controllable-line-commutated converter (CLCC) technology, a hybrid application of IGBT with thyristors. The paper covers how commutation performances can be improved by adding IGBTs and thereby allowing forced commutation of the bridge arm current. The introduced concept includes a configuration with of a main branch and an auxiliary arm consisting of thyristors and IGBTs. The commutation process during normal mode and under AC fault conditions are clearly explained. The improvements in commutation failure performance are demonstrated by tests and on- site measurements from a real project with multi-infeed region of East China power grid.

Paper B4-10193 "System Design and Control Strategy of Baihetan-Jiangsu ±800kV Hybrid Cascaded UHVDC Transmission"

The paper proposes an HVDC transmission system consisting of LCC on the rectifier side and a combination of LCC valves and three parallel VSC MMC valves on the inverter side. The topology is described, and a switchable energy dissipation device based on arresters is introduced. Strategies for control, start-stop, valve switching, and FRT are presented and selected off-line simulations are discussed.

Paper B4-10194 "Research and application of new technology and equipment for Baihetan-Jiangsu ±800 kV UHVDC project"

The paper describes new aspects of the Baihetan Jiangsu project. This includes the switchable energy dissipation device connected to the VSC part, its operating principle, type tests, an adapted converter tower design, and control measures to suppress harmonics on the inverter side.

Paper B4- 10196 "Series Connected Multi-terminal LCC UHVDC Transmission -- System Studies for Jinshang-Hubei ±800 kV Project"

This paper describes a series connected multi-terminal LCC HVDC transmission system in China. The configuration is special since the two series converter valves at one end are located at two geographically separate locations. The paper describes the approach taken in the design and the various technical challenges associated with such a series valve design.

Paper B4-10538 "LCC UHVDC System Improvements, with a novel Converter Transformer Configuration."

This paper provides an overview of an extended delta converter transformer configuration for application in LCC UHVDC systems, including physical & electrical configuration and performance considerations.

Paper B4-10601 "Labrador Island Link Overload Design Considerations"

This paper describes design and maintenance considerations to achieve the over-load requirements of the Labrador Island Link (LIL) in Canada to improve the reliability in the event of a pole trip. The link is designed to operate up to 2.0 per unit for 10 minutes and 1.5 pu continuously. The paper describes various considerations related to main circuit equipment, other equipment including auxiliaries and electrode stations to achieve the overload ratings.

Paper B4-10772 "A HVDC 800 kV link, enlarging regional interconnection, to increase the utilization of variable renewable generation"

This paper provides details of system studies planning concept, and main technical parameters of a ± 800 kV, 5 GW, HVDC LCC scheme in Brazil. The link will be arranged in bipolar configuration with close to 1,500 km long overhead transmission line connecting the Northeast region to the Southeast region in Brazil. The paper includes details of studies carried out to evaluate system performance using steady state to phasor-domain transients and EMT simulations. A special feature of the link is the need for installing synchronous condensers at both converter stations.

Paper B4-10773 "Crustal Conductance - an Index for the Estimate of the Minimum Electrode Size and Electrode - Converter Substation Distance."

This paper provides an overview of experience with ground electrode design in the Brazilian power system and proposes a methodology for anticipating the design of ground electrodes during HVDC project planning.

Question 1.1:

Several papers propose improved LCC or hybrid LCC and VSC converters. MMC-based VSC technology has reached a high level of maturity with additional features compared to LCC, achieving power ratings in the range of 3-5 GW or more and losses around those of LCC.

a. For which applications and circumstances is LCC still relevant for new HVDC projects?
b. What advantages can be expected from LCC and improved LCC topology schemes compared to pure MMC-VSC based converters that may be connected in parallel to realize DC currents above 4 kA?

Question 1.2:

With increasing numbers of HVDC projects including both LCC and HVDC connected to the same synchronous grids, are there still concerns with multi-infeed impacts? What is the experience with integrating independent VSC and LCC HVDC systems together into the grid in proximity with one another?

PS1.1-2 – VSC HVDC planning, design, performance, testing and commissioning

Paper B4-10407 "Application of Harmonic Loci-Based Control Design in Frequency and Time Domain for a Consistent Design of VSC HVDC Harmonic Active Solutions"

The paper describes the possibility of performing stability analysis using the Loci method. With this approach, intermediate control designs could be quickly verified. The method is illustrated by a case study applied to HVDC.

Paper B4-10492 "Safe test method for staged ground faults on a VSC-HVDC overhead line"

The paper describes the successful testing of the implementation of a staged ground fault in the Swedish HVDC South West Link project, which is based on two independent symmetrical monopoles (+/-300kV HVDC OHL). The test method is based on a dropable weight. Technical challenges, test procedure details and test design are discussed.

Paper B4-10493 "Verification of DC-line fault recovery performance on a VSC-HVDC with a staged ground fault test"

This paper deals with two different DC line fault recovery tests on the South West Link in Sweden. The tests which were performed between DC and ground of a symmetrical monopole have demonstrated the expected performance.

Paper B4-10623 "New VSC-HVDC Interconnection Between the Iberian Peninsula and Balearic Archipelago to Enable Energy Transition."

This paper provides a high-level overview of technology enablers and challenges for the decarbonization of the Balearic Archipelago, with particular focus on a new VSC-HVDC link to the Iberian Peninsula.

Paper B4-10731 "The experience of the Power Oscillation Damping Study based on the hybrid simulation method for Bukdangjin 2nd project in South Korea."

This paper describes hybrid phasor domain transient (PDT) and electromagnetic transient (EMT) simulation studies completed for the Bukdangjin HVDC system in South Korea to tune and assess the performance of the power oscillation damping (POD) control function.

Paper B4-10905 "The Greenlink Interconnector – A new 504 MW HVDC Interconnector"

This paper provides Details of the Greenlink Interconnector, which is a +/-320 kV, 504 MW VSC HVDC link set to be commissioned and in operation by the end of 2024. The paper provides a summary of key technical parameters of the HVDC link including the overload ratings and ancillary services. It also demonstrates the key benefits provided by this link to the transmission system operators in both Ireland and Great Britain.

