



GE VERNOVA

HVDC Market Perspective

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ERCOT Office, Austin

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Outline



State of Global HVDC technology

Ongoing and upcoming HVDC projects in North America

Future HVDC landscape



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HVDC Market Perspective

HVDC – Global Perspective

Most Active HVDC Market in History

Growth in Demand Driven by Country Renewable Portfolio Standards 2030, 2035, 2040, 2050

Europe is Dominating Demand

- Interconnectors, Offshore Wind, Offshore Energy Hubs

US Market Growth

- Offshore Wind
- FERC1000 Upgrades (CAISO San Jose),
- State RPS (e.g. MA 83D)
- Historically High Attrition Rate of HVDC Projects Signs of Change?

HVDC Vendor Pool / Supply Chain Constraints



What's Driving The Growth? Integration of Renewables & Interconnectors

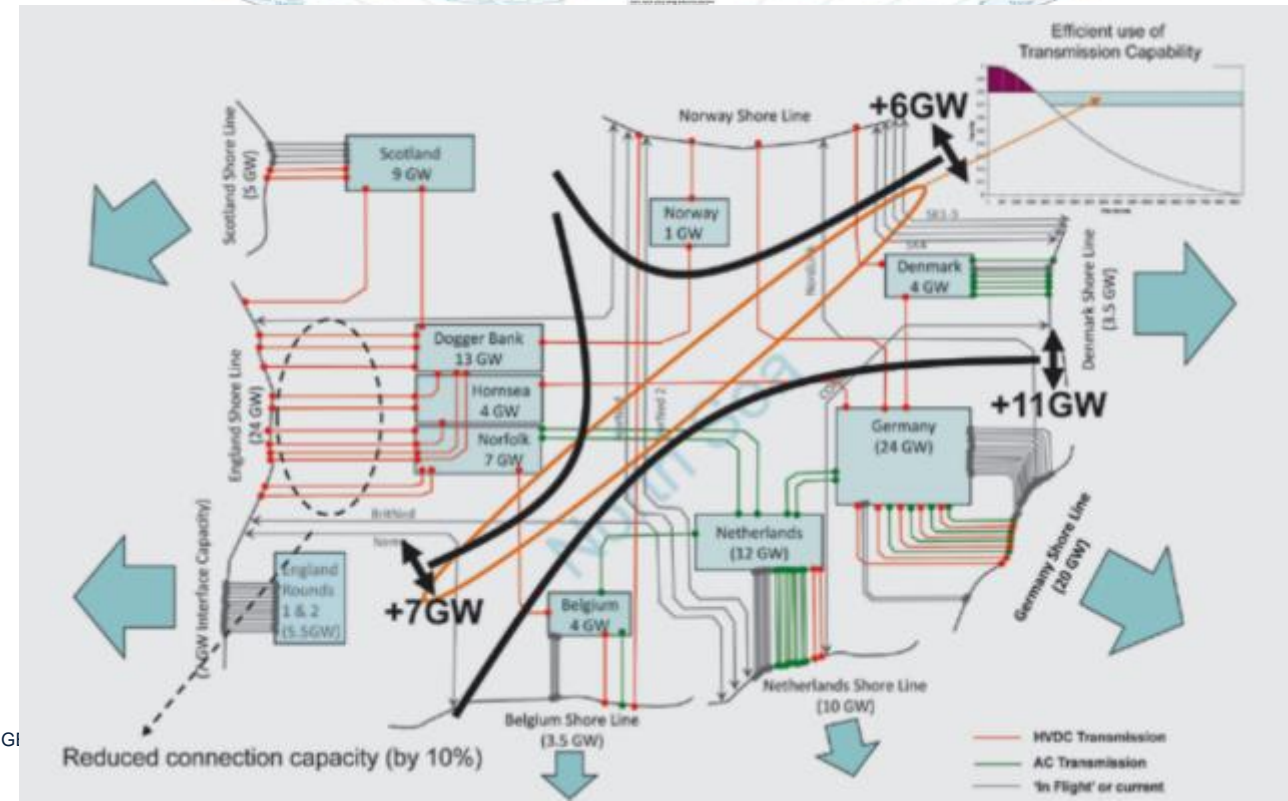
Historically, Integration of Remote **Hydro** Generation
Recent Rapid Growth in Remote **Renewable** Generation

- Wind Onshore
- Wind Offshore
- Solar

European Drive For Combination of Both:

- Renewable Bulk Offshore Wind To Meet Environmental Goals
- Interconnections Between Countries Achieving:
 - Access to Markets
 - Reliability Improvement

VSC Technology is the "Enabler"



North American Transmission Needs – Where Can HVDC Help ?



