

Key Takeaways - CIGRE Paris Session 2026

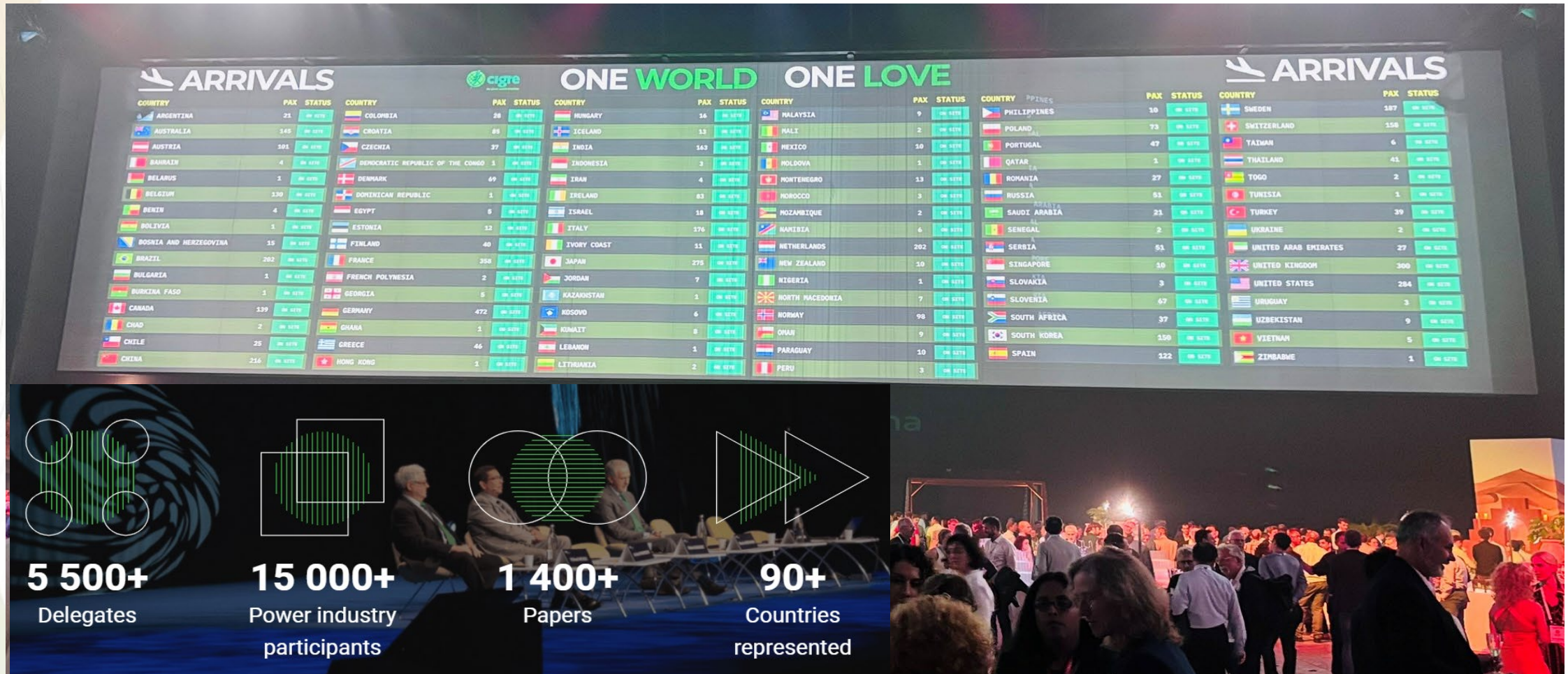
SC B4 – DC Systems and Power Electronic

Nadew Belda (PhD), Asset Specialist HVDC, TenneT TSO

Outline

- ❖ Overview of Papers
- ❖ Key Takeaways - Main events and activities
 - 4 X Workshops
 - 1 X Tutorials
 - Poster Sessions
 - Group Discussion Meetings
 - SC meeting & Company Exhibitions
- ❖ Latest updates – publications, call for (J)WG

Arrivals → 90+ Countries represented! 70%↑ over the past 10 years



SC B4 - Key figures

172 synopses → 169 accepted → 142 full papers → 19 rejected

➤ 123 accepted full papers → available on [e-cigre](https://www.e-cigre.org)

Three preferential subjects (PS)

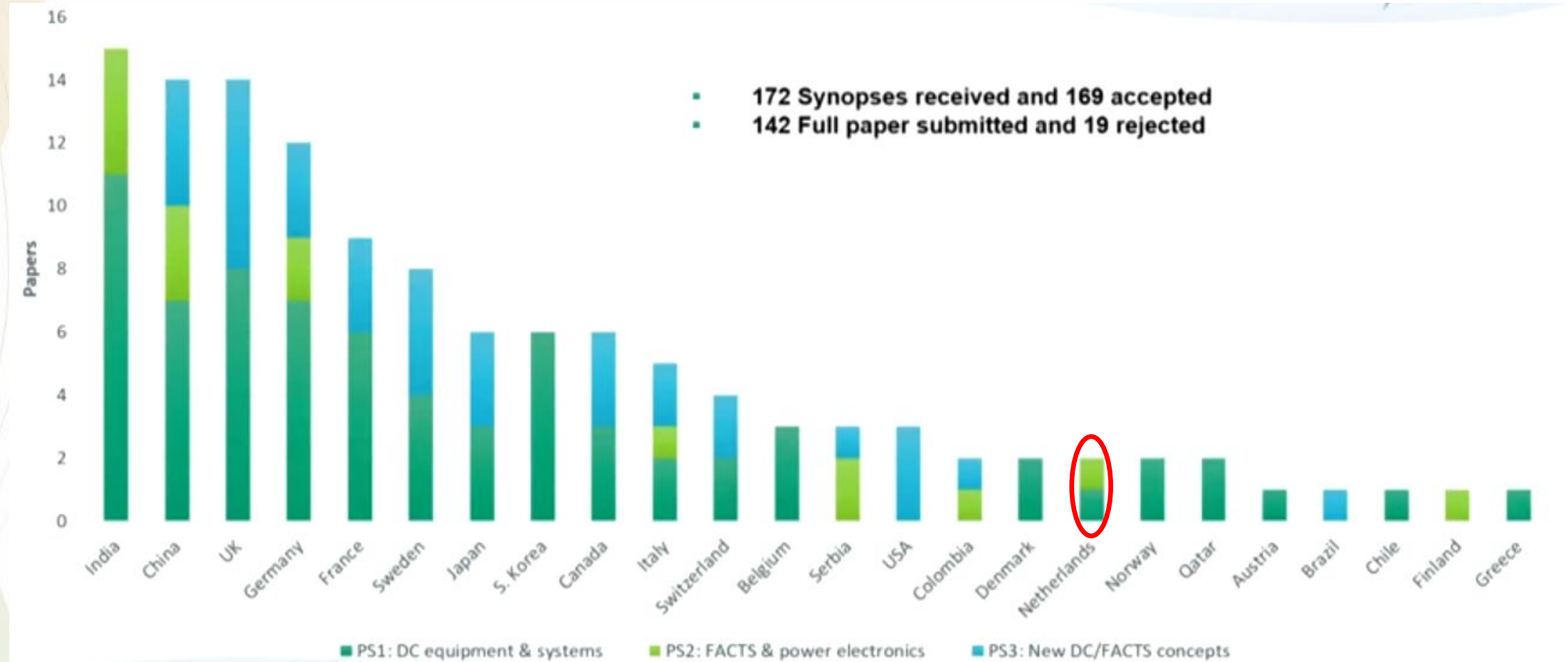
- DC Equipment and Systems - 71
- FACTS and Power Electronics - 16
- New Technologies and Concepts – Enabling Energy Transition - 36

