

Transition toward future DC Grids

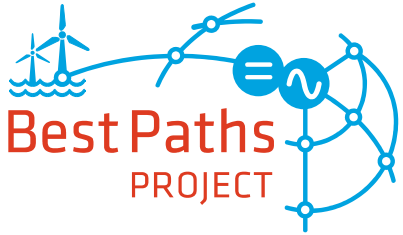


Hitachi Energy has been, is and will be main active player in defining DC Grids of the future

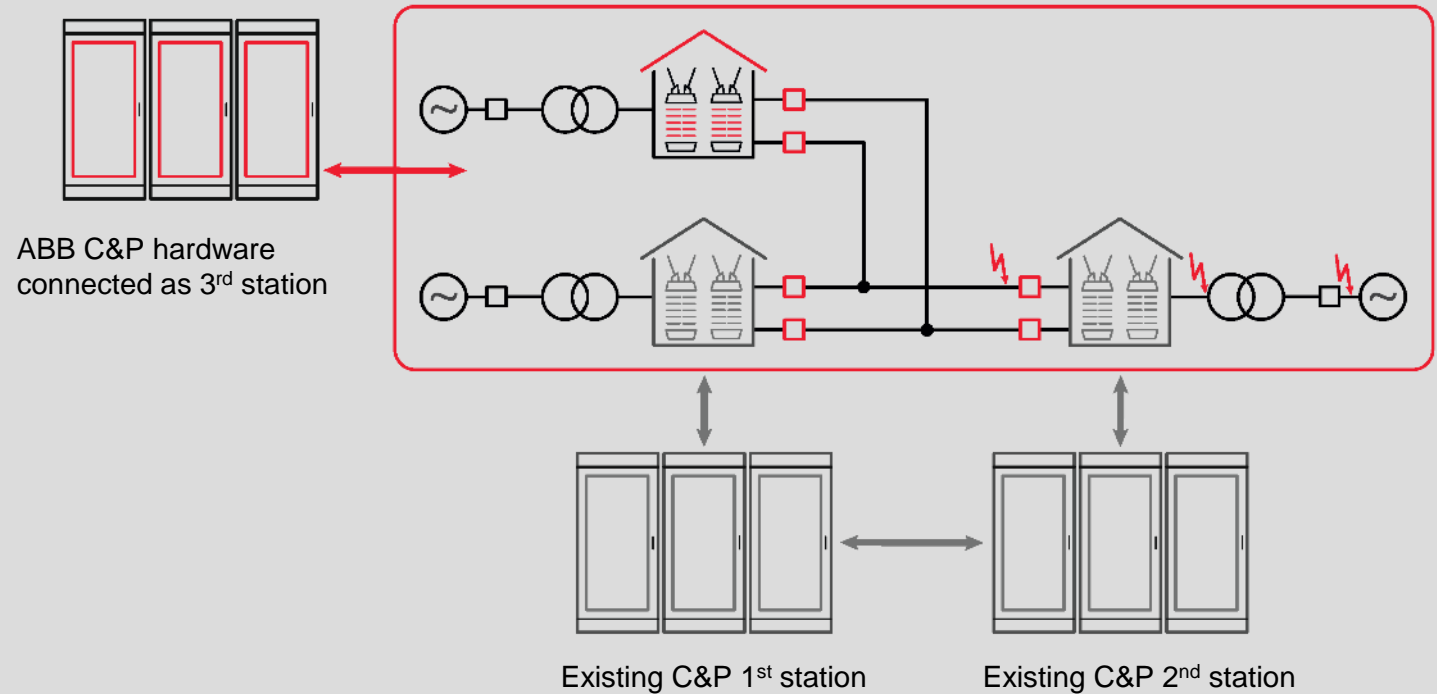
Project driven by SuperGrid Institute and collecting consortium of (HVDC system manufacturers, TSOs, third party HVDC system integrators, wind turbine manufacturers, offshore wind farm devel.
Main objective:
Enable interoperability of multi-vendor HVDC.
Main Hitachi Energy task:
Control and Protection Development and System Integration in Multi Vendor Environment

With nearly 40 leading organizations from research, industry, utilities, and transmission systems operators. Hitachi Energy part of the project, together with Siemens, GE, Toshiba. 50Hertz, Elia, Terna, EnerginetDK, Statnett, RTE, Red Electrica examples of Utility partners.
Main Objective:
Project will help to overcome the challenges of integrating renewable energies into Europe's energy mix.

Technical Committee with participation from Hitachi energy, Siemens, GE and different European TSOs.
Main Objective:
Development of guidelines for HVDC Grids Systems.
Task completed, approved EU standard "HVDC Grid Systems and connected Converter Stations – Guideline and parameter List for Functional Specification" Base for InterOPERA work.
Ongoing translation to an IEC standard.

