High Voltage Direct Current – HVDC Transmission Systems

Enabling the grids of the future

POWERING GOOD FOR SUSTAINABLE ENERGY

2021-05-31

HITACHI ABB POWER GRIDS

Agenda

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01. **A changing energy system**
The importance of interconnections

02. **Why HVDC**
An introduction to HVDC advantages

03. **HVDC Technology**
Our shared success

04. **Realize and maintain HVDC**
From concept to decades of operation

05. **HVDC Project Experiences**
Answers to customer needs

06. **Conclusion**
Partnership for success

Mega trends - The world is changing fast

Mega trends

- Public attention to environmental issue
- Environmental regulatory framework
- More concentration of population
- Technology development
- Digitalization

The Energy Revolution

Decarbonization of power production
+
Electrification of industry, transport and infrastructure

The Digital Revolution

Connection of every asset
+
Data as key to better outcomes

Impact

Generation

- **More generation**
- **From fossil … to renewables**
- **More distributed**

Consumers

- **Cleaner industrial processes**
- **From fossil fuels … to e-mobility**
- **More dataflows to be powered**

Leading toward a sustainable energy system

Challenges facing the grid

The conversations that we have every day with customers

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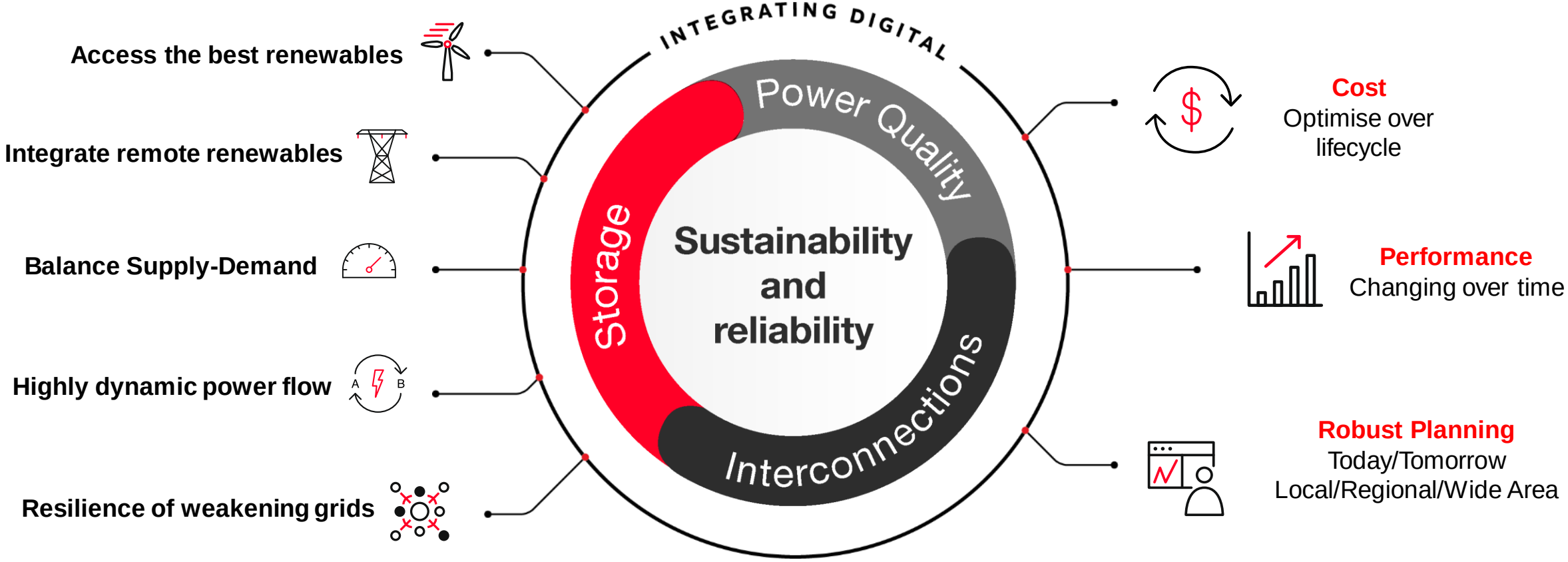


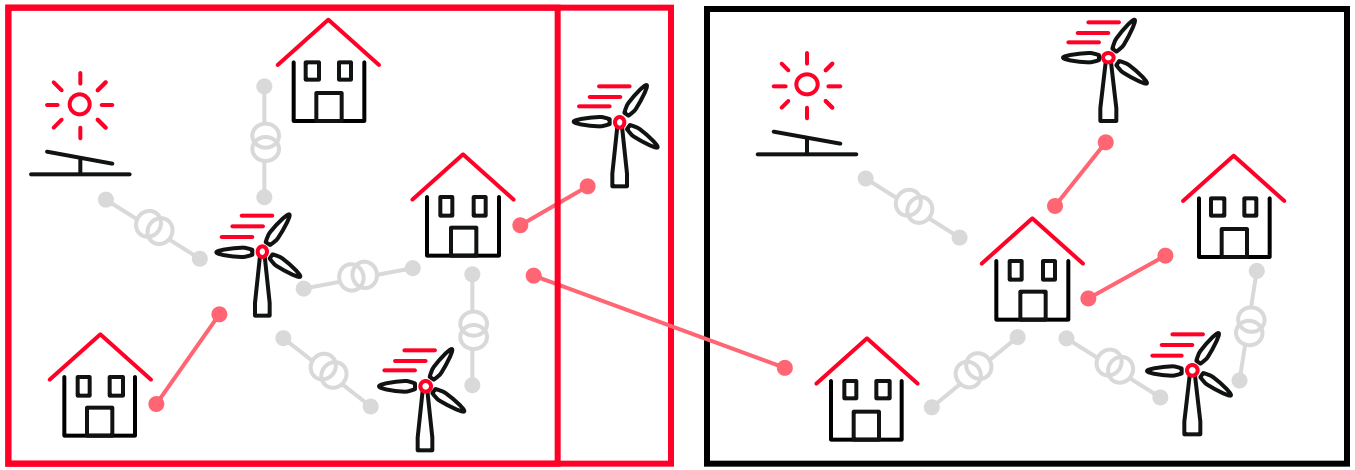
Strongly interconnected grids will better manage the energy system transformation

Interconnections – getting stronger together

Synchronous grid

Same frequency and synchronous operation

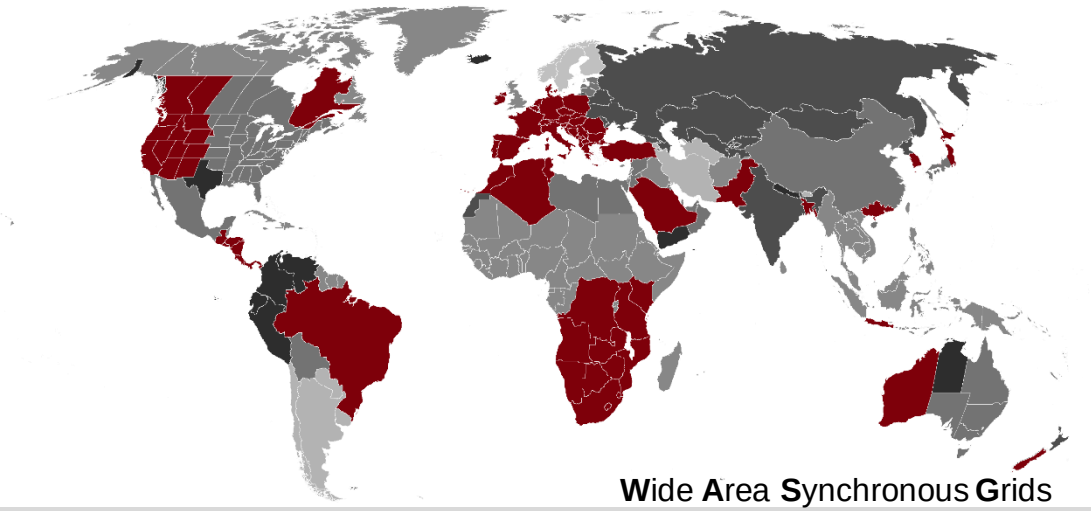
- HVAC & HVDC connections
- Optimization through several options
- Peripheric expansion for connecting remote RES



Asynchronous grid

Different frequency or asynchronous operation

- Connection through HVDC links
- Controllability and flexibility
- Maintain resilience of AC grids

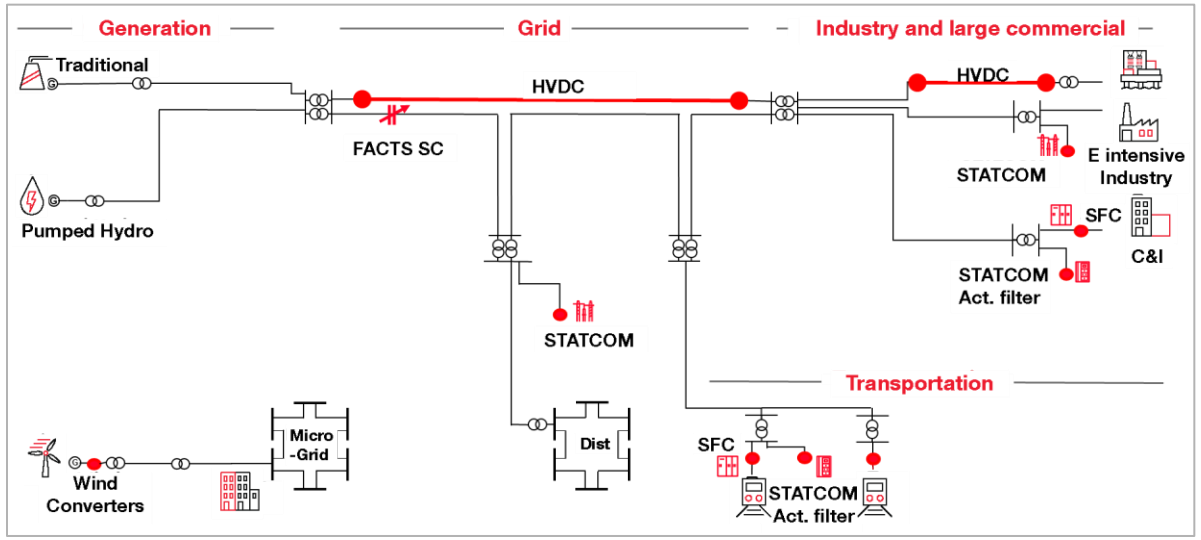


Wide **A**rea **S**ynchronous **G**rids

Strengthening and expansion of synchronous grid - Stronger than ever need to interconnect asynchronous grid