Long Distance Inter-Region Transmission

Access to Offshore Generation

Inner City Supply

Remote Community Supply

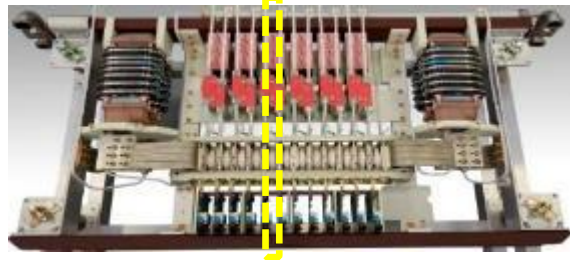
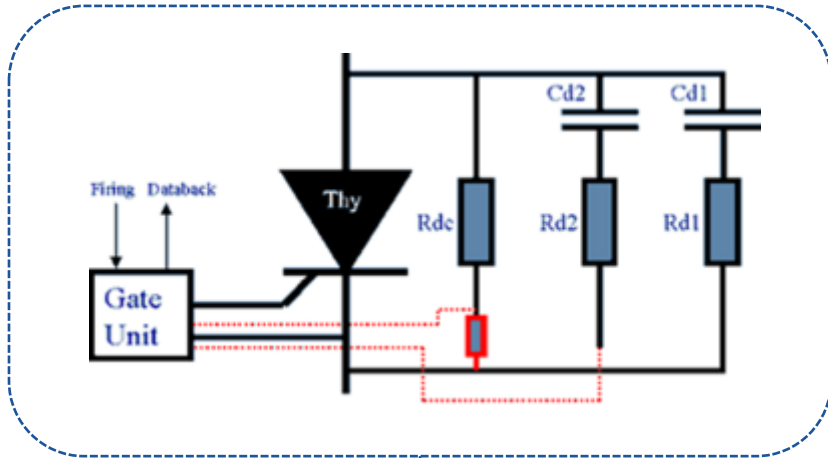
Grid Segmentation / Autonomy



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— What is an HVDC System ?