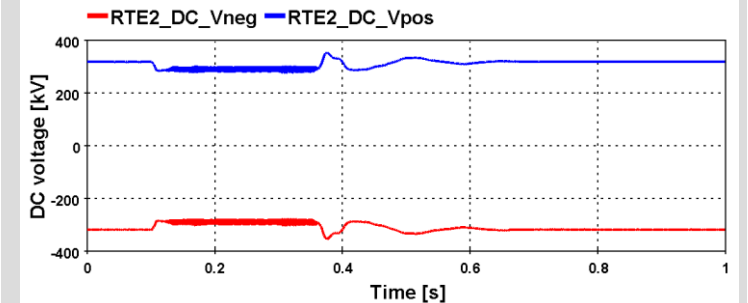
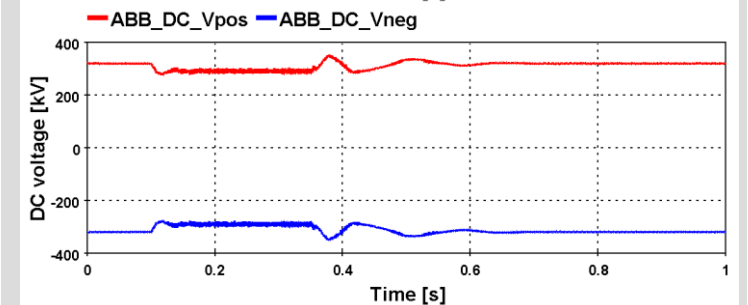
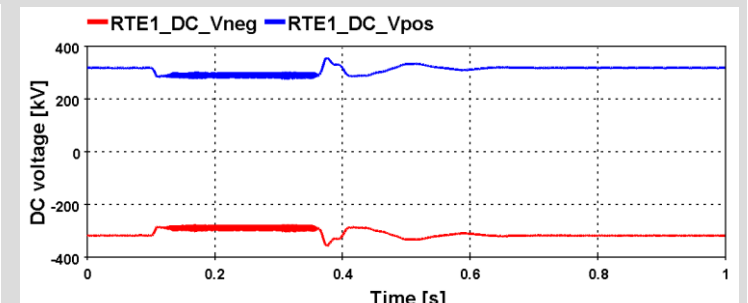
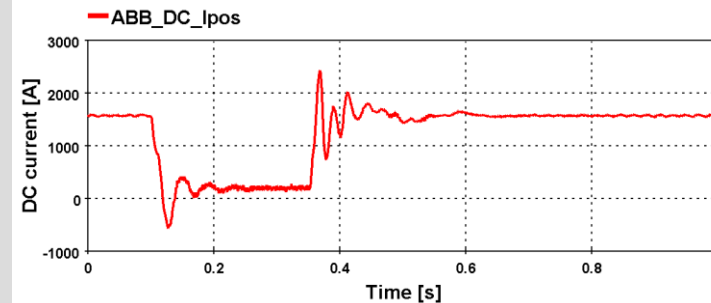
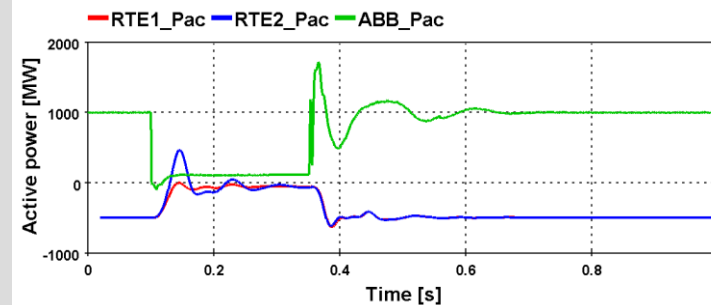
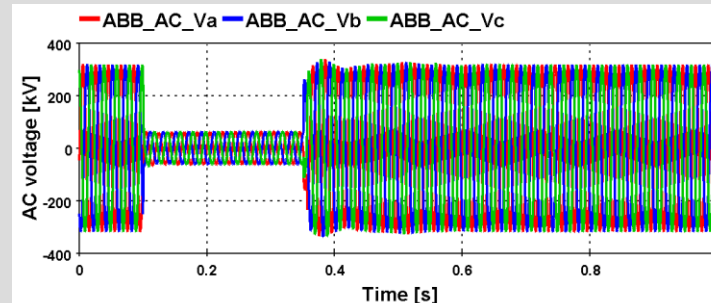
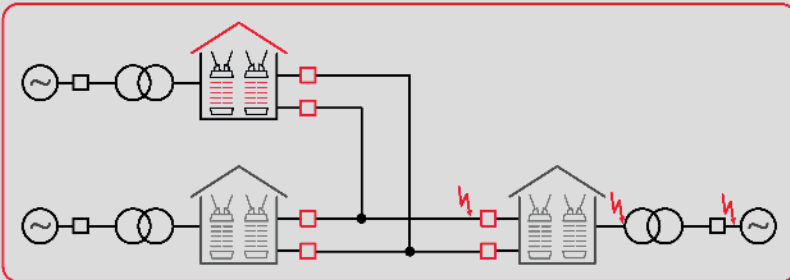


- Hitachi Energy was the only vendor for the real-time studies with C&P hardware.
- However, realistic multivendor studies were performed.
- Hitachi Energy connected as 3rd station to an existing point-to-point link delivered by another vendor.
- Hitachi Energy connected as well as 2nd station in a point-to-point setup.
- Since Hitachi Energy was the only active vendor, all tuning and all changes were made in Hitachi Energy's C&P setup. The already existing C&P equipment from the other vendor was not tuned or changed.



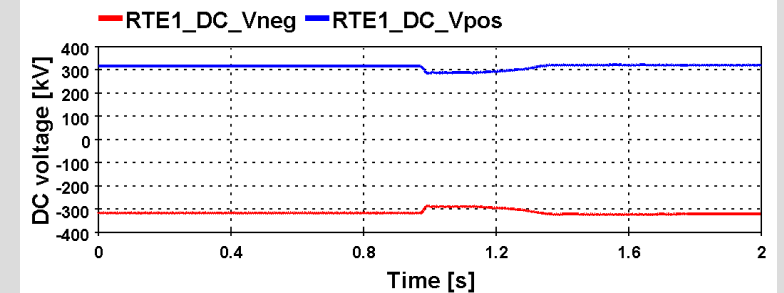
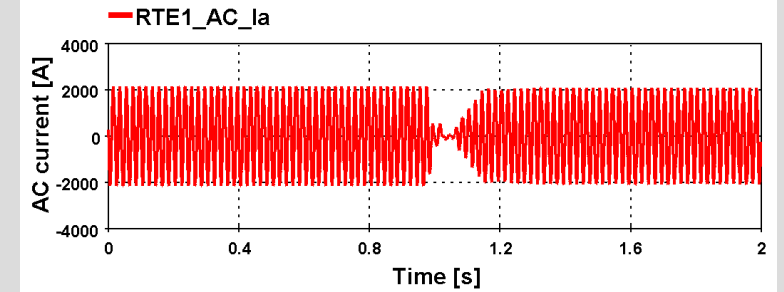
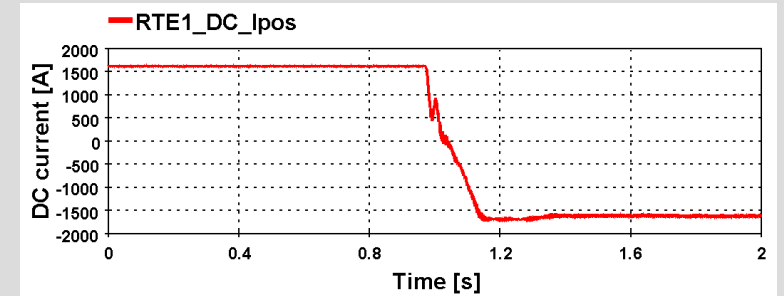
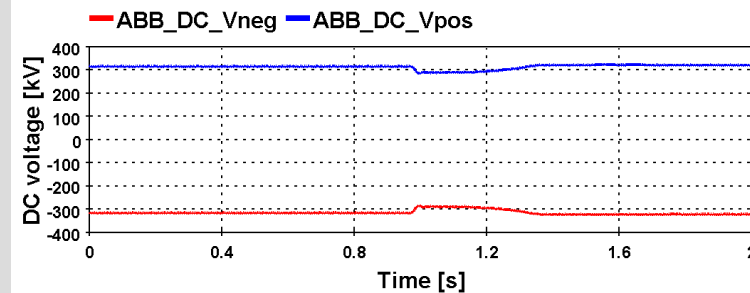
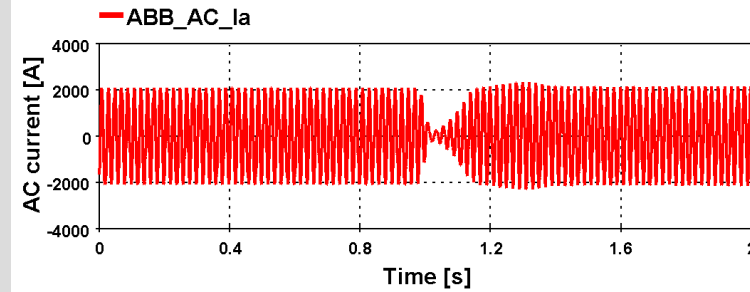
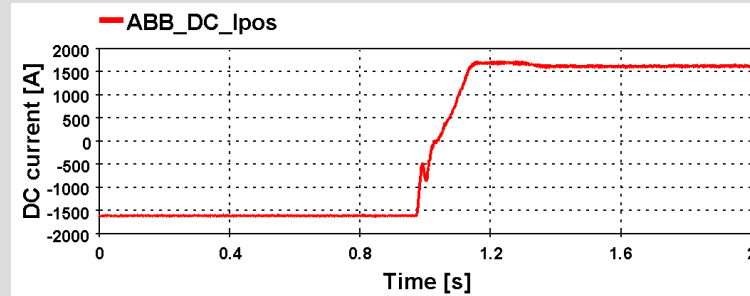
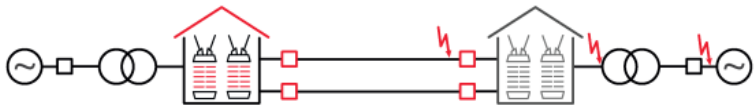
Hitachi Energy station connected as 3rd station to existing point-to-point link