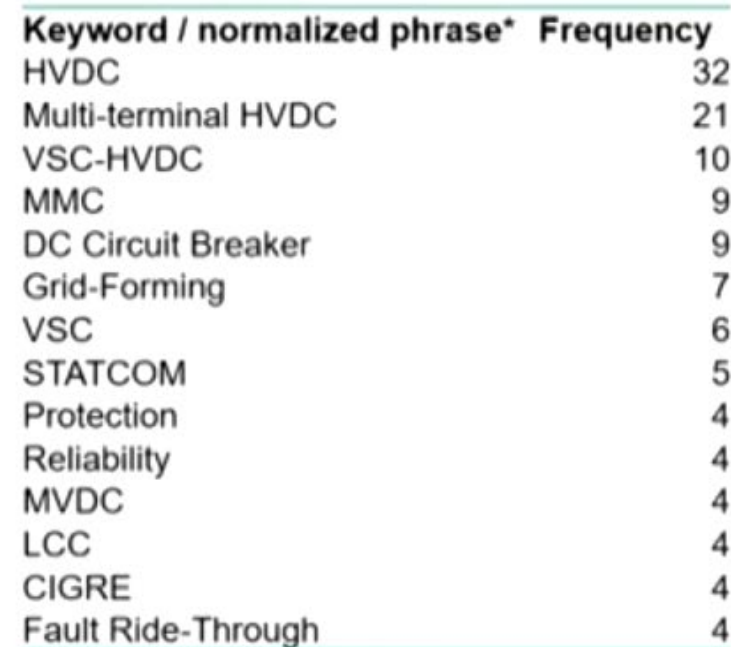
For 2028 session – additional areas of PS3 → Focus on LVDC a& MVDC



➤ 87 contributions (54 contributions accepted for the GDM)

Paper distribution by countries – 24 countries





6

2026 Session SC B4 Best Papers

No	Title	Preferential Subjects
11418	Effect of Temporary VSC-HVDC converter blocking on Multiterminal HVDC and offshore windfarm performance	
12359	Impact of DC Circuit Breakers on Transient Stresses within Modular Multilevel Converters in Bipolar HVDC Systems	B4 PS1 - DC equipment and systems
12289	A hybrid HVDC Breaker for 525 kV DC Switching Station Applications	
11365	Synchronous Grid-forming STATCOM Supercapacitor Energy Storage - Control During Active-Power Involving Events	B4 PS2 - FACTS and power electronics (PE)
10810	An Owner's Perspective on the Implementation of Grid-Forming Controls for VSC HVDC and STATCOM Projects	
11282	TenneT 2GW Bipole Offshore HVDC Transmission Schemes – Key Advanced Control Features	B4 PS3 - New technologies and concepts of DC and FACTS enabling energy transition

Workshop - Evolution of HVDC protection

Demonstrating maturity and harmonizing for multi-vendor competitive solutions

- ❑ The shift towards MTDC and the need for DC protection - the German hubs case
 - Single vendor, multi-terminal projects
- ❑ GB perspectives on DC protection – past, present, future – Project Aquila
- ❑ The DC-protection frameworks for competitive multi-vendor tenders – InterOPERA (EU project)
 - Technology neutral functional specification → DC fault ride through capability and DC fault separation
- ❑ The German multivendor project approach – defining requirements, TSO responsibility in design studies & tendering
 - DC4X



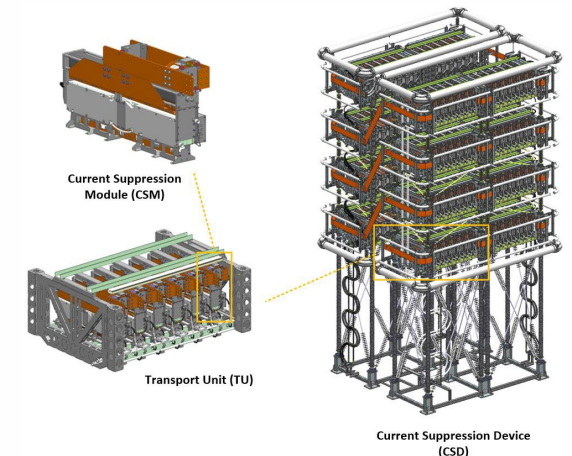
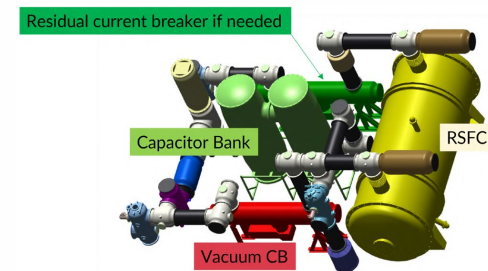
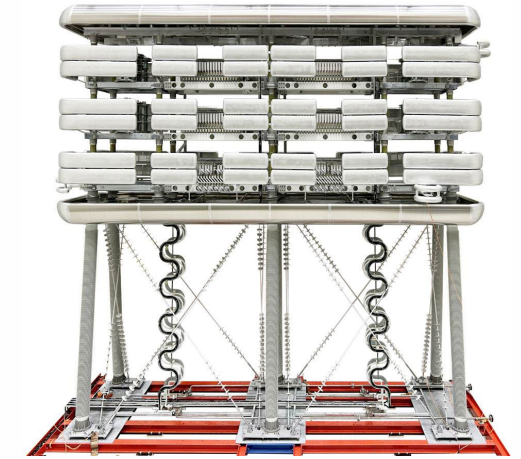
Workshop - Evolution of HVDC protection



