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Enhancing Power Systems stability with HVDC Technology

Benedikt Kurth

HVDC Market Product Manager

Panel: HVDC Systems in Turkey's Grid Transformation Process

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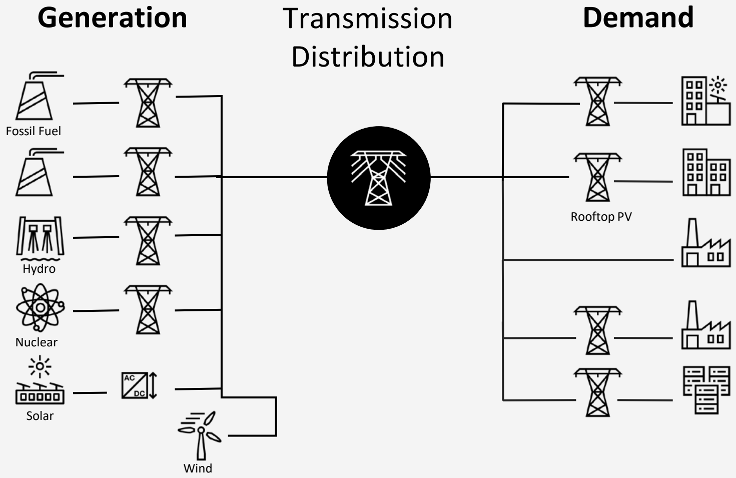
The evolution of the power grid

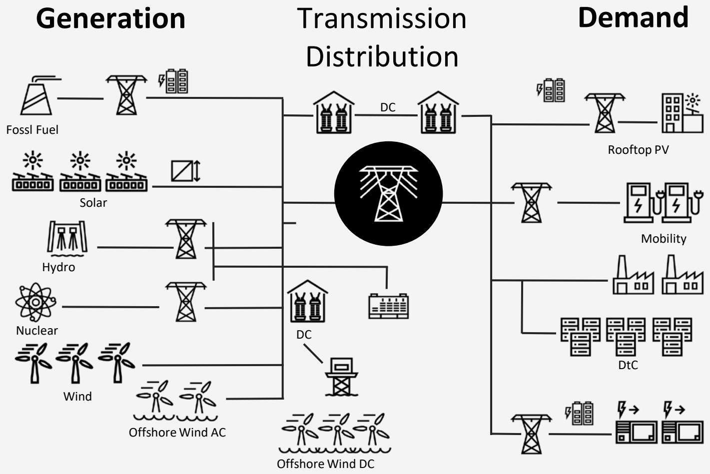
Scale to **Potential**

Legacy grid | 2020



Centralized and Passive Grid

Net-Zero grid | 2050



Decentralized and Active Grid

Grid challenges

01 Reduction of inertia

02 Power imbalances

03 Voltage stability

04 Limited interconnection capacity

High-Voltage Direct Current transmission (HVDC) will be the backbone of the entire energy system with large amount of renewables

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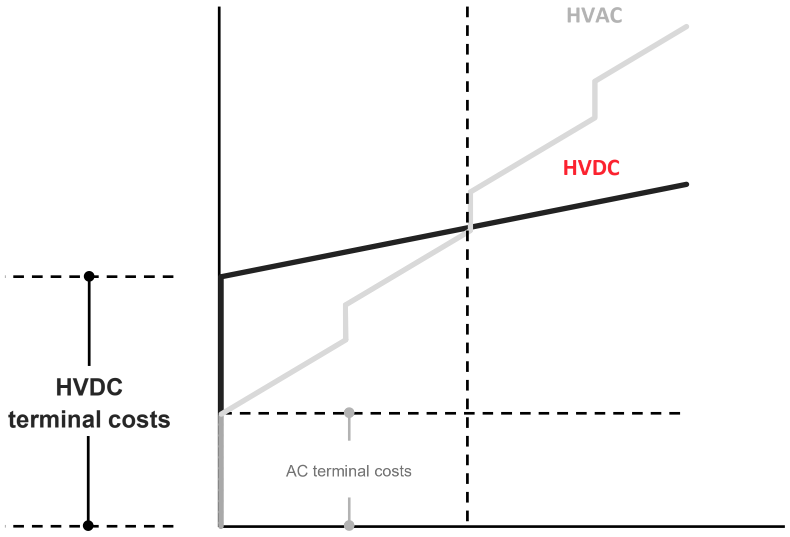
Customer grid

HVDC Converter Station
Classic or Light®

High Voltage Direct Current Power Transmission
Land or Submarine cables or Overhead lines