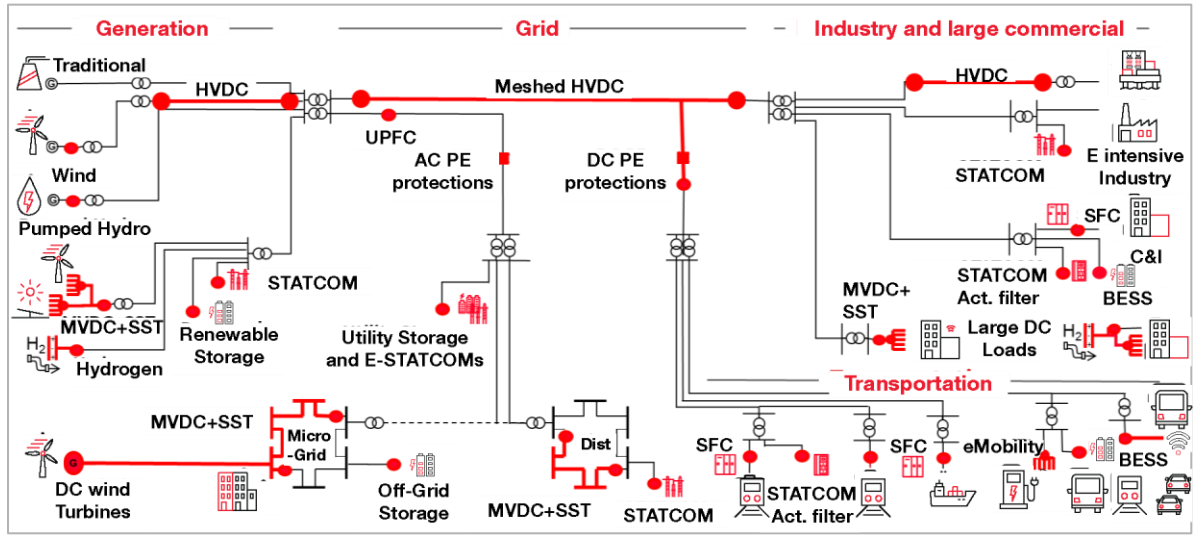
Future Power Systems – Technology trends

Past … The conventional utility grid



Power Electronics a niche application

Future … The carbon-neutral future is electric



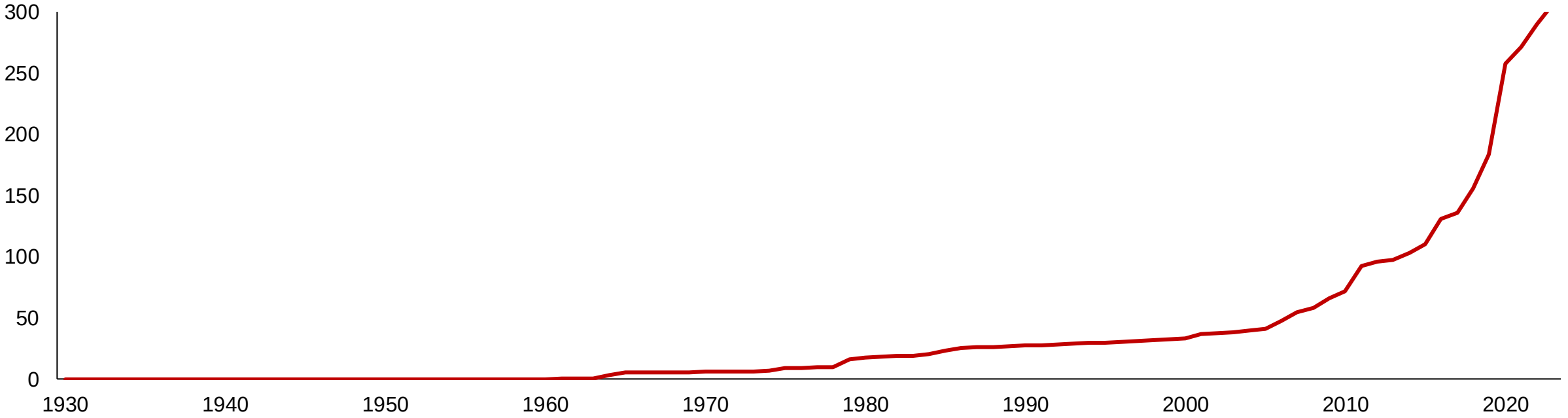
Power Electronics across the total Power Grid

Power Electronics coupled with Digital enables electricity to be the backbone of the carbon-neutral future

From an idea to global industrialization

HVDC is the solution for today's grid challenge

Cumulated GW installed



1928

Dr Uno Lamm began developing HVDC in Ludvika, Sweden

1954

The world's first commercial HVDC link at Gotland, Sweden

1960s

Mercury arc valves replaced with thyristor semiconductor valves

1997

The world's first VSC[1] HVDC installation

2017

VSC HVDC highest performance ever – 3,000 MW, 640 kV, 2,000 km

Exponential growth has been driven by Technical developments and Grid transformation needs

1. VSC: Voltage Source Converter

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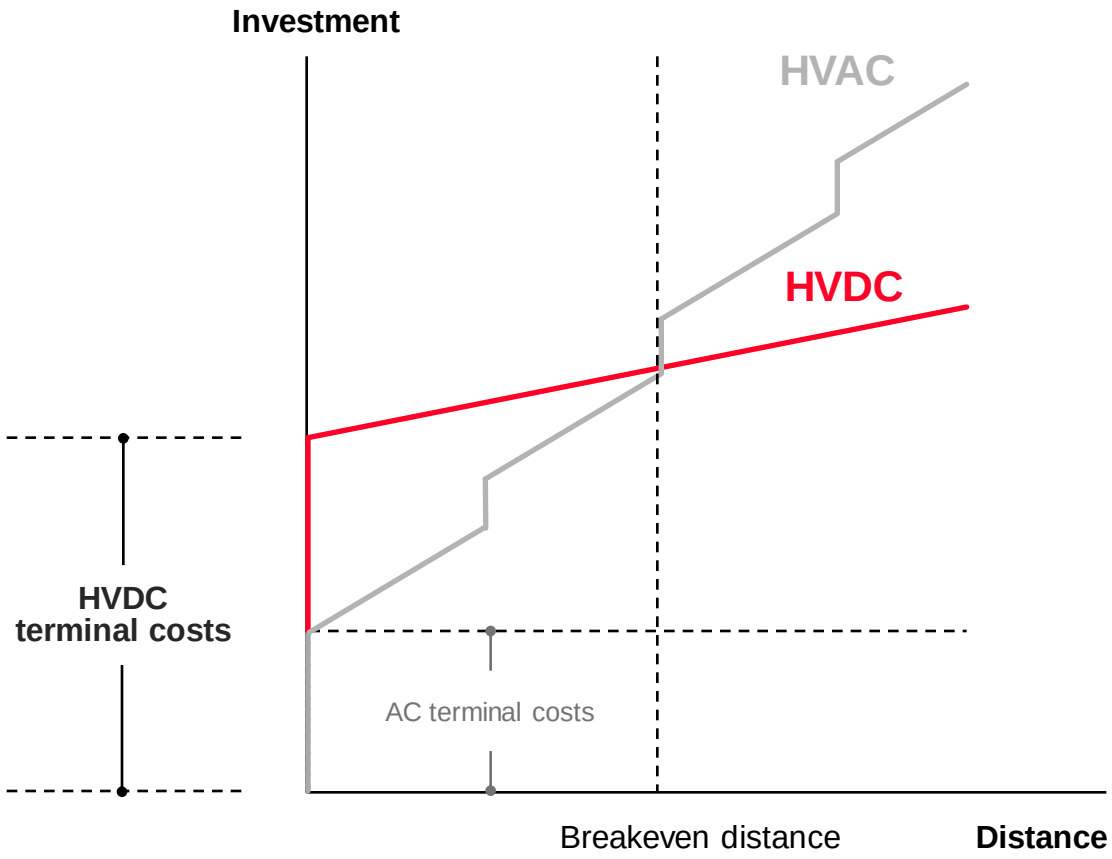
HVDC vs HVAC

Including AC line compensation for equivalent power quality

Investment



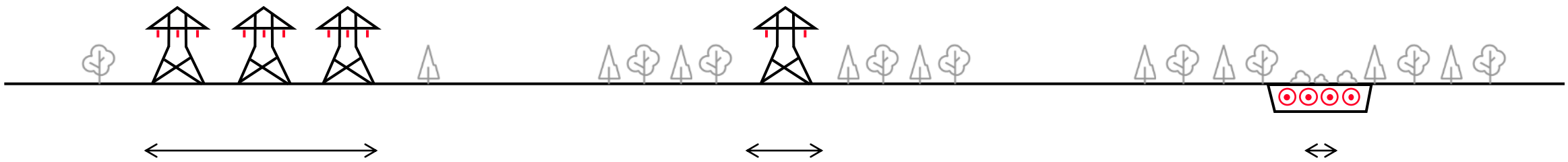
HVDC Value

- Lower losses
- More power
- Controlled power flows
- More grid stability and versatility
- Smaller footprint
- More sustainable