Demonstrating maturity and harmonizing for multi-vendor competitive solutions

Vendor views

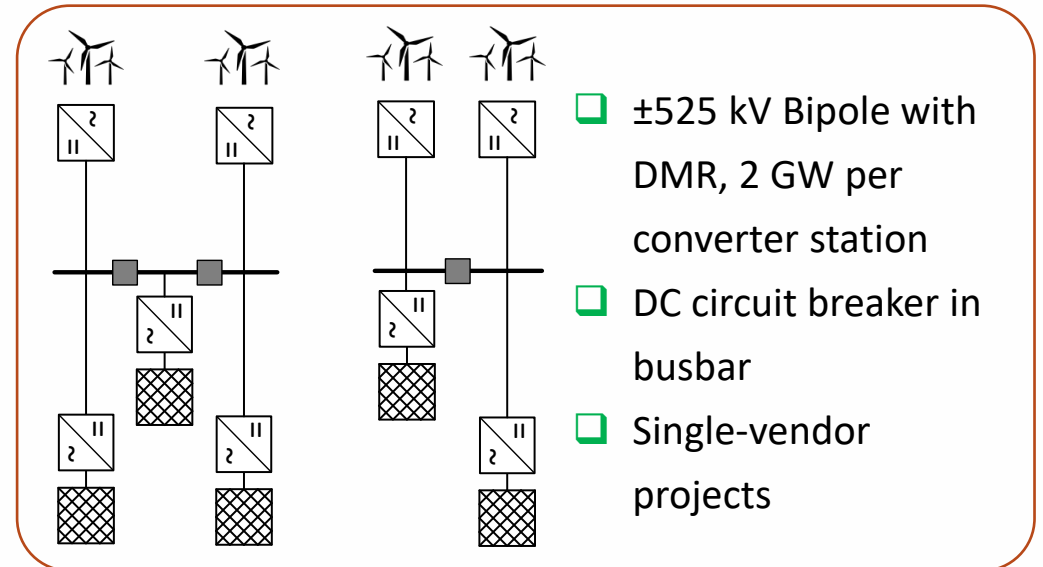
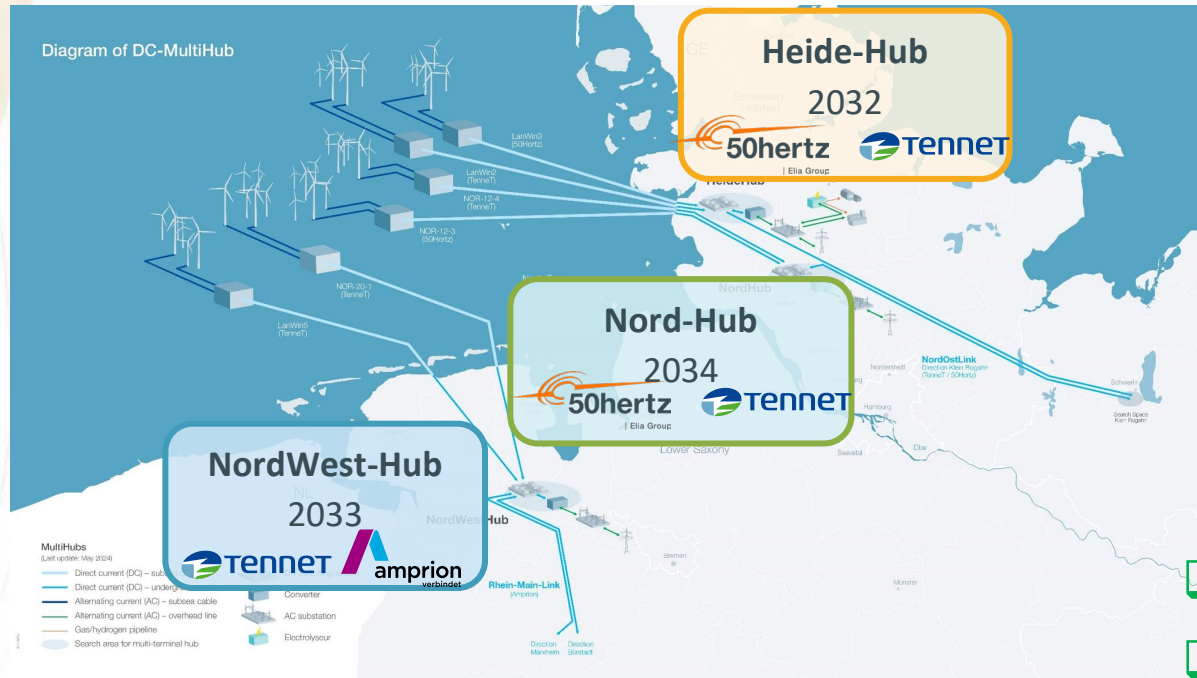
- DC grids resilience & hybrid HVDC breakers (Hitachi Energy)
- A fully selective protection strategy without telecommunication for multiterminal HVDC systems (GE Vernova)
- A stepwise approach to multi-vendor multi-terminal HVDC Grids protection (Siemens Energy)
- Resistive superconductive fault current limiters for the protection of MTDC grids (SuperGrid Institute)



The shift towards MTDC

- the German hubs case

and the need for DC protection



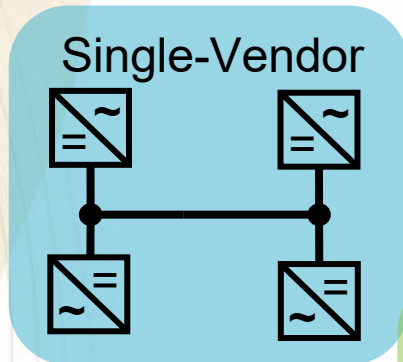
TSOs: TenneT, 50Hertz, Amprion, TransnetBW

HVDC system vendors:

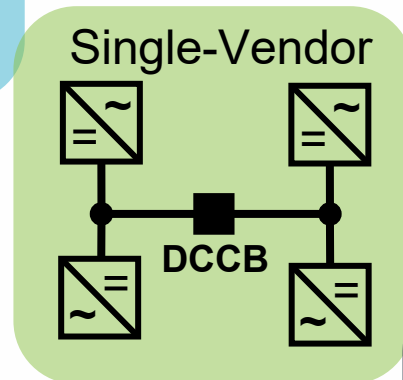
- Hitachi Energy
- Siemens Energy (with Mitsubishi Electric)
- GE Vernova (with Supergrid Institute)

Development & Execution
Stage 2

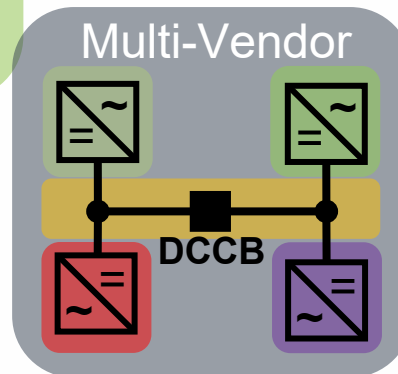
Multi-Vendor as next strategic development stage



Stage 1



Stage 2



Stage 3

Stage 1: Single-Vendor Multi-Terminal HVDC-Projects without DC-Breaker

Interconnection of two point-to-point offshore systems (non-selective)

Stage 2: Single-Vendor Multi-Terminal HVDC-Projects with DC-Breaker

Interconnection of converter stations via an onshore DC switching station with DC-breaker (partial selective)

Stage 3: Multi-Vendor Multi-Terminal HVDC-Projects w w/o DCCB

Interconnection of converter stations of different HVDC suppliers via DC switching stations. Key building block for a DC grid structure (partial selective / full selective)

Overview DC4x-topology

- ±525 kV Bipole with DMR
- 2 GW per converter station
- Foreseen in-service date 2037+
- Consisting of projects at different stages of development and approval
- Planned as multi-vendor project by 50Hertz, TransnetBW and TenneT