LCC Converters



Module



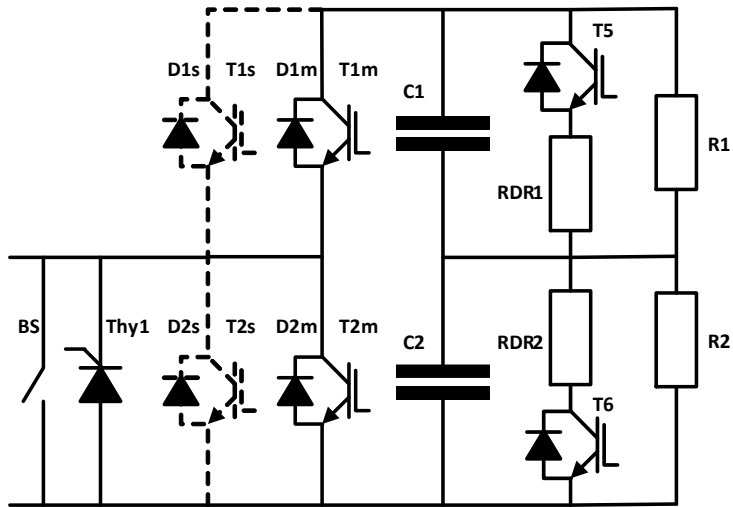
Valve



Converter

VSC Converters

Modular Multi-Level Converter



Sub-Module



Module



Valve



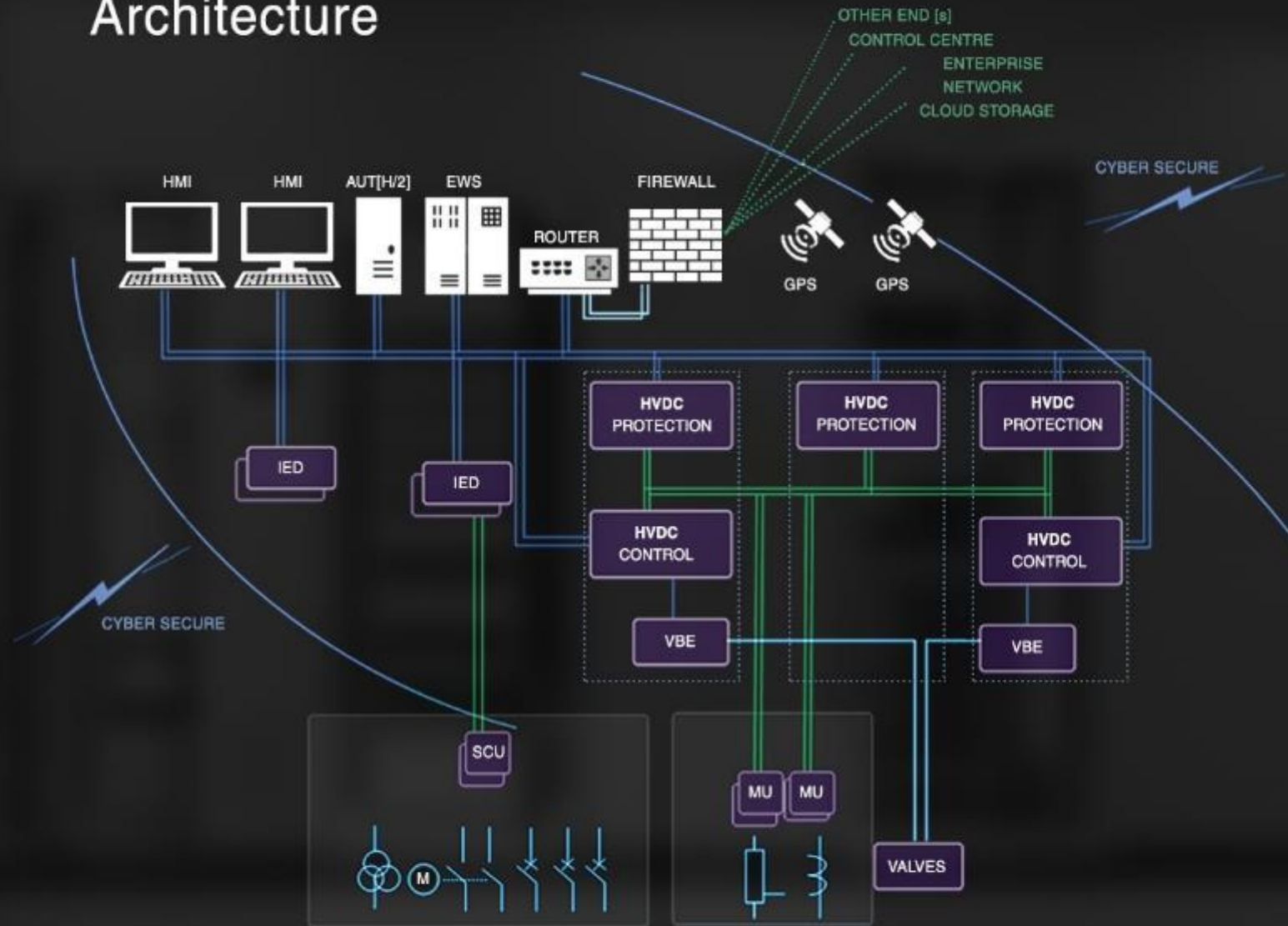
Converter

HVDC Control System eLumina™

Improved system resiliency through simplified, fully-redundant system architecture that **maximizes system availability**

- IEC61850 compliant for ultimate interoperability
- Dual-redundant converter control with seamless changeover
- Triple-redundant converter protection
- Modular, Secure, Simple
- Maximized availability and increased reliability
- Cyber-secure compliant with utility practice and regulations (ex. NERC/CIP)

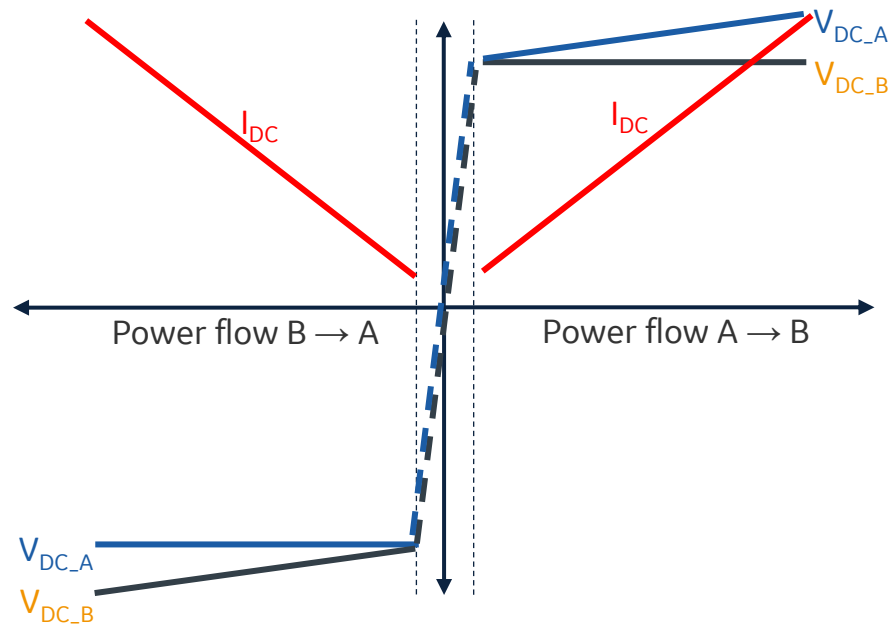
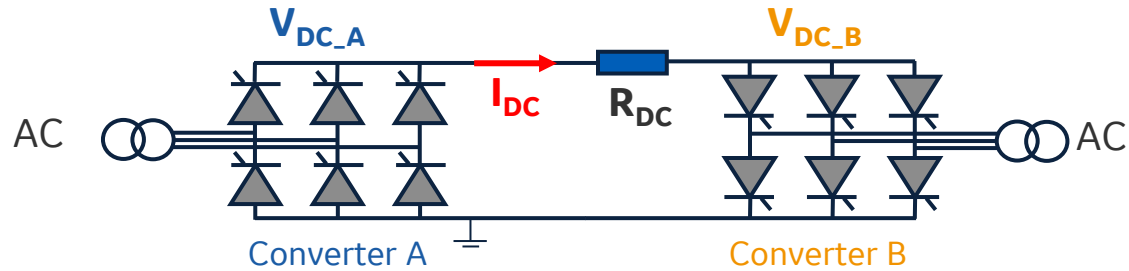
System Architecture



