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Hitachi Energy

IERE Webinar

HVDC application and project cases

2025 / Oct / 15

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1 What is HVDC?

2 HVDC application

3 Project cases

1 What is HVDC?

2 HVDC applications

3 Project cases

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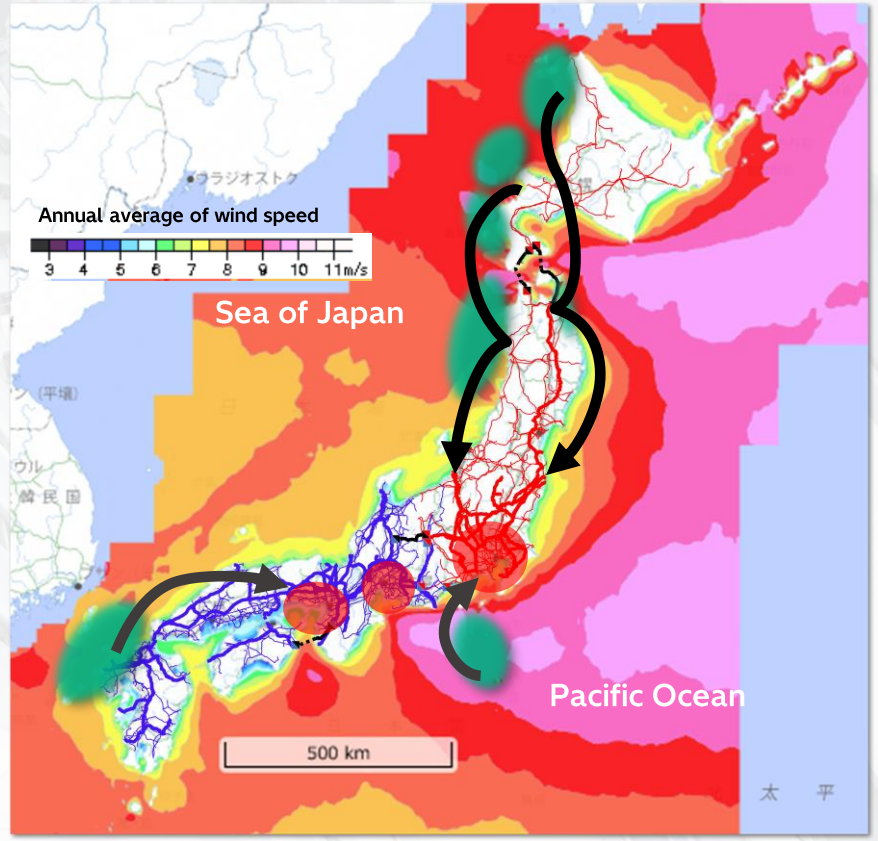
① Long distance・low losses

What is HVDC?

① **HVDC can transmits remote and large-scale renewable energy to demand centers, over a long distance with low losses**

(example of Japan)



：Demand center　：Large renewables

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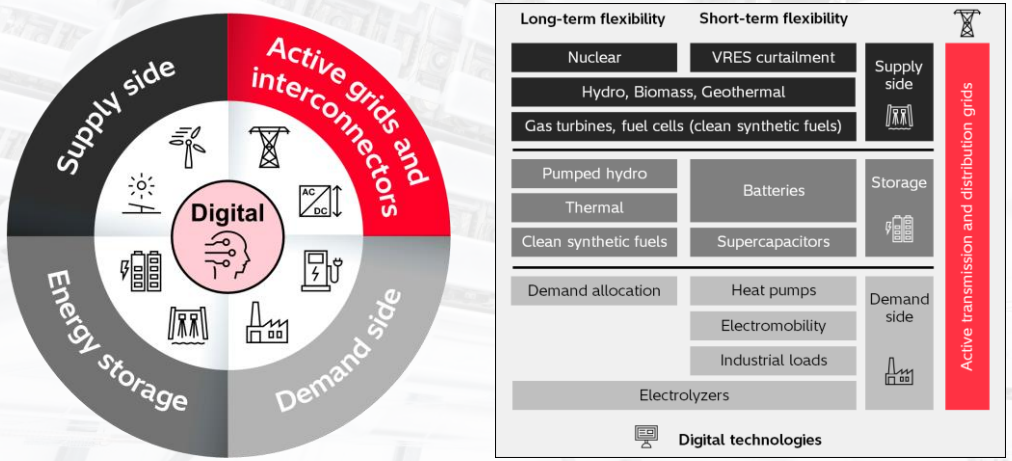
① Long distance・low losses, ② Cross-borders

What is HVDC?

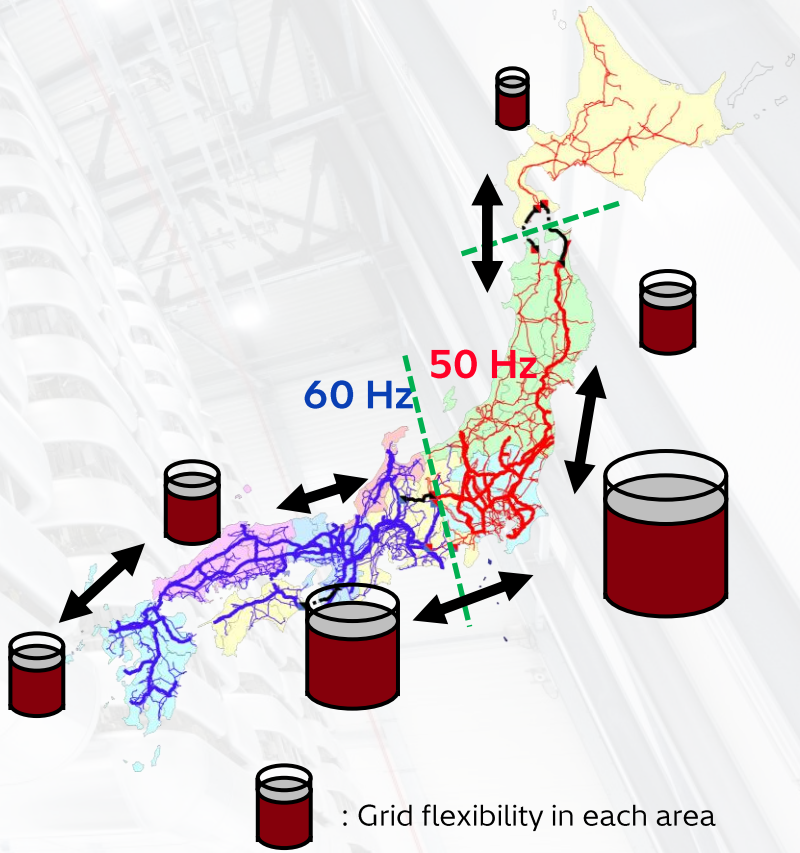
① HVDC transmits remote and large-scale renewable energy to demand centers, over a long distance with low losses

② **HVDC enables to share・exchange grid flexibility across borders (countries, regions)**

Four dimensions of "flexibility"



(example of Japan)



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① Long distance・low losses, ② Cross-borders, ③ Grid stability

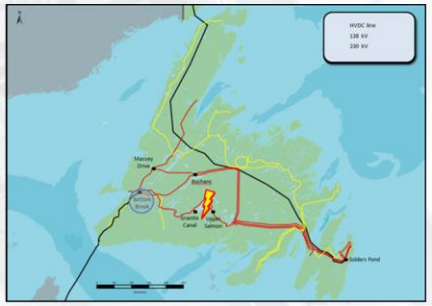
What is HVDC?

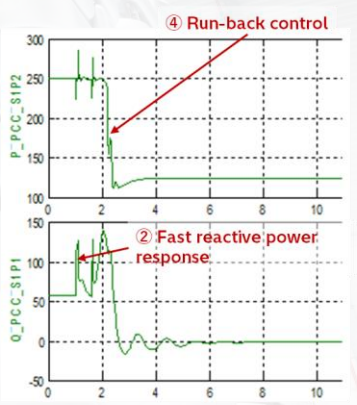
① HVDC transmits remote and large-scale renewable energy to demand centers, over a long distance with low losses

② HVDC enables to share network flexibility across borders (countries, regions)

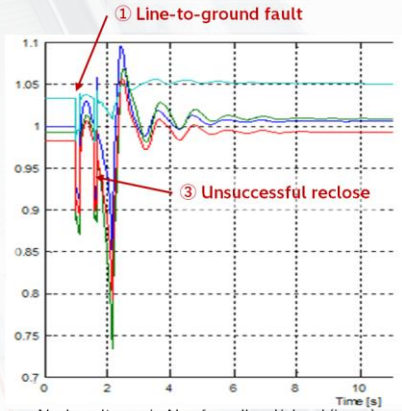
③ **HVDC supports grid stability by Fast Frequency Response, synthetic inertia response, fast reactive power (voltage) control, grid forming, islanded network control, black start etc.**

Key technology for Energy Transition





Active and reactive power response at Bottom Brook HVDC station

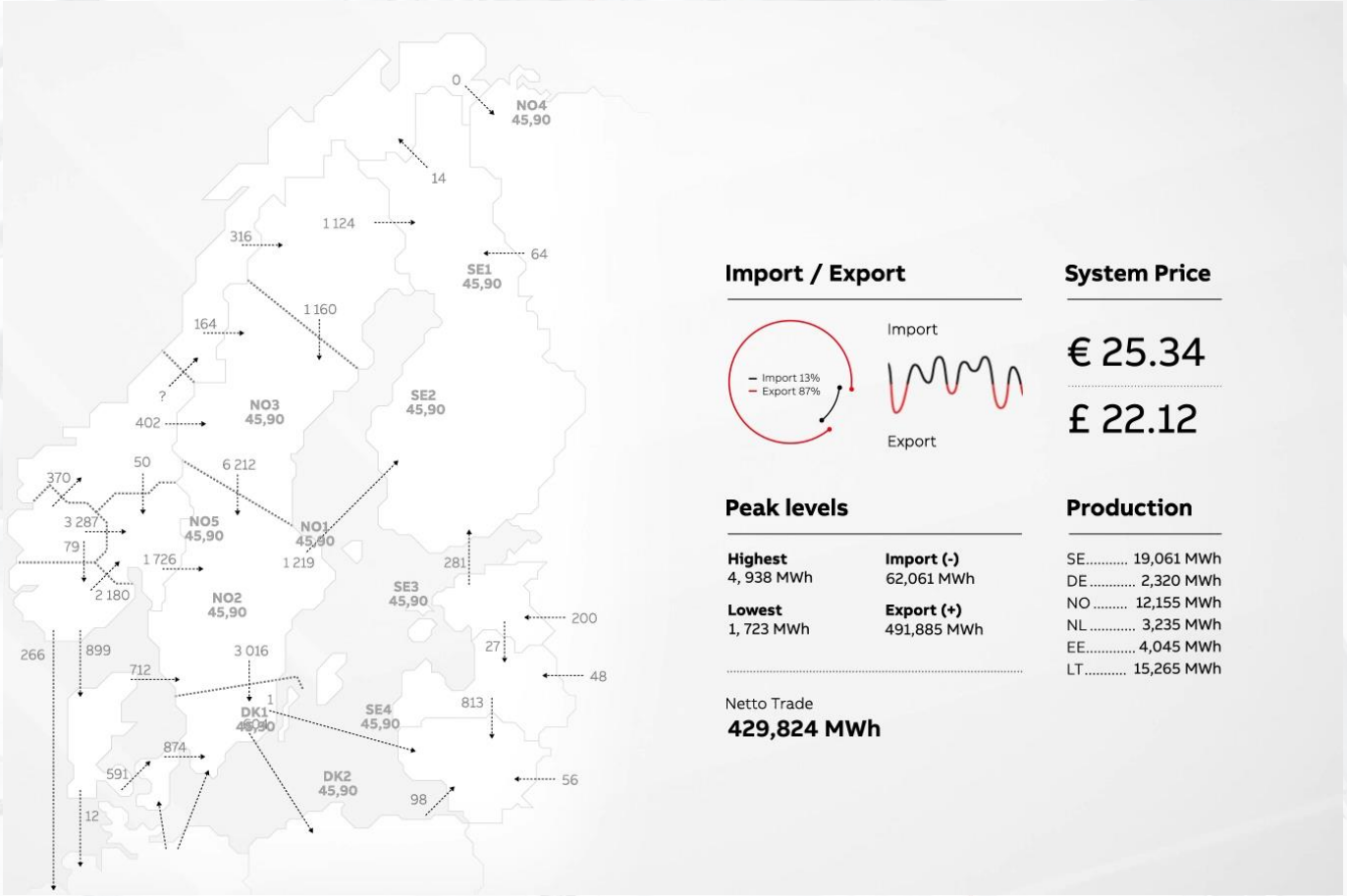


Node voltages in Newfoundland island (in pu)

Precise energy trading

Energy trading is enabled by coupling electricity markets with network interconnections. These interconnections can link separate power systems within a country or connect the national grids of separate countries.