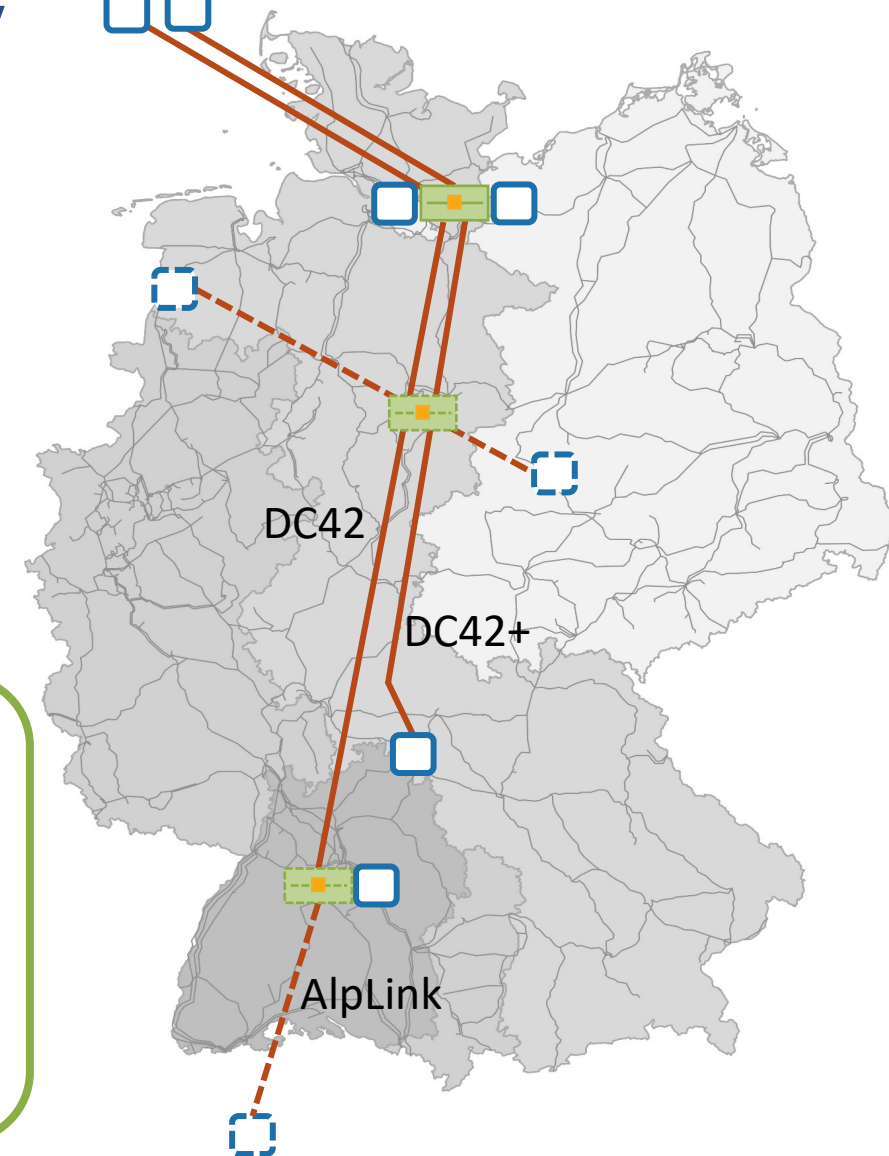
Multi-vendor sub-systems

- HVDC Converters
- Transmission systems
- DC Switching station
- DC Circuit Breakers
- DC Grid controllers

NOR 13-2

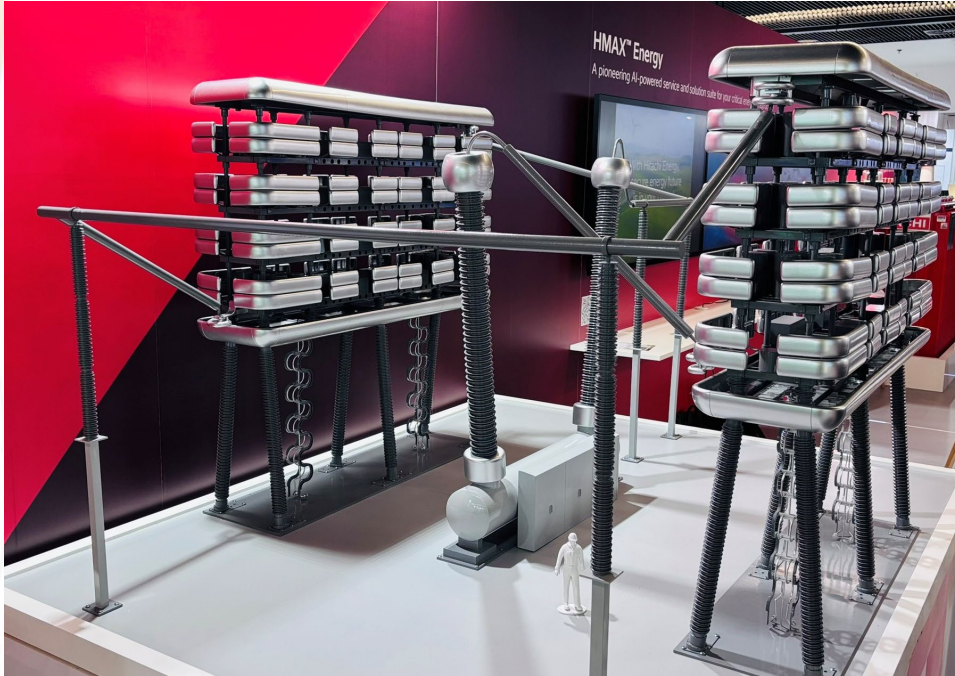


NOR 16-2

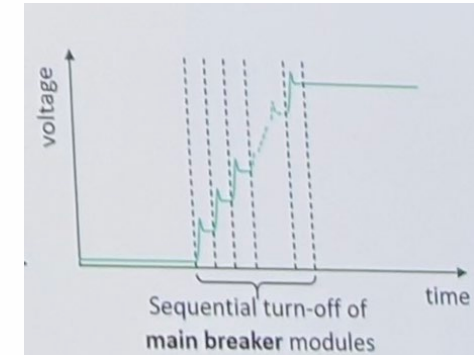


HVDC Circuit breakers – are back!

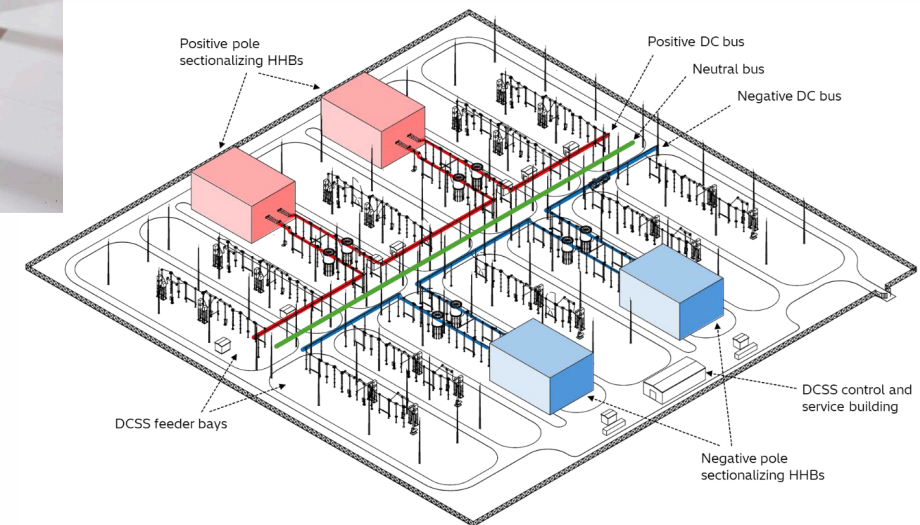
DC grids resilience & hybrid HVDC breakers (Hitachi Energy)