Paper B4-11100 "A classification framework for HVDC-based transmission grid architectures"

The paper describes a framework for classifying HVDC-based transmission grid architectures that provides a systematic categorization to support understanding and planning of complex AC/DC grids. The paper outlines how the suggested approach would facilitate information exchange, define test systems, and allow specifications to be developed for various categories.

Paper B4-11152 "Switching Voltage Capability of Air-Core Dry-Type VSC Converter Reactors"

This paper describes switching voltage withstand capability of low inductance air core dry-type reactors used in both ac side and dc side of VSC converters and introduces a series of switching impulse tests and corresponding test results to demonstrate the withstand capability. The proposed test method and results can be considered as a reference for typical tests of such air-core dry-type reactors.

Paper B4-11433 "Overvoltages experienced by Metallic Return Cables in Bipolar HVDC Configuration"

This paper investigates overvoltages on dedicated metallic return cables in bipolar HVDC schemes. It describes a parametric study performed to investigate overvoltages levels on metallic return cables of such bipole schemes. The paper reveals that overvoltages levels are strongly related to the design of the converter station, the grounding concept of the neutral bus and the design of the neutral bus surge arresters. The results of the paper provide information relevant to the insulation coordination of metallic return cables.

Paper B4-11455 "Insulation Coordination Criteria of VSC-HVDC Overhead Power Lines in Colombia Considering Climatic and Environmental Conditions"

The paper discusses a methodology for calculating lightning overvoltages in HVDC systems based on OHL transmission used for insulation coordination design. Simulations have shown that for the studied case of the Colombian region, with special environmental conditions and high probability of lightning strikes, the pole-to-tower voltages reach values several times higher than the nominal values. It also indicates a high risk of back-flashover in the HVDC line for the case studied.

Paper B4-11903 "Integrated Design Scheme of VSC-HVDC System for 10GW Large-Scale New Energy Ultra-long-distance Transmission."

This paper discusses an integrated design scheme for a Voltage Source Converter High Voltage Direct Current (VSC-HVDC) system for ultra-long-distance transmission of large-scale new energy, specifically targeting a 10GW capacity.

Question 1.3:

VSC based technology has become the first choice for new HVDC projects or upgrades. The number of current and future projects has increased dramatically, forcing the need for a minimum feature set required in HVDC systems. For grid access in Europe, a standard has been set based on 525 kV bipolar with DMR and a capacity of 2 GW. However, there is still room for harmonization and reduction of requirements between different TSOs in order to accelerate the project execution times, reduce costs, and the path to faster CO_2 reduction.

a. How can minimum functional requirements be derived for standardization of VSC HVDC converters, and what accelerations can be expected?
b. What are the challenges in operating such systems?
c. Is there a need to define further standard designs, e.g. for 1000 MW or 3000 MW?

Question 1.4:

VSC based HVDC schemes have traditionally been mostly limited to submarine and/or underground cable-based transmission (other than Caprivi Link), however several overhead line-based projects including hybrid overhead-cable transmission projects are also planned or in operation now. One of the main disadvantages of half bridge VSC based HVDC schemes is their fault ride through performance compared to a LCC based scheme, however overhead transmission provides several advantages including higher power levels and lower cost. The cost and operational experience of HVDC breakers are concerns for the planners for making these decisions. Obtaining environmental approvals for overhead line projects is also a major challenge.

a. What are the main challenges for selecting overhead line as transmission medium for VSC based HVDC projects and how can those issues be minimized with innovative approaches?
b. Fault clearing and restoration times with half-bridge VSC are one of the main concerns. Do we have enough operational experience with HVDC breakers to accept their performance at the additional cost?

PS1.1-3 – Offshore HVDC planning, design, performance, testing and commissioning

Paper B4-10142 "Technical-economic analysis of different HVDC transmission topologies for large offshore wind power connection."

This paper introduces four different topologies for large offshore wind interconnections and provides a comparison of their technical and economic attributes.

Paper B4-10521 “Modular offshore HVDC transmission planning principles”

This paper describes planning and design considerations for modular offshore platforms for HVDC converter stations. The paper mainly addresses the aspects to be considered for modularity and potential approaches for different topologies.

Paper B4-10523 “±525 kV 2 GW Bipole VSC-HVDC Offshore Transmission (TenneT Projects) - Key Design Aspects”

The paper describes a TSO's standardized 2 GW bipolar grid access system. A vendor's design details such as basic electrical layout, rated capacities, multi-terminal readiness, and basic layout at the offshore and onshore stations are explained and described.

Paper B4-10835 “Expansion planning of offshore HVDC grids considering protection system design.”

This paper presents an in-depth analysis and methodology for the planning and expansion of offshore HVDC grids, with a particular focus on the impact of protection system design on grid development.

Paper B4-10883 “Generic EMT study of short circuit current and TOV for the design of a DC link.”

This paper presents an in-depth analysis of DC transient overvoltage and short circuit current for HVDC system design, aiming to assist in standardizing technical specifications for HVDC projects and considering various parameters that may impact system design.

Paper B4-11589 “Sunrise Wind: USA’s first HVDC connected offshore wind farm.”

This paper provides an end-to-end description of the Sunrise Wind Project, including key design and performance considerations, optimization of the project for interconnection to the Long Island power grid, and challenges specific to adapting offshore wind technologies to North American grid requirements.

Paper B4-11751 “A Novel Methodology to Derisk HVDC and Offshore Wind Connections to a Network - GB Practice.”

This paper presents a systematic approach to managing the risks associated with integrating HVDC and offshore wind connections, particularly in the context of the UK's push for renewable energy integration.

Question 1.5:

Offshore wind farms play a major role in the pursuit to increase the world’s use of renewables and lower its carbon footprint. At higher power levels and beyond certain distances from the shore, HVDC becomes the only viable solution for bringing offshore wind power to the shore and to the grid. Apart from the installation and maintenance in harsh conditions and components needing to withstand extreme weather, the cost has become a major concern for offshore installations.

a. Standard design approach for offshore HVDC platforms introduced for certain projects in Europe can be considered as an initial step towards reducing costs. What other approaches can be suggested to bring the costs down?
b. Standard design has been optimized for a 2 GW bipolar system, however there can be disadvantages to limiting the design to 2 GW. What other considerations can lead to more cost optimized systems?