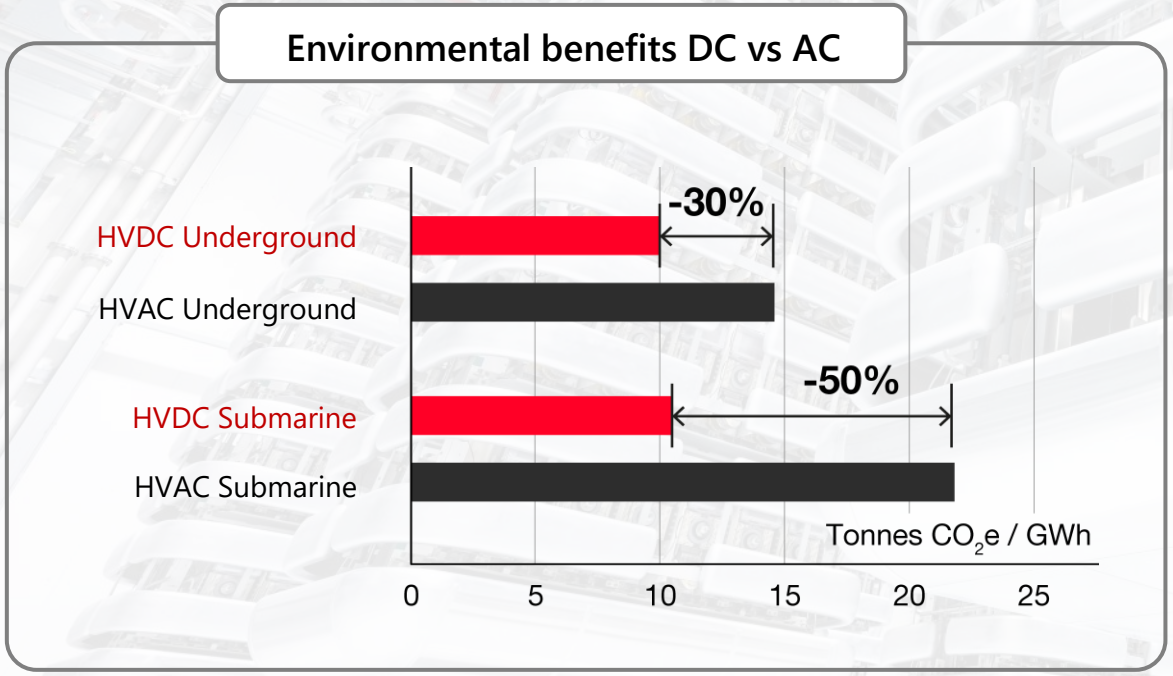
- International HVDC interconnectors
- HVDC systems allow our customers to share and trade electricity. Sending power where it is most profitable and needed most.
- HVDC enables precise controlled power flow across electricity markets.



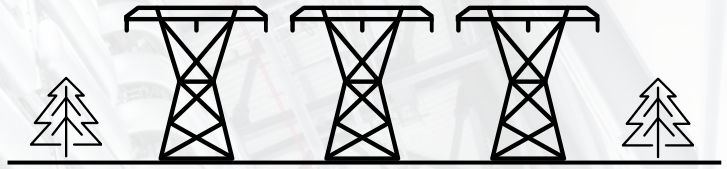
Environmental benefits DC vs AC

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

- Lower transmission losses
- Materials for cables



*100 km cable transmission, 900MW
Including: HVDC or HVAC Station, Cable, Total Losses and End of Life



Traditional overhead line with AC

HVDC (High Voltage Direct Current) Classic overhead line

Underground line with HVDC Light® or AC cable

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Benefits of HVDC

HVDC transmission delivers significant benefits not only from a technical power system standpoint but also from an economic, environmental and societal perspectives.

Technical	Economic	Environmental	Societal
● Enables high power transmission capacity, currently up to 12 GW at ±1,100 kV spanning>3,000 km. ● Minimizes long-distance power losses. ● Contributes to AC grid flexibility with independent voltage and frequency control. ● Enhances grid regilience with black start capability. ● Connects grids with different frequencies (asynchronous grids) ● Manages congestion through its more precise control of power flow.	● Lowers wholesale electricity prices by integrating diverse energy markets. ● Reduces balancing and redispatch costs with improved control. ● Offers lower operational costs over its whole life cycle owing to reduced energy losses and cuts infrastructure costs with narrower Right of Way. ● Reduces the need for intermediate substations due to fewer voltage drops over long distances. ● Encourages generation capacity investments by improving grid reliability and stability.	● Accelerates decarbonization by integrating clean energy sources such as wind, solar and hydro electricity. ● Minimizes landscape impact by reducing the transmission footprint (fewer towers and conductors). ● Optimizes resource use by enabling the transfer of electricity from regions with surplus to those with limited generation capacity. ● Lowers electromagnetic field emissions.	● Increases ability to integrate renewables, thereby enhancing public health outcomes by improving air quality. ● Boosts the environmental well-being of local communities by reducing land use. ● Reduces the socio-economic impact of outages with black start capability, which enables the rapid restoration of grids. ● Promotes regional collaboration through energy trading.

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Benefits of HVDC ～Europe's case～

In Europe, enhancing cross-border interconnection capacity is seen as being socially and economically effective. EU's plan for cross-border capacity keeps increasing (according to Ten Year Network Development Plan).

TYNDP **2020**

93 GW

cross-border capacity increases needed by 2040

93 GW in 20 years

※ Average **4.6 GW / year**

Accelerating

TYNDP **2022**

64 GW

cross-border capacity increases needed by 2030

(2025～2030)

64 GW in 5 years

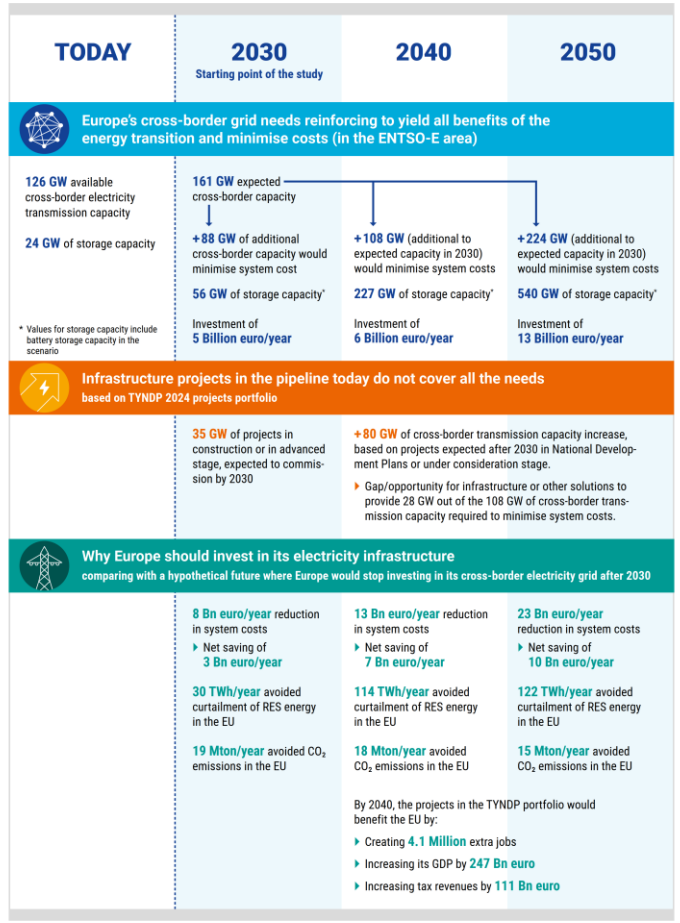
※ Average **12.8 GW / year**

Accelerating further

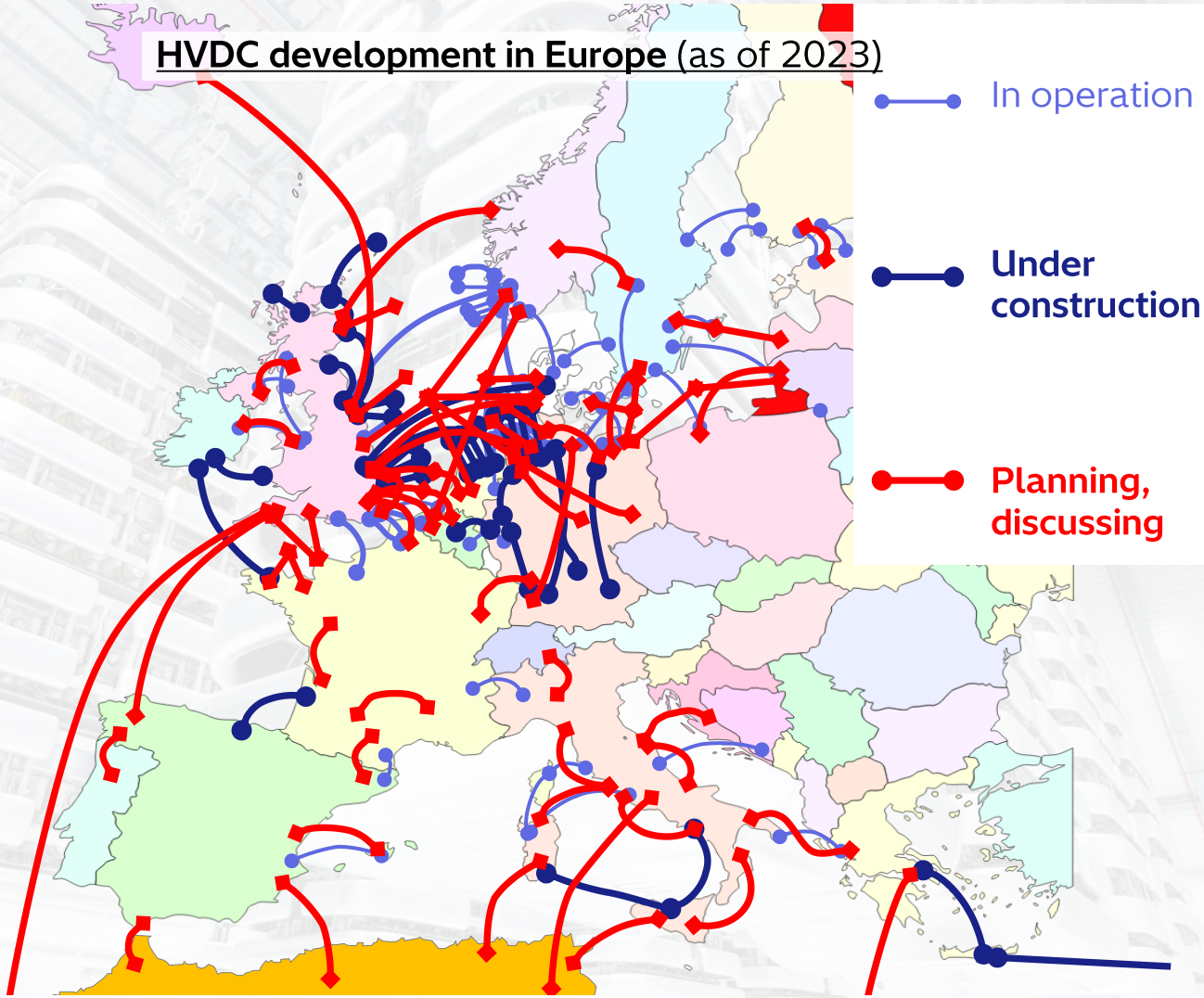
✓ **Strong government policy toward energy transition and cost / benefit analysis (CBA) drive grid enhancement with HVDC.**