- ❑ 550 kV hybrid HVDC Circuit Breaker - Hitachi
- ❑ Rated current 4 kA
- ❑ Breaking current 25 kA, breaker operation <3ms
- ❑ Proactive current limiting
- ❑ Part of [Axonic™](#)



Controllable TIV

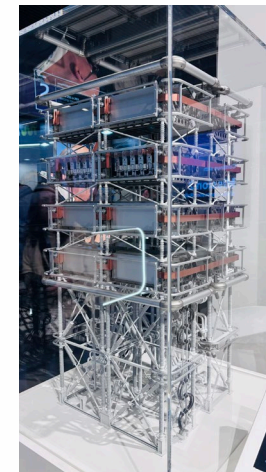
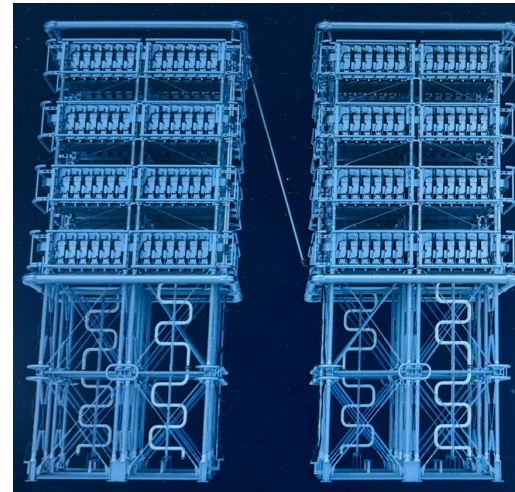
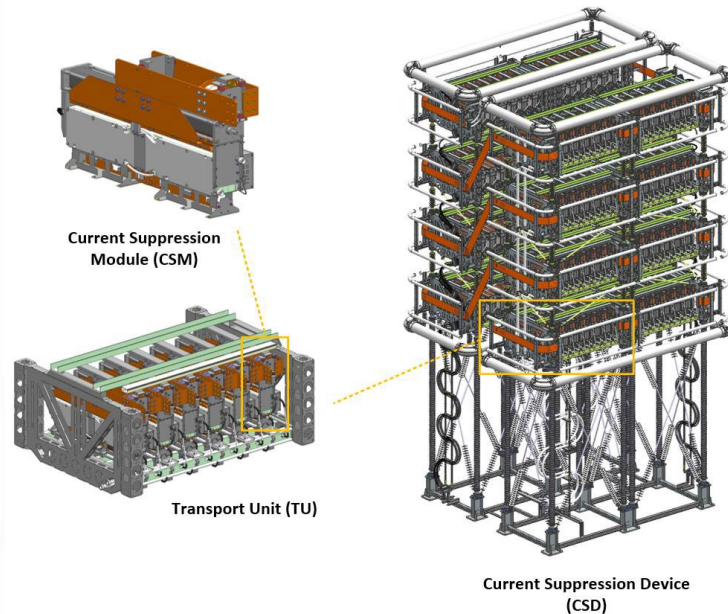


DC Switching station – NordWestHub

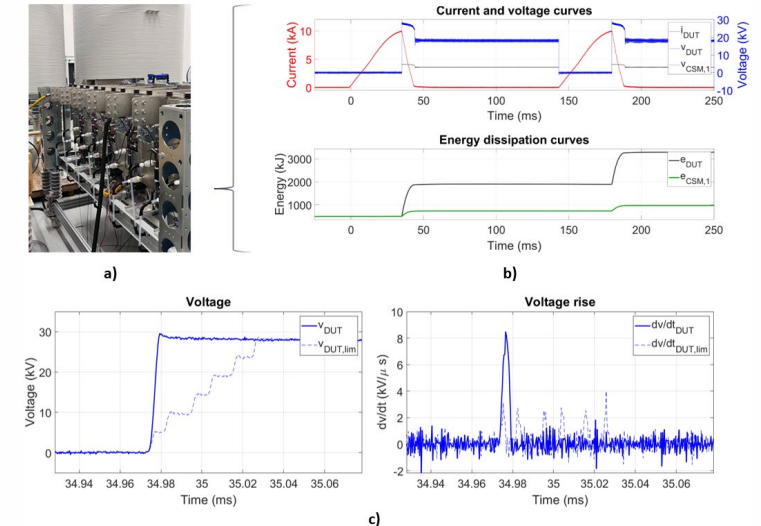
HVDC Circuit Breakers – are back!



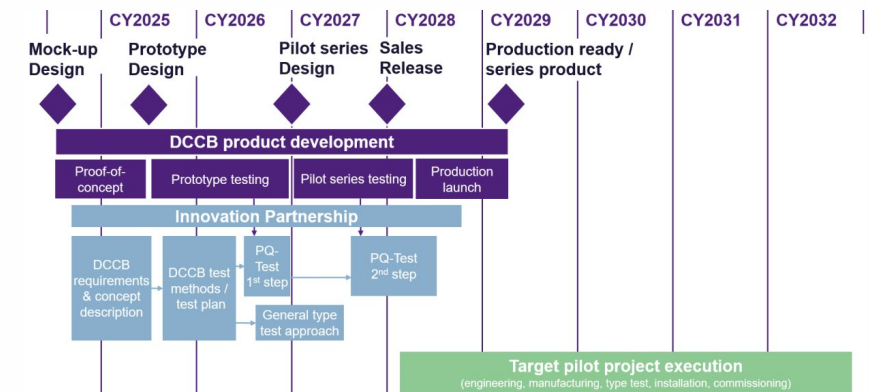
A stepwise approach to multi-vendor multi-terminal HVDC Grids protection (Siemens Energy)



- ❑ Power Electronic Current Suppression Device (CSD)
- ❑ Rated current 3,15 kA,
- ❑ Breaking current 10 kA, Breaker operation < 100 μ s
- ❑ Fitting into existing HVDC converter Structure
- ❑ Current limiting Feature, Variable TIV

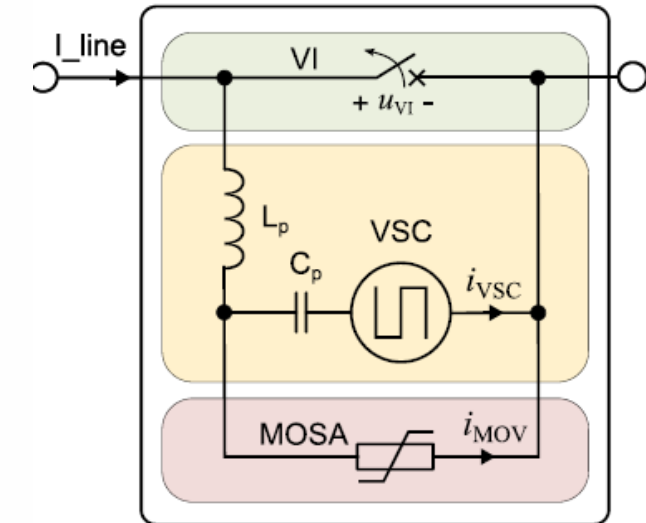


Prototype test results – of one transport unit



HVDC Circuit breakers – are back!