PS1.1-4 – MTDC and DC Grid planning, design, performance, testing and commissioning

Paper B4-10143 "EMT simulation of an MTDC system integrating Modular Multilevel DC/DC converter with DC voltage control."

This paper presents an MTDC test case integrating a DC/DC converter where the converter is working with a DC voltage controller and participating in the DC voltage management system. The influence of voltage-controlled DC/DC converter is studied by introducing power disturbances in the MTDC system.

Paper B4-10145 "A contribution to HVDC protection interoperability through components sizing margin evaluation"

This paper describes a method to evaluate the interoperability of a protection system identified as Fault Neutralisation System (FNS) in a multi terminal HVDC system. The dc fault clearing time and reactor size of the FNS components are tested considering a few typical scenarios. The main contribution is to present a generic method for interoperability testing of HVDC grids.

Paper B4-10192 "Key Techniques and Engineering Applications of ± 500kV High Voltage and Large Capacity DC grid Based on Voltage Source Converter with 100% New Energy."

This paper presents the DC grid techniques discussion, based on the Zhangbei ±500kV DC grid Project, including bipolar DC grid topology with DC breakers, the characteristics of DC line fault and converter fault, fault current limitation method and power surplus issue caused by new energy fault.

Paper B4-10363 "Innovative Design of a Reduced Scale Prototype for the New Multiterminal Italian HVDC Network with SiC-based HVDC Hybrid Circuit Breaker"

The paper presents potential modeling of HVDC systems with down-scaled low-voltage demonstrators. The first mock-up represents the SACOI3 HVDC multiterminal system including AC grids, three converter stations and cables, the second mock-up represents a DC circuit for analysis during fault clearing. The electrical behavior during DC faults is shown based on offline simulation.

Paper B4-10406 "Software-In-the-Loop Real-Time Simulation of a HVDC Terminal"

This paper describes a real-time black-box platform that allows HVDC OEMs to upload and run their control and protection software in real-time alongside the main real time simulator used for modelling the network and rest of the system. The proprietary control information is 'black-boxed' and ensures that intellectual property is not compromised in this process. The paper discusses the development approach undertaken to understand if the real-time software execution of a 'real' HVDC project control and protection system can be performed using this real-time black-box platform and includes results of some validation testing of the real-time black-box platform benchmarked against simulation results.

Paper B4-10689 "DC Circuit Breaker Feasibility Study – Protection System Design"

The paper outlines HVDC multi-terminal protection for extended network structures based on a case study in the UK. Together with TOTEX calculations it describes how different DCCB configurations can achieve compliance with AC system constraints (maximum acceptable infeed loss).

Paper B4-11116 "Assessment of Operational Challenges of HVDC Multi-Purpose Interconnectors with Low Short Circuit Levels."

This paper presents findings and recommendations from real-time simulations performed on a theoretical multi-purpose interconnector (MPI) system consisting of interconnected VSC HVDC bipoles, offshore windfarms and asynchronous AC grid interconnections.

Paper B4-11593 "DC/DC Conversion and Distributed Grid based Solution of HVDC Tapping"

The paper proposes a low-cost HVDC tapping solution for interconnecting decentralized power systems using an MMC diode bridge with DC/DC converter connected to a DC distribution system. A high-level description of the topology and control algorithms used is given, and case studies for normal operation and dynamic performance are presented.

Paper B4-11894 "Test procedures for ± 500 kV HVDC circuit breakers: how to assess their performances based on current world laboratory facilities"

Based on existing CIGRE and IEC documents, the paper proposes a general type test plan for a full-scale HVDC CB, considering the technical feasibility of test laboratories. It describes which tests to perform and how to perform them. It gives a recommendation on how to perform making and breaking tests and states that full-scale tests are preferable to downscaled tests to capture the full interaction between the components of the HVDC CB.

Paper B4-11904 "Phased Approach to MTDC: Proposed integration of DC Circuit Breakers in a DC Switching Station facilitating a partially selective protection scheme."

This paper summarizes an evaluation of four options for deploying the Mesh Corner, a square mesh arrangement of DCCBs, to enable integration of DCCBs when they reach sufficient technology readiness as well as possible next steps and recommendations for further or subsequent evaluations.

Question 1.6:

Several studies have been conducted on the realization of MT systems and DC grids. Protection concepts have been proposed and HVDC circuit breaker topologies have been tested or set in operation. However, there are very few studies that consider DC system aspects together with real converter design aspects.

a. What are the converter design and DC system implications of HVDC breaker performance, e.g., breaking time, di/dt limitations?
b. Which are the main technical challenges for the realization of such systems?
c. What requirements and limitations (e.g. limitations of protection devices) can be expected in terms of selectivity and converter ride through capability in case of DC faults?

Question 1.7:

DC systems are becoming increasingly diverse, and the systems are growing larger. Multi-terminal systems and DC grid projects are gradually increasing. There is a need to standardize the research of related technical issues and system design to promote progress.

a. What would be the best approach for multiple suppliers to work together collaboratively to standardize DC system design? What kind of contents should be part of the overall standardization of design and what is more dependent based on standards and regulations?
b. What kind of coordination and communication mechanisms should be set up to better promote the integration of multiple technologies and various equipment?

PS1.2 - Refurbishment and upgrade of existing DC systems.

Paper B4-10144 "Study and mitigation of DC harmonics on Corsica's SACOI HVDC-LCC station causing long unavailability, a case study."

This paper presents a detailed overview of investigations, including field measurements and EMT simulations, into repeated equipment failures caused by unexpected harmonics in an older LCC-HVDC link following a refurbishment of certain components.

Paper B4-10347 "A Staged Approach for Upgrade of the Square Butte HVDC System"

This paper provides details of the selected upgrade configuration for the Square Butte HVDC converter stations. The paper describes the main criteria, different challenges, various reasoning for choosing a certain configuration and the process followed in the selection of a particular configuration for the future upgrade. The paper includes details of a staged approach considered for replacing the ageing converter equipment to allow uprating the voltage and overall power rating from the current ±250 kV 500 MW, to an intermediate stage of ±262.5 kV, 900 MW and to eventually to a ±525 kV, 3000 MW link.