- entso-e: The European association for the cooperation of Transmission System Operators (TSOs) for electricity
- TYNDP: https://tyndp.entsoe.eu/

TYNDP **2024**



Acceleration of the market



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Todays' HVDC Applications and Technologies

Shaping the grids of the future

Connecting remote generation

Offshore wind connections

VSC enabled

Interconnecting grids

DC links in AC grids

Connecting remote loads

VSC enabled

Power from shore

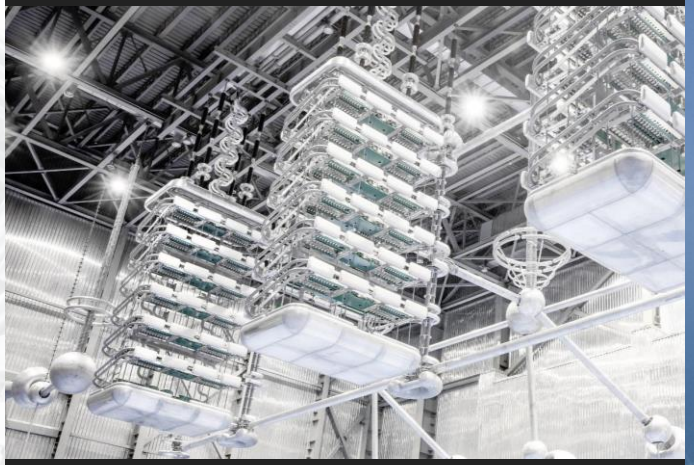
VSC enabled

City center infeed

VSC enabled

Upgrades/life-cycle services

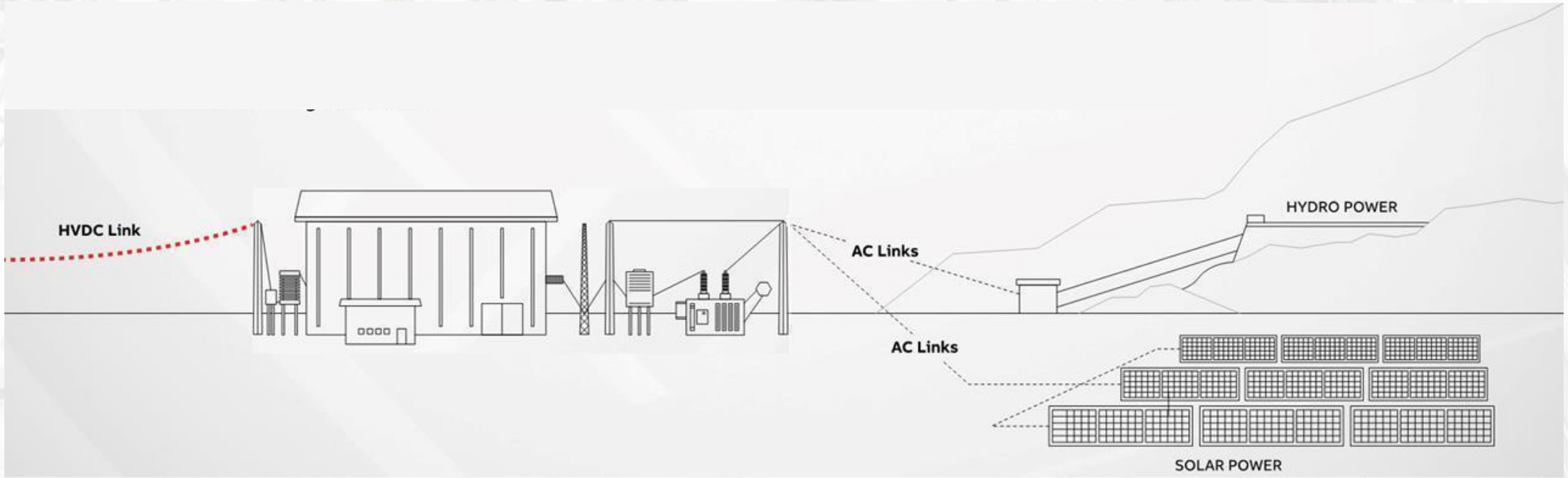
LCC (HVDC Classic) 150 – 12,000 MW



VSC (HVDC Light®) 50 – 3,600 MW

Connecting remote generation

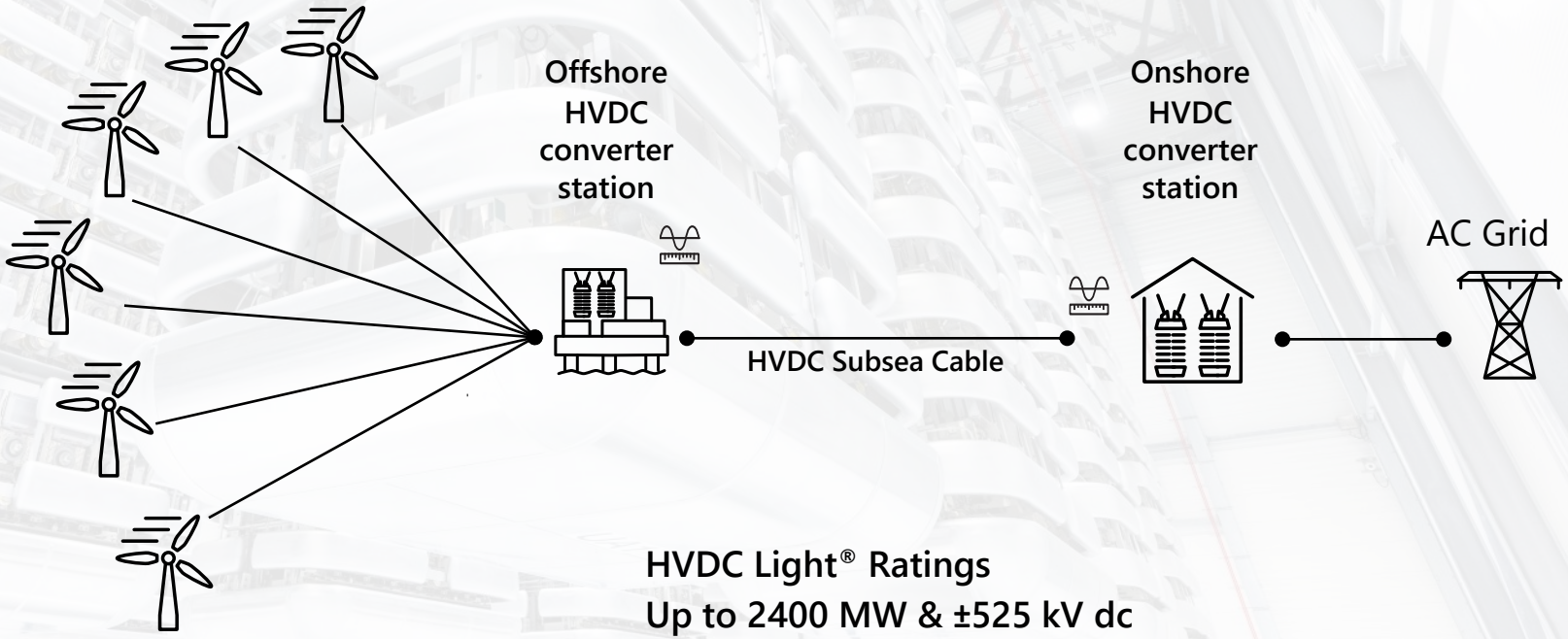
- Down to half of the losses of AC
- HVDC technology established over many decades
- Built in grid support (voltage and frequency support)
- Generators isolated from grid transients
- Black start capability
- Smaller footprint along the right of way (high power density)



Offshore wind connections

- Down to half of the losses of AC
- Around a third of offshore wind capacity connected by HVDC
- HVDC technology established over many decades

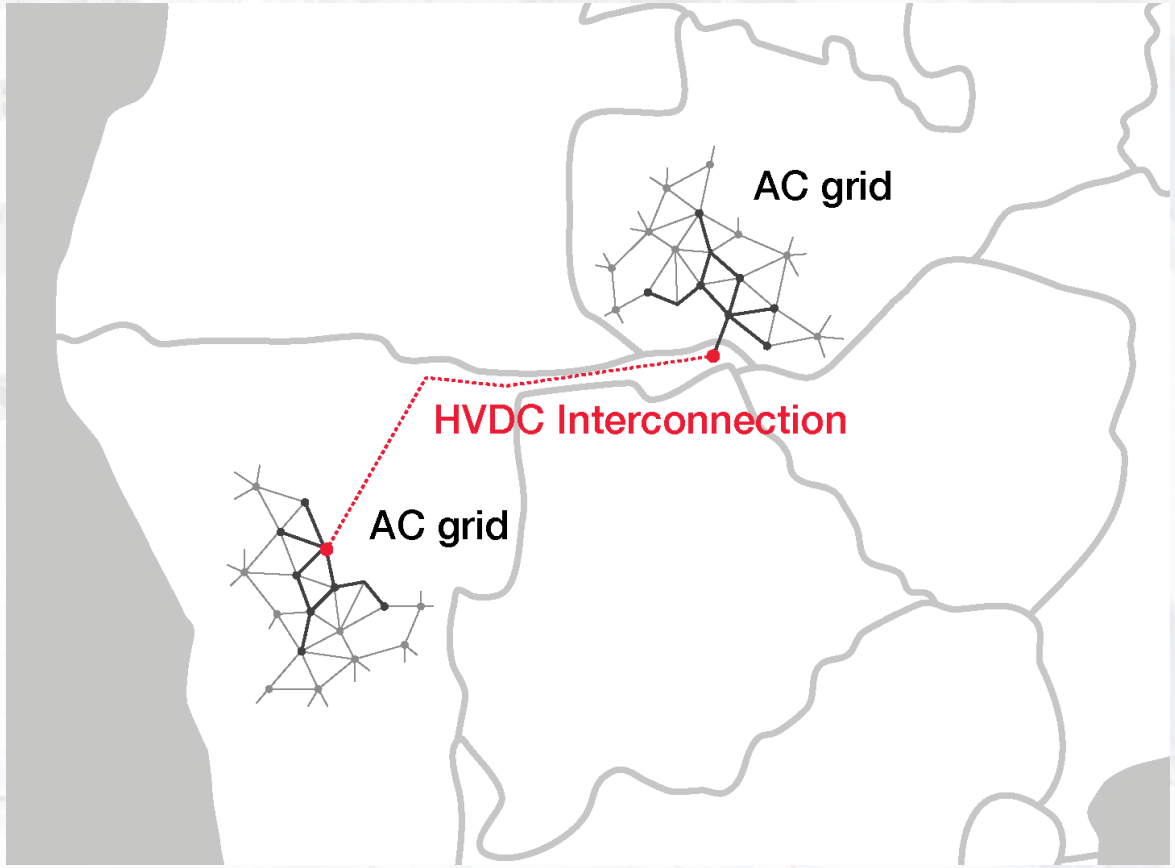
- Built in grid support (voltage and frequency support)
- Isolates the offshore grid from onshore grid transients