HVDC

The traditional advantages of HVDC vs HVAC

More power, less space



Land use with
AC overhead lines

Land use with
HVDC overhead lines

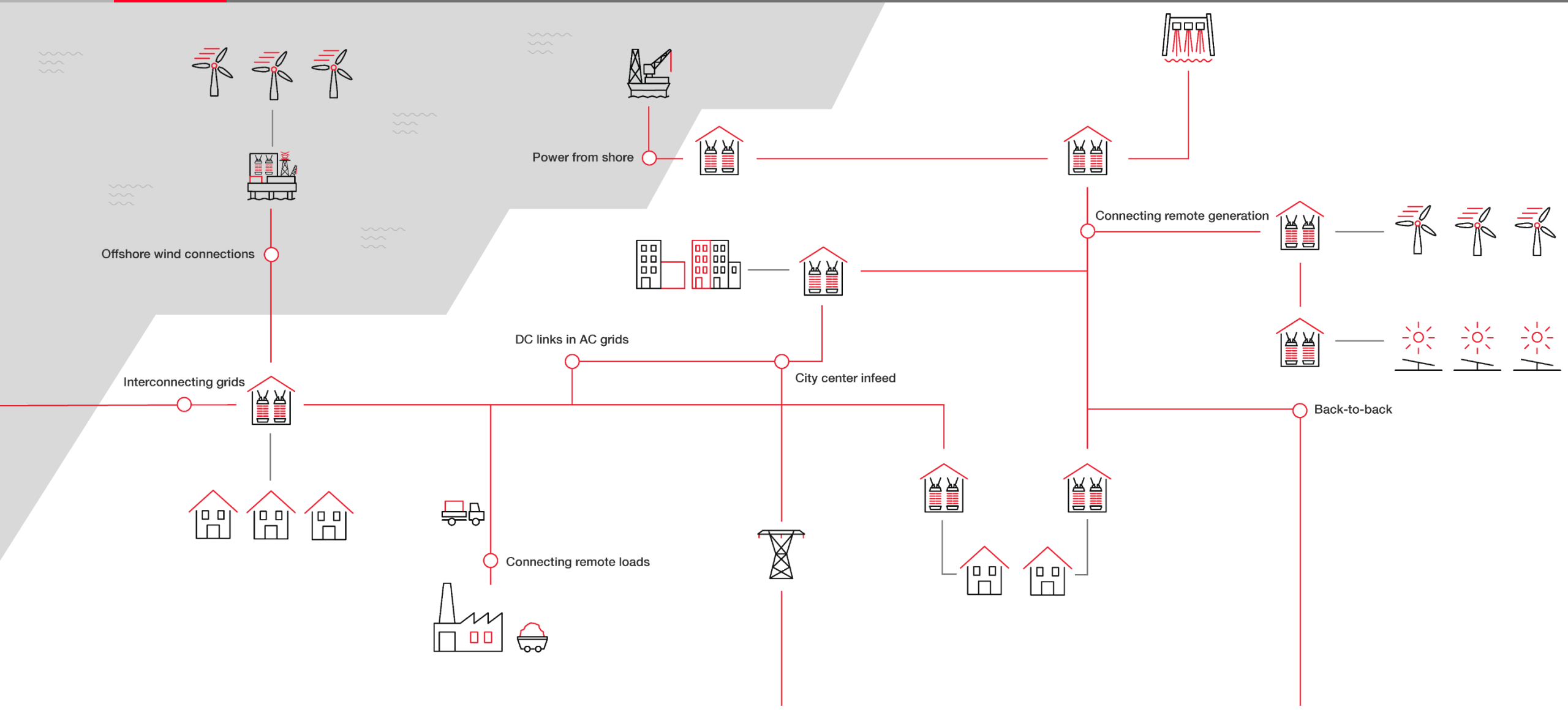
Land use with
HVDC Cable

HVDC technology can save up to 50% of land usage

Illustration shows typical 3 GW transmission line

HVDC applications

Shaping the grids of the future



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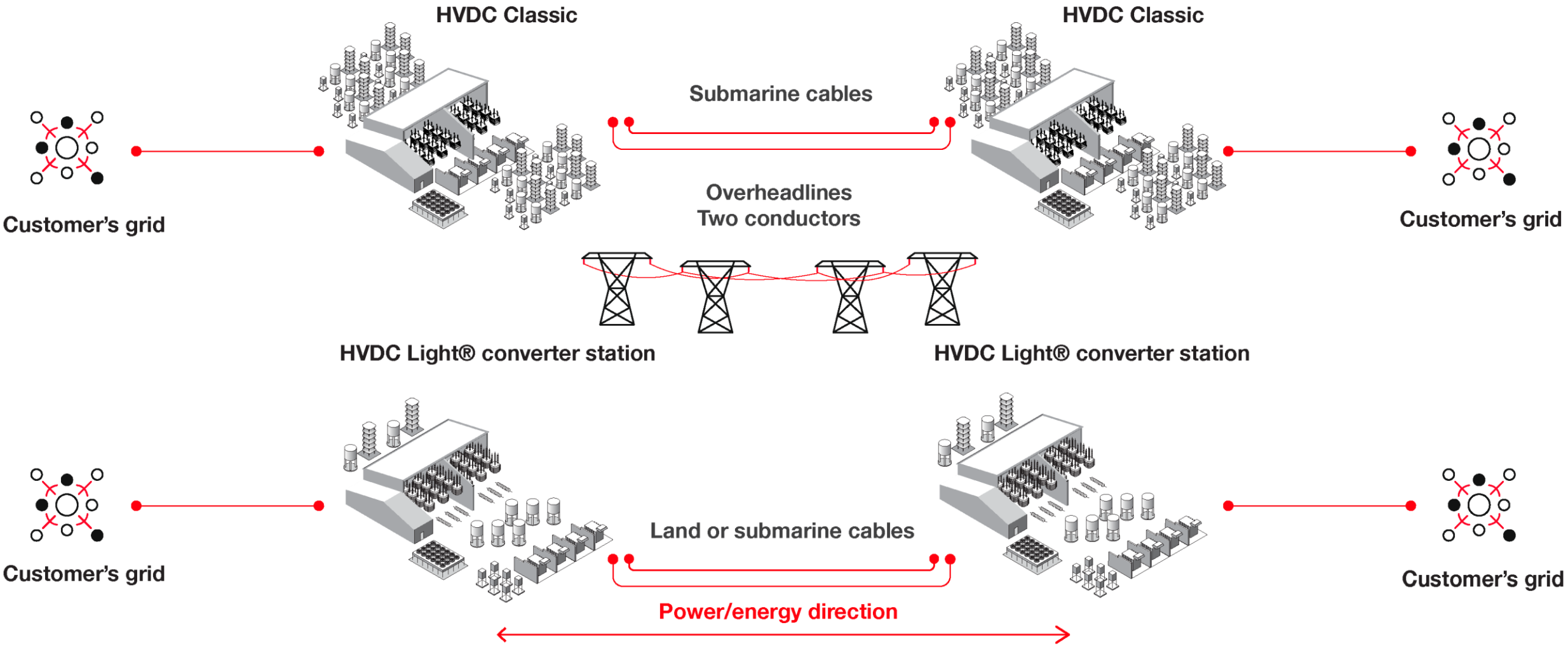
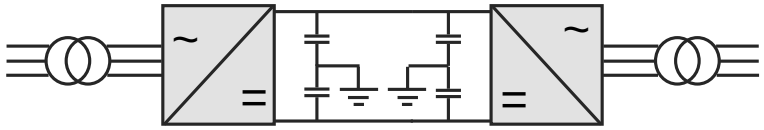
What is an HVDC transmission system?

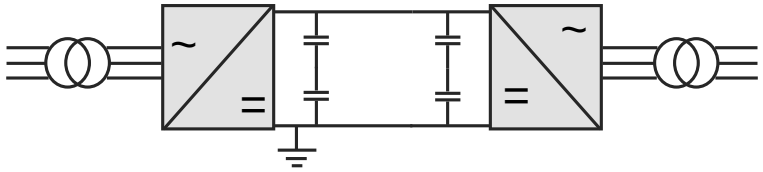


The right rating and system design

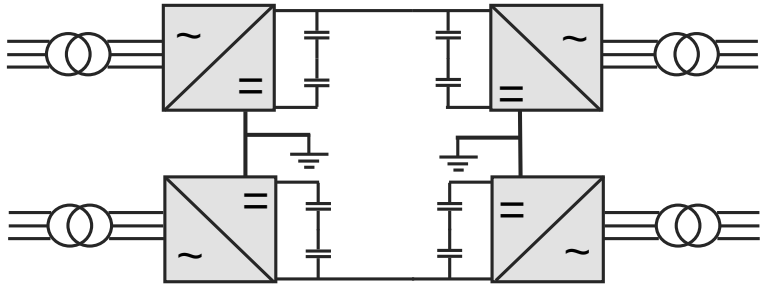
Symmetric monopole



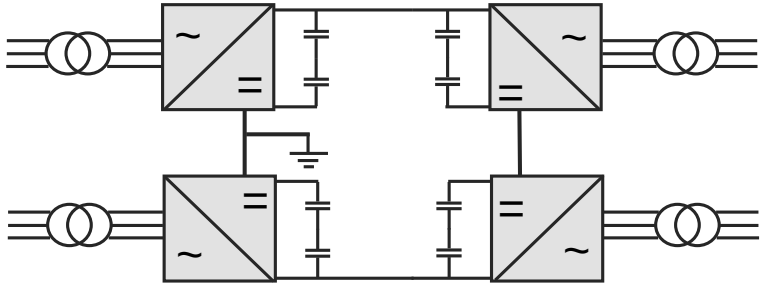
Asymmetric monopole



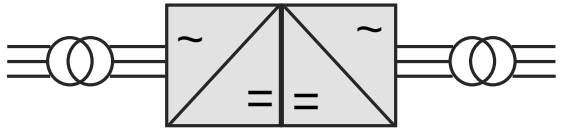
Bipole



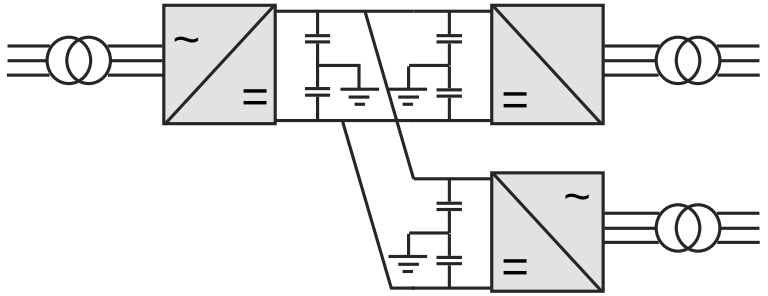
Rigid bipole



Back-to-Back



Multi-terminal

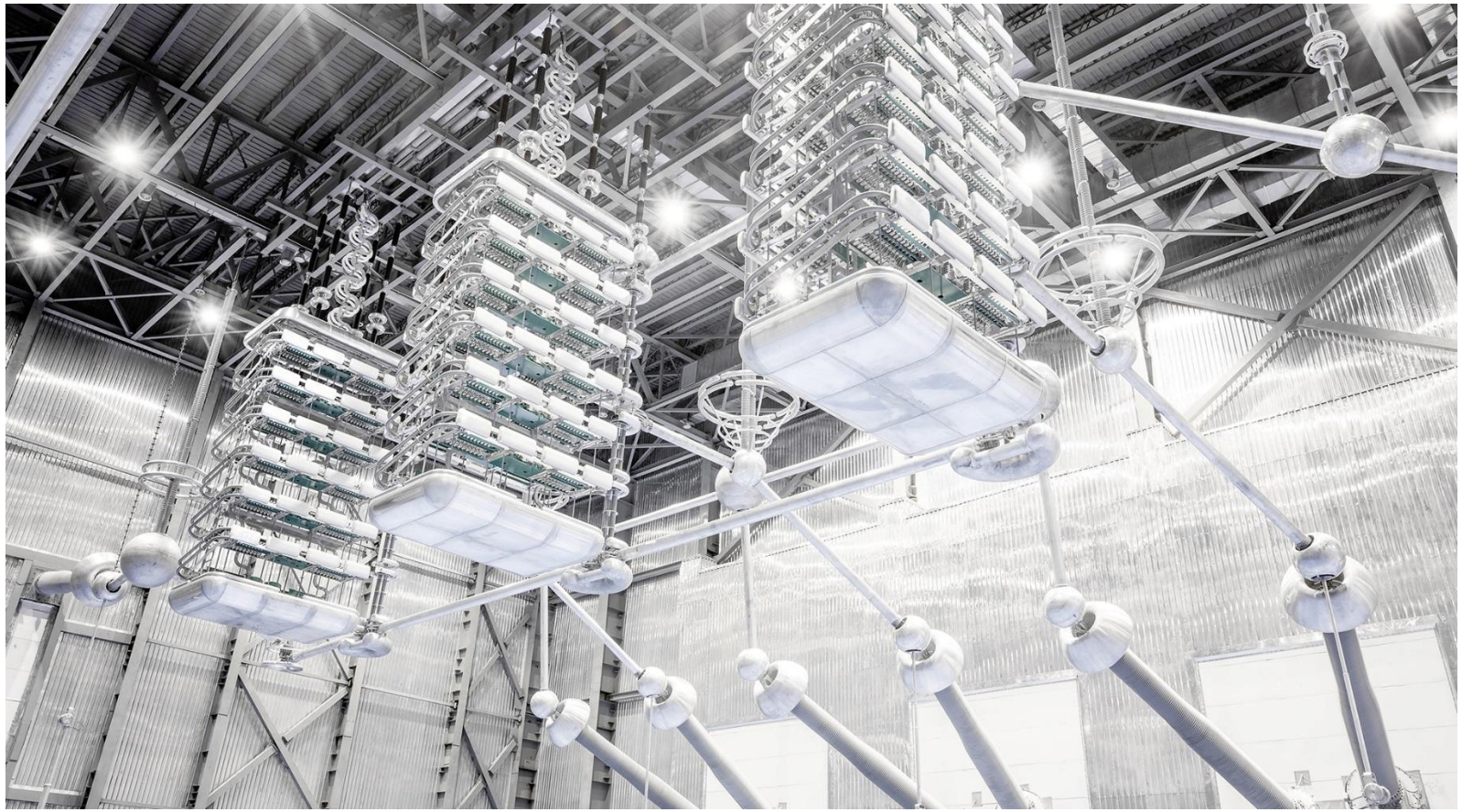


HVDC Classic

High power transmission

HVDC Classic from Hitachi ABB Power Grids:

- Low losses
- High reliability
- High availability
- World’s largest greenfield project experience
- Extensive Service and Upgrade experience



Cost effective, bulk transmission (3 to 12 GW+)

HVDC Light®

Your grid challenges, solved by HVDC Light®

Weak network?