VSC Assisted Resonant DC Breaker (Mitsubishi Electric)



- ❑ 525 kV VARC – VSC Assisted Resonant Breaker - Mitsubishi
- ❑ Breaker operation < 2 ms

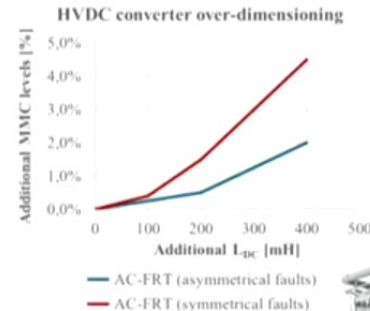
Fault Current Limiters



Resistive superconductive fault current limiters for the protection of MTDC grids (SuperGrid Institute)

Discussion about DC reactor-based fault current limiters

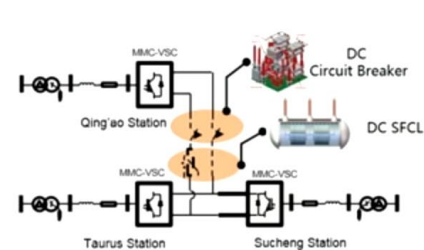
- Pros and cons on system dynamic behaviour
- Impact on converter valve (hardware dimensioning) for FRT
- Losses



HVDC application in service

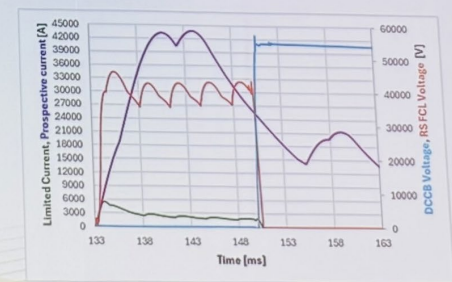
Nan'ao Project (China)

- 2020 World-first application of RSFCL technology in an MTDC grid (Symmetric monopole ± 160 kV)
- RSFCL aim: to expand the grid into a 4-terminal MTDC configuration to limit short-circuit current (prospective current exceeding 16 kA, while the original DCCB design was rated for 9 kA).
- RSFCL Ratings :
 - 160-kV/1-kA, $I_c = 1,5$ kA, YBCO based, LN 77K (8Ω within 10 m during pole-to-pole fault)



Demonstration tests at SuperGrid Institute (France)

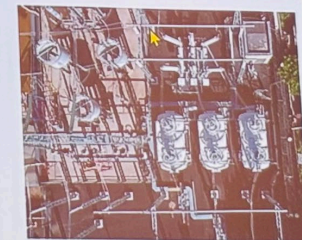
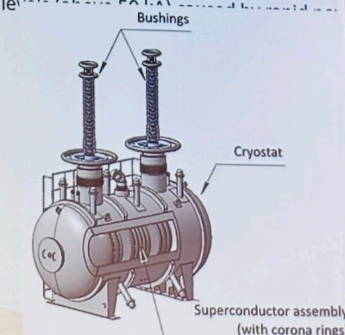
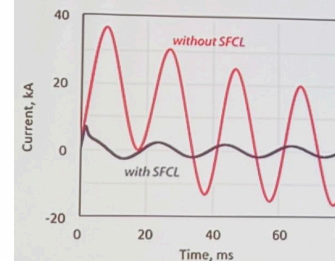
- 50 kVDC tests
- RSFCL with 2 tapes in parallel
- Limitation of current from 43 kAp down to 5,5 kAp
- Interrupted current 2,5 kA



HVAC application in service

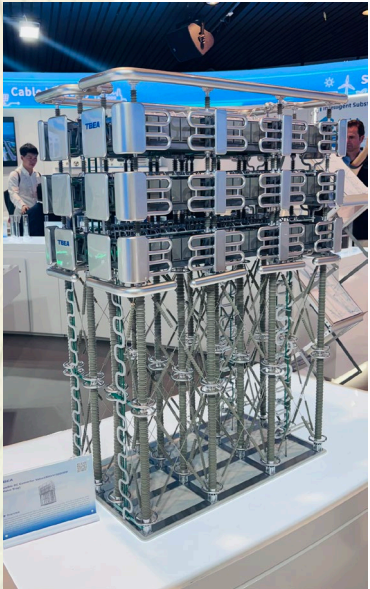
Mnevniki substation (Moscow)

- 2019 World-first 220 kV – 1.2 kA RSFCL installed in a 220/20 kV substation
- RSFCL aim: mitigate high fault current levels (above 20 kA) caused by load loss consumption growth



HVDC Converters — 6+ suppliers from China + Hyosung Heavy Industries + Mitsubishi Electric Corporation