HVDC Light® Ratings
Up to 2400 MW & ±525 kV dc

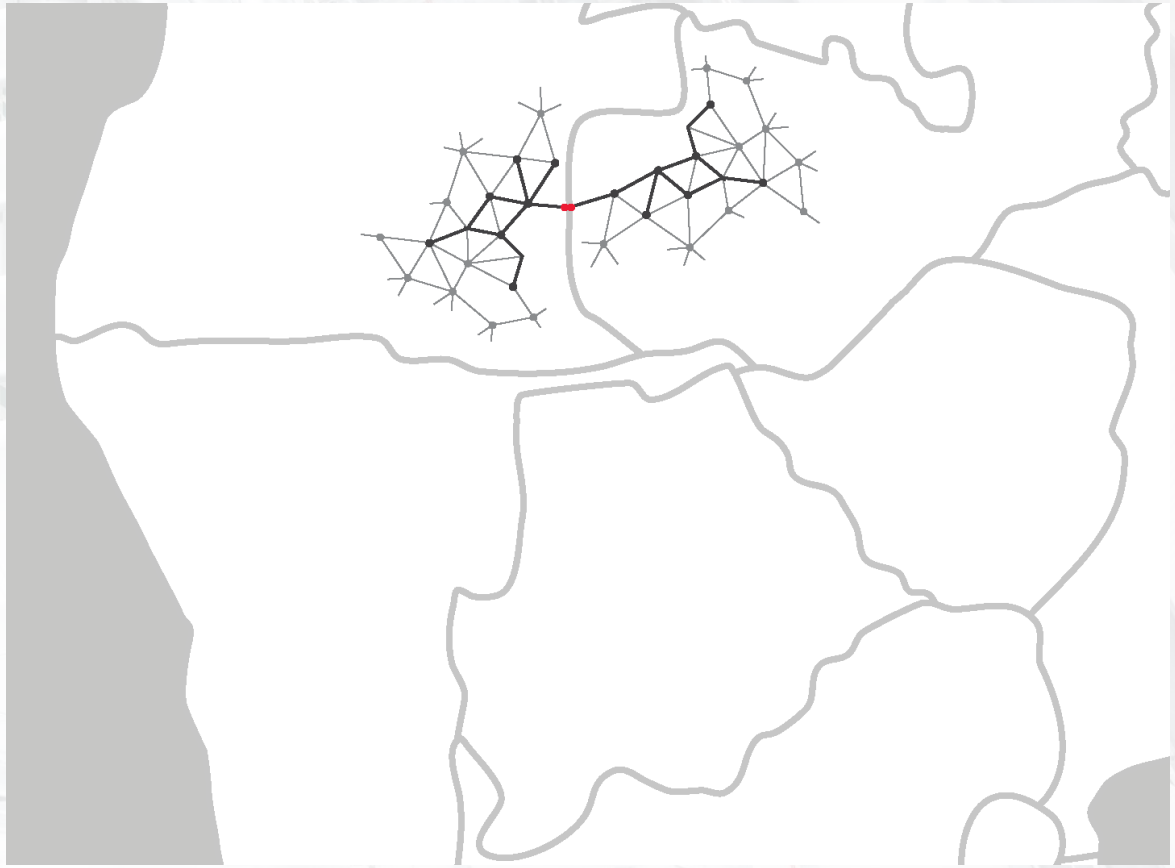
Interconnecting grids

- Grid stabilizing with independent voltage and frequency support
  - Solving today's grid resilience challenges
- Energy trading for asynchronous grids
  - Uniting & securing energy markets
- HVDC interconnectors
  - Up to thousands of kilometers and several GW power
- Could be combined with other applications – multi-purpose links



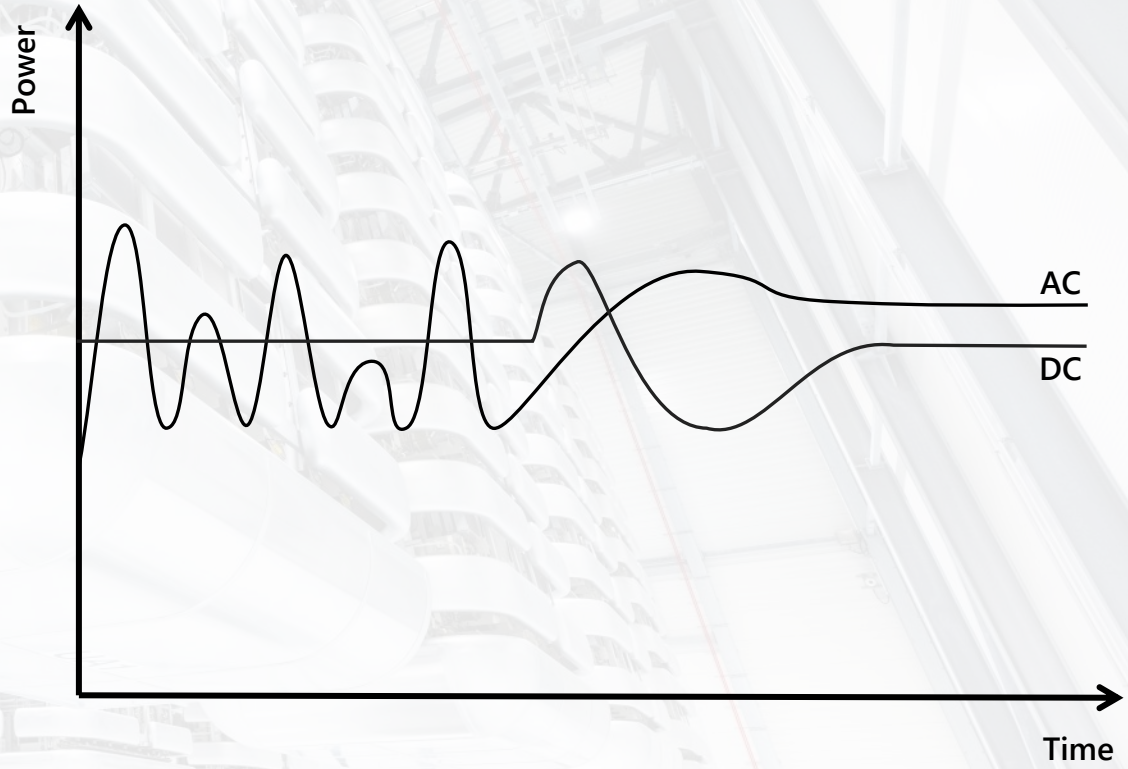
Back-to-back

- Share spinning reserves between adjacent networks
- Energy trading for asynchronous grids – uniting & securing energy markets
- Remove grid operational constraints
- Enhance grid resilience
- Leading to a reduced total cost of electricity



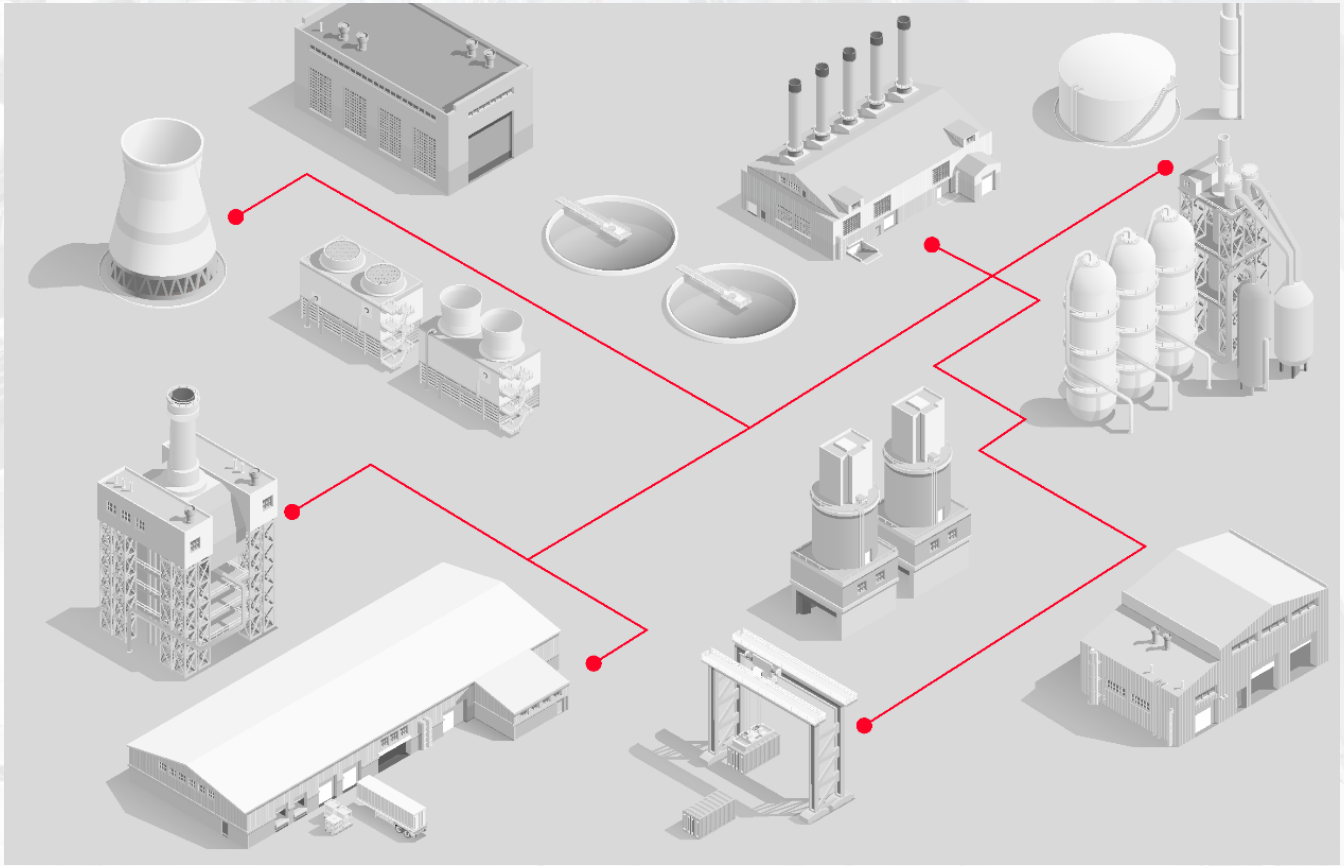
DC links in AC grids

- Reduce system losses
- Prevent overloading of AC lines
- Allow for higher loading of generators and other AC lines
- Remove grid operational constraints
- Enhance grid resilience
- Leading to a reduced total cost of electricity