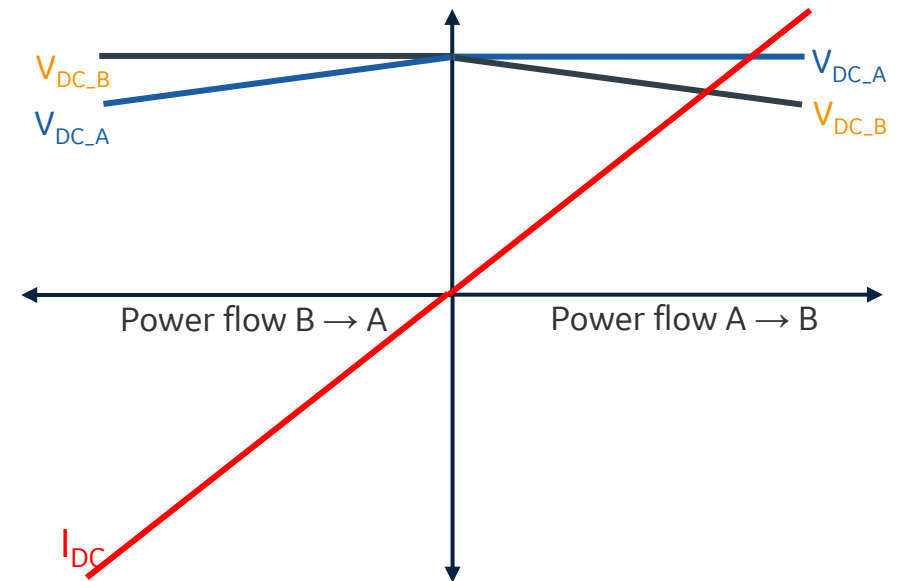
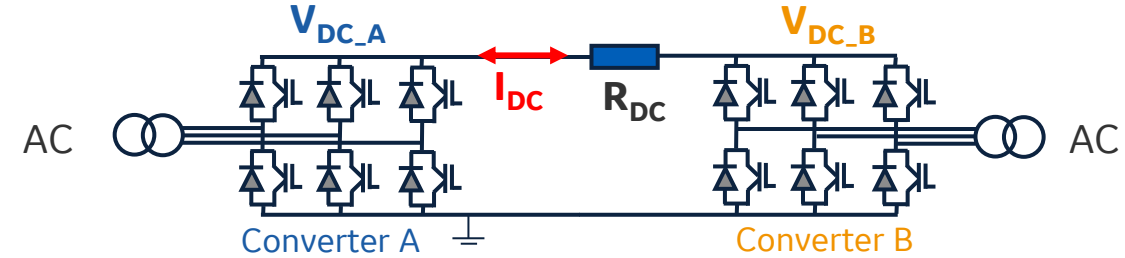
Designed for **99.9%** availability