- Hitachi Energy C&P hardware connected to the existing point-to-point link from the other vendor.
- 3 terminal
- Hitachi Energy station sending 1000 MW, other stations receiving 500 MW each.
- 3 phase fault on AC side near Hitachi Energy station, 20% remaining voltage for 200 ms.

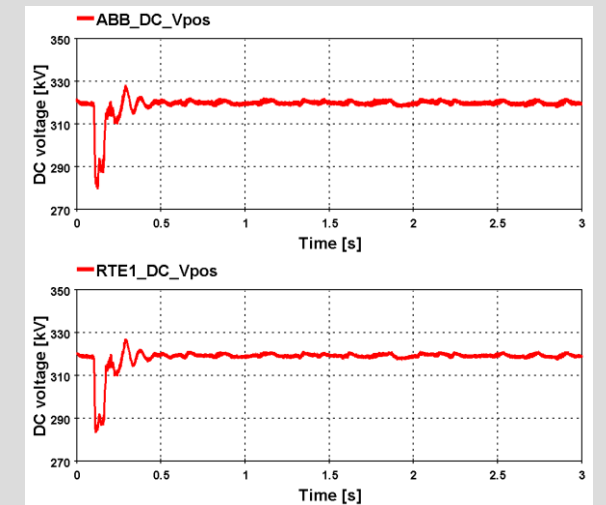
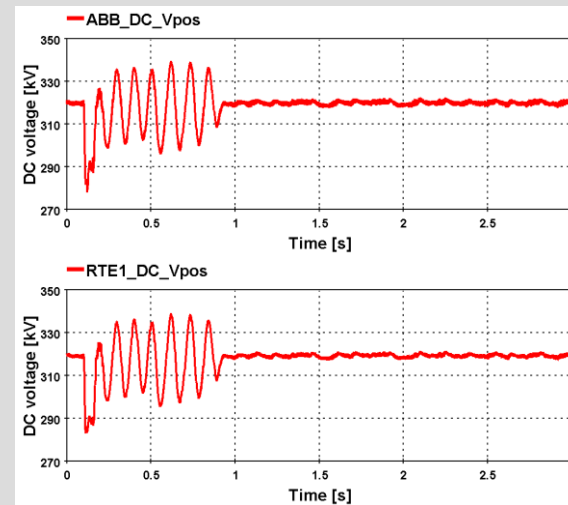
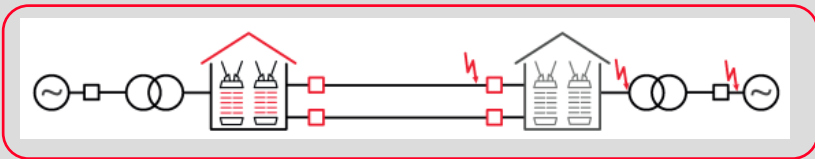
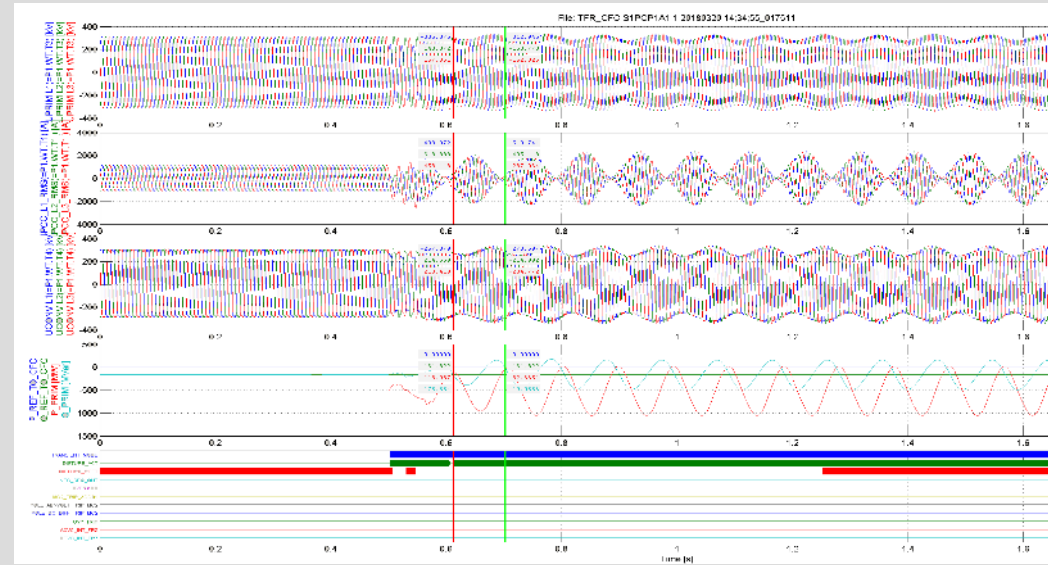


Hitachi Energy station – Another vendor

- Hitachi Energy station replica connected to one station from the other vendor.
- Point-to-point
- Fast power flow reversal (+1000 MW to -1000 MW)



- Interoperability issues were solved.
- Hitachi Energy station replica connected to one station from the other vendor in point-to-point
- AC fault caused oscillations in voltage, current and power.
- Since Hitachi Energy was the only active vendor the control adaptations were made only in ABB C&P setup.



Paving the way

What is needed?