Paper B4-10600 "Two Approaches to HVDC IT System Replacement"

This paper describes approaches taken by two distinct utilities to replace IT systems in their HVDC systems. The two approaches demonstrate the trade-offs involved in extending the life of HVDC IT equipment, with one utility prioritizing minimal risk and cost savings through virtualization and the other utility focusing on enhanced reliability, reduced vulnerabilities and simplified management through comprehensive hardware and software upgrades. Each approach is taken based on each utility's risk tolerance, economic considerations, and long-term cybersecurity procedures.

Paper B4-10602 "Hydro-Québec's Chateauguay Back-to-Back HVDC Converter Replacement Project: Integration of New Operating Modes for System Resiliency Improvement and Water Management Effectiveness using VSC Technology."

The paper describes the replacement Chateauguay back-to-back HVDC station, which is unusual in its use of VSC and its extremely high AC voltage levels. The operational benefits of the choice of VSC technology are explained and various modes of operation are also identified that are demonstrated with the help of simulations.

Paper B4-10964 "Refurbishment of the control and protection system devices and thyristor valve modules in the 300 MW Shin-Shinano No.2 Frequency Converter."

This paper introduces features and considerations in the refurbishment for the control and protection system and thyristor valve modules of the Shin-Shinano No. 2 FC, including multi-vendor coordination and thyristor technology improvements to enhance reliability.

Paper B4-11077 "Refurbishment and System Test of High Voltage Converter Unit 3 (HVCU3) at Vyborg Back-to-Back HVDC Link"

This paper describes the details of the refurbishment of High Voltage Converter Unit 3 (HVCU3) at Vyborg Back-to-Back HVDC Link in Russia and the system tests carried out during commissioning. The refurbished system includes some additional protection functions that have been tested successfully.

Paper B4-11655 "Challenges, Design Considerations & Field Studies for Relocation of Earth Electrode Station- User's Perspective."

This paper provides a comprehensive overview of the process of relocating an Earth Electrode Station for an HVDC link, emphasizing the importance of geophysical investigations and detailed design considerations to ensure the safe and efficient operation of the HVDC system.

Question 1.8:

Refurbishment and upgrade projects range in size and complexity from individual component replacements to full system replacement with new and updated technologies. Determination of the appropriate timing, scope, and scale depends on many factors.

a. What are the most important factors when considering timing, scope, and scale for different types of refurbishment projects for existing HVDC systems?
b. With continued acceleration of technological advancements for HVDC system components, will refurbishments of existing systems become less attractive compared to full replacements?
c. What other experiences are there with techno-economic analysis of HVDC system refurbishments and upgrades, and how do they confirm, modify, or expand upon the findings from the papers submitted for this session?

PS1.3 – Service, maintenance, and operating experience of DC converter stations and systems.

Paper B4-10547 "Health Monitoring Approaches for High Voltage Capacitors in Power Converters"

The paper gives an overview of the different options for on-line monitoring of the condition of power capacitors in high power converters. The determination of two parameters, capacitance and dissipation factor, for monitoring is discussed.

Paper B4-10609 "Survey of the Reliability of HVDC Systems Throughout the World During 2021-2022."

This paper provides a summary of the reliability performance of HVDC systems in operation worldwide during 2021 and 2022. It contains data on energy availability, energy utilization, forced and scheduled outages and other data in accordance with a reporting protocol developed by the Advisory Group.

Paper B4-10729 "Development and Application of HVDC Analysis System for Improving Operational Reliability"

This paper describes a database driven analysis system that supports fast analysis of disturbances and facilitate the monitoring of HVDC system operation. The paper explains how the HVDC Analysis System has been able to demonstrate significant advancements in enhancing the operational reliability of HVDC systems by providing prompt fault analysis and pro-active diagnostic information thereby reducing the average fault analysis time by about 77% for the Jindo-Jeju BP2 HVDC link. The paper includes some description of the architecture and the main parameters of the HVDC Analysis System.

Paper B4-10961 "Measures to secure the lifetime of an LCC based HVDC link with potentially aged cable."

This paper presents the problem of premature cable failures in an LCC DC link between Norway and the Netherlands, along with innovative short-term and long-term solutions for lowering cable stresses and reducing the risk of further cable failures.

Paper B4-11169 "Advanced Maintenance Recommendation for HVDC and FACTS Air-core Dry type Reactors"

The paper describes recommended monitoring and lifetime maintenance practices for large air-core reactors which are an essential element in HVDC and FACTS technology.

Paper B4-11628 "HVDC Valve Hall Fire Incident: A Case Study at Al Fadhili HVDC"

This paper describes the fire incident that occurred a few years at the Al Fadhili HVDC back-to-back converter station and highlights the importance of HVDC system operation, maintenance, and fire protection. The paper explains the reason behind the fire incident and highlights the necessity of having strategic spares readily available, enabling the prompt replacement of damaged components with minimal downtime. The paper provides useful recommendation for operation of HVDC converter stations.

Paper B4-11645 "Dynamic Performance of Dual HVDC Terminals (±800 KV LCC and ±320 KV VSC) at common AC busbar- Operational Experience."

This paper presents the operational dynamics and performance of dual HVDC systems connected to a common AC busbar, highlighting the successful integration and operation of LCC and VSC different HVDC technologies in the Indian power grid.

Paper B4-11657 "Operational Experience on the Black-Start Exercise of VSC-Based HVDC System in Southern Regional Grid of India"

The paper deals with a real black start test of an MMC-based HVDC in India. It describes the system investigated and the procedures used. Both black start without load and black start with load have been investigated and analyzed. For the case of black start with load, the challenges related to power surges and frequency drop are discussed.

Paper B4-11688 "Addressing operational contingencies faced in parallel Operation of ±800 kV 6000 MW Champa Kurukshetra HVDC Link"

This paper illustrates operational challenges faced in parallel operation of Champa Kurukshetra HVDC link and discusses different mitigation strategies assumed to handle those challenges. The paper provides some potential advice that can be used for future HVDC projects that would require integration of bipole converters in parallel to an existing bipole HVDC scheme. The paper advices how such challenges can be addressed during design stage and commissioning stage.