VSC vs LCC HVDC Power Flow

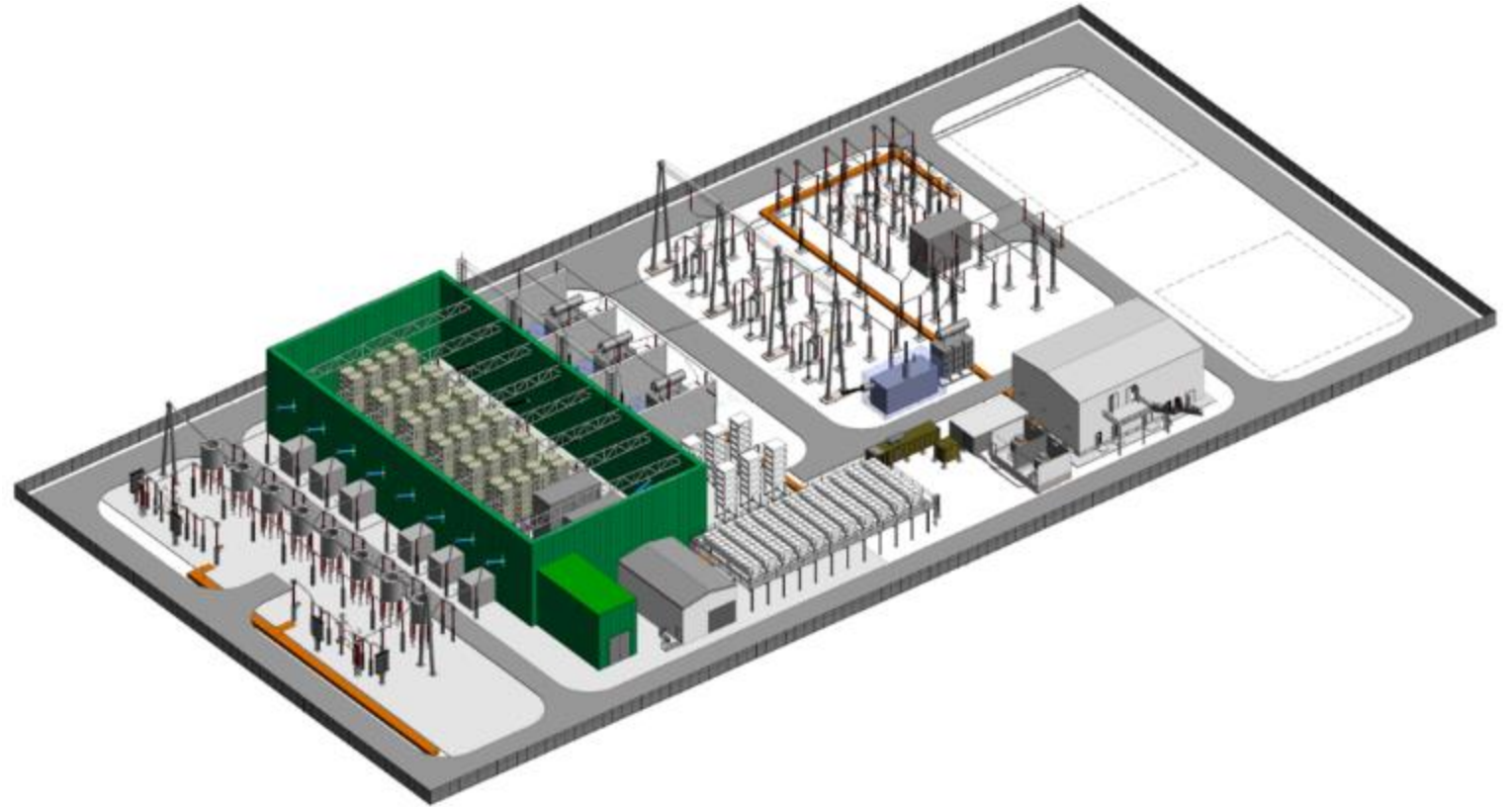
Line Commutated Converter (LCC)



Voltage Source Converter (VSC)



Offshore Transmission - Converter Platform & Onshore Converter Station





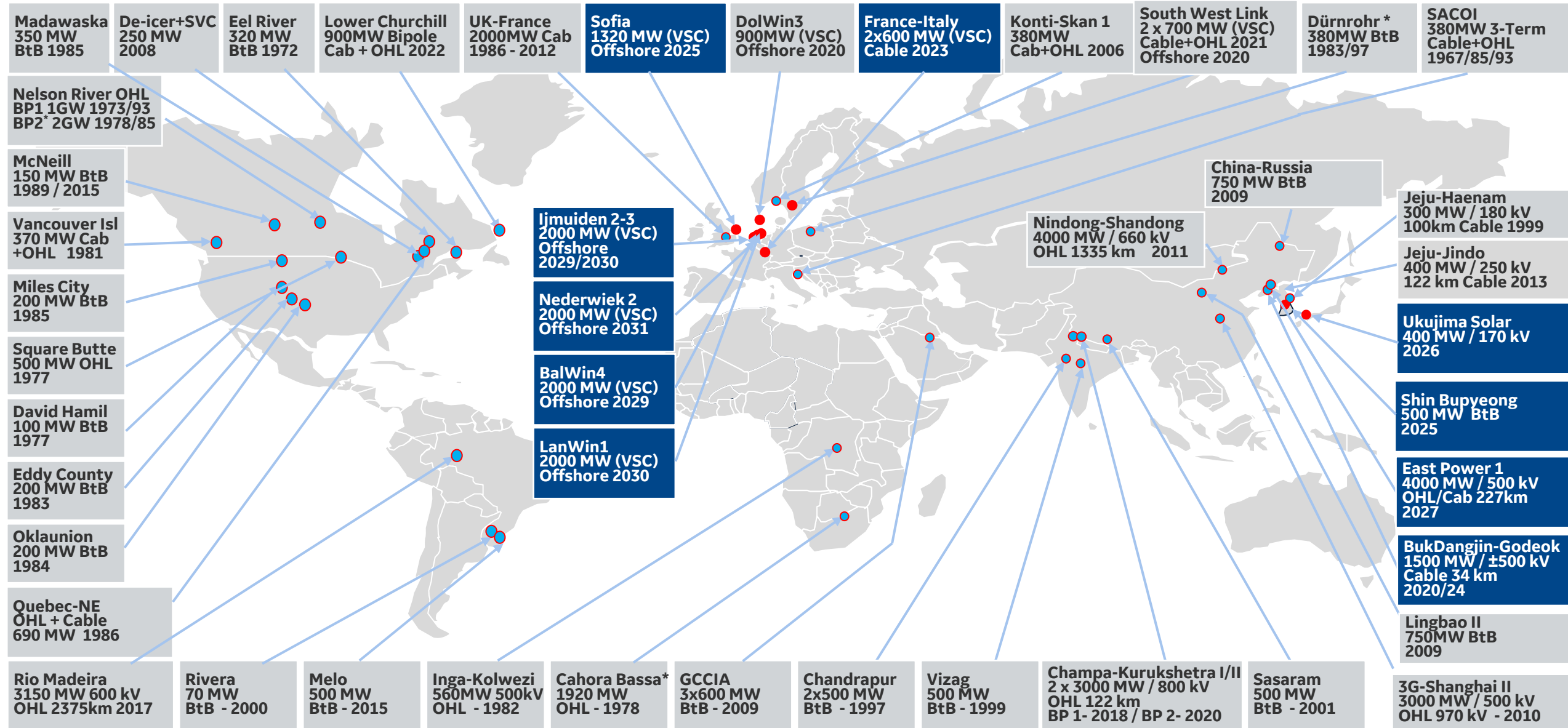
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— Selected HVDC Projects