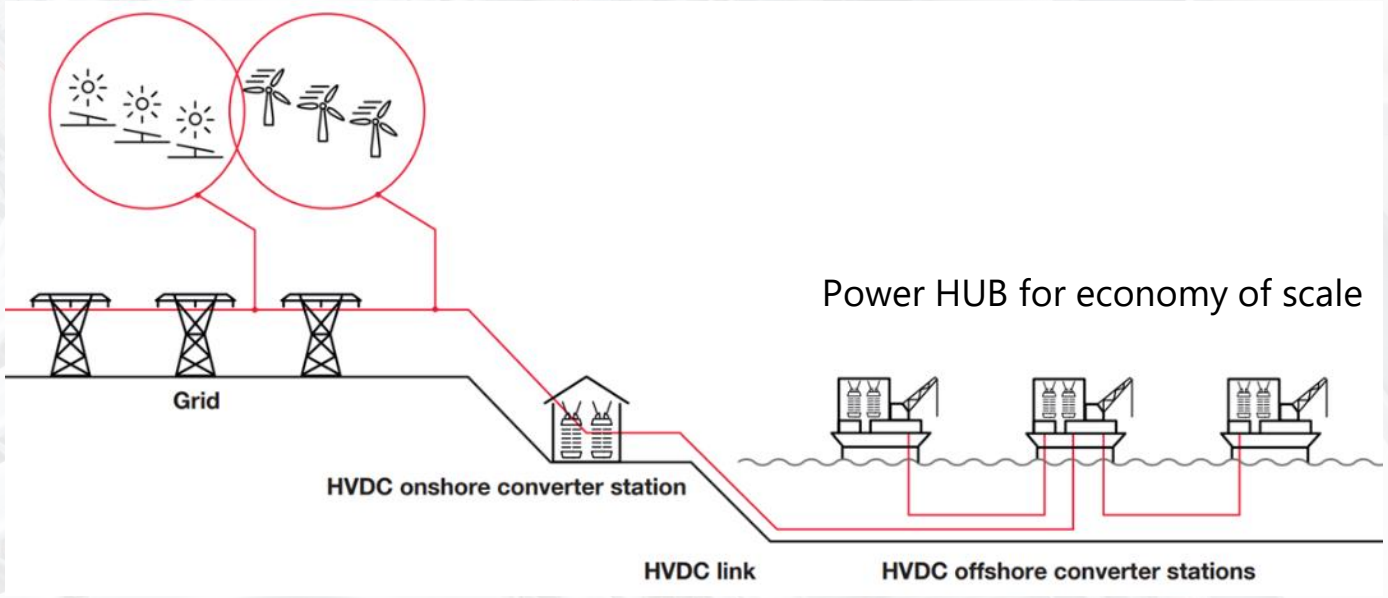
Connecting remote loads

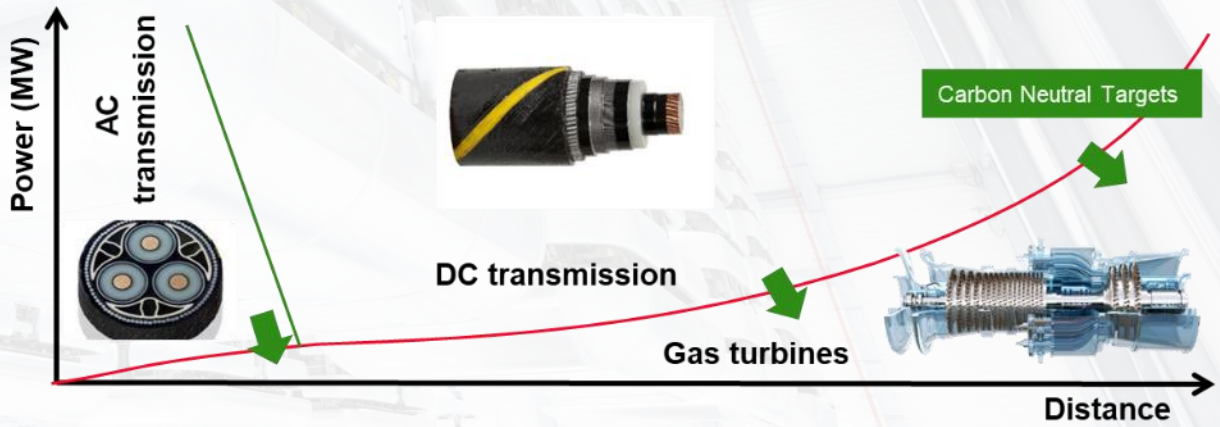
- Proven electrical transmission system for remote loads
- Eliminate polluting, inefficient and expensive local generation
- Provides remote, off-the-grid locations with reliable, environmentally friendly power supplies
- The surplus energy produced, from local renewable generation, can easily be exported and the back-bone AC network supported as needed



Power from shore

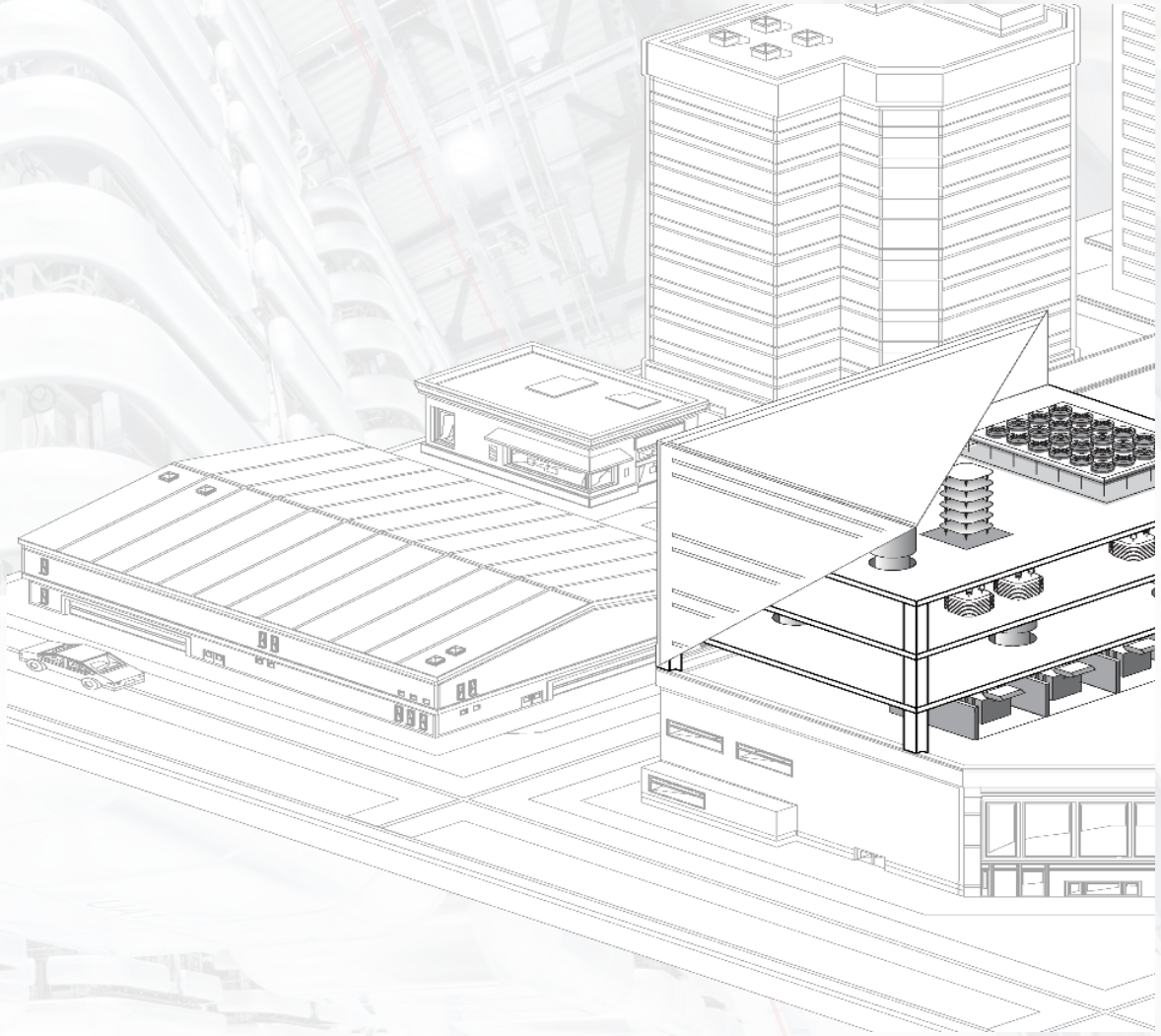
- High availability and reliability
- Reduced operational costs – OPEX
- Lower GHG emissions (CO2, NOX…)
- Improved Health, Safety and working conditions (noise, vibrations…)
- Compact offshore footprint
- No power or distance limitations
- Simple frequency conversion (50/60 Hz)
- Built in grid support





City center infeed

- Compact power station ideal for feeding large power with low losses into densely populated urban centers
- Power control capabilities are used to optimize the power flow in the existing AC lines
- Controlled contribution to short circuit currents
- Helping to reduce overall losses in the grid, increases capacity and improving stability
- Power is transmitted via oil-free extruded polymer underground cables



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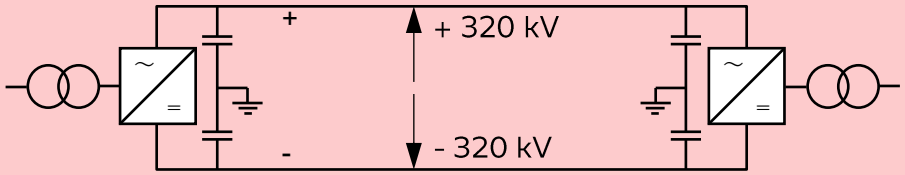
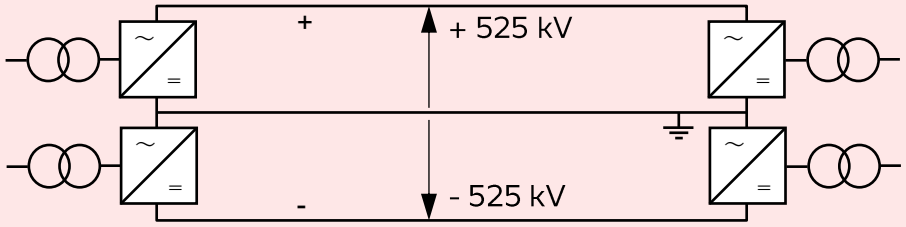
Typical HVDC (power / DC voltage / configuration)