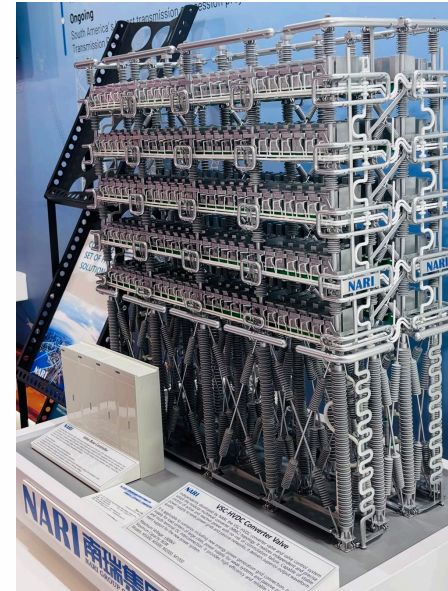
TBEA – 800 kV, 5 GW



China Electric Equipment



NR Electric



NARI

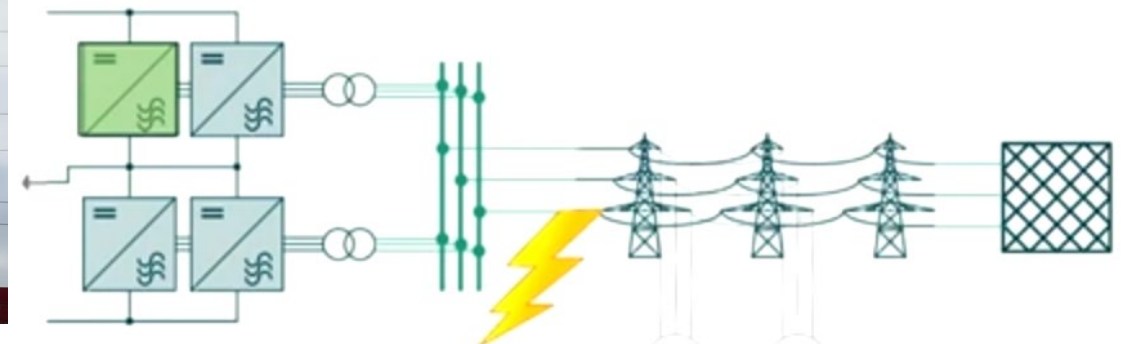
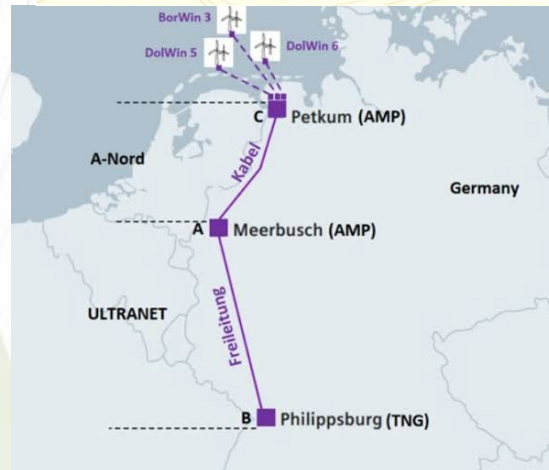
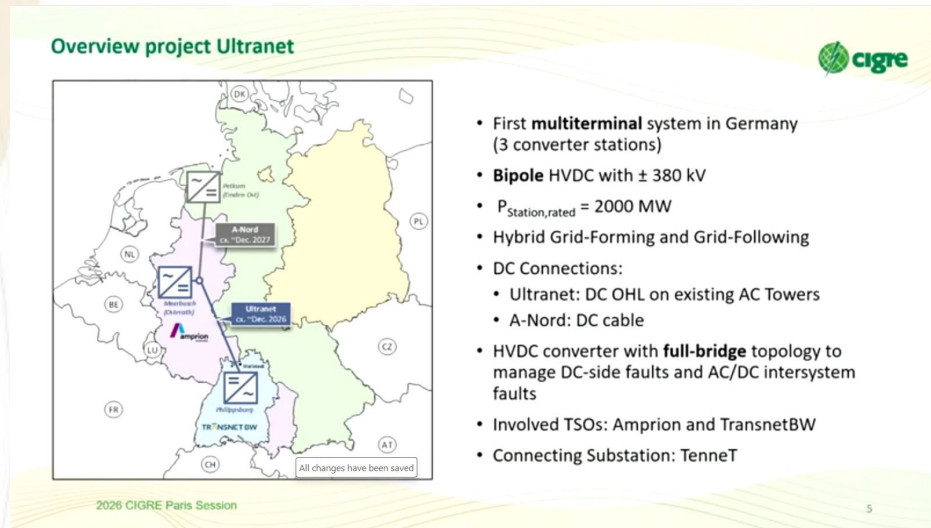
China Southern Power Grid



Hyosung Heavy Industries

Bipolar MTDC with Full bridge - VSC

Hybrid-OHL and cable – Ultramet – Amprion + Siemens + Transnet BV



Grid Forming Converter Technologies and Control in Modern Power Systems

□ B4 contribution: Grid Forming Converter Technologies

- *Siemens Energy - E-STATCOM: Design and performance of a supercapacitor energy storage integrated into a STATCOM*
 - *TenneT project example*
- GE Vernova: The application of synchronous grid forming and constrained-synchronous grid forming to point-to-point HVDC transmission and the impact on main circuit design
 - Definitions and capabilities
- Hitachi Energy: Grid forming HVDC project examples and Grid forming requirements
- University study: Widescale deployment of GFM in Transmission Grids: Challenges and Opportunities
- Hyosung Heavy Industries - Application of GFM control functions in a ± 525 kV 2 GW VSC-HVDC System for Korea's West Coast Energy Highway
- NR Electric: GFM BESS - An OEM's perspective on its Testing & Application Examples
 - Testing aspects → components level vs system level testing

□ C4 - Power System perspectives on the integration of Grid-Forming Capabilities

E-STATCOM: Project Example

Main Components

Power Transformer



Multilevel Voltage Sourced Converter



Super-Capacitor Unit



STATCOM

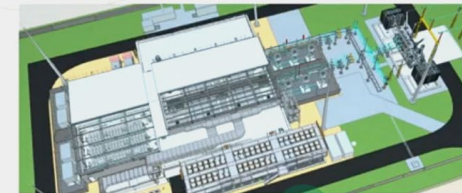
- Voltage control in magnitude and phase-angle.
- Simultaneous injection of active and reactive currents
- Programmable controller w. grid-forming control



Short-term energy reserve

- Emulated inertia provision
 - Islanded operation
-
- Low losses
 - Long lifetime > 20a
 - High availability

E-STATCOM: System Design Pilot Project at 400kV Substation Mehrum, Germany.
In service since Dec 2025



System Voltage	400 kV, 50 Hz
Installed Power S_{nom}	300 MVA
Reactive Power Q_{nom}	+/-300 MVAR
Active Power P_{max}	+/-200 MW
Frequency Range	47.5 – 51.5 Hz
Maximum RoCoF	2.5 Hz/s
Time P_{max} out- / input	1.0 s , 0.6 s
Control Performance	Grid Forming w. Inertia Contribution
Emulated Kinetic Energy E_{kin}	6000 MWs
Acceleration Time Constant T_a	40s related to S_{nom}



Emulated Inertia: Active Power Response P at Frequency Gradient „RoCoF“:

$$P = 2 E_{kin} \frac{RoCoF}{f_g} = T_a S_{nom} \frac{RoCoF}{f_g} = 2 H S_{nom} \frac{RoCoF}{f_g};$$

Shaping the Future of Grids - Resilience, Intelligence, and Innovation for the Energy Transition



- 10 study committees → B2, B3, B4, C1, C2, C3, C4, C5, D1 and D2

Call for papers - CIGRE Symposium 2027



Mon 08 November 2027 To Fri 12 November 2027 / **Symposium**
Call for papers - CIGRE Symposium 2027 - [Add to calendar](#)
CIGRE Thailand

Shaping the Future of Grids - Resilience, Intelligence, and Innovation for the Energy Transition



CALL FOR PAPER - NOW OPEN

CALL FOR PAPERS NOW OPEN

CIGRE 2027 INTERNATIONAL SYMPOSIUM
BANGKOK, THAILAND
8-12 NOVEMBER 2027

SUBMIT SYNOPSES BY 11 JANUARY 2027

NEW CONFTOOL ACCOUNT REQUIRED
Previous event credentials will not be recognized.

www.cigre-thailand.com



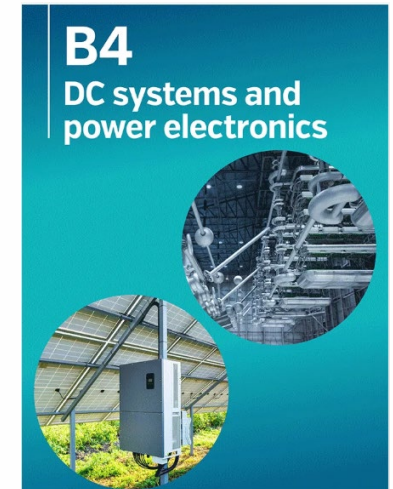
Thank you for your attention!