HVDC Converter Station
Classic or Light®

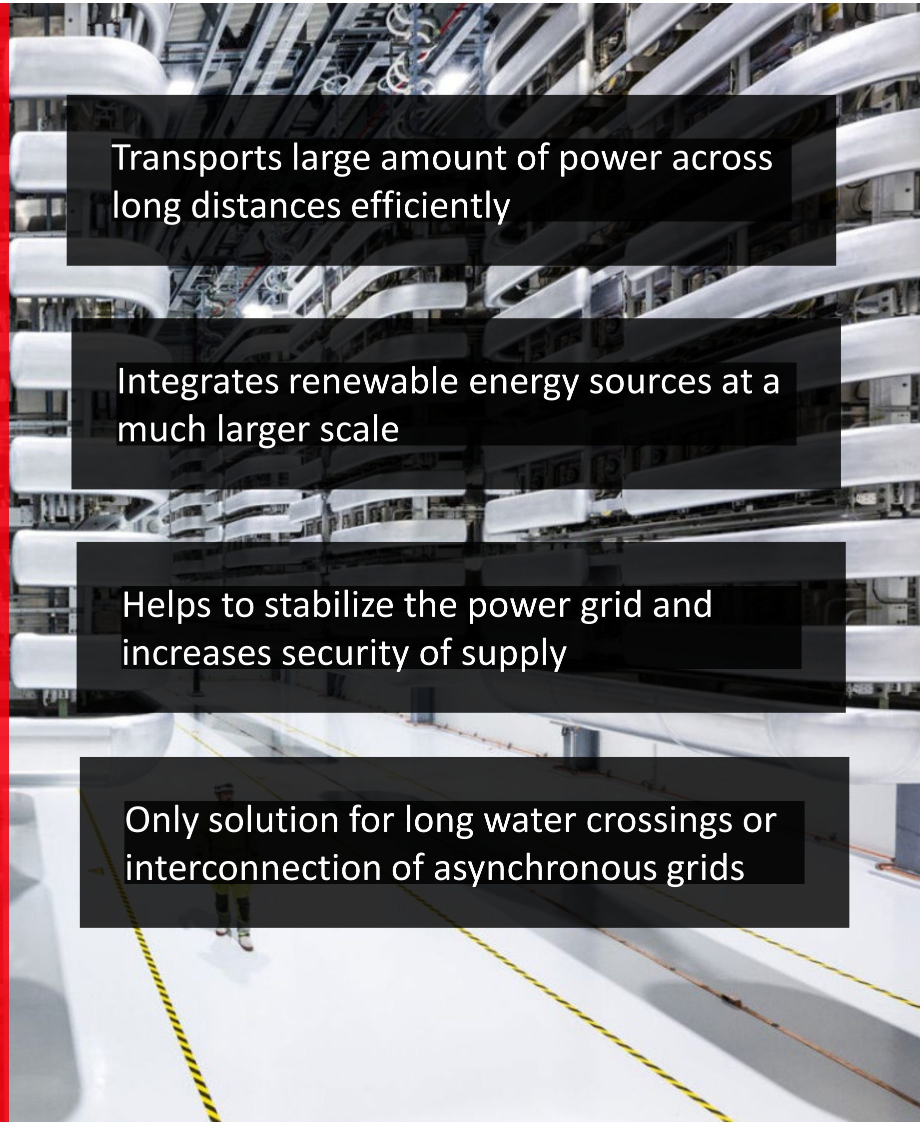
Customer grid



Lower losses — **More power**

Controlled power flows — **More grid stability and flexibility**

Smaller footprint — **More sustainable**



Transports large amount of power across long distances efficiently

Integrates renewable energy sources at a much larger scale

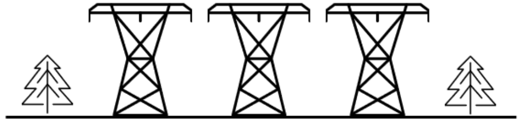
Helps to stabilize the power grid and increases security of supply

Only solution for long water crossings or interconnection of asynchronous grids

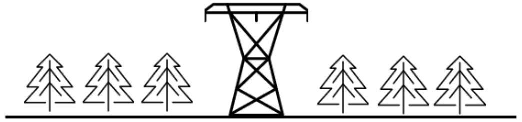
Environmental benefits DC vs AC and Performance requirements

HVDC has a lower climate impact above certain distances, thanks to:

- Lower transmission losses
- Materials for cables



Traditional overhead line with AC



HVDC (High Voltage Direct Current) Classic overhead line

Underground line with HVDC Light® or AC cable

Typical performance requirements

Total losses of a HVDC converter station (calculation according to IEC 61803)	<0.8%
Total availability (forced and scheduled unavailability considered)	>98.5%
Maintenance-free interval	1 – 2 years
Telephone interference (TIF)	<40
Electromagnetic compatibility (EMC)	According to Cigré TB391
Electric and magnetic fields	According to applicable standards and regulations[1]

[1)] Minimum requirements: Directive 2013/35/EU and ICNIRP Guidelines for limiting exposure to time