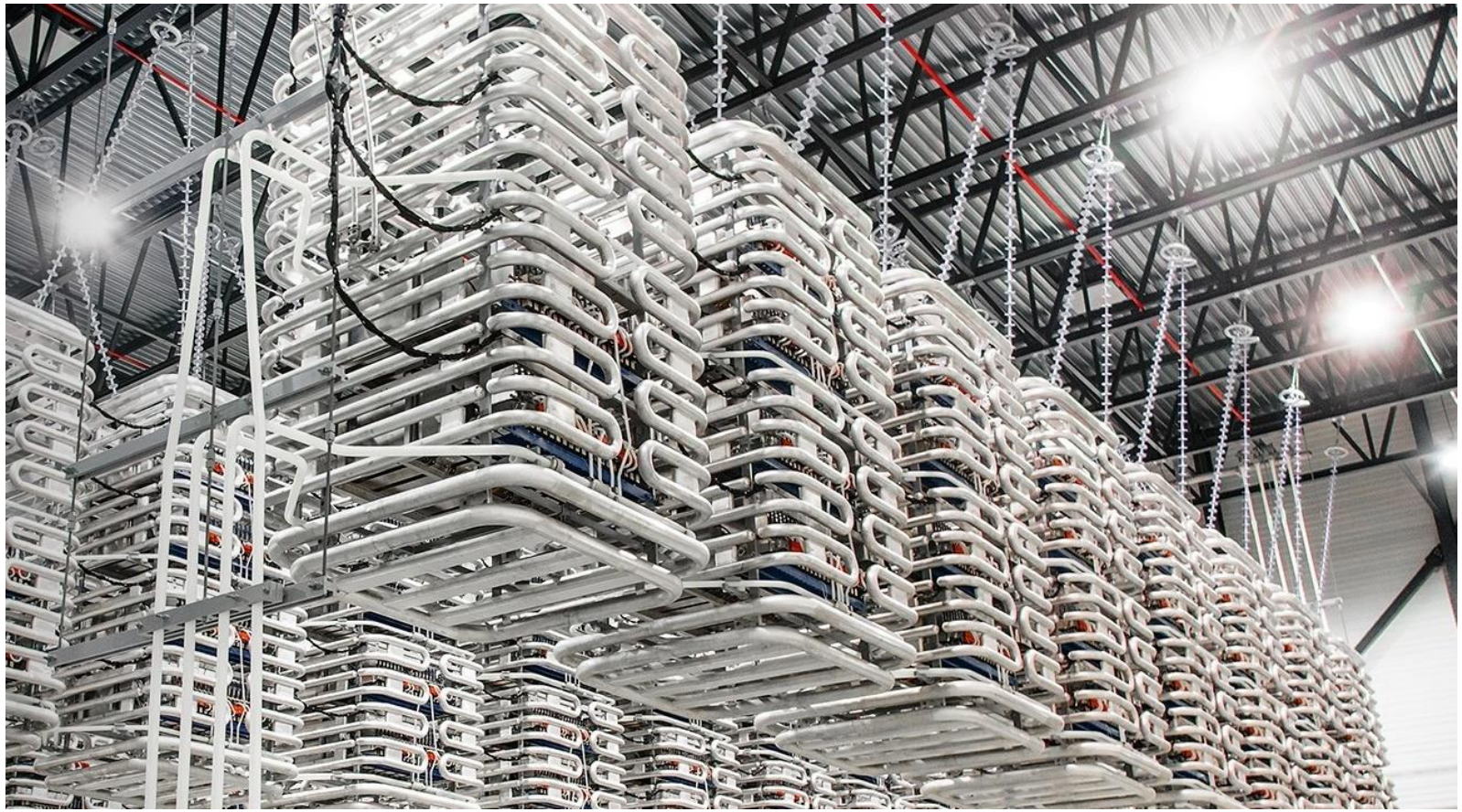
- Black start power restoration
- Active/reactive power control (STATCOM functionality)
- AC voltage and frequency stabilization (possibly increasing AC grid utilization)

Bi-directional power trade?

- Fast power reversal

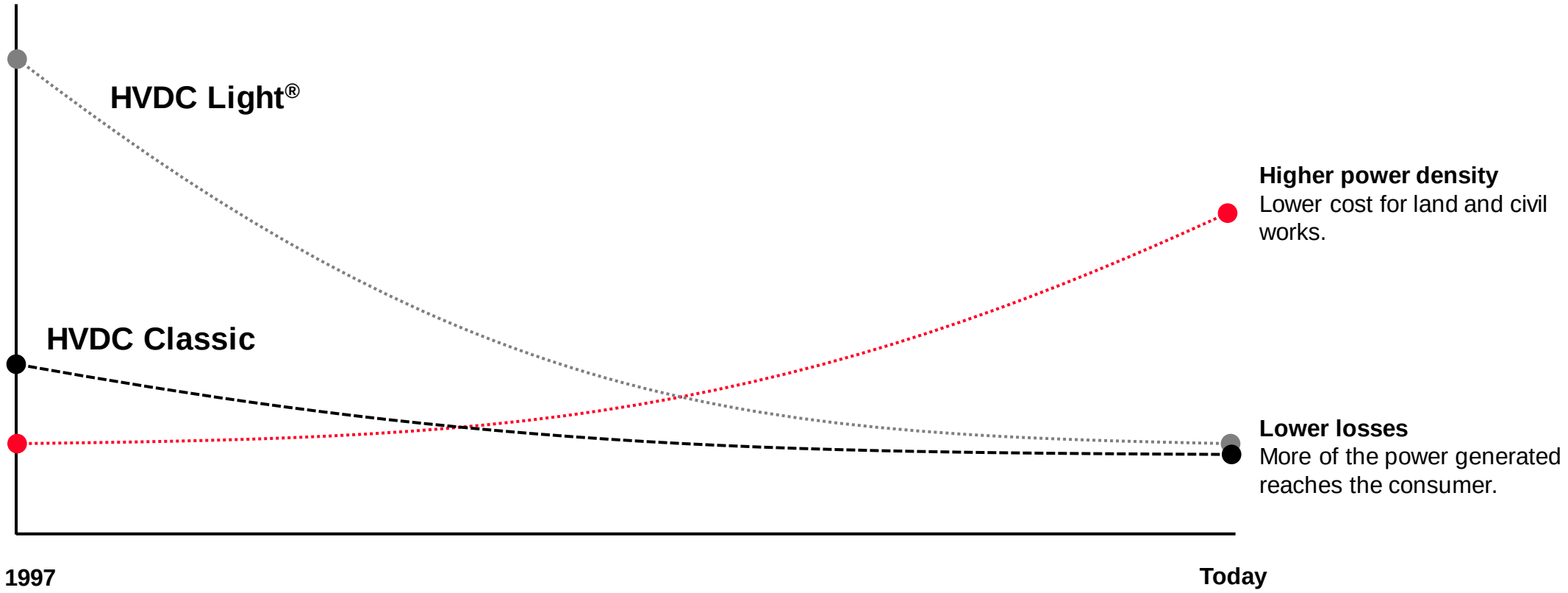
Integration of renewables?

- Power and voltage control



Up to 640 kV and 3,500 MW

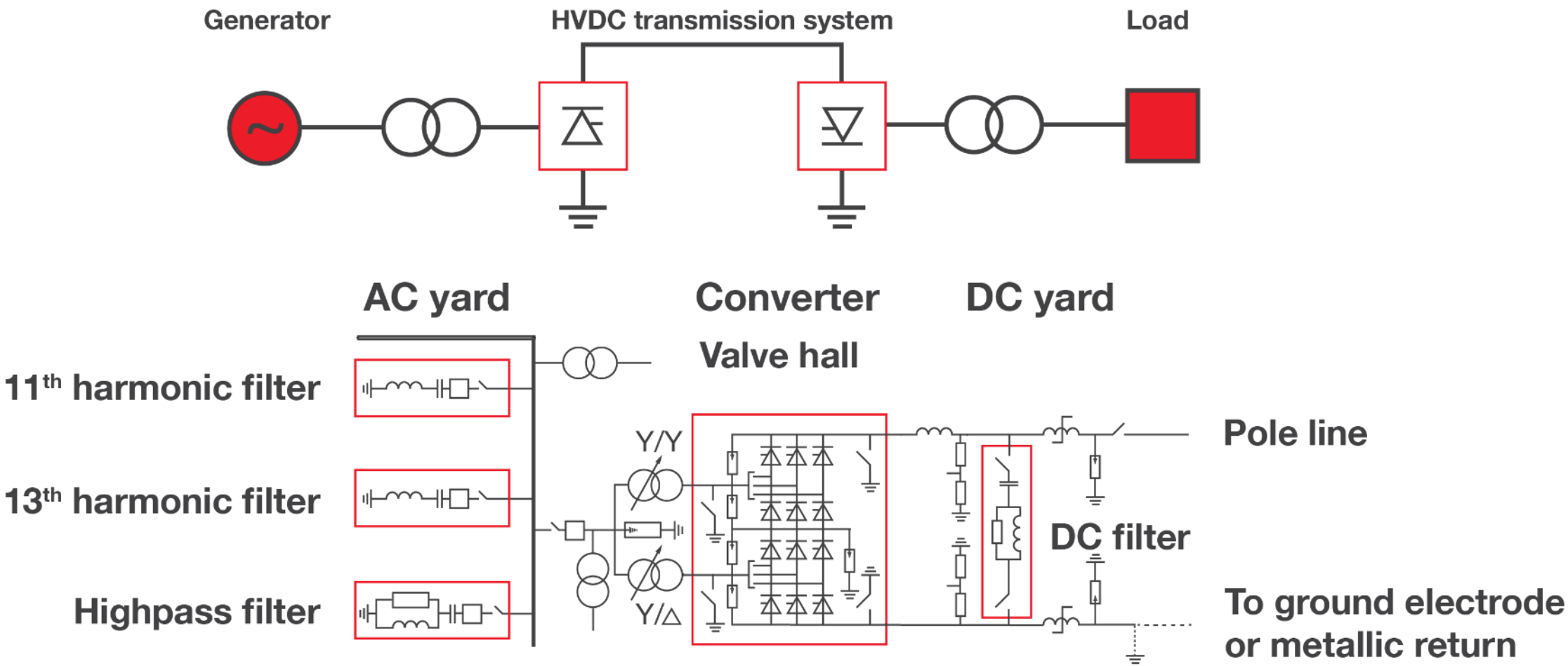
HVDC – two solutions for state-of-the-art solutions