MPI Master Controller

Enable Multiterminal concept

DC Switchgear station

Define C&P strategies

DC Protection solution

Interoperability for expansion

Technical interoperability

DC GridCode / Ownership

New Procurement Process

New business cases definition

Hitachi Energy contribution

Realization of KriegersFlak CGS

Caithness-Morey-Shetland & other multiterminal links

DC Breaker development

Protection algorithms

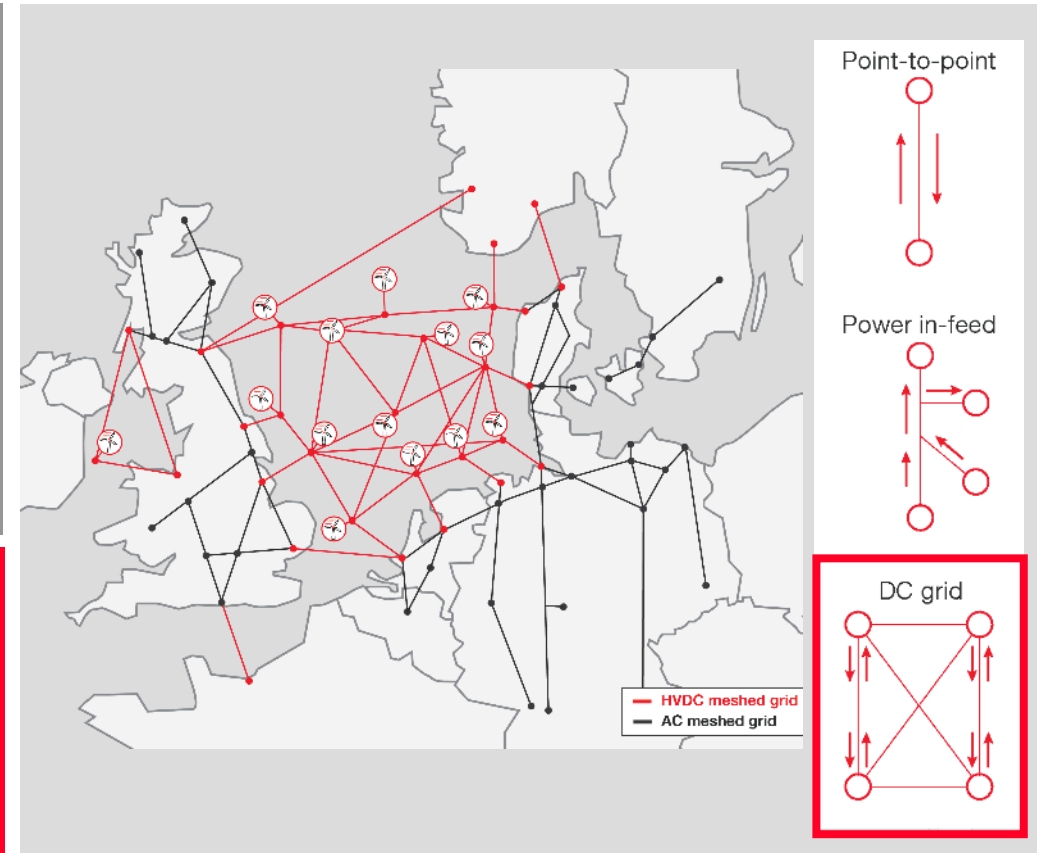
Active in Interoperability projects like: Aquila, InterOPERA, READY4DC, Grön Platform

Support industrial consultations

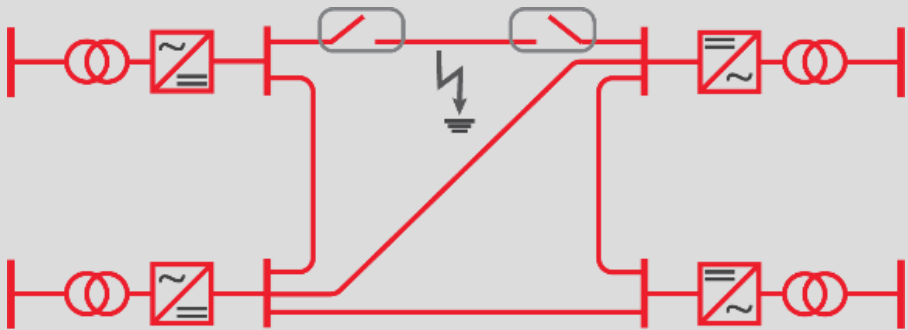
Support RES dev.s, O&G, TSO

Technology

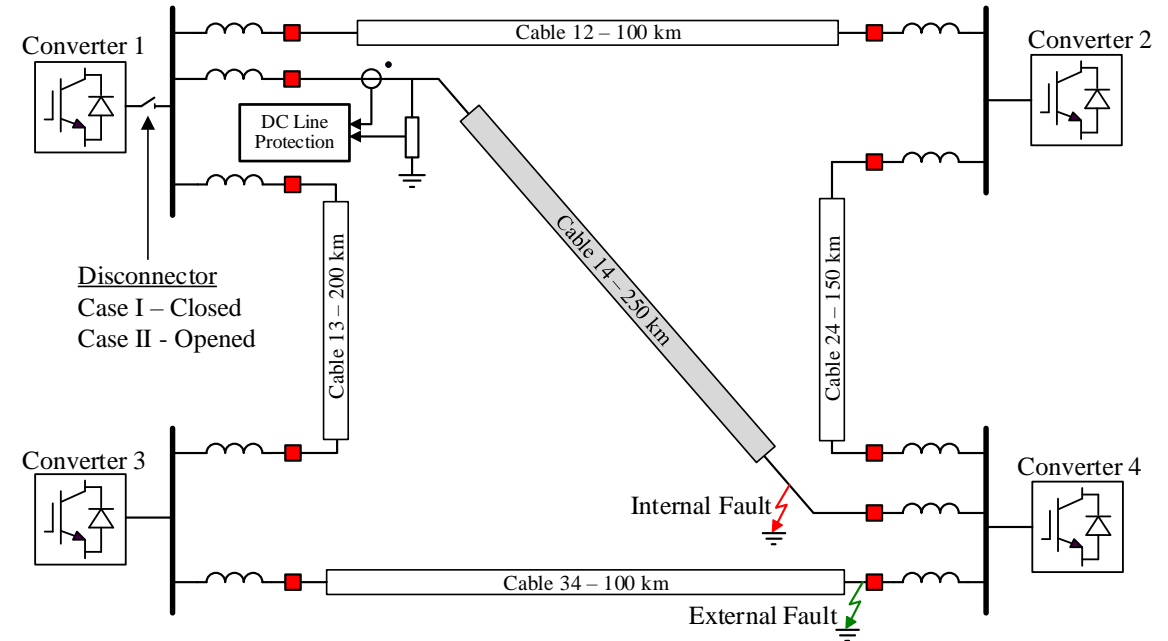
Commercial and regulation



- Enabler for larger multiterminal systems and HVDC grids
- In case of a fault, ensures that only affected part of the grid is disconnected
- Increasing availability and reliability of the system
- To enable different protection zones in the DC grid
- ... through fast response, high reliability, low losses