Paper B4-11689 "Evolving of protection strategies for DMR Faults in the Champa Kurukshetra HVDC Link: Optimization Approaches and Operational Considerations"

This paper is an attempt to introduce fault detection techniques and fault clearing strategies for faults on DMR lines of Champa Kurukshetra HVDC link. The advantage and disadvantage of each approach are generally analyzed and plots from a real example are included in the paper to show effectiveness of the approach.

Question 1.9:

The monitoring of the health status of equipment in DC transmission systems is increasingly gaining attention. The monitoring result should help owners to judge the health status of the equipment and decide when it is necessary to replace or upgrade. Such practices can extend the life of equipment and identify issues faster such that the downtime of the system can be minimized.

a. What are the biggest obstacles for obtaining data and assessing the health index of a major equipment within a converter station?

b. What kind of sharing mechanism should be established to promote the data of equipment operation health status in the power transmission industry? For example, a batch of typical VSC HVDC project's IGBT, capacitors, and other health status data should be provided every 5 years.
c. Can the industry move into an Artificial Intelligence based advanced monitoring systems to correctly predict potential failures and take actions in advance?
d. What additional steps can the HVDC community take to share knowledge such that unexpected failures of major equipment can be avoided?

Question 1.10:

Paper 11628 describes a HVDC valve hall fire incident that damaged the valves. HVDC valves and other components within valve halls are designed with fire risks in mind, however such incidents still occur, although rare.

a. What additional design aspects than what is already considered, and different maintenance practices would help reduce such fire risks further?
b. Is it safe to only rely on VESDA systems to detect such incidents? Should we consider different technologies?
c. How should the Owners account for additional spare parts for such rare events which could have high consequences?

Question 1.11:

VSC technology has been used for offshore windfarm interconnection for more than 10 years.

a. What are the operational and maintenance experiences of offshore VSC HVDC systems?
b. Taking into consideration the special conditions of offshore converter stations on platforms, what is the estimated lifetime of these stations? What kind of special care should the owner take when compared to regular onshore converter stations?

PS 2 – FACTS and Power Electronics

PS2.1-1 – STATCOM & SVC Planning, Control, Protection, Operation, Design & Performance

Paper B4-10603 "Application of Large STATCOMs for Dynamic Reactive Support in California 500kV Series Compensated Transmission System."

This paper presents a comprehensive overview of the technical and engineering considerations on the application of large Static Synchronous Compensators (STATCOMs) to enhance the dynamic reactive power support and voltage stability of California's high-voltage transmission system.

Paper B4-10777 "Hunting Issues in the Brazilian Interconnected Power System – A Case Study of Multiple SVCs."

This paper highlights concerns of uncoordinated operations and control instabilities impacting electrically-close existing and planned SVCs in the Brazilian power system and presents results from control interaction simulation studies and mitigations.

Paper B4-11603 "Control strategies for parallel operation of STATCOMs – Securing grid stability for bulk renewable energy transmission."

The paper describes the design and some special aspects of a reactive power support system integrated into the Indian grid. This system includes two STATCOM branches and mechanical switched capacitors and reactors. Special design aspects such as parallel operation of the STATCOMs, redundancy, AC fault behavior and test results are discussed. It shows how such

systems can mitigate grid disturbances in transmission systems with high levels of renewable energy generation.

Question 2.1:

There are many STATCOM installations with parallel branches worldwide. What are the design challenges and operational experiences of these systems?

PS2.1-2 – PE and other FACTS Planning, Control, Protection, Operation, Design & Performance

Paper B4-10197 "220kV Direct-connected Static Synchronous Series Compensation and the First Demonstration Application in China."

This paper provides an overview of key technical considerations and performance of a direct-connected static synchronous series compensator (DSSSC) developed to provide flexible power flow control capability in the Chinese power grid.

Paper B4-10199 "Design of hybrid active AC filter scheme in Min-Yue back-to-back DC Project"

The paper describes the design of a hybrid active filter used in an LCC back-to-back system. Design aspects of the active filter, its integration into the system and two different types of control (current control and impedance control) are described.

Paper B4-10200 "Key Technologies and Engineering Application of Distributed Power Flow Controller."

This paper describes a distributed power flow controller (DPFC, also known as SSSC) application in China with particular focus control system design, simulation and field testing for two key control and protection functions: AC relay coordination and submodule fault control coordination.

Paper B4-10627 "Transformer-coupled Static Synchronous Series Compensators for transmission and distribution operators, based on industrial-class converters."

This paper presents an overview of lessons learned from 10 years of operation of a transformer-based Static Synchronous Series Compensator (SSSC) demonstration project in Spain, including advances in technology since the original installation and discussion of advantages compared with newer transformer-less SSSC applications.

Paper B4-10880 "The Vectorized Approach: An Efficient Method to Model VSC Converters and its Verification Against Tests"

The paper describes an approach for simplified modeling of an MMC with the aim of reducing the offline simulation time of EMT. It shows the results obtained using detailed equivalent model and verification results against measurements on real hardware in the lab real and measurements cable energization tests during the commissioning of a real project.

Paper B4-10882 "Improved dynamic voltage control based on network sensitivity characteristics."

This paper provides discussion of theoretical concepts behind frequency-domain small-signal dynamic for the analysis and design of AC voltage controls, including comparison of the voltage control interactions and performance of different control strategies.

Paper B4-11212 "Subsynchronous Resonance Analysis for an M-SSSC FACTS Installation in the Atlantico Region of the Colombian Transmission System."

This paper describes torsional interaction and electromagnetic transients analysis to determine if there is a subsynchronous resonance (SSR) impact from the planned M-SSSC technology and how it compares to the SSR impact of a traditional fixed series capacitor.

Paper B4-11214 "Modular Static Synchronous Series Compensator (M-SSSC): EMT Modeling for Real Time and Offline Applications."