Technology driven by customer needs – now a bulk power solution with system benefits

HVDC Classic - LCC

Monopolar HVDC Classic configuration



HVDC Theory – LCC

Basic control features

Fast control of active power enables:

- Frequency Control
- Damping Control
- Emergency Power Control

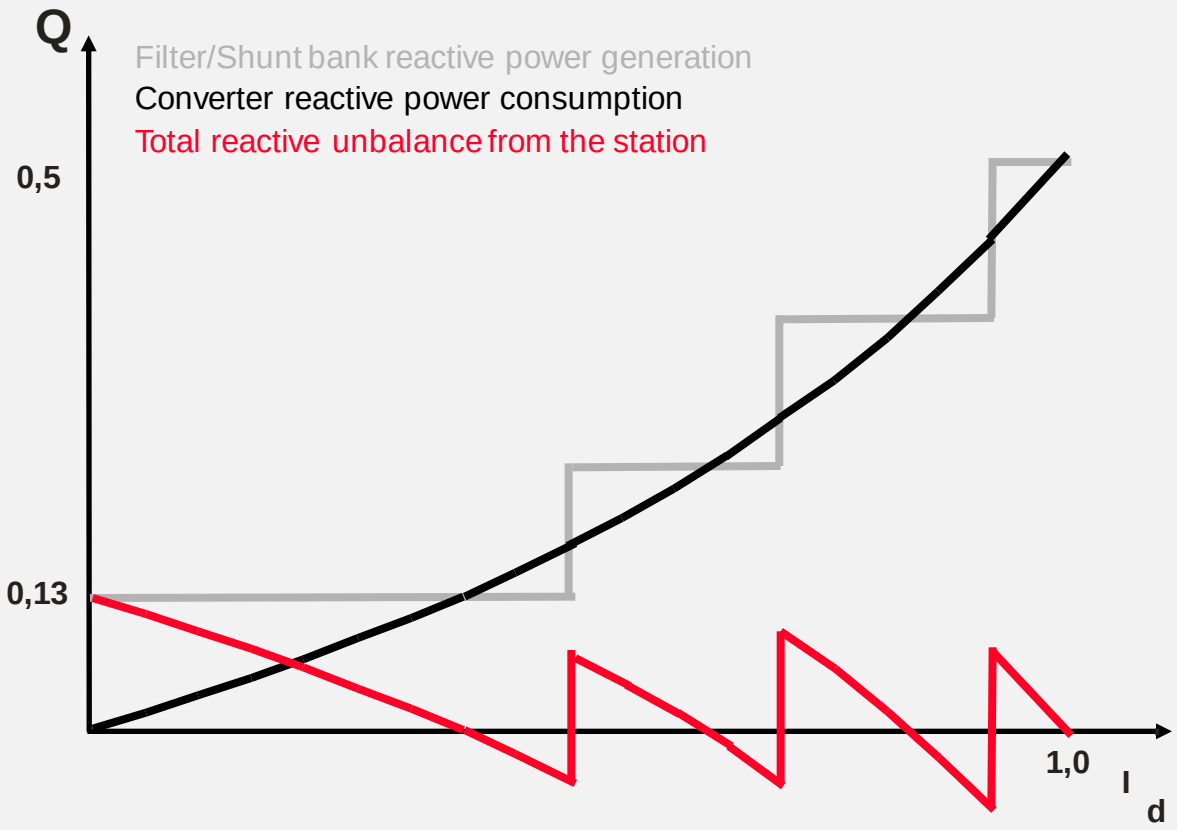
Fast restart after AC faults

Fast detection and restart at DC line faults

Fast power reversal

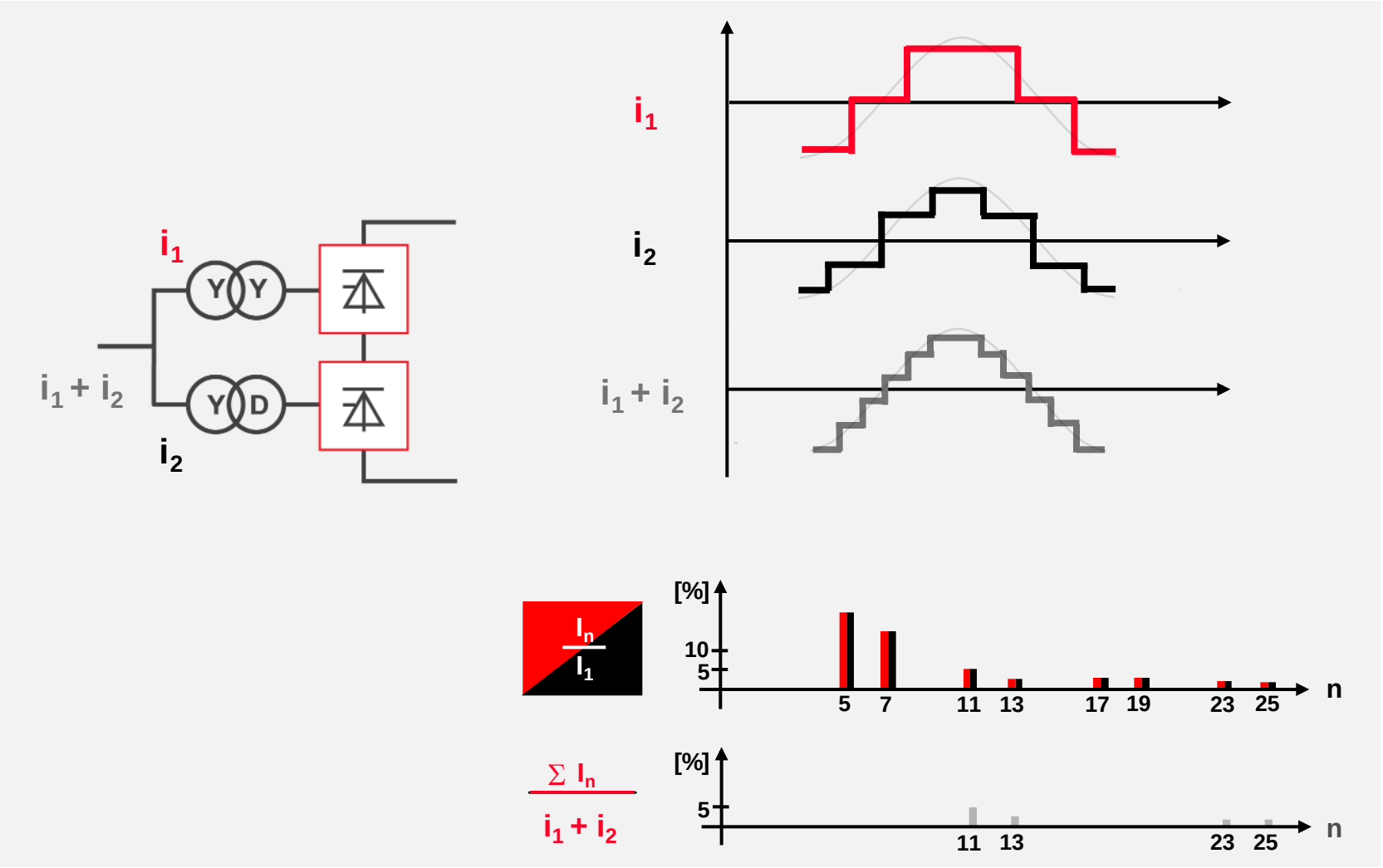
Reactive power balance – Compensation

- HVDC converters absorb reactive power due to firing angles ≠ 0
- Harmonic filters are installed on the AC side for filtering the AC current harmonics **and for generation of reactive power**
- Q absorption increases with the transmitted active power
- Need for filtering of harmonics increases with the transmitted power
- Q absorption grows slowly at low power, and increasingly at high power
- Filter needs grow behave in the opposite fashion
- Q balance with ac network is managed by switching in/out filters and shunt banks



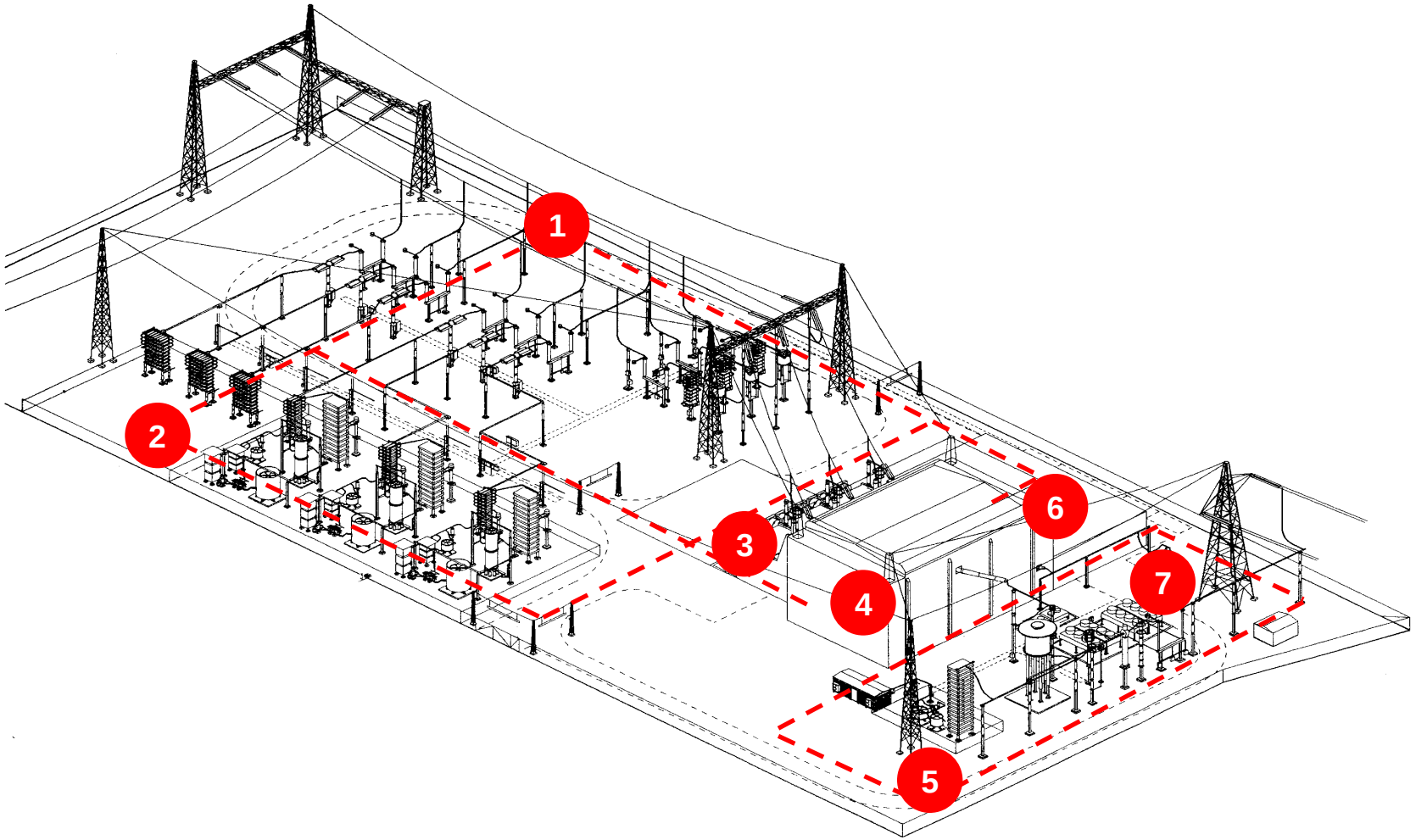
Harmonic current generation

- AC side current harmonics: $f_h=12n\pm1$, i.e., 11th, 13th, 23rd, 25th, …
- Typical ac filter performance criteria: THD<1.5%, D_h<1%, TIF < 45
- DC side voltage harmonics: $f_h=12n$
- Typical dc filter performance criteria: I_{eq} < 250 mA
- Typically 35% of station rating in installed ac filters
- Harmonics diminish with increasing harmonic number