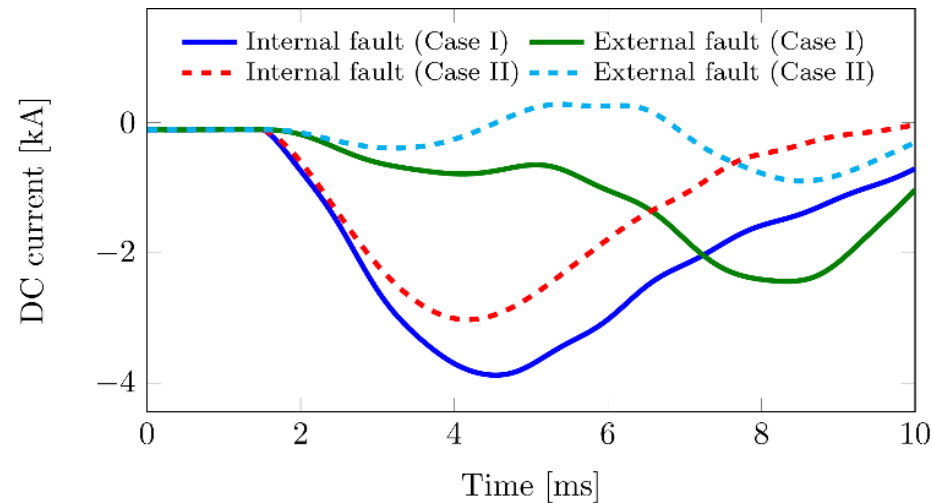
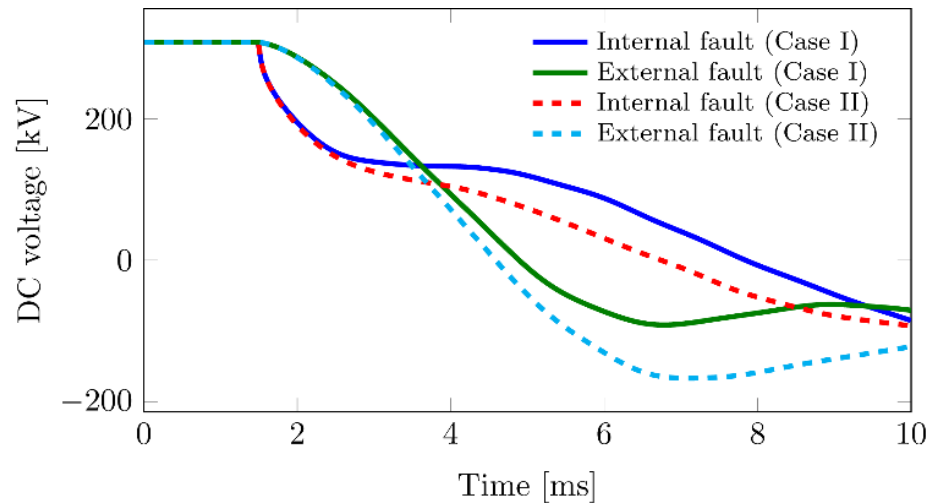
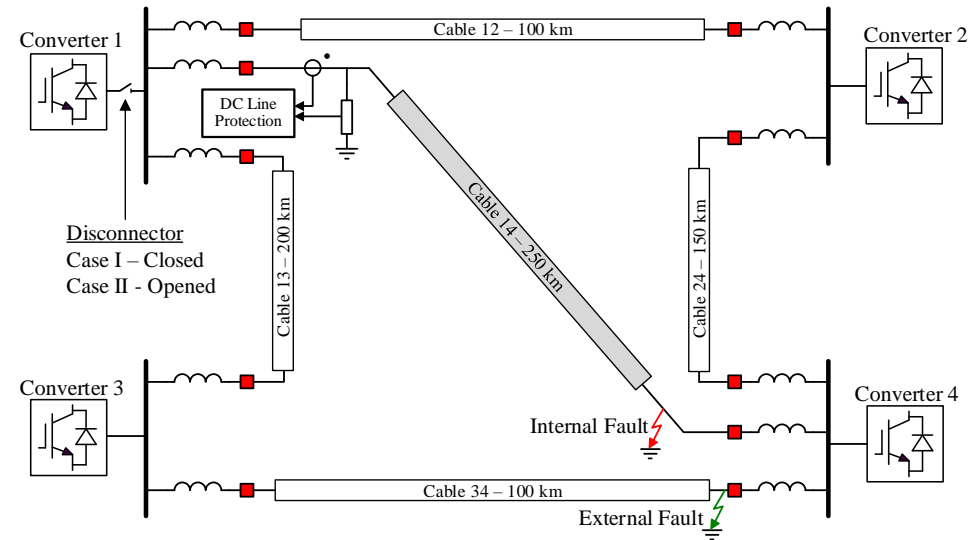


- The protection in the protection zone should be able to distinguish between internal or external faults
- When the protection trips possible actions are:
 - Send trip signal to its own DC breaker
 - Start DC breaker failure
 - Send trip signal to other side of line
- Backup protection is:
 - If any DC breaker has overcurrent but has not received any trip signal. It will start preparing to perform current limiting action.
 - While doing current limiting there are two possible outcomes. First is if the fault is isolated the DC breaker will transfer back to normal mode. If not, the DC breaker will trip.
- DC breaker failure actions:
 - Trip next in line breaker (DC or AC breaker)



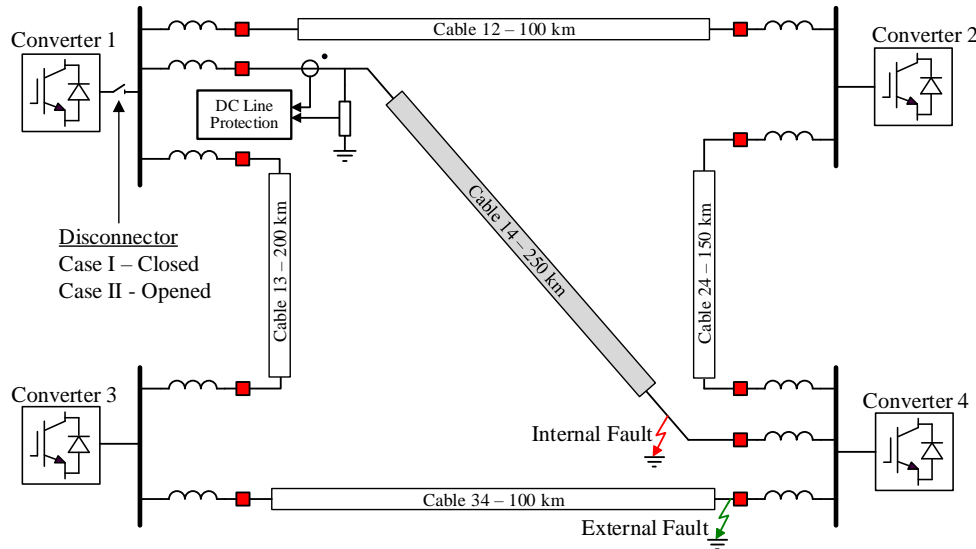
Different networks conditions gives different reflections