This paper presents an overview of a M-SSSC technology, its control and protection strategy, and an EMT model representation of it, along with several simulations from implementation of the model.

Question 2.2:

With increasing numbers of FACTS and inverter-based resources being integrated to the same systems, along with existing synchronous machines, the risk of subsynchronous interactions increases. What is the experience with performing SSR, SSTI, and SSCI studies in networks with large numbers of PE-based systems, particularly for STATCOMs, SVCs, and SSSCs in proximity to generators? Where issues have been identified, what has been the proposed solution?

Question 2.3:

Offshore islanded wind power plants connected to the onshore power grid network using VSC HVDC transmission utilize chopper-controlled resistors installed at pole level to limit the DC line over-voltage when there is a fault on the onshore AC grid and power transfer to the grid is obstructed. Onshore islanded power plants connected using VSC HVDC transmission may instead utilize chopper-controlled resistors installed on AC side of the converters to support wind power ride through for a fault on the receiving side or pole to ground fault. These choppers can use different power electronics devices based on the application.

a. How can such choppers be included in the studies (when mature models are not readily available) and then the requirements can be identified in technical specifications?
b. Can there be alternative approaches to chopper-controlled resistors to allow ride through capability for islanded wind or solar power plants?

PS2.3 – Service, maintenance, and operating experience of FACTS systems

Paper B4-10765 "The Analysis of SSR between TCSC and Synchronous Generator using Real-Time Digital Simulator and TCSC Replica."

The paper describes the use of real time simulation and replica control systems for investigation of potential for SSR issues under multiple contingency situations due to TCSCs installed in the KEPCO system.

Paper B4-11213 "Operation of Static Synchronous Series Compensators integrated into the Colombian Power System: Challenges, Experiences and Lessons Learned."

This paper presents insights into the practical application and challenges of operating SSSC technology in a power system, specifically within the context of the Colombian power system, and offers lessons learned for the secure, reliable, and economic operation of the electric grid.

Paper B4-11476 "Reflection on applicable standards and learnings from actual failures of power inverters."

This paper presents experiences and learnings obtained from several case studies involving solar PV inverter failure investigations which identified root causes across the lifecycle of design, manufacturing and installation. The paper includes a review of available standards and recommends further development of common power inverter design and testing standards to increase overall reliability.

Question 2.4:

The need for power electronics-based power flow controllers like TCSC and SSSC is growing as the power system becomes more variable and complex. TCSCs have been in operation for over three decades, while SSSC applications have been growing significantly over about the last decade.

a. How do the performance benefits, costs, and lifecycle considerations for TCSC and SSSC applications compare?
b. What is the experience with performance, operation, and maintenance of TCSC and SSSC applications as they age?
c. What technical improvements may be considered for these systems when designing a control system upgrade or refurbishment?
d. For the hardware components of these systems, is it feasible to retrofit with new and updated technologies or will they typically be decommissioned replaced with completely new systems when they reach end of life?

PS 3 – New Technologies and Concepts of DC and FACTS Enabling Energy Transition

PS3.1-1 – Modeling & Analysis for new technologies/concepts to address network issues associated with green energy transition

Paper B4-10201 "Oscillation Analysis of Renewable Energy Generation Integrated into MMC- HVDC system through Islanded and Grid-connected Modes"

This paper presents a small signal and harmonic impedance modeling to verify possible interaction between power electronic devices. It provides investigations on impedance analysis derived by mathematical calculations and EMT simulations for both, grid connected mode (PQ) and islanded mode (V/f) connecting renewable energy generation. These investigations are compared with HIL tests showing oscillation risks for both modes.

Paper B4-10348 "Modeling, Analysis, and Control of an Islanded Grid-Connected RES-Hydrogen DC Microgrid with Floating Solar Integration."

This paper introduces the underlying theoretical computational concepts for a DC microgrid designed specifically for marine port power system applications to reduce reliance on carbon-based resources by combining diverse energy resources and technologies.

Paper B4-10557 "Analysis of Converter Interactions in HVDC systems"

This paper presents a methodology for conducting interaction studies within a network comprising multiple HVDC-connected offshore wind plants. The paper particularly considers events that leads to large disturbances.

Paper B4-10605 "Application of Synchronous Grid Forming Back-to-Back HVDC System for System Frequency Support"

This paper describes studies performed to evaluate application of a synchronous grid forming back-to-back HVDC system (SGFM-HVDC) on the Montana-Alberta Tie Line (MATL) in Canada. The paper investigates the benefits of frequency support under weak network conditions, as well as reactive power support when HVDC system operates in STATCOM mode.

Paper B4-10624 "Development of an EMT model of the Balearic power system."

This paper describes considerations and challenges in the development of an electromagnetic transient (EMT) model of the Balearic Archipelago power system to enable detailed integration and performance studies of many types of technologies implemented as part of decarbonization efforts in the region.

Paper B4-10626 "Performance of Generic grid forming RMS models under standardized test contingencies."

This paper investigates the effectiveness of generic grid-forming models for RMS and EMT analysis by comparing performance across a set of standardized test simulations.

Paper B4-10667 "Experimental validation of the General Power Theory using Power-Hardware in the Loop - opportunities for new converter controls."

This paper presents the experimental validation of the General Power Theory (GPT) using Power Hardware-in-the-Loop (PHIL) for new converter controls, and highlights the potential benefits of GPT for improving the efficiency and control of power systems.

Paper B4-10836 "Model-based systems engineering for HVDC grids – state-of-the-art and future outlook."

This paper presents the application of Model-Based Systems Engineering (MBSE) in the design of High Voltage Direct Current (HVDC) grids, and emphasizes the potential of MBSE in HVDC system design, especially in multi-vendor and expandable system environments, and suggests future challenges and possible research directions that need to be addressed in this field.

Paper B4-10838 "DC System power quality and stability assessment and management: method, simulation, and on-site validation."

The paper presents an overview of several equivalent circuit approaches for modeling and evaluating multi-timescale stability problems in DC distribution systems.

Paper B4-10863 "Analysis of Power Oscillation Damping Performance in Grid-forming VSC HVDC System."