Technology Developments

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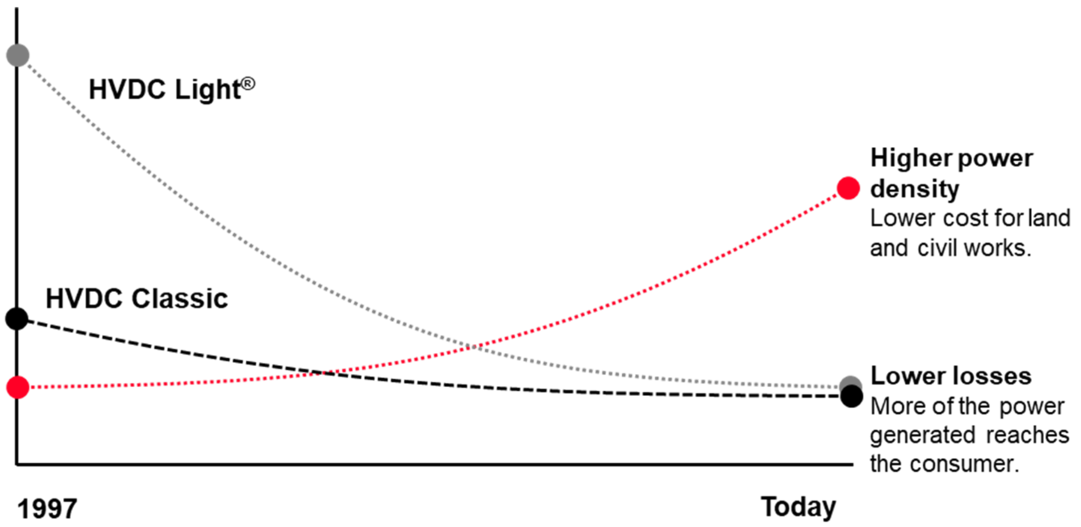

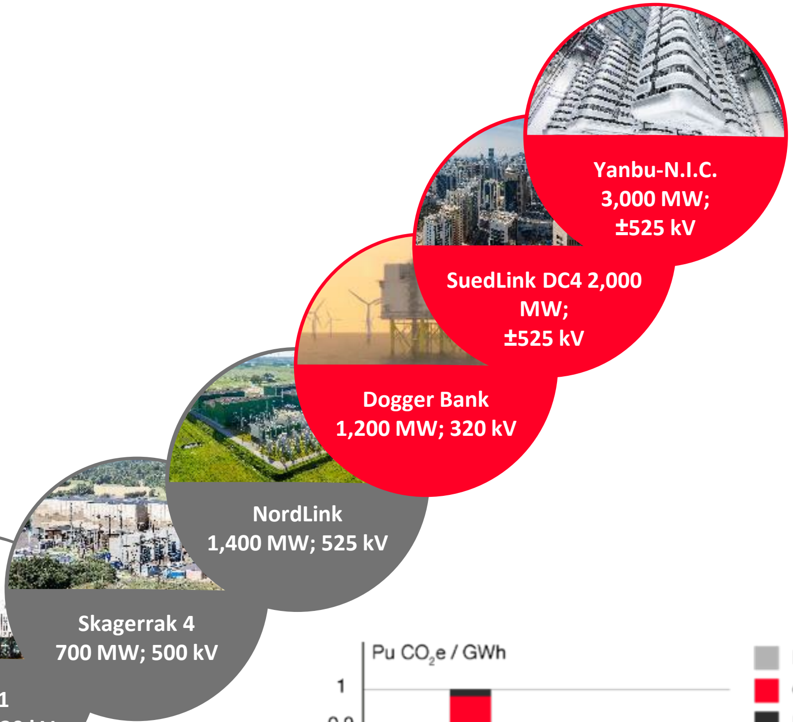

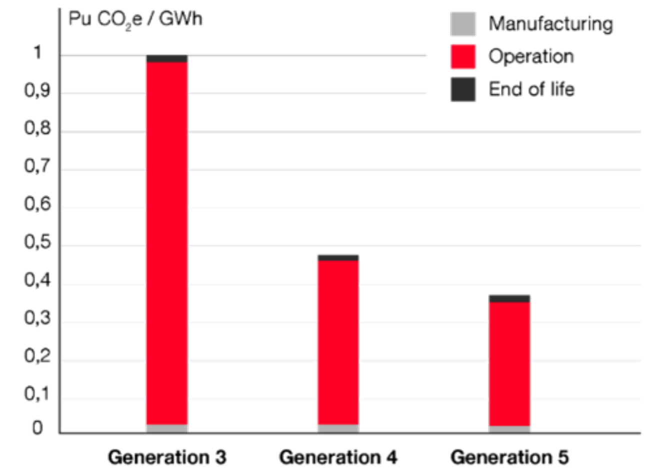

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30 years of continuous development and evolution

Converter development

- Two level PWM converter – 10~100 MW, ±80 kV
- Three-level PWM converter – 50~300 MW, ±150 kV
- Two level opt. PWM converter – 50~500 MW, ±150 kV
- CTL converter – 50~1,500 MW, ±320 kV
- MMC converter – 50~3,000 MW, ±525 kV→ 640 kV