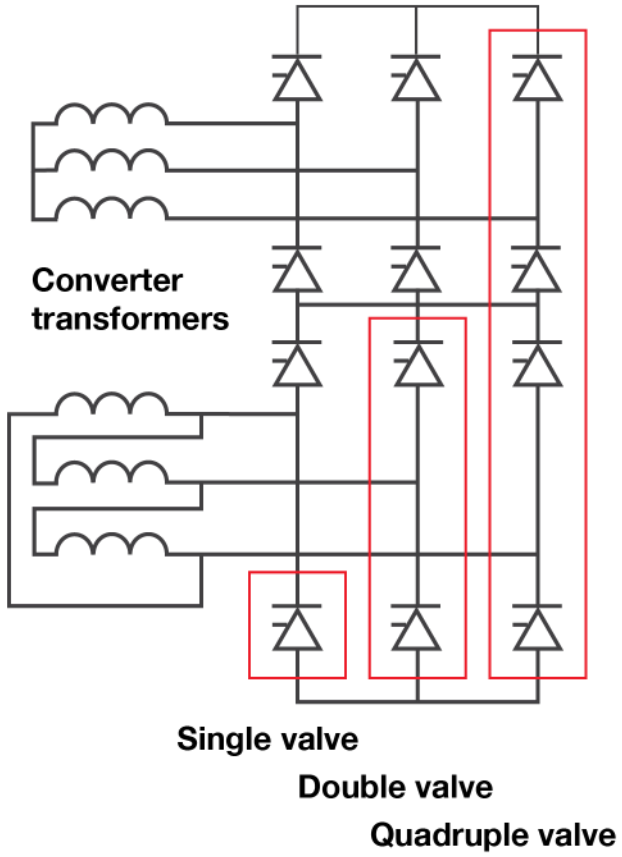
Identification of areas

1. AC bus
2. AC filter and shunt banks area
3. Transformer area
4. Valve hall
5. DC yard
6. Service building
7. Coolers



Station layout – Monopolar configuration

Valve hall – Thyristor valves



Thyristor Module

Heat Sink

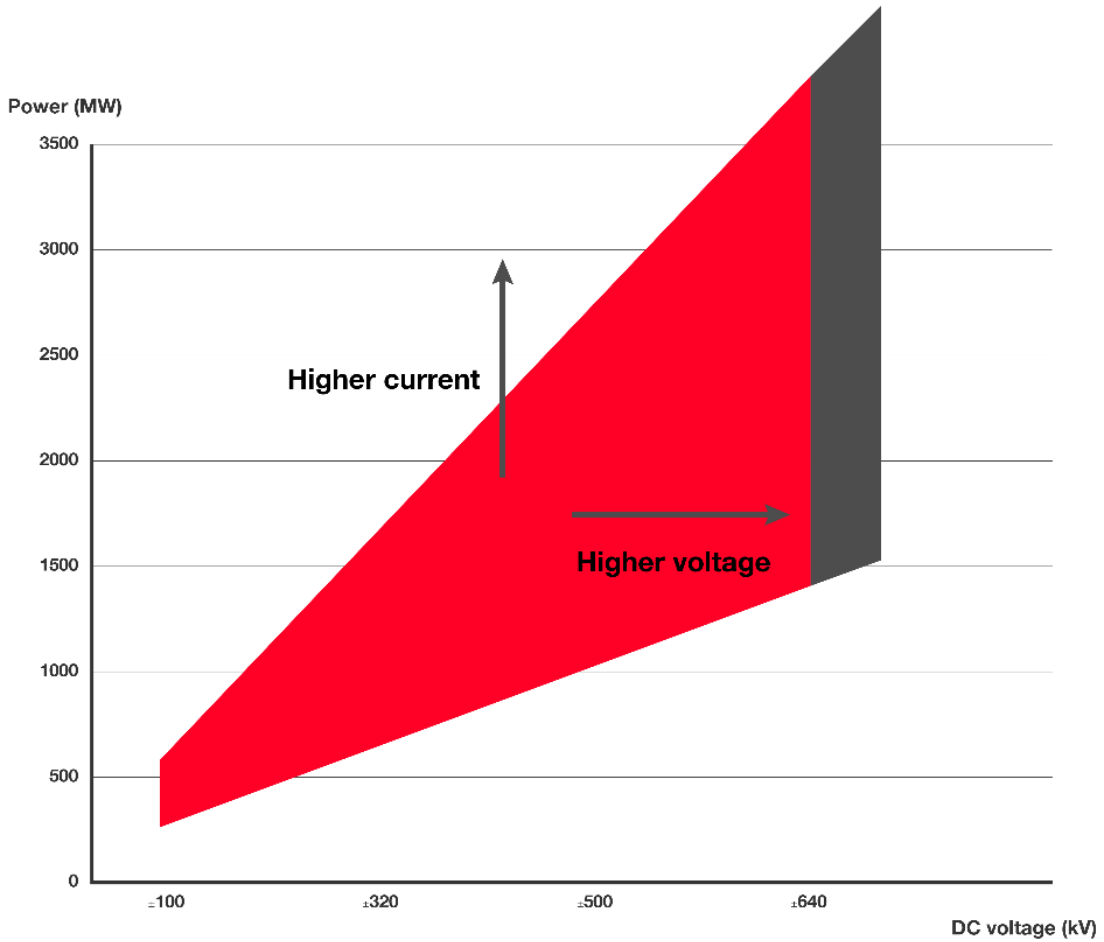
Gate Unit

Thyristor

Reactor Module

HVDC Light® - VSC

Power ratings available 2020

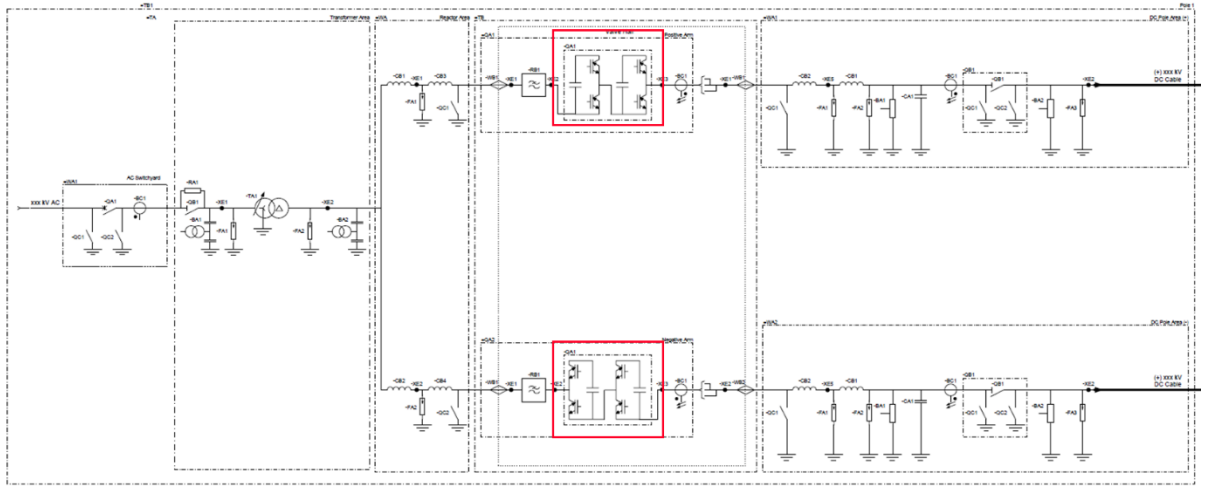


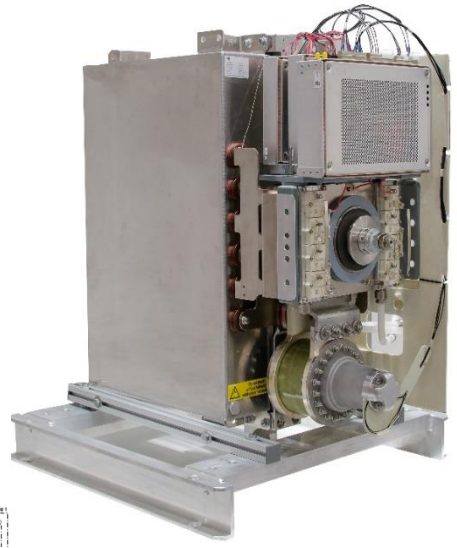
HVDC Light® ready for 800 kV, 4.8 GW

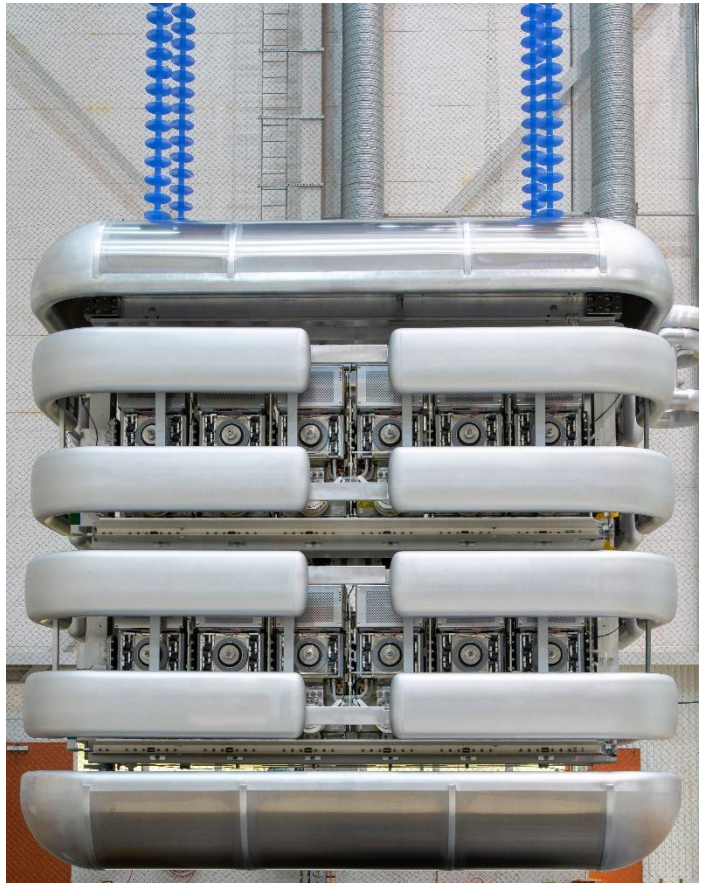
What is a valve?