Topology	Power DC voltage	Typical layout	Projects
Symmetrical monopole 	**900 ~ 1,800 MW** **± 320 kV** **or** **± 400 kV**		DolWin 1 (800 MW) DolWin 2 (900 MW) DolWin 5 (900 MW) IFA 2 (1,000 MW) Dogger Bank A (1,200 MW) Dogger Bank B (1,200 MW) Dogger Bank C (1,200 MW) CMS (1,200 MW) Hornsea 3 (1,340 MW x 2) Lightning Zakum (1,000 MW x 2) Marinus Link (750 MW) Centre Manche (1,250 MW x 2) Oléron (1,200 MW) etc
Bipole 	**2,000 ~ 3,000 MW** **± 525 kV**		NordLink (1,400 MW) North Sea Link (1,400 MW) Zhangbei (3,000 MW) SunZia (3,000 MW) Yanbu (3,000 MW) SuedLink DC4 (2,000 MW) Lanwin 5 (2,000 MW) Doordewind 1 (2,000 MW) Doordewind 2 (2,000 MW) Nederwiek 1 (2,000 MW) Nederwiek 3 (2,000 MW) IJmuiden Ver Alpha (2,000 MW) Eastern Green Link 2 (2,000 MW) Spittal – Peterhead (2,000 MW) Western Isles (2,000 MW) etc

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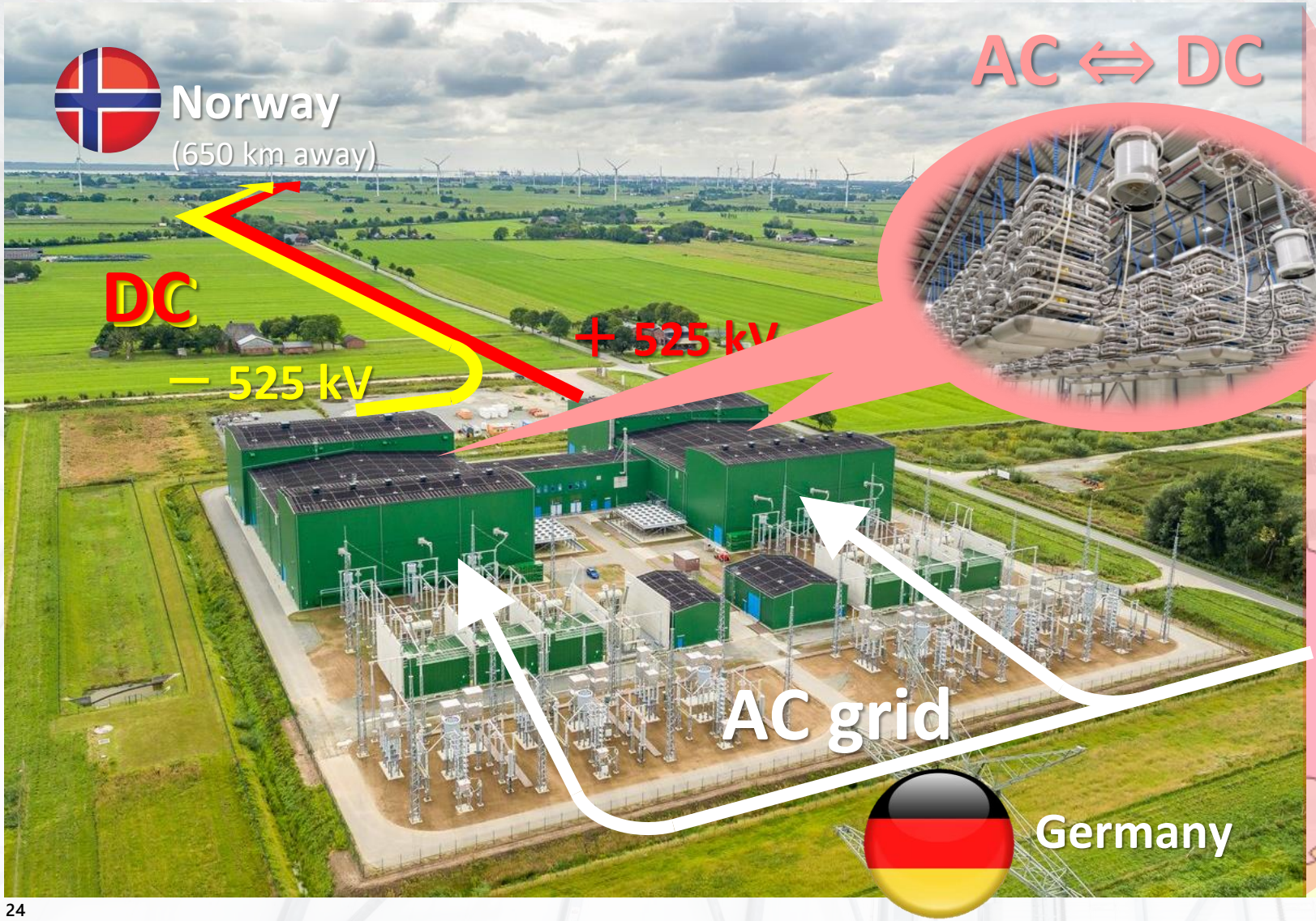
HVDC converter station ～example of HVDC, a long-distance interconnector～



※ Power flows both ways

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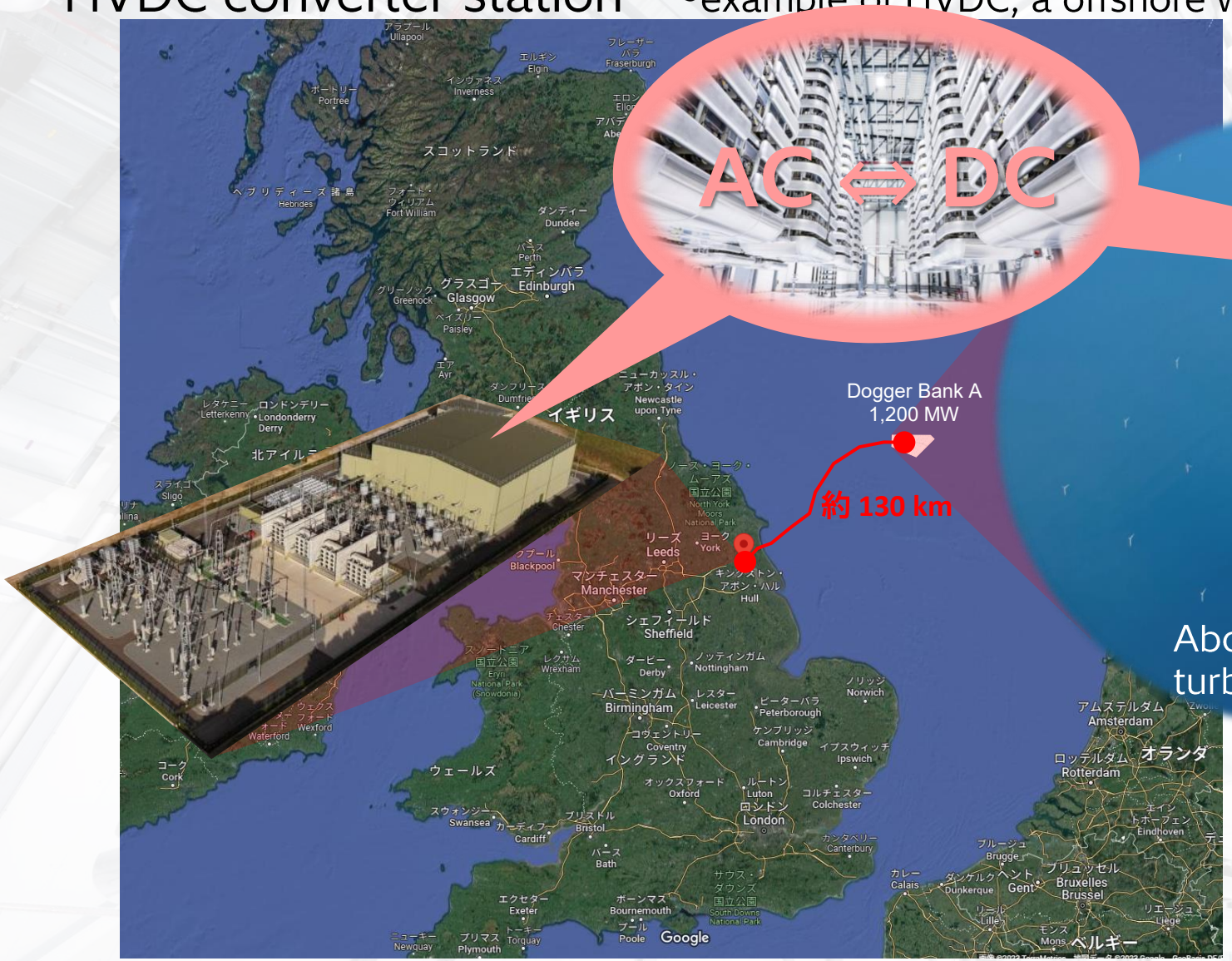
HVDC converter station ～example of HVDC, a offshore wind connection～



One HVDC system enables investment to a large offshore wind farm.

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Long submarine cable interconnection: North Sea Link

Customer
Statnett SF in Norway and National Grid in United Kingdom

Customer needs
- Security of supply
- Meet EU´s target for CO_2 reduction
- Energy trade

Our response
- Two 1,400 MW, ±515 kV HVDC Light® converter stations

Customer benefits
- Security of supply
- Fluctuations in power demand to be met by using the other country's renewable surplus power

Year
2021

HVDC Light® converter stations

- Bipolar ±515 kVdc
- Kvilldal: 420 kV
- Blyth: 400 kV

Land and sea DC cable system

Increased security of power supply and social-economic benefits for both countries

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Long submarine cable interconnection: North Sea Link

Commissioned in 2021, VSC ± 515 kV / 1400 MW (bipole), cable length: 720 km

UK

Norway

https://www.youtube.com/watch?v=gbUNrCWF3sI

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Offshore wind connection: Dogger Bank A, B & C

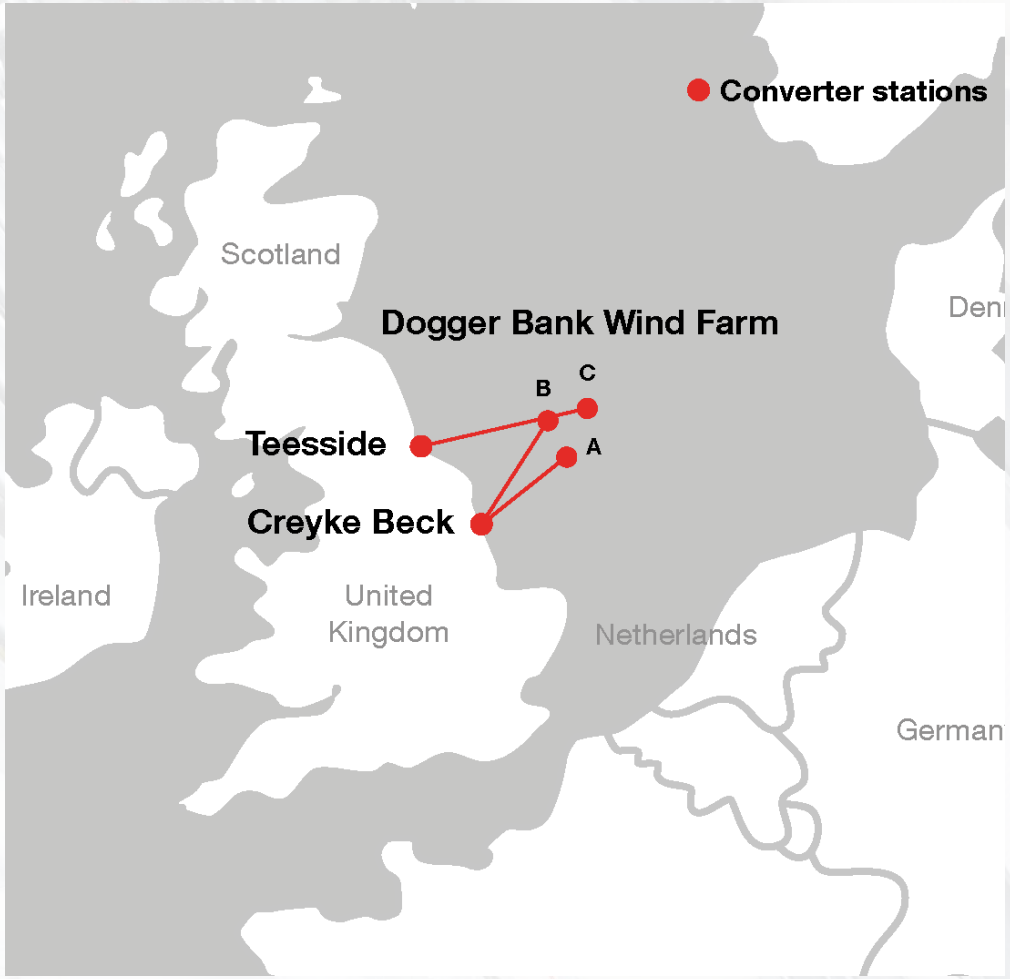
Customer
SSE & Equinor, United Kingdom

Customer needs
- 200 km long subsea and underground power connection
- Robust grid connection