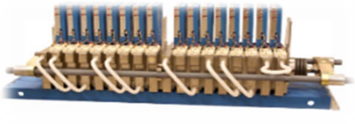
Semiconductor development

- 2.5 kV IGBT – first HVDC commercial component
- Series connection - presspack solution – SCFM
- Losses optimization toward higher switching freq.
- Optimization toward lower conduction losses

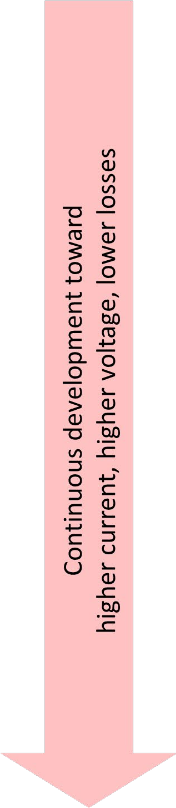
Cable development in parallel to converter technology development

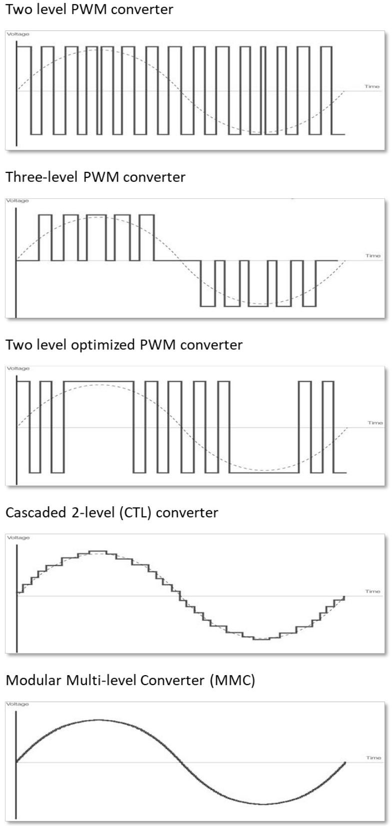
- 80 kV → 150 kV → 320 kV → 525 kV











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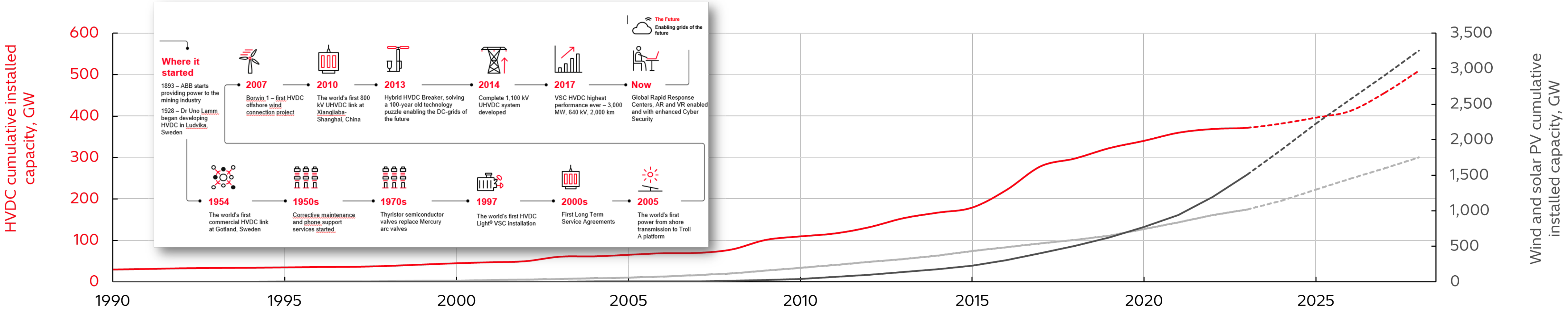
HVDC Interconnectors are key for integrating renewable energy



1928	1954	1960s	1997	2017	2019	2023
Dr Uno Lamm began developing HVDC in Ludvika, Sweden	The world's first commercial HVDC link at Gotland, Sweden	Mercury arc valves replaced with thyristor semiconductor valves	The world's first VSC HVDC installation	VSC HVDC highest performance ever – >3,000 MW, 640 kV	Caithness-Moray HVDC Link - a unique multi-terminal system	Ijmuiden Ver Alpha, first of six OW projects as a part of TenneT's 2GW Program

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

Todays' HVDC Applications and technologies

Shaping the grids of the future

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LCC (HVDC Classic) 150 – 12,000 MW