Duties and deliverables

- Converts AC to DC and vice versa
- Consists of series connected cells
- Includes StakPak BiGT (Bi-mode IGBT), capacitors, electronics, bypass and cooling
- Inherent series redundancy







LCC vs VSC station size

500kV bipol up to 3 GW

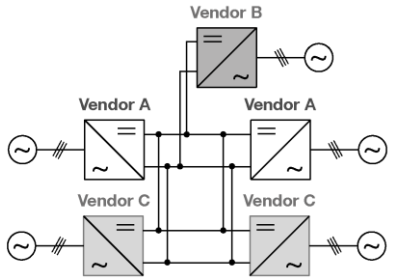
Approx. 313 m x 313 m

Approx. 230 m x 180 m

Forward looking – DC grid technology development

Multi-terminal

- Ability to manage different DC lines from 1 station
- Multi-terminal ready and multi-terminal prepared
- Project examples: NordBalt and Shetland



DC breaker

- Ability to isolate fault current on DC mesh
- Demonstration as part of EU-funded PROMOTION

DC grid control and protection

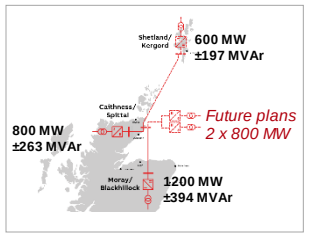
- Ability to supervise power flows across a DC Simulation part of DC grid program (CIGRE)

HVDC GIS

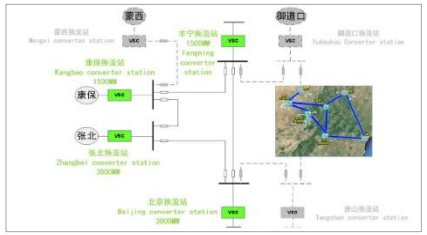
- Ability to isolate AC fault current on DC station
- Test at KEMA as part of EU PROMOTION project