This paper describes basic theory behind power oscillation damping and grid-forming controls and presents results from simulations comparing the performance of grid-forming and grid-following VSC HVDC controls for power oscillation damping in a representative power system.

Paper B4-11272 "A study on the mitigation effect of hybrid STATCOM system on low inertia and voltage regulation issue."

The paper presents simulation results for a Hybrid STATCOM (H-STATCOM) concept, which combines a synchronous condenser and a STATCOM under a coordinated master controller, to address the challenges of low inertia and voltage regulation issues arising from increased renewable energy penetration.

Paper B4-11902 "Stability Analysis and Mitigation of Power Oscillations Between Parallel MMC-HVDC Connections Operating in Grid-Forming Mode in Offshore Energy Hubs."

This paper describes a cross-coupling virtual impedance to couple the internal voltage to the changes in the current in the control loop to prevent instability without adding dynamics or requiring complex tuning for parallel HVDC converters operated in GMF mode.

Question 3.1:

Several papers deal with the development and verification of EMT models for HVDC and FACTS systems and varying portions of the network they are interconnected to. As the presence of power electronics-based systems continues to grow worldwide and PE-based systems are integrated into the same networks, timely and accurate EMT modeling becomes increasingly important to ensure control systems are coordinated.

a. What are best practices for determining the appropriate size and complexity of EMT network models for performing studies on growing levels of inverter-based resources, HVDC, and FACTS devices?
b. Should EMT network models be maintained and updated on a regular basis, or should they be built from scratch for each new application? Who should be responsible for maintaining these EMT network models? How often should they be updated?
c. What are the most important considerations for individual PE-based systems to be standardized or "black-boxed" to facilitate better integration and modeling of systems from multiple vendors? Where would such standardized models be appropriate for system design and analysis, and where would they be insufficient?

Question 3.2:

Hardware-in-the-loop (HIL) simulation methods are very effective for testing the performance and functionality of power electronic equipment. However, these tests typically require the inclusion of a power grid system environment and may involve a large number of power electronic devices, resulting in a very large testing system.

a. Are there any new and effective technical methods that can simplify the testing system while ensuring the validity and accuracy of the tests? What are the new trends in the modeling and simulation techniques for power electronic systems?

PS3.1-2 – Network Integration & Application of new technologies/concepts to address network issues associated with green energy transition

Paper B4-10203 "Oscillation Suppression of Islanded Control for VSC-HVDC System with Large-scale Renewable Energy Integration."

This paper presents the research on the wide-range oscillation and suppression method in Zhangbei project, where the sub- synchronous oscillation (SSO) and high-frequency oscillation (HFO), range from 44Hz to above 3900Hz, were encountered in the project.

Paper B4-10408 "Dynamic Demand Control Applied to Synchronous Grid Forming Controlled HVDC"

This paper proposes a control mechanism that provides both power ramp tracking and a fast power recovery after fault clearance, without limiting the potential of Synchronous Grid Forming (SGFM) controlled converters. The paper includes description of time domain simulations performed to show the effectiveness of the proposed concept. The simulations consider different scenarios and grid-conditions, both strong and weak AC grids with high and low inertia constants.

Paper B4-10518 "Stability Enhancement of Weak Grids with High Penetration of Renewables with Grid-Forming STATCOM/Enhanced-STATCOM"

The paper deals with improving the stability by using GFM control of Statcoms connected to very weak grids with a high proportion of inverter-based generation. Statcoms without and with ultracapacitors are presented and their limitations are discussed. Simulations show the superior performance of Statcoms with ultracapacitors in such grids for very low SSO frequencies.

Paper B4-10744 "Grid Connection of Offshore Wind with Grid Forming Turbines."

This paper presents a comprehensive overview of the potential benefits and challenges of integrating grid-forming wind turbines into offshore wind farms, and how these technologies can impact system stability and control architectures.

Paper B4-11043 "Application of VSC-HVDC Dynamic Capacity: Technical, commercial and legal opportunities and challenges"

The paper defines the dynamic capacity of a VSC HVDC as temporary operation outside of the guaranteed capabilities in favorable conditions. It describes use cases and boundary conditions for different types of HVDC applications, focusing on technical, commercial, and legal aspects. Concerns related to limitations of this operation, as well as warranty and legal aspects are addressed.

Paper B4-11059 "DC Switching Stations with High-speed DC Breakers: Enabling Multi-vendor DC Grids"

The paper addresses some aspects of the DC switchgear of multiterminal systems: additional reactance, acceptable power loss in the AC grid, converter oversizing, effect of different CB opening times, DC switchgear topology considerations, main interdependencies between the function and performance of the DC switchgear and the design of the converters.

Paper B4-11597 "Energy Dissipation Strategies for Offshore MT-HVDC Systems."

This paper investigates different strategies for dissipating energy during fault-ride-through events in a multi-terminal high-voltage DC (MT-HVDC) system. The study is based on a 4 GW MT-HVDC grid model that connects Denmark, Belgium, and the Danish North Sea Energy Island.

Paper B4-11633 "DC Voltage Control Strategy for NEOM Multi-terminal HVDC Grid"

This paper describes DC voltage control strategy for a four-terminal HVDC system called NEOM Grid which consists of 100% renewable energy resources. The paper investigates control interactions between co-located converters, load demand uncertainty, and fault propagation through simulation studies and how the grid can be built to be resilient for N-1 and N-2 contingencies. The paper covers strategy for handling DC voltage control of the U-shape module for credible N-1 and N-2 contingencies.

Paper B4-11895 "Optimal Control Selection for Grid-Forming MMC-Based Assets: An analysis of interplay between GFM and internal MMC controls."

This paper contributes to the understanding of how different control strategies for MMC-based assets can impact the overall operation of the power system, particularly in the context of the energy transition and the increased integration of power-electronic assets into the grid.

Question 3.3:

Currently, grid-forming converters are being developed as standard for new HVDC projects and also increasingly for FACTS projects like STATCOMs (with or without energy storage). However, current grid code requirements and typical performance specifications have been

defined for grid-following HVDC and FACTS systems, which in some cases contradicts the philosophy of GFM behavior.

a. Is there a need for future HVDC, FACTS, and other PE-based systems to provide both GFM and GFL control modes and what are the implications for converter and system design?

b. Is there a middle ground between GFM and GFL control schemes, and if so, what kind of control technology would be required for this middle ground?

c. Is there a need to revise grid code requirements to avoid inconsistencies?