VSC (HVDC Light®) 50 – 3,600 MW

Internal

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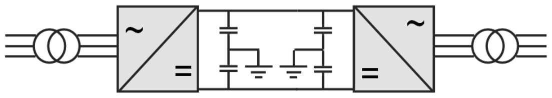
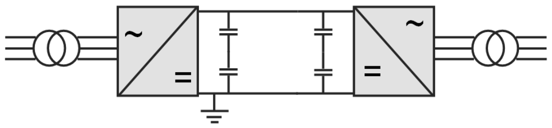
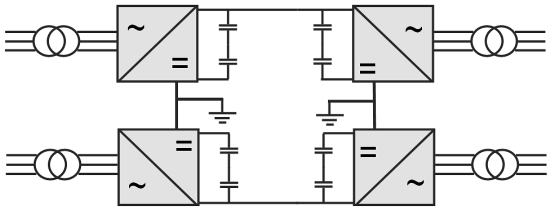
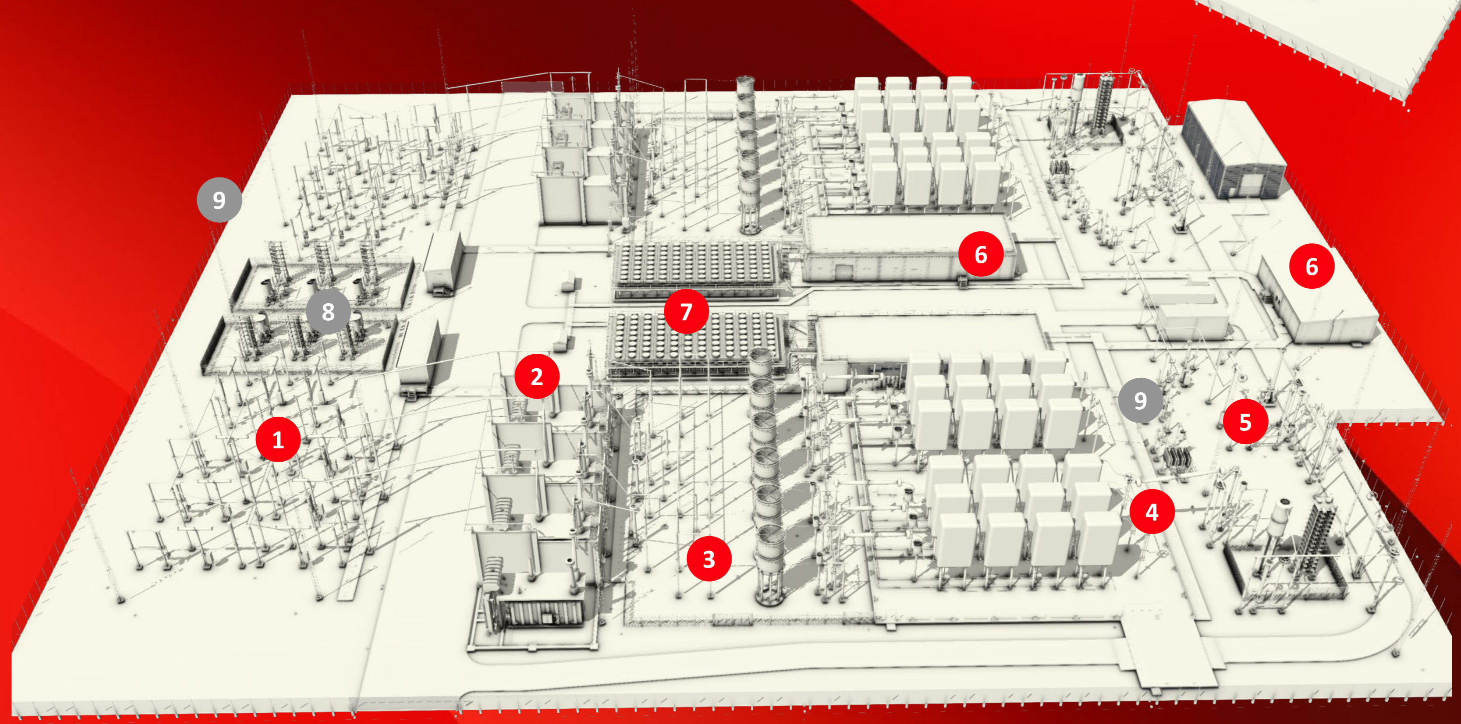
	Symmetric monopole	Asymmetric monopole	Bipole
	Most suitable for low-mid power range		Most suitable for large power range
			
Positive	– Lowest cost per MW and kV_{dc} – Most compact solution per MW and kV_{dc}	– Only one high voltage cable – Bipole enabled	– High availability for half power – High voltage standard solution for high power and long distances
Negative	– Loss of 100% power at trip – Less suitable for high voltage levels due to increased TOV	– Less compact – Staggered approach increases needed effort	– Temporary ground current (can be avoided at the expense of a metallic return conductor)

HVDC Light® ±525kV Bipolar solution

1. AC Yard (Insertion resistor)
2. Transformer area
3. Arm reactor area
4. Converter valve hall area
5. DC yard Area
6. Control and operating station
7. Cooling heat exchangers