- Case 1: Converter 1 connected
Case 2: Converter 1 not connected
- Due to the different network conditions, voltage and current differ (different reflections)

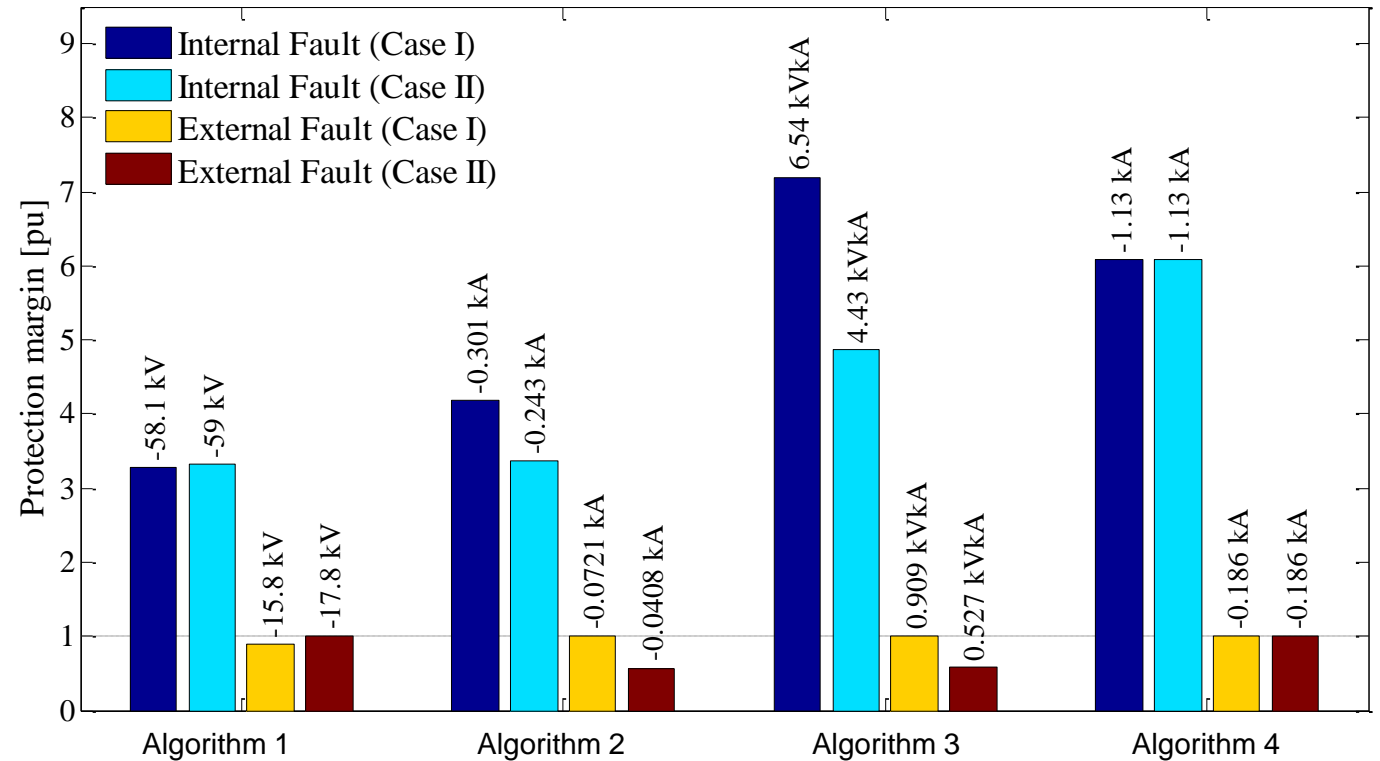


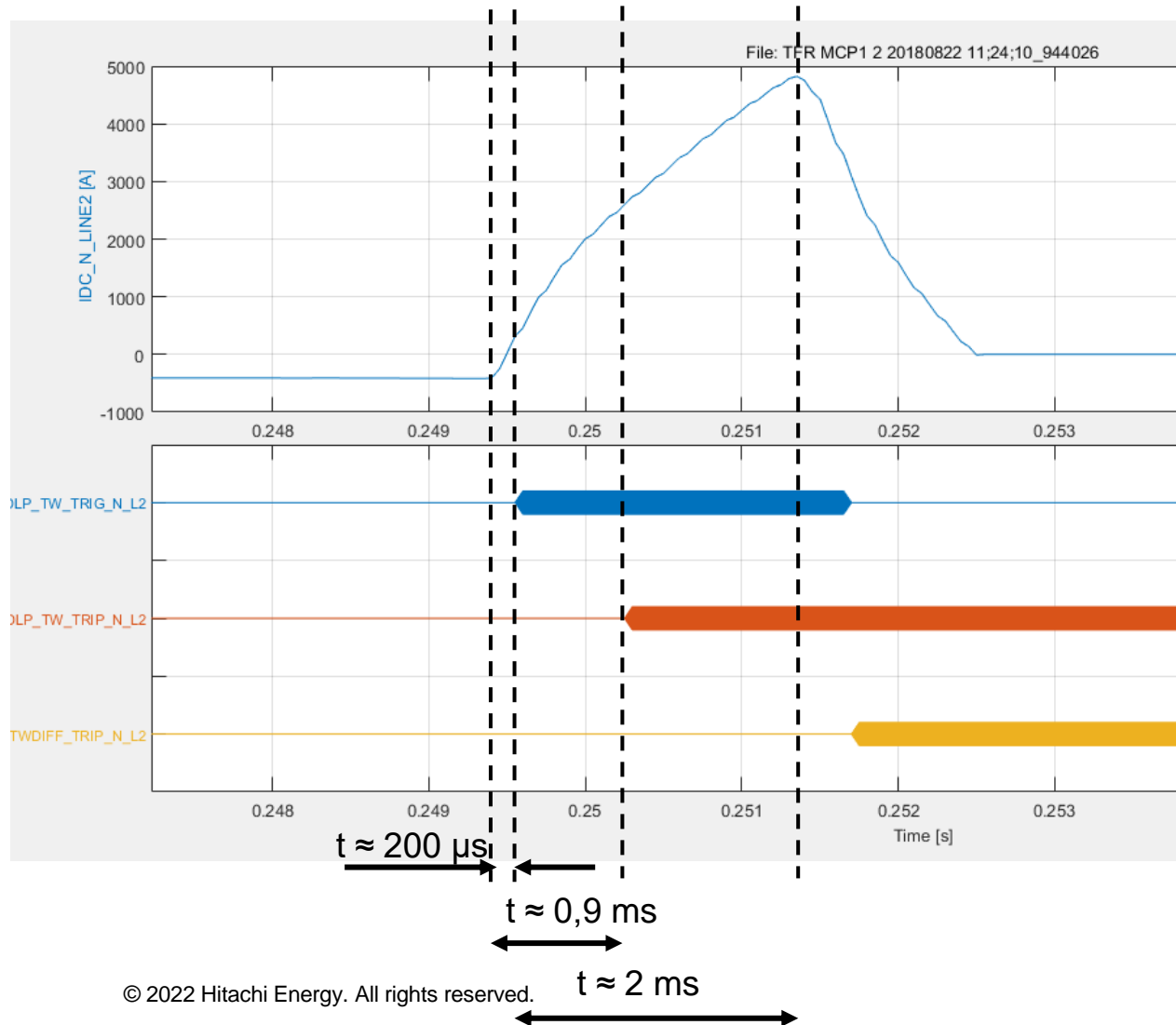
Independent of boundary conditions

Good practice is that the protection algorithm should be independent of boundary conditions at the terminal.



Here algorithm 4 is the preferred solution, since its output is independent of the boundary conditions.





Single-ended

- Single-ended protection schemes are very fast
- Limited reach (depending on main circuit and margins) but can provide detection of the most critical faults (e.g. “first” tower)
- Additional time does not improve selectivity

However

- For reliable operation and practical application, backup is needed

Communication based protections

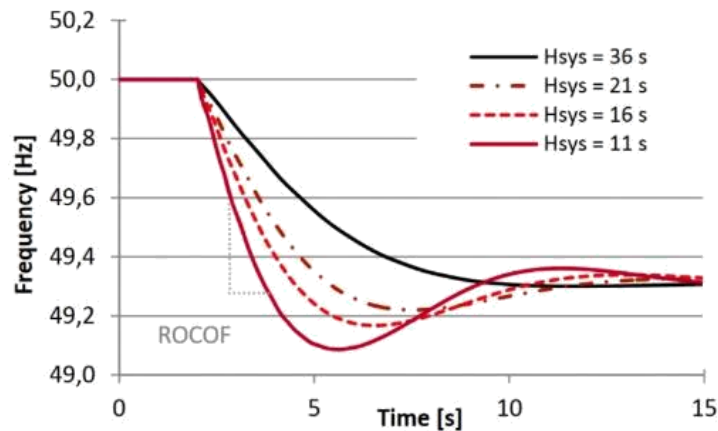
- Slower, due to communication delay
- Detection of all faults
- Relaxing the requirements of wave-front protections