Our response
- 3 x 1200 MW, ± 320 kV, HVDC Light® system
- Engineered package and supply for offshore and onshore converters

Customer benefits
- Environmentally sound power transport
- Low losses and high reliability
- Increasing current offshore wind capacity by 3,6 GW and reduce CO_2 emissions

Year*
2023, 2024, 2025



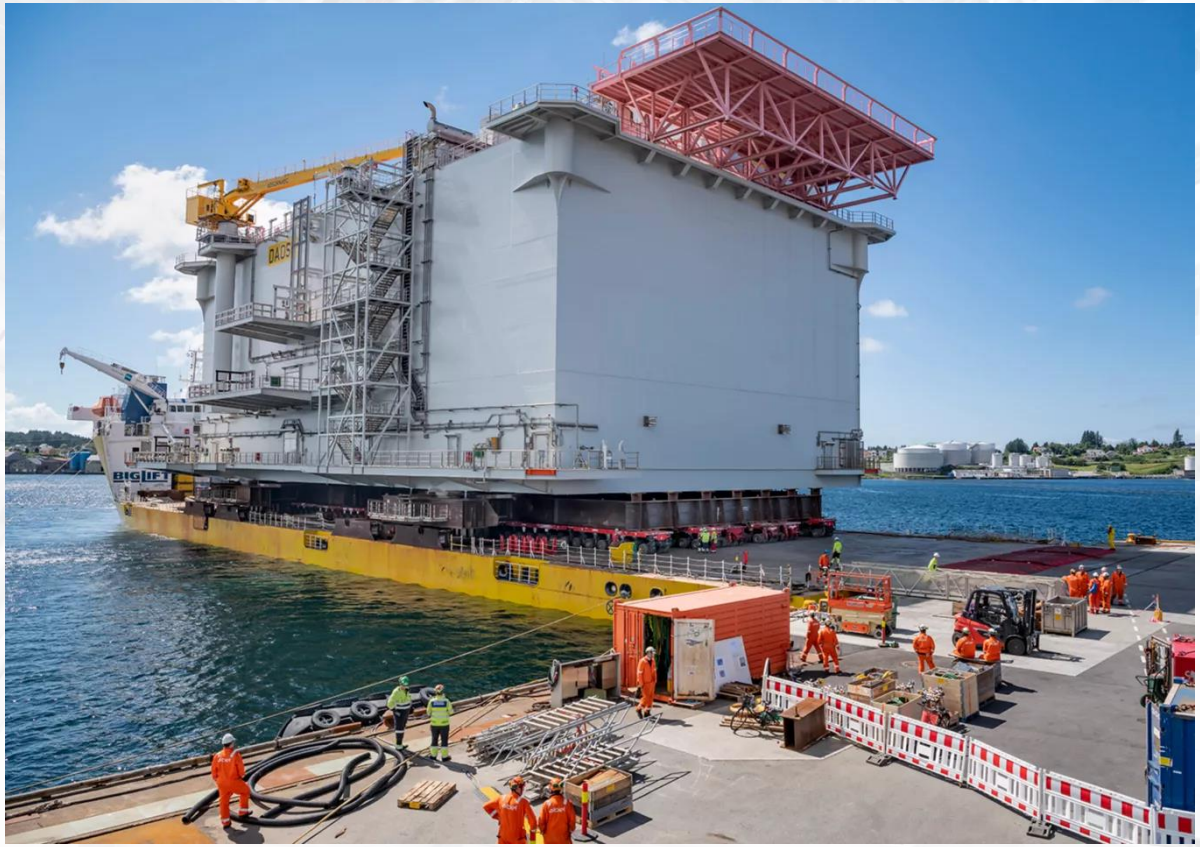
HVDC Light® converter stations

Symmetrical monopole

System capacity of 3 x 1200 megawatts (MW)

Supporting UK's clean electricity demand, powering six million UK homes

Offshore wind connection: Dogger Bank A, B & C



Illustrated image of offshore wind connection by Aibel

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Subsea option Caithness-Moray for faster deployment of transmission reinforcement.

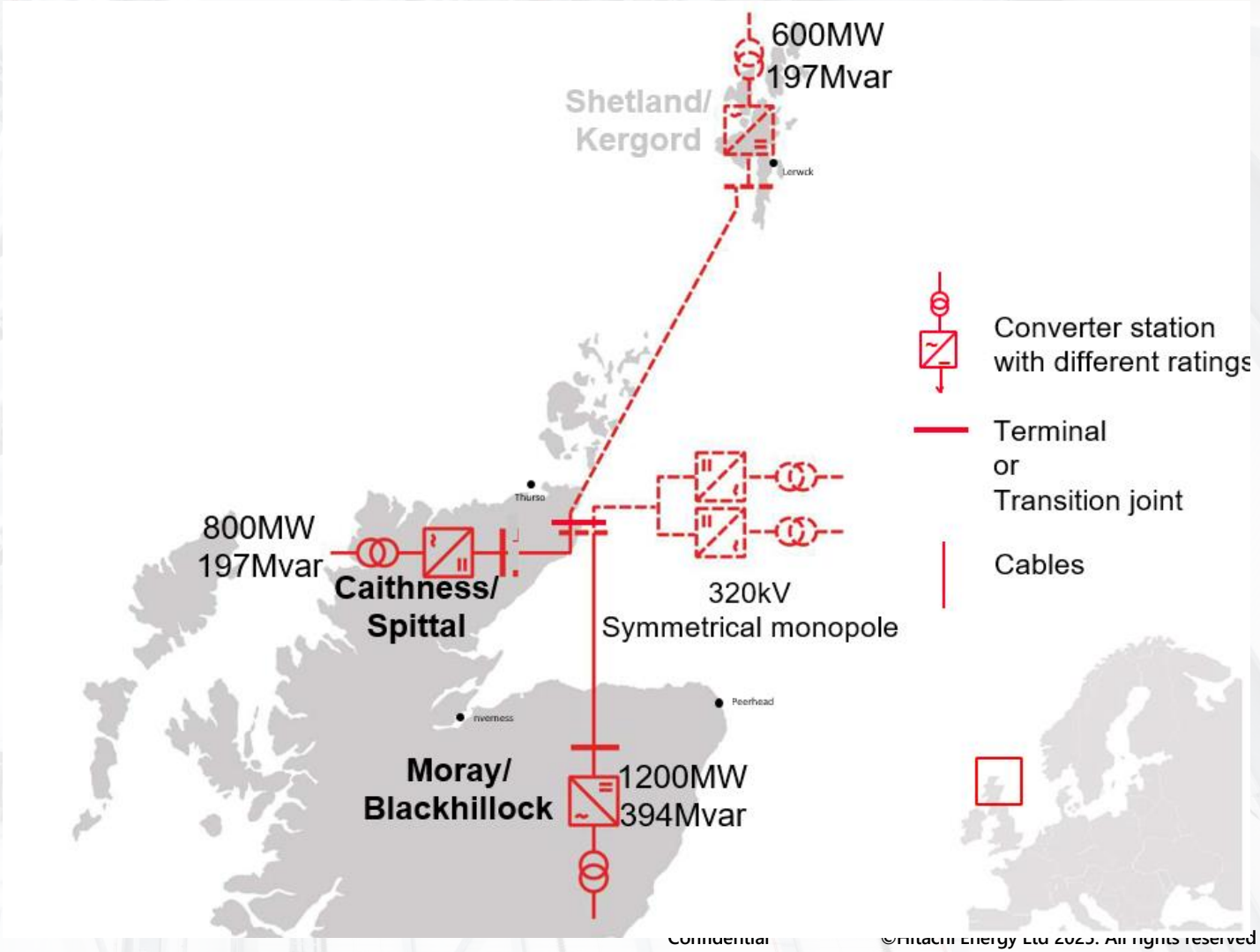
Less visual impact.

Additional technology benefits:

Multi-purpose HVDC –

embedded HVDC link with interconnector/radial renewable power infeed.

CigréParis session 48, 2020, B4-116 Linden, Hanson and McHardy, Planning and implementation of an HVDC link embedded in a low fault level AC system with high penetration of wind generation"



Power from shore "Project Lightning"

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Customer
ADNOC, United Arab Emirates

Customer needs
- Enable power supply from mainland to platform complex to minimize emission of large amounts of CO_2

Our response
- Two HVDC Links with four HVDC Light® converter stations
- Zakum Cluster: Al Ghallan 132 kV (off-shore) and Mirfa 400 kV (on-shore), 2 x 1,000 MW
- DAS Cluster: Das 132 kV (offshore) and Shuweihat 400 kV (on-shore), 2 x 600 MW

Customer benefits
- Enable sustainable, flexible and secure power supply to offshore platforms
- Reduction of carbon footprint for offshore operation
- High power ratings, compactness of converters on islands and long submarine cable distance

Year
2024

HVDC Light® converter stations

- Symmetrical monopole to Al Ghallan island
- Bipole to DAS island

System capacity of 3,200 megawatts (MW)

The first-of-its-kind sub-sea power transmission network in the MENA region advancing a sustainable energy future for Abu Dhabi