Question 3.4:

Several papers have identified applications of grid forming (GFM) converters and issues associated with such systems. There are different approaches to GFM converter implementation and identifying potential issues and finding solutions need a detailed understanding of controls which can become a roadblock due to intellectual property concerns.

a. What approaches can be taken to identify potential future issues during early stages of a project when models may not be advanced enough?

b. Is there a need to develop standardized technical specification and performance requirements for GFM systems?

c. How urgent is to develop standards for GFM converters?

PS3.2 – New Technologies & Concepts for design of DC converters and PE devices for both transmission and distribution systems including interfacing generation and storage to the network, energy hubs/islands, etc.

Paper B4-10160 “Application of Multi-ports Power Hub to Coordinated Control of Renewable Energy, Distributed Generation Network, Load and Storage at Micro-grid”

The paper includes description of a "Multi-Port Power Hub" which has various VSC converters that connects to AC networks and renewable energy sources. The multi-port hub is also connected to several loads and battery energy storage systems. The system introduced in this paper has a ±20 kV DC bus which connects generation and loads through a DC hub.

Paper B4-10190 “Advancement in HVDC Technology: Exploring Controllable Current Source Converters Utilizing Reverse Blocking IGCTs”

The paper proposes a current source converter topology for HVDC using Reverse Blocking IGCTs. A brief explanation of the control and modulation concept is given and simulations, especially for AC FRT events, are provided. The topology is compared with LCC and MMC VSCs and technical challenges of the proposed concept are addressed.

Paper B4-10311 “Linear PV power plant based on MVDC collection network.”

This paper presents research on Linear Photovoltaic (PV) power plants based on Medium Voltage Direct Current (MVDC) collection networks, and provides an in-depth analysis of linear PV power plants and their role in achieving renewable energy goals, discussing the potential of MVDC technology to improve energy efficiency and reduce losses.

Paper B4-10364 “The innovative Damping Resistor System adopted in the Italian Transmission Grid.”

This paper provides an overview of the need and basic technical design characteristics of a standardized converter-modulated resistive damping system equipped with STATCOM capability to provide both frequency and voltage regulation in the Italian power grid.

Paper B4-10365 “An improved modular Statcom topology equipped with short-time energy storage and Grid Forming control for HV network voltage and frequency regulation”

This paper presents an E-Statcom Cascaded H-Bridge Delta connected with a supercapacitor connected to the submodule capacitor via a DC/DC converter. The main design concepts are discussed, including the main operating sequences and the relevant protection and maintenance concepts. The grid forming control is also described, including simulations for various events.

Paper B4-10494 “On the Role of Energy Storage in the Future HVDC Systems.”

This paper discusses challenges and opportunities for the integration of grid-forming control applications into VSC HVDC systems, with particular focus on new functionalities and features created by the integration of energy storage with the VSC HVDC systems.

Paper B4-10668 “Battery storage with power oscillation damper for improved stability performance”

This paper discusses how a battery energy storage system (BESS) with power oscillation damping (POD) capability can improve stability performance of transmission network close to a generating station in Namibia. The paper shows why the added POD functionality is crucial to maintain transient stability during and after network fault conditions, especially enabling both the P- and Q-control at the same time to maximize damping performance.

Paper B4-10742 “Grid-Forming Variable-Speed Full Converter Pumped-Storage Hydropower.”

This paper presents the implementation of Grid-Forming (GFM) control in Converter-Fed variable-speed Synchronous Machines (CFSM) for Pumped-Storage Hydropower (PSH) plants and its advantages over traditional GFL control in terms of grid support and flexibility.

Paper B4-10743 “Bi-mode Insulated Gate Transistor BIGT - An Outstanding Key Component in Present and Future HVDC Systems”

The paper focuses on a specific power semiconductor device, a reverse conducting IGBT, also known as BIGT. The paper provides an overview of the semiconductor technology, its use in HVDC converters and DC breakers, the evolution from the first to the second generation of the device and key performance characteristics.

Paper B4-11121 “Grid Forming Solution for Offshore Wind Park with HVDC Connection”

This paper presents a control scheme for HVDC transmission links that are connected to offshore wind farms, where both the HVDC converters and the wind turbine generators operate in Grid Forming (GFM) control mode. The paper includes information of an example implementation on a 900 MW HVDC link with a symmetrical monopolar configuration. It includes details of investigations performed to demonstrate that the proposed control scheme can provide instantaneous support to the onshore system during various disturbances.

Paper B4-11590 “Dynamic Analysis of a Synchroverter with Virtual Inertia for Wind Power System Integration”

This paper presents a synchroverter-based control strategy for a wind power system with simulation demonstrating frequency-response capability for the system to contribute to grid stability.

Question 3.5:

HVDC systems must operate reliably in rapidly evolving AC grid environments with changing grid damping behavior (e.g., grid strength, high frequency resonances, SSR, etc.). Therefore, a robust control design that ensures damping behavior in the relevant frequency ranges becomes mandatory to enable higher penetration of power electronics in the grid.

a. Is there a need to standardize the damping and robustness requirements for all power electronic devices connected to the grid?
b. What is the experience with real-life performance of damping controllers in the network compared to system design studies?

Question 3.6:

Facing the requirements for carbon emission reduction, power electronic technologies and equipment based on converters need to undertake more technical research and product development in the areas of energy conservation and loss reduction.

a. What specific technical research and product development in the areas of energy conservation and loss reduction should be undertaken?
b. How can these efforts facilitate the transformation and upgrading of the industrial sector and support the achievement of carbon emission reduction targets?

Question 3.7:

The paper 10363 presented the use of SiC in circuit breakers, which is a new type of device applied in power electronic equipment.

a. How do the invention and development of power semiconductor devices and the advancement of power electronic technology promote each other?
b. And what is the new trend and direction of power semiconductor development to promote the advancement of direct current (DC) and power electronic systems?