What is Grid Forming?

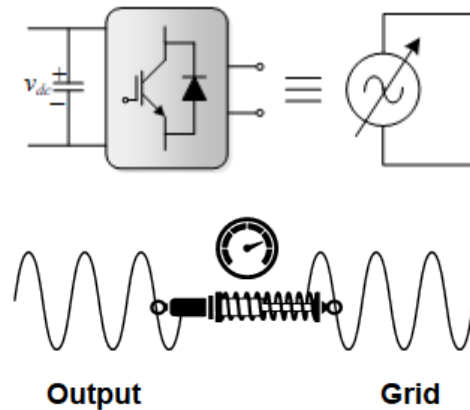
Networks with a high degree of power electronic-interfaced renewable generation will face problems with low inertia and will require robust smart control functions

- Lower inertia results in larger frequency variations
- Behaviour is similar to a conventional rotating machine – tuned for stable behaviour
- Available active power range provides synthetic inertia.



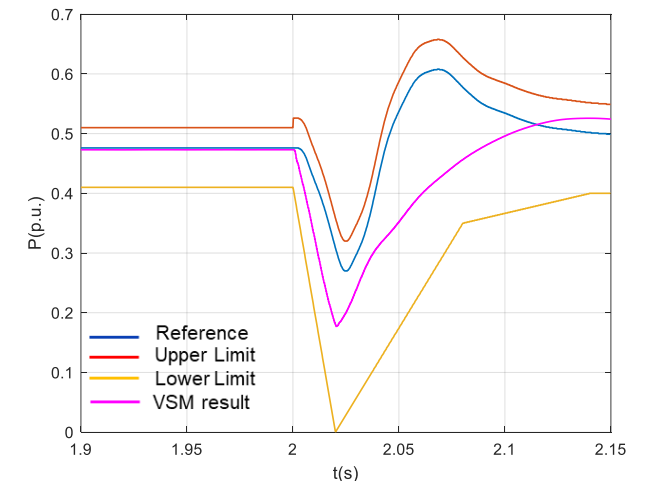
Why new development?

- We already had delivered “grid forming” control in for example Caprivi project as Extreme weak control in 2004.
- Now there are requirements to have Grid forming control for strong grids as well.
- Would it be possible to develop a control that is independent of network strength?



Achievements

- Network strength independent solution
- Synchronization with Inertia emulation
- No mode shifts
- Fulfils FNN requirements





Ability of a system
to work **together with other
systems**, now or in the
future, **without restriction**