Installed and Ongoing HVDC Projects - 2023



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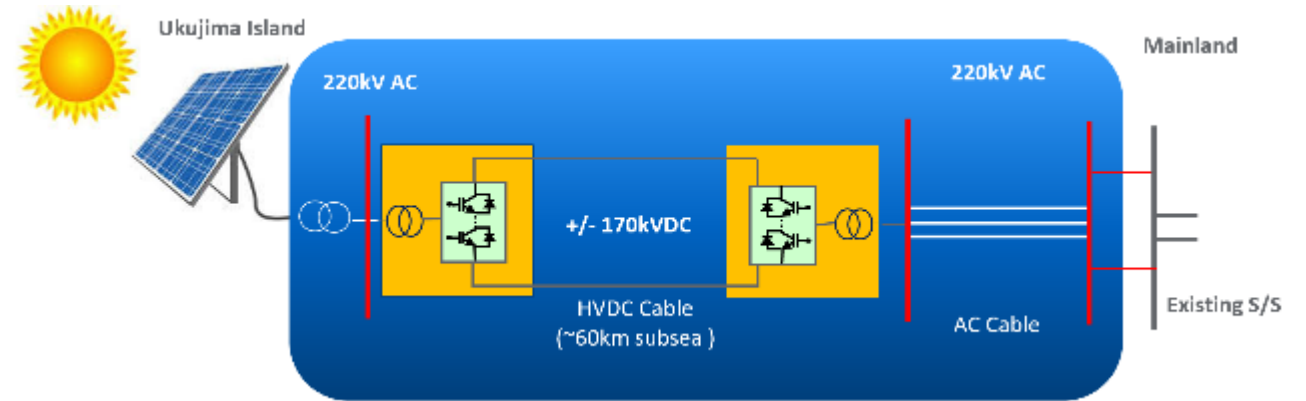


Indicates completed contracts Indicates ongoing contracts Indicates projects in development

* GE partnering with the German HVDC Group

Ukujima

Main Project Data	
Customer	Kyudenko Corporation, Japan
Commissioning year	2027
Technology	VSC
Configuration	Symmetrical Monopole
Power rating	400 MW
DC voltage	± 170 kV
Solar Gen (0.3kW)	1,650,000x (480 MW)
Length of DC OHL	N/A
Length of DC sub cable	~60 km
Length of DC U/G cable	~1 km
Customer benefit	Evacuation of power generated by Mega solar park on remote island
Application	Solar park integration via HVDC link



TenneT 2GW HVDC

5 Contracts Awarded to GE

TenneT Germany (2):

GE + McDermott

BalWin4

LanWin1

Onshore Connection: Unterweser

TenneT Netherlands (3):