Latest updates

□ Technical brochures published in 2026

- TB 992 - Application guide for the insulation coordination of Voltage Source Converter HVDC (VSC HVDC) stations
- TB 988 - Surge and Extended Overvoltage Evaluation of HVDC Cable Systems for Testing
- TB 982 - Condition Health Monitoring and Predictive Maintenance of HVDC Converter Stations
- TB 981 - Application of VSC HVDC in a System Black Start Restoration
- TB 958 - Guidelines for use of real-code in EMT models for HVDC, FACTs and inverter based generators in power systems analysis
- TB 961 - Interoperability in HVDC systems based on partially open software
- TB 972 - The impact of offshore wind power hybrid AC/DC connections on system operations and system design
- TB 956 - Protocol for Reporting the Operational Performance of HVDC Systems
- **B4.87 - Voltage Source Converter (VSC) HVDC responses to disturbances and faults in AC systems which have low synchronous generation – (In the queue)**



Latest updates

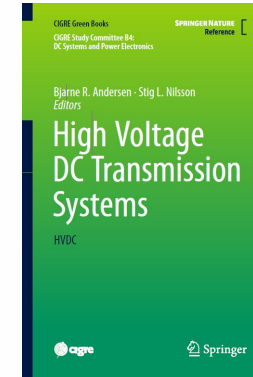
❑ HVDC Green Book → Only on HVDC

- 3 Volumes! 54 Chapters! 2350 pages! 40,000 downloads!

❑ Proposal for new Green Book – Grid Forming (joint C4)

❑ Several new (joint) working groups formed

- [TOR JWG B4 C4.100](#) **Guide for electromagnetic transient studies of VSC-HVDC connected offshore or onshore islanded wind farms**
- [TOR WG B4.108](#) **Roadmap and Technical Challenges for Integrated DC Power Grid**
- [TOR JWG B4 C4 105](#) **Benchmark Models for Multi Infeed HVDC Studies**
- [TOR WG B4 107](#) **Synchronous Grid forming STATCOMs with and without energy storage**
- [TOR JWG C1 B4.58](#) **VSC-HVDC transmission system planning**
- [TOR JWG B4 B1.106](#) **Guideline of VSC HVDC Converter and DC Cable Interface Management**
- [TOR JWG C4 B1 B2 B4.78](#) **Interference effects between HVDC circuits and nearby metallic infrastructure**
- [TOR JWG C4 B4.82](#) **Impedance based Stability Assessment of Modern Power Systems**



Ongoing WGs

- ❑ JWG B4/A3.86 – Fault Current Limiting Technologies for DC Grids → 90 % complete
- ❑ TF B4/B1.88 – Insulation coordination procedure for DC cable systems in HVDC stations with Voltage Source Converters (VSC) → delayed due to discussion between SC B4 and B1 → targeted 60-day review Q4 2026
- ❑ WG B4.90 – Operation and Maintenance of HVDC and FACTS Facilities → 60 % complete → Targeted Completion: End of 2026 → Complains about a lot of inactive members
- ❑ WG B4.91 – Power-Electronics-Based Transformer Technology, Design, Grid Integration and Services Provision to the Distribution Grid → Targeted Completion Date: End of 2026
- ❑ WG B4.93 – Development of Grid-Forming Converters for Secure and Reliable Operation of Future Electricity Systems → target → Q1 2027
- ❑ TF B4/B1/B3/C4/D1.95 – Harmonization of voltage designations and definitions across different HVDC component technologies → **no progress report**
- ❑ JWG C4/B4.72 – Lightning and Switching Induced Electromagnetic Compatibility (EMC) issues in DC power systems and new emerging power electronics-based DC equipment → No progress report
- ❑ WG B4.95 – Developments in Power Semiconductor Technologies and Applications in HVDC/FACTS → Q4 2027/Q1 2028
- ❑ WG B4.96 – HVDC connection of power system with high proportion of photovoltaic (PV) generation → 60 % complete – target Q4 2027 → Looking for experts from HVDC side, especially for the stability issues

Ongoing WGs...

- ❑ JWG C4/A3/B2/B4.75 – Guide to procedures for the creation of contamination maps required for outdoor insulation coordination → Q4 2027
- ❑ JWG B4/C1.97 – Benchmarking of simulations models for control interaction in meshed AC networks with multiple converters → target summer 2027
- ❑ JWG C1/B4.49 – Offshore transmission planning → **No update**
- ❑ WG B4.98 – Design considerations in integration of DC systems to meshed DC/AC Transmission networks → 60-day review Jan 2027
- ❑ WG B4.99 – Design and Construction of offshore Voltage Sourced Converter (VSC) Stations → target → Q4 2026
- ❑ WG B4.100 – Dynamic Active and Reactive Power Supporting Devices for VSC HVDC Systems → 80 % complete → target → draft TB Q1 2027 → Experts on DC choppers requested!
- ❑ WG B4.101 – Industrial Implementation and Application of Grid Forming Energy Storage Systems (GFM ESS) → Draft Q4 2026
- ❑ WG B4/C4.103 – AC Network Equivalents for HVDC and FACTS Project Studies → target → Q4 2027
- ❑ WG B4.104 – HVDC Digital Twin – concepts and roadmap → target 60-day review Dec 2026 → WG tutorial in Thailand 2027

Ongoing WGs...

- ❑ Grid Forming Coordination Task Force
 - Needs more engagement from convenors of on-going CIGRE WG's related to this topic
 - Suggestion – all WGs related to GFM should have the 60-day review also go to this TF for review of TB
 - **new Green Book on GFM**
- ❑ JWG C4/B1/B2/B4 – Interference effects between HVDC circuits and nearby metallic pipelines → **no report**
- ❑ WG B4/C4.105 – Benchmark Models for Multi-Infeed HVDC Studies → target Q2 2029
- ❑ WG B4/C4.100 – Guide for Electromagnetic Transient Studies of VSC-HVDC connected offshore or onshore islanded wind farms → target Dec 2029
- ❑ WG B4.106 – Guideline of VSC HVDC Converter and DC Cable Interface Management → Target Draft TB Q4 2028
- ❑ WG B4.107 – Synchronous Grid forming STATCOMs with and without energy storage → **No report**
- ❑ WG C4/B4.82 – Impedance-based Stability Assessment of Modern Power Systems → target Q4 2028
 - Recruiting members now
- ❑ WG B4.108 – Roadmap and Technical Challenges for Integrated DC Power Grid → first draft Q1 2028

Suggestions for new WGs

- ❑ B4 - Engineering Guidance of Seismic Design for HVDC Converter Station
- ❑ B4 - EMT Modeling and Simulation of AIDC Power Supply System
- ❑ B4 - Grid Forming Capabilities and Technical Requirements of Wind Farms
- ❑ B4- AI-based Condition Perception Technology for VSC Valve
- ❑ B4- Task force to coordinate multiple working groups on HVDC interactions
- ❑ Liason with IEC → IEC TC115 → Yanny Fu
 - IEC/SC22F – Power electronics for electrical transmission and distribution systems