Optional, depending on needs

8. AC Harmonic filters
9. DC or AC Choppers



Internal

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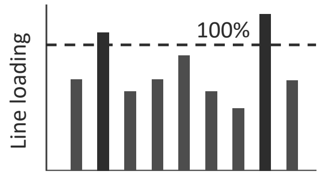
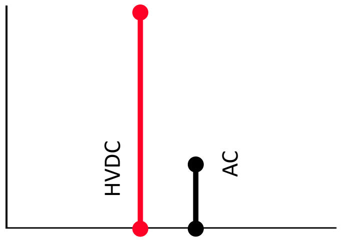
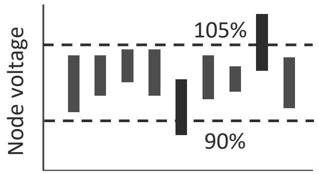
Power system capacity (steady state)



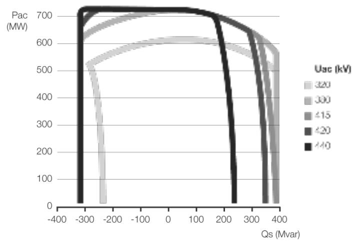
Current limits



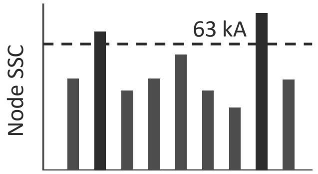
More power
Power flow control



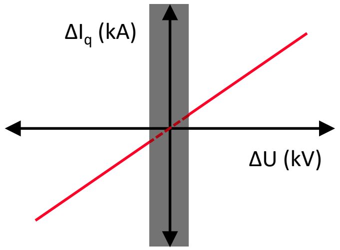
Voltage limits



Reactive power control



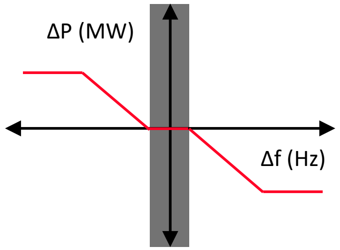
Short-circuit current limits



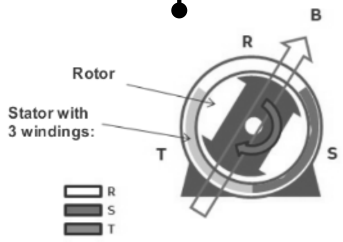
Controlled short-circuit current

Power system stability (transient state)

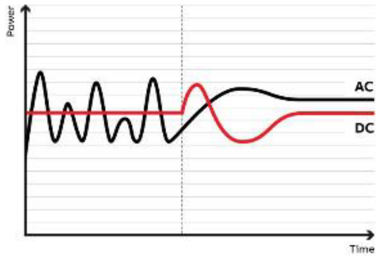
Frequency



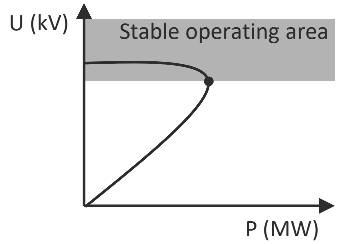
Frequency control



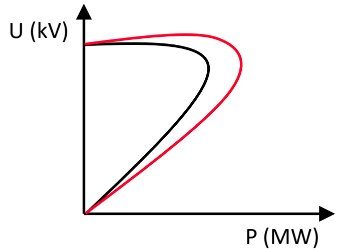
Rotor angle



Damping control



Voltage



Dynamic voltage control

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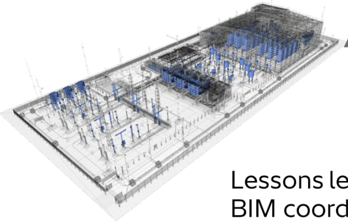
HVDC Project Execution
DIGITAL MODELS

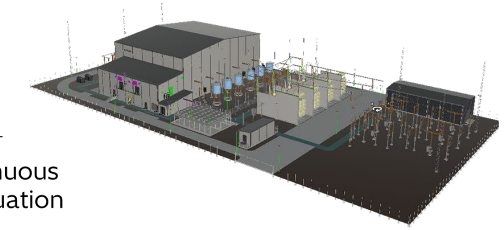
IdentiQ™
DIGITAL WORLD + PHYSICAL WORLD

STRUCTURED INTEROPERABLE DATA

2D 3D | AIM Data | Docs /Tags



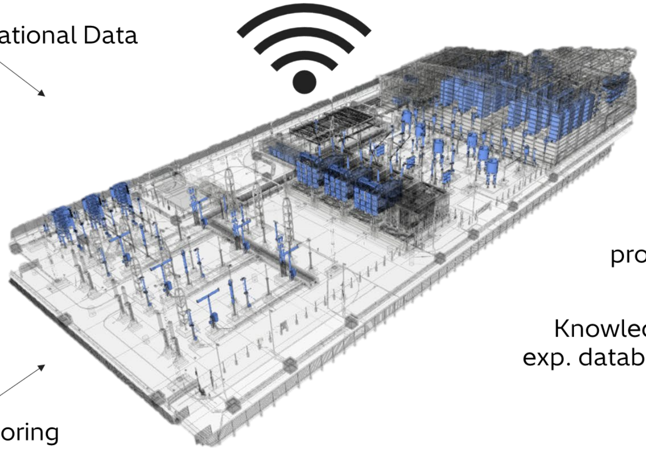
2D 3D | 4D+ | AIM Data | Docs /Tag



Lessons learned and continuous BIM coordination and evaluation

Sys. design | GI Valve | GI MACH | Plant design | Civil | C&C

- Real Time Operational Data
- Access from anywhere
- Condition monitoring



Fully connected HVDC Station

Asset properties → Interactive 3D Visualization → Connected Docs → Task & Event Scheduling → Knowledge exp. database