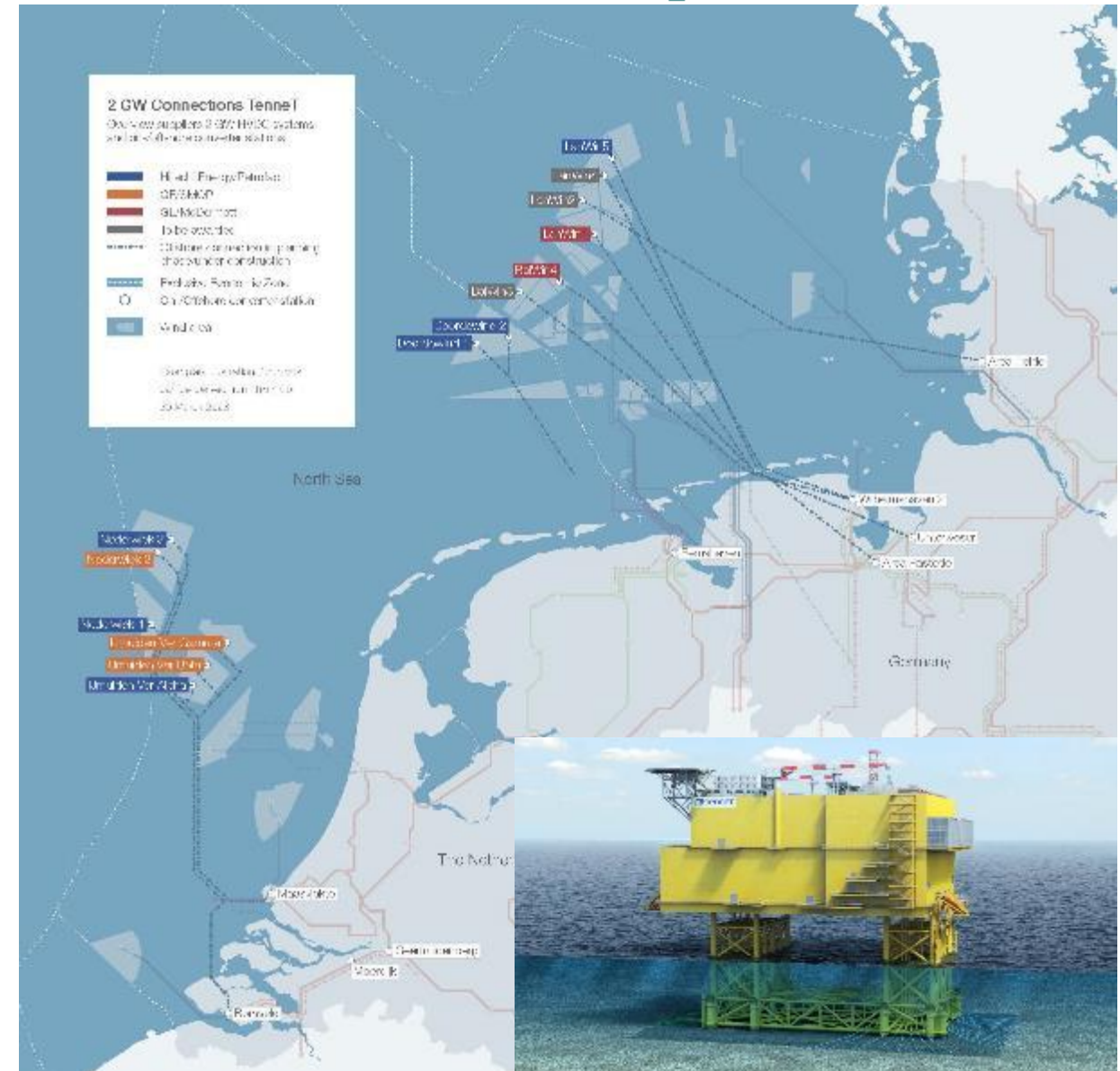
GE + SMOP

IJmuiden Ver Beta

IJmuiden Ver Gamma

Nederwiek 2

Onshore Connection: Maasvlakte, Rotterdam



TenneT 2GW Program – 5 Projects



Main Project Data	
Customer	TenneT (NL + DE)
Commissioning year	2029-2031
Technology	VSC
Configuration	Bipole
Power rating	2,000 MW
DC voltage	± 525 kV
WTG (~18MW)	~120x (2,160 MW)
Length of DC OHL	-
Length of DC sub cable	150-200 km
Length of DC U/G cable	20-100 km
Customer benefit	Controllable transmission of Offshore Wind to Onshore Network
Application	Offshore wind integration



ShinBuPyeong (SBY)



Main Project Data	
Customer	KEPCO
Commissioning year	2025
Technology	VSC
Configuration	Back-to-Back
Power rating	500 MW
DC voltage	± 130 kV
Customer benefit	Provides rapid active power flow control and compensation of reactive power to relieve overload and overvoltage conditions in the high-growth, Incheon region
Application	Infeed Urban Areas



Sofia

Main Project Data	
Customer	SOWFL (RWE)
Commissioning year	2025
Technology	VSC
Configuration	Symmetrical Monopole
Power rating	1,320 MW
DC voltage	± 320 kV
WTG (14MW)	100x (1,400 MW)
Length of DC OHL	-
Length of DC sub cable	220 km
Length of DC U/G cable	7 km
Customer benefit	Contract for difference transmission scheme
Application	Offshore wind integration