**Needed for expansion
possibility of DC Grids**

System

Defined by its external
interfaces and
functionalities

**Together
with other
systems**

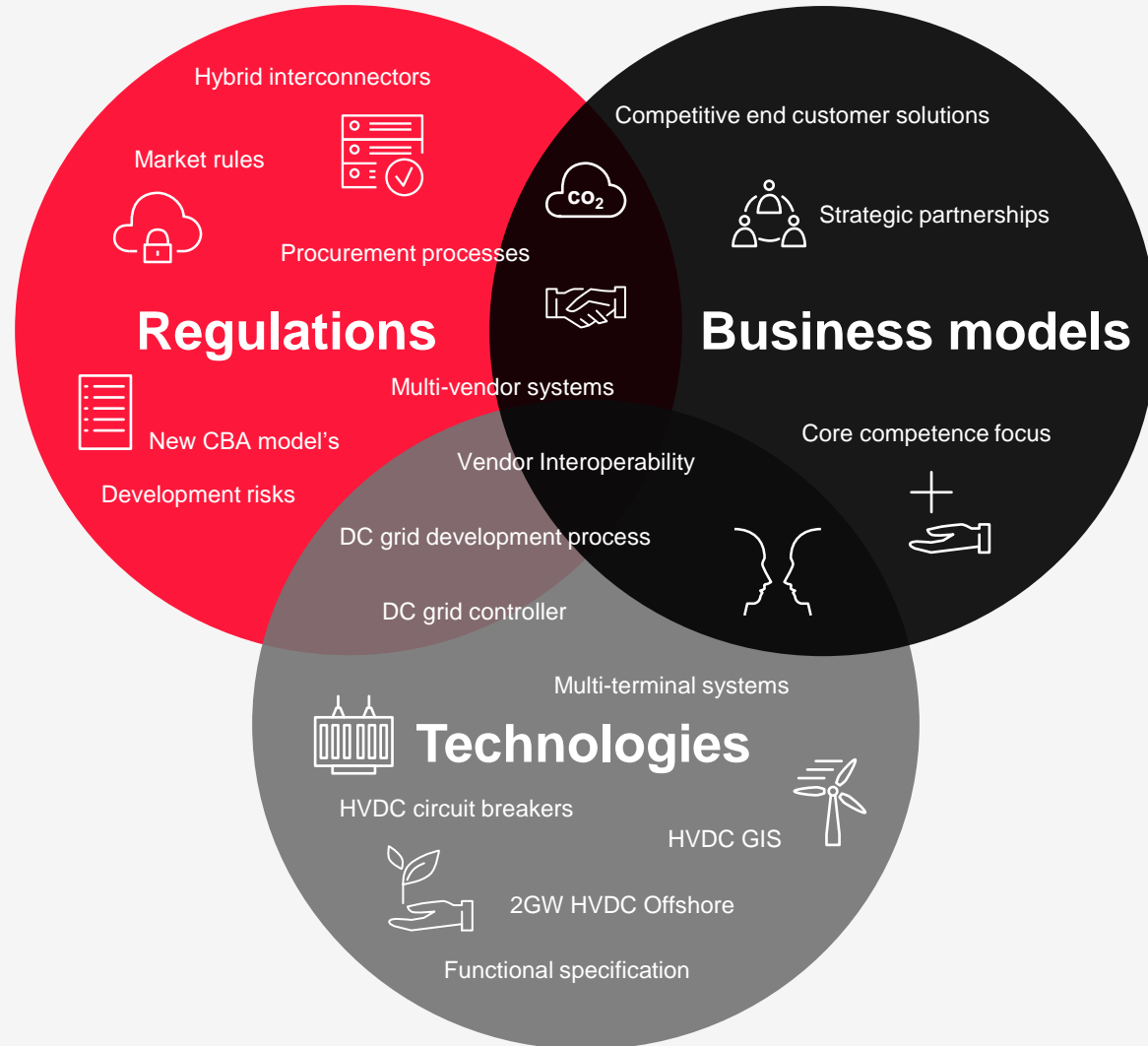
Ability to communicate and
coordinate with other systems
directly connected

**In the
future**

Multi-stage (stepwise)
development

**Without
restrictions**

Performance according
to specifications



Industrial scaling

- Rapid, consistent regulation development
- Industrial pilot projects
- Evolved business models
- Industry talent attraction

- DC Grid is enabler to energy transition
- The DC Grid will evolve (Point-to-Point – Energy HUB – MPI – Meshed)
- All concepts are in place, risk is manageable
- We support DC Grid scalability through **Multi-Vendor Interoperability**
- Interoperability is not only OEM technical matter! (Regulations, DC Grid Code, Functional Spec, planning activities, business models, procurement...)

The drivers behind future DC Grids

World energy trends

- 1.3% global growth in energy demand by 2040
- >50% wind and solar PV of the additional power generation by 2040
- 30 million people employed in global renewable energy sector
- \$1 trillion potential investment in additional renewable energy projects
- 20 Gt CO₂ emission reductions in the Sustainable Development Goals
- 40% extra decarbonization in battery costs (technology breakthrough)

Energy shift and grid interconnections are interdependent

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Future scenarios - Offshore wind expansion

Meshed Offshore Grid (MOG)

- Strengthens European energy markets
- Enables efficient integration and exchange of renewables
- Increased security of supply across Europe
- Allows higher utilization of infrastructure

- Energy islands and small, performant HVDC links equipped across the North Sea and connected to each other via DC and to nearest onshore ports independent of E.ON
- Provides interconnection between countries during periods of low wind

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The first regional DC Grid in Europe

Customer: Scottish and Southern Electricity Networks (SSEN) Transmission

Customer needs: To link Scotland to the UK transmission system

Our response:

- First multi-terminal HVDC interconnection in Europe, with option of three new terminals
- 800MW (250 kV)

Customer benefits:

- Multi-terminal HVDC interconnector provides flexibility to transfer power in multiple directions, based on supply and demand, with minimal power losses
- Reduced renewable energy curtailment and increased security of power supply
- Helps to connect and control wind power generation on the islands in the UK
- Contributes to meeting the greenhouse gas emissions in net-zero 2050

Year: 2024

Key milestones:

- Contract award (2019)
- Breakdown (2020)
- Supply (2021)
- Support (2022)

Key features:

- AC switching station
- AC switching station
- AC switching station

Caithness-Moray-Shetland HVDC Link - Phase 2 – Under construction

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Hitachi Energy Involvement

Inter OPERA: Project driven by SuperGrid Institute and collecting consortium of HVDC system manufacturers, TSOs, and early HVDC system integrators, wind turbine manufacturers, offshore wind farm developer.

Best Paths: With nearly 40 leading organizations from research, industry, utilities, and transmission systems operators, Hitachi Energy part of the project, together with Siemens, GE, Toshiba, Söhlert, Eka, Tema, Energinet, Stabnet, RTE, Rede Electrica examples of Utility partners.

GENELEC: Technical Committee with participation from Hitachi Energy, Siemens, GE and different European TSOs.

Main Objective: Development of guidelines for HVDC Grids Systems.

Task completed: approved EU standard HVDC Grid Systems and covered Converter Station – objectives and parameter (after Functional Specification) Basis for InterOPERA work. Ongoing transition to an IEC standard.

Reference Hitachi energy participants: Christian Wikström, Peter Lundberg

Reference Hitachi energy participants: Christian Wikström, Peter Lundberg

Reference Hitachi energy participants: Mats Hylander, Peter Lundberg

Hitachi energy has been, is and will be main active player in defining DC Grids of the future

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Enabling DC Grid – HVDC Breaker

- Enabler for Meshed HVDC grids
- In case of a fault, ensures that only affected part of the grid is disconnected
- Increasing availability and reliability of the system
- Conventional breakers are not suitable for DC grids
- To enable different protection zones in the DC grid
- ... through fast response, high reliability, low losses

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HVDC Interoperability – Functional Grid Code solution

Existing "Point-to-Point" HVDC system

Future HVDC grid system

Key elements to be set:

- DC system coordinator
- DC Grid Functional Specifications (DC Code)
- DC Code (DC Code)
- DC Code (DC Code)

Ensuring interoperability with AC grid codes and DC functional specifications

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