Concept Design → Design → Construction → Operations → Maintenance

Internal

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Korridor B (V48 and V49)

Customer
- Amprion, Germany

Customer needs
- To transport wind energy from the North Sea coast to the load centers in Ruhr Region

Our response
- Two HVDC links, V48 and V49, each 2000 MW, ± 525 kV with four HVDC Light® converter stations and Long-term service agreement, EnCompass™

Customer benefits
- Replacing the conventional power generation used to power the industrial load centers
- Increased security of supply and increased grid capacity

Year
2032

HVDC Light® converter stations

Both V48 and V49 are Bipole

System capacity of each system is 2,000 megawatts (MW)

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SuedLink DC4

Customer

- TenneT and TransnetBW, Germany

Customer needs

- Efficient transmission of emission-free electricity between north and south of Germany

Our response

- Two HVDC Light® converter stations, Wilster 400 kV & Bergrheinfeld 400 kV
- 2,000 MW, ±525 kV solution

Customer benefits

- Helping German energy transition and enabling a reduction in the use of fossil fuels
- Transferring vast amounts of renewable energy for up to 5 million households

Year

2029

HVDC Light® converter stations

Rigid Bipole

System capacity of 2,000 megawatts (MW)

Hitachi Energy, the partner of choice for largest-ever HVDC wind energy project in U.S.

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SunZia

Customer

- Pattern Energy, United States of America

Customer needs

- To connect the 3,500-megawatt (MW) SunZia Wind project in New Mexico to the power grid in Arizona and Southern California

Our response

- Turnkey 3,000 MW at ±525 kV HVDC link with two HVDC Light® converter stations; Corona, New Mexico and Pinal County, Arizona

Customer benefits

- Efficient transfer, with low losses, and integration of huge volumes of wind power over more than 885 kilometers (550 miles) into the regional power grid

Year

2025

HVDC Light® converter stations | Bipole | System capacity of 3,000 megawatts (MW)

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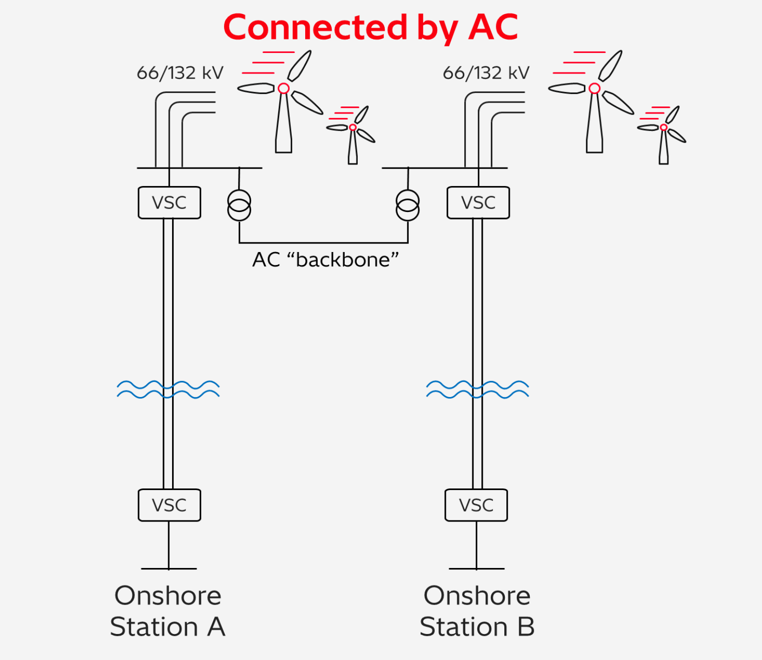
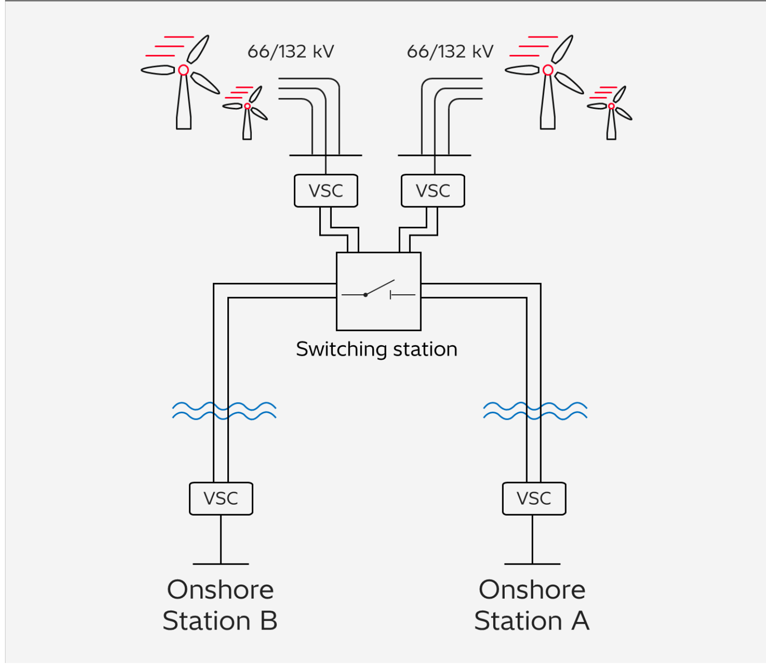
Radials, Multi-terminal, Meshed grid and Energy Islands