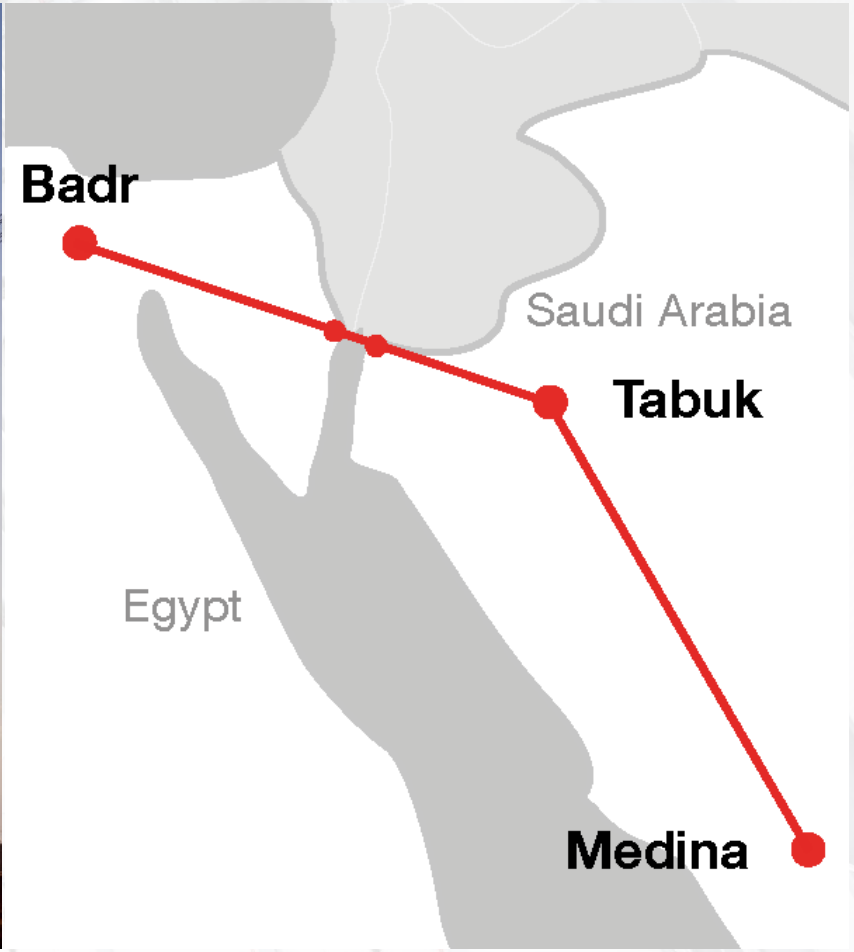
Saudi Arabia – Egypt

Saudi Arabia – Egypt

Customer	Saudi Electricity Company (SEC), Saudi Arabia and Egyptian Electricity Transmission Company (EETC), Egypt
Customer needs	• Power transmission and energy trading between countries

Our response	• 3000 MW ±500 kV multi-terminal solution with power flow in multiple directions
	• Three turnkey HVDC converter stations:
	  • Medina: 3000 MW (Saudi Arabia)
	  • Tabuk 1500 MW (Saudi Arabia)
	  • Badr 3000 MW (Egypt)

Customer benefits	• Facilitate electricity trade between Saudi Arabia and Egypt • Connecting the two grids with strengthening grid resilience • Power supply security • Optimization of energy production • Addressing power consumption peaks by exchanging the surplus power with each other
Year	• 2025



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Proven track record for HVDC

Majority of projects over 70 years

North America

- Maritime Link
- Quebec – New England Upgrade
- CU Upgrade
- Madawaska Upgrade
- Celilo Upgrade
- Highgate Upgrade
- Railroad DC Tile
- Oklaunion
- Mackinac
- IPP Upgrade
- Blackwater Upgrade
- Outaouais
- Sharyland
- Rapic City
- Cross Sound
- Eagle Pass
- Quebec – New England
- Pacific Intertie Expansion
- IPP Intermountain — Adelanto
- Pacific Intertie Upgrade
- Madawaska
- Highgate
- Chateauguay Upgrade
- CU project
- Square Butte Upgrade
- Eel River Upgrade
- Pacific Intertie
- Vancouver Island Pole 1 & 2
- Nelson River, Bipole
- EATL
- WATL
- Nelson River 1 & 2
- McNeill
- Lower Churchill
- Black Sea
- Trans Bay Cable
- Hudson
- Neptune RTS
- Lamar
- Celilo upgrade
- Sylmar East Valve
- Welsh 1995/2017
- Virginia Smith/Sidney
- Poste Châteauguay
- Square Butte
- Eel River
- Eddy County BtB
- Stegall BtB

South America

- Itaipu
- Rio Madeira Back-to-back
- Rio Madeira
- Brazil – Argentina
- Interconnection I & II
- Rio Madeira
- Melo
- Rivera HVDC Brazil
- Acaray

Africa

- Caprivi Link
- Inga – Kolwezi Upgrade
- Cahora Bassa, Songo
- Apollo Upgrade
- Inga – Kolwezi
- Cahora Bassa
- Cahora Bassa
- Ethiopia – Kenya HVDC Interconnector

Europe

- Dogger Bank C
- Shetland
- Dogger Bank A
- Dogger Bank B
- IFA2
- Nordlink
- North-sea Link
- Caithness – Moray
- Kriegers Flak Cgs
- Johan Svedrup
- Gotland Upgrade
- Kontek Upgrade
- Troll 1 & 2
- Troll 3 & 4
- Borwin 1
- Dolwin 1
- Dolwin 2
- Dolwin 5
- Åland
- Nordbalt
- Litpol Link
- East West Interconnector
- Sapei
- Valhall
- Norned
- Estlink
- Italy – Greece
- Tjæreborg
- Swepol
- Gotland Light
- Hällsjön
- Kontek
- Baltic Cable
- Fennoskan 1 & 2
- Dürnohr
- Skagerrak 1-3
- Skagerrak 4
- Gotland 1-3
- Konti-skan 1 & 2
- English Channel
- Borwin 3,5
- Konti-Skan 1 Cable
- SACOI
- Western HVDC Link
- EstLink 2
- COMETA
- BritNed
- Storebælt
- Moyle Interconnector
- Etzenricht
- Wien-Suedost
- Dürnrohr
- Borwin 2
- Dolwin 3
- Helwin 1
- Helwin 2
- INELFE
- Sylwin 1
- MONITA
- Italy-France

Asia

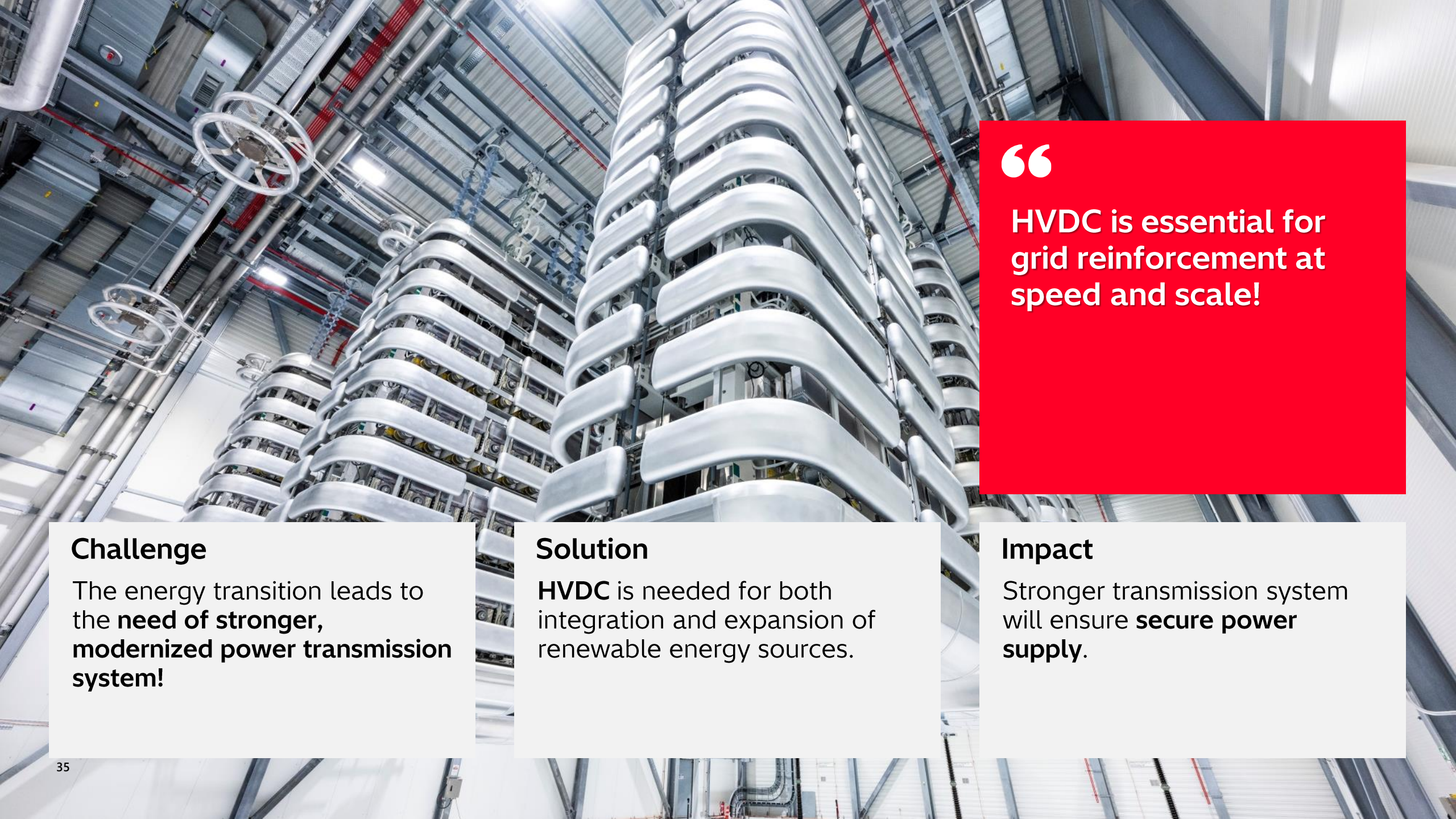
- Higashi-Shimizu
- Jeju 3
- Changji-Guquan
- Raigarh-Pugalur
- North East Agra
- Jinping – Sunan
- Hülünbeir – Liaoning
- Qinghai-Tibet
- Yunnan-Guangxi
- Lingboa Ii Extension
- Xiangjiaba – Shanghai
- Three Gorges – Shanghai
- Vizag Li
- Three Gorges – Guangdong
- Three Gorges – Changzhou
- Xiluodu-Zhexi
- Hami-Zhengzhou
- Lingzhou-Shaoxing
- Jinbei-Nanjing
- Jiuquan-Hunan
- Shanghaimiao-Shandong
- Ximeng-Taizhou
- Dianxibei-Guangdong
- Zhalute-Qingzhou
- Chapad
- Rihand-Delhi
- Gezhouba – Shanghai
- Vindyachai
- Sakuma
- Champa-Kurukshetra I/2
- Zhangbei
- Leyte-Luzon
- Buk-Dangjin-Godeok
- Jeju-Jindo
- Nindong-Shandong
- 3G-Shanghai 2
- GCCIA
- Lingbao 2
- China-Russia
- Sasaram
- Jeju-Haenam
- Chandrapur
- Nuozhadu – Guangdong
- Xiluodu – Guangdong
- Back-to-Back Bangladesh
- Mundra – Haryana
- Ballia – Bhiwadi
- Yunnan – Guangdong
- Guizhou – Guangdong II
- Guizhou – Guangdong
- East-South Inter connector II and Upgrade
- Thailand-Malaysia
- Tianshengqiao – Guangzhou
- Wudongde-Guangdong-Guangxi
- YU-E

Australia and Oceania

- Murraylink
- Directlink
- NewZealand 1
- NewZealand 2
- Broken Hill
- Inter-Island link Pole 3
- Basslink

Project executed by Hitachi Energy / Project delivered by ALL other suppliers

Summary



HVDC is essential for grid reinforcement at speed and scale!

Challenge

The energy transition leads to the **need of stronger, modernized power transmission system!**

Solution

HVDC is needed for both integration and expansion of renewable energy sources.

Impact

Stronger transmission system will ensure **secure power supply**.

Thank you for attention!

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