Real-world hybrids and DC grids

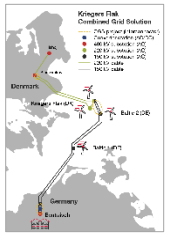
Caithness-Moray Shetlands grid

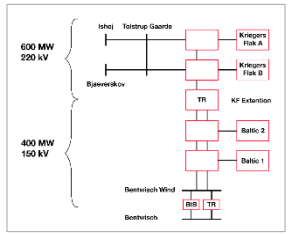


Zhangbei DC grid project



Kriegers Flak CGS





DC grid technology is ready for the emerging grid

Agenda

HVDC becoming mainstream in all corners of the world

Interconnecting Grids

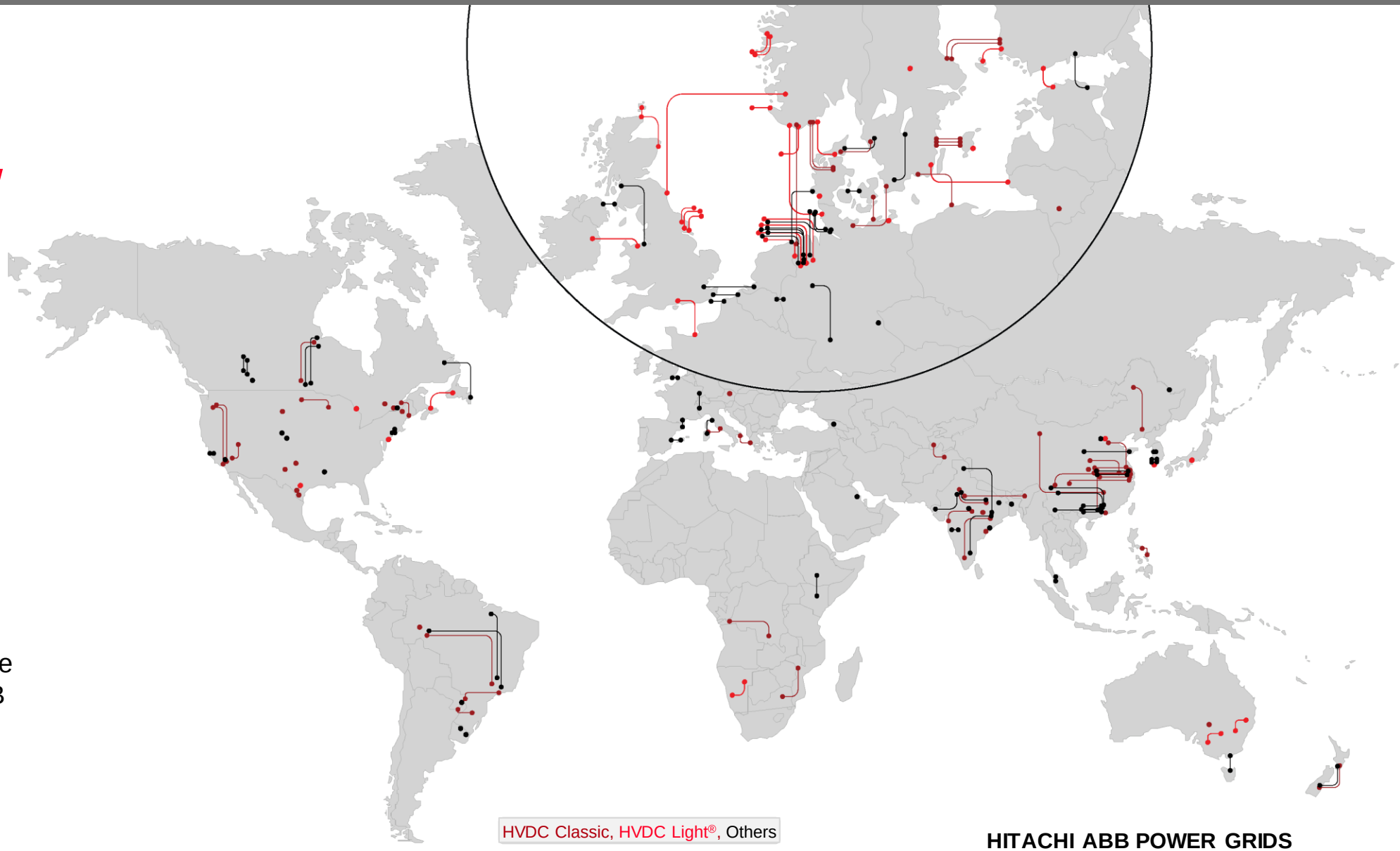
HITACHI ABB

Heavyweight market

~300 GW
Operating world
Installed base

~3x
Growth rate
vs. world GDP

>50%
World installed base
equipped with ABB



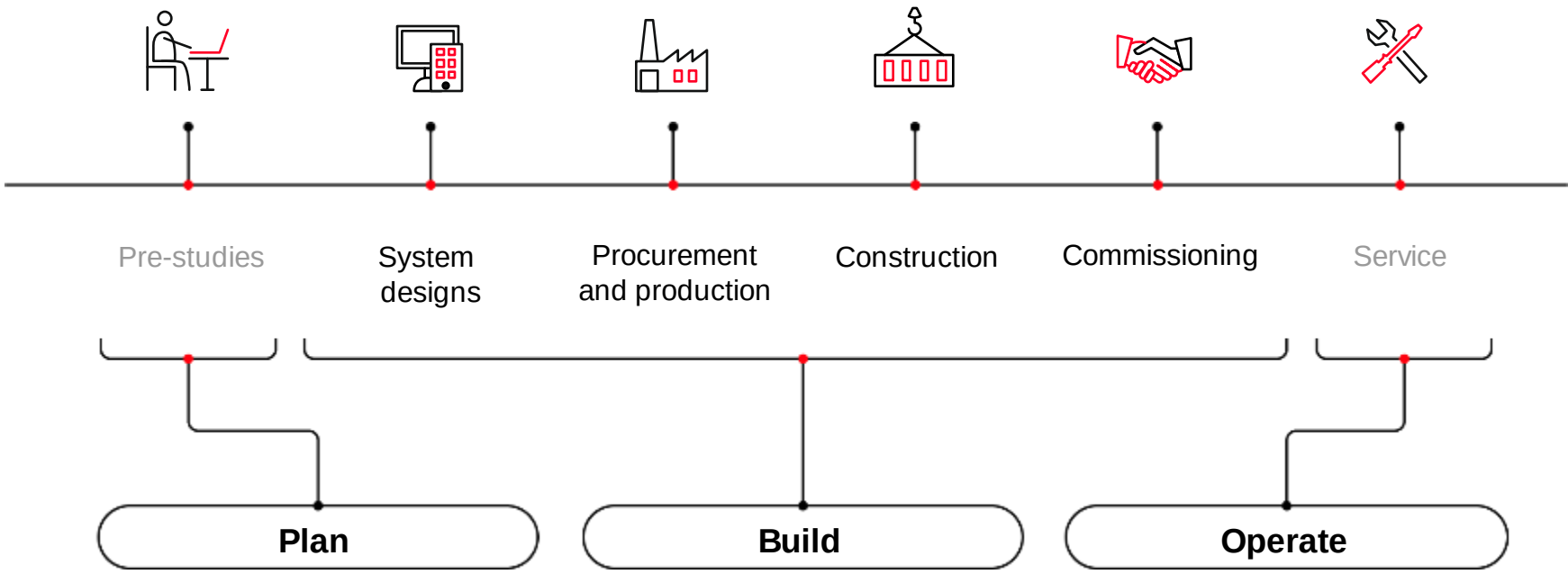
HITACHI ABB POWER GRIDS

Project execution

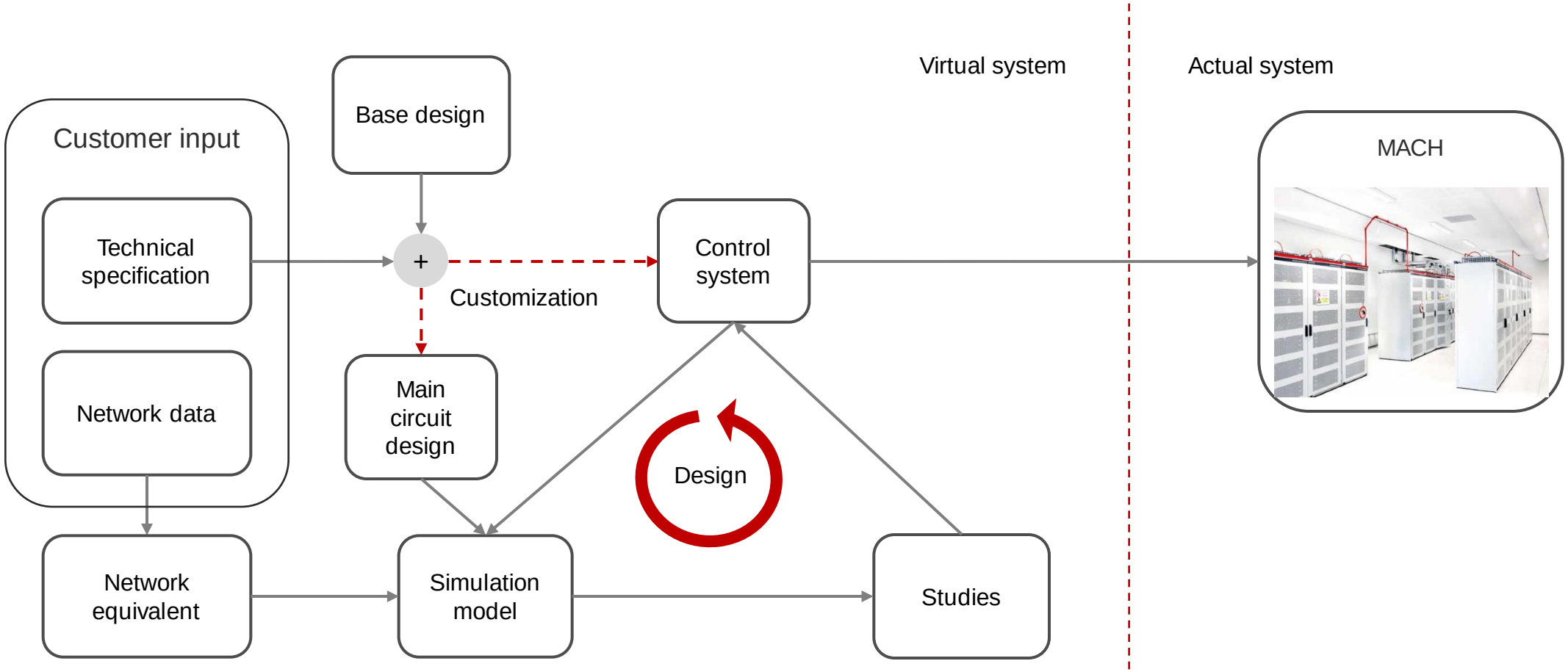
From start to finish an open & focused collaboration

- **Safety first**
- **Listen to the customer**
- **Transparency**
- **Execution focus**
- **Continuous improvement of our execution process**

Years in the making, decades in operation



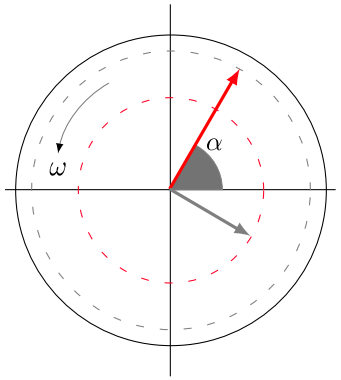
HVDC control design process

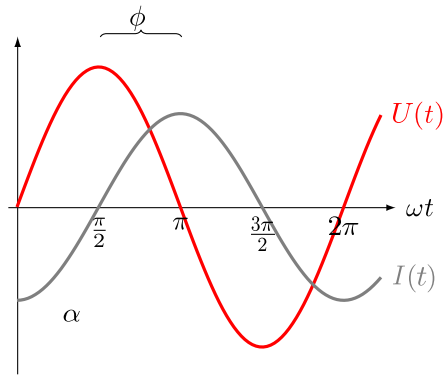


Close interaction with our customers is key for ensuring best system performance

Control system representation

From simulation to site





RMS test

High-level control design

Stability studies

Network model

Fast calculation

f<50 Hz, t=3-30 s

EMT test

Converter firing control design

Transient studies

Reduced AC network

Slow calculation

f>50 Hz, t=0.001-3 s

Factory test

Control implementation

Hardware test

AC equivalent

Real time

t=0.01-∞ s

Site test

Commissioning

Real network

Real life

0<f< ∞, t=0,001-∞ s

HVDC Valves Test

Quality assurance

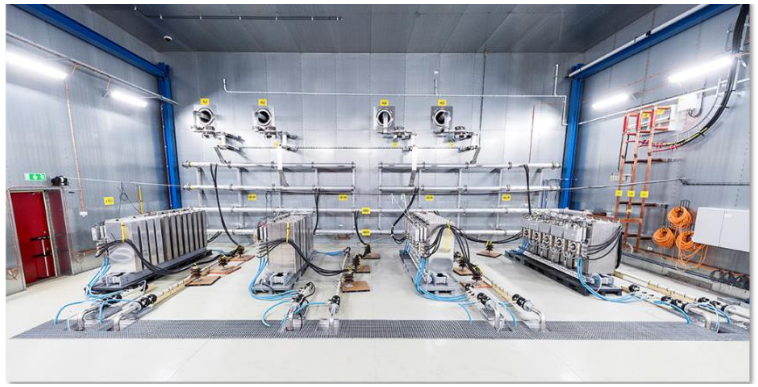
Dielectric tests

Purpose of dielectric testing:

- Fulfill the demands of the standard, IEC 62501
- Verify the design with respect to voltage

Tests performed at STRI and UHVEN

Operational tests



Purpose of operational testing:

- Fulfill the demands of the standard, IEC 62501
- Verifying max. operating conditions

Test performed in loop configuration (circulating current)

Production tests

Routine test: every single position to verify correct assembly, proper functions, voltage withstand capability and ensure consistency in production

Sample tests: Operational test

HVDC station construction process

Integration engineering is critical for success

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Nord Link

Norway – Germany

Customer	Statnett/Tennet*
Customer needs	• Meet EU's target for CO2 reduction • Security of supply
ABB's response	• Two 1,400 MW, ±525 kV HVDC Light® converter stations • 525 kV DC subsea and land MI cables for over 200 km of the route
Customer benefits	• Daily and seasonal fluctuations in power demand can be met by using the other country's renewable surplus power • Higher availability
Year	• 2020

- NordLink Norge AS, owned by Statnett in Norway and DC Nordseekabel GmbH & Co. owned by TenneT and KfW in Germany
- Available video on Nord Link project: **https://www.youtube.com/watch?v=wQYE3o3eNd4**

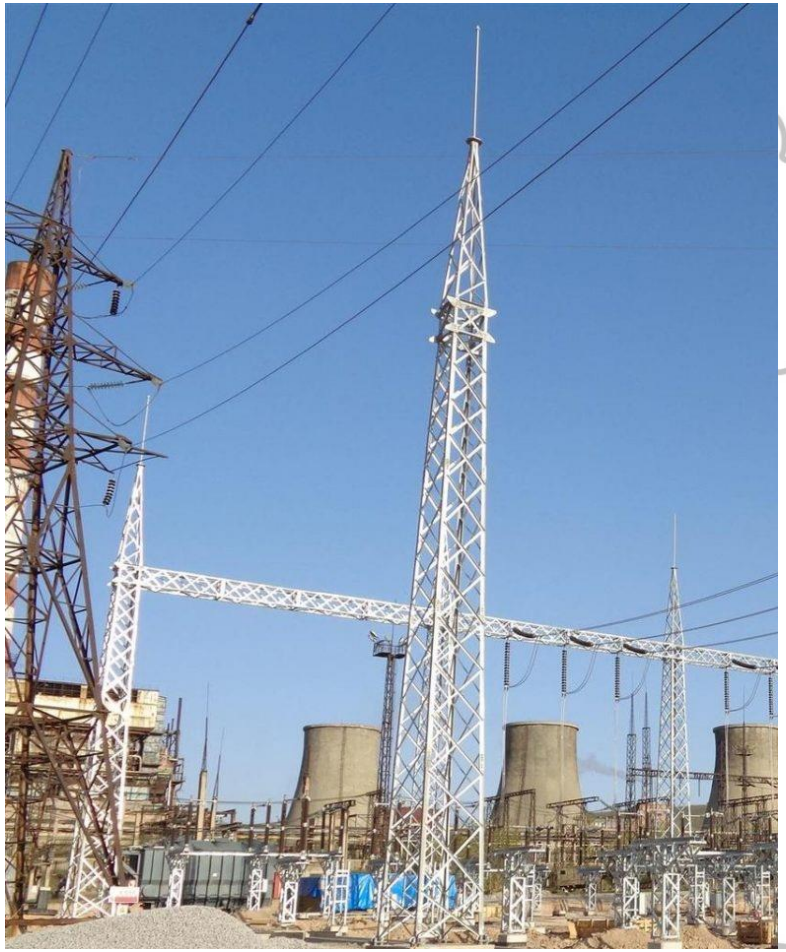
Kriegers Flak

Germany

Customer	Energinet.dk SOV, (Denmark) and 50Hertz Transmission Gmb (Germany)
Customer needs	• Interconnecting asynchronous grids • Connection of offshore wind energy • Energy trade
ABB's response	• 410 MW HVDC Light® back-to-back station
Customer benefits	• Enabling energy trade between Germany and Denmark • Securing the energy supply in Denmark and Germany • Integrating renewable power from four offshore wind farms into the grid • Advanced control of the Combined Grid Solution
Year	• 2019

Tajikistan – Pakistan

Customer	Barki Tojik and NTDC
Customer needs	• Bulk power transmission of renewable hydropower over 800 kilometers from generation sites in Tajikistan to consumption areas in Pakistan
ABB's response	• Two HVDC converter stations in Tajikistan and Pakistan • 1300 MW ±500 kV HVDC link
Customer benefits	• Facilitate electricity trade between Central and South Asian countries • Allows Tajikistan to better utilize their hydropower resources • Brought needed and clean electricity to consumers in Pakistan
Year	• 2024



Agenda

HITACHI ABB

01. **A changing energy system**
The importance of interconnections

02. **Why HVDC**
An introduction to HVDC advantages

03. **HVDC Technology**
Our shared success

04. **Realize and maintain HVDC**
From concept to decades of operation

05. **HVDC Project Experiences**
Answers to customer needs

06. **Conclusion**
Partnership for success

Conclusion

Genuine partnerships for real success

More sustainable energy… for millions

Benefits are big… challenges are many

HVDC becoming mainstream all over the world

- **More power though long distances**
- **More grid stability**
- **Sustainable solution**

Technology is ready, robust, well proven… and the journey continues

Cooperation Customer – Supplier along the whole journey is key for success

Our mission is to support our customers to introduce or expand their existing HVDC networks. We do this with a strong Health, Safety & Environmentally focussed culture. In addition, we continue our quest to lead the industry in innovation, both in project execution quality and technology development.

This we do to ensure more sustainable and healthier environment for our customers and the community.

Andreas Berthou

Global HVDC Manager
Hitachi ABB Power Grids

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