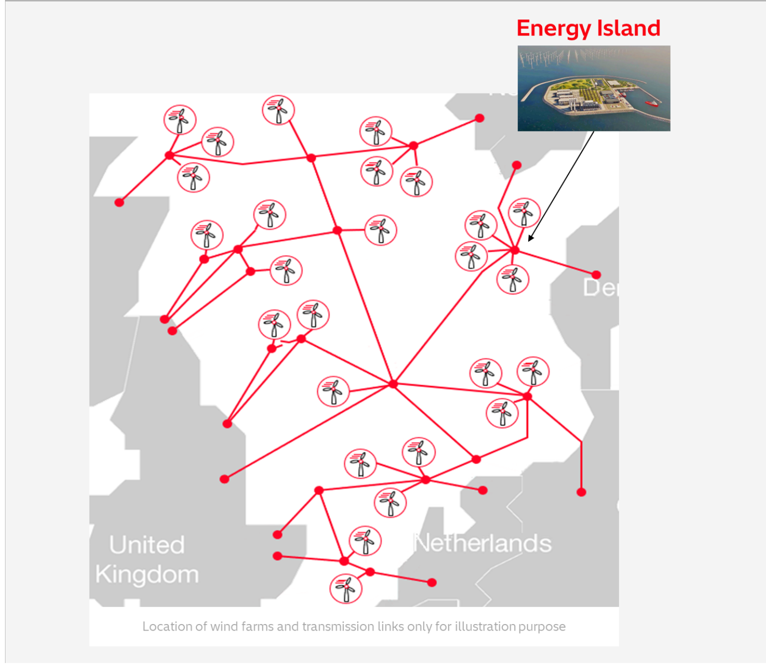
Radial Connections



Multi-Purpose Interconnections



Meshed DC Grid



1986
Québec – New England
Canada – USA
2,000-2,250 MW;
±450-500 kV
LCC

2017
North – East Agra
India
6,000 MW;
±800 kV
LCC

2019
Raigarh – Pugalur
India
6,000 MW;
±800 kV
LCC

2020
Zhangbei China
3,000 MW;
±500 kV
VSC

2024
Caithness-Moray-Shetland
United Kingdom
600-1,200 MW;
±320 kV
VSC

2025
Saudi Arabia – Egypt
1,500-3,000 MW;
±500 kV
LCC

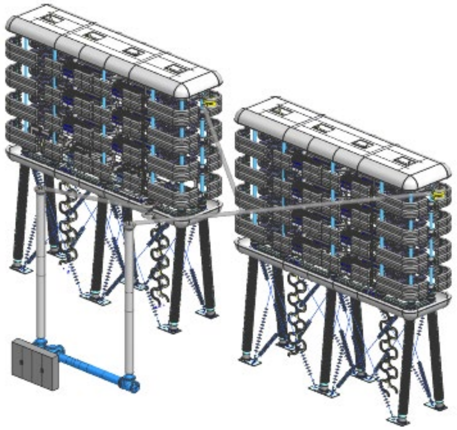
2029
SACOI3 Italy
400 MW;
±200 kV
VSC

The journey continues…

Technology enabling multi-terminal

Hybrid HVDC Breaker - HHB

- Enabling DC fault protection, selectivity and higher resilience o
  Grids
- Fast, reliable and efficient solution
- Full-scale prototype demonstration in 2020
  350 kV, 20 kA
- Scalable and modular design



From technology to system solutions

Definition of new frameworks for Multiterminal DC grid procurement and execution

- Manage the complexity
- From concept to specifications
- New roles and responsibilities

System solutions development

- HHB as DC grid sectionalizer
- DC Switching station designs
- Optimize verification concepts

Industry cross-cooperation

CENELEC — Best Paths — interOPERA

To way toward the grid of the future: experience + enabling technology + industrial cooperation

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