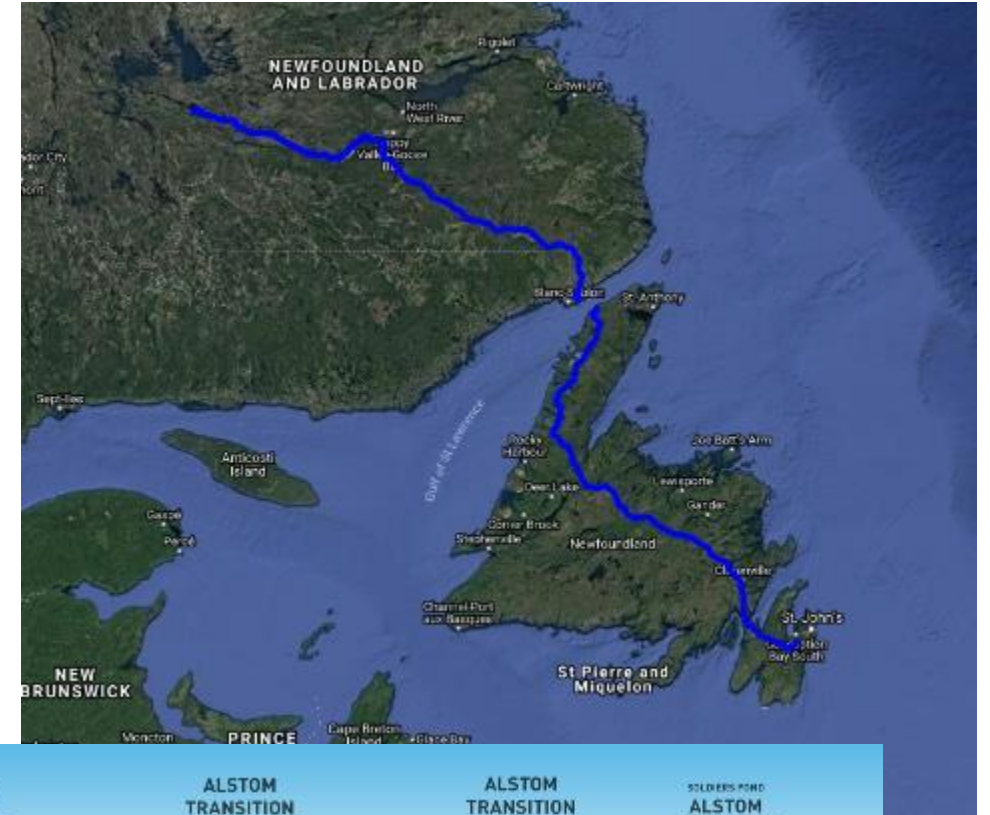
DolWin3

Main Project Data	
Customer	TenneT
Commissioning year	2020
Technology	VSC
Configuration	Symmetrical Monopole
Power rating	900 MW
DC voltage	± 320 kV
Length of DC OHL	-
Length of DC sub cable	83 km
Length of DC U/G cable	79 km
Customer benefit	Controllable transmission of Offshore Wind to Onshore Network
Application	Offshore wind integration



Lower Churchill

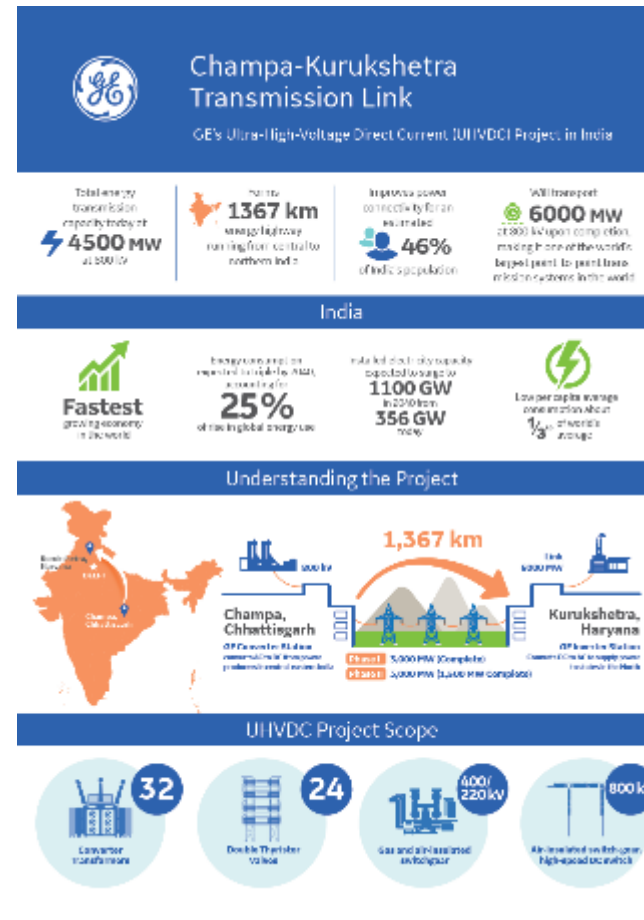
Main Project Data	
Customer	Nalcor Energy
Commissioning year	2018 (Pole 1) / 2020 (Bipole)
Technology	LCC
Configuration	Bipole
Power rating	900 MW
DC voltage	±350 kV
Length of DC OHL	1100 km
Length of DC submarine cable	35 km
Length of DC U/G cable	N/A
Customer benefit	Economical long-distance transmission
Application	Bulk transmission of Hydro generation



Champa-Kurukshetra 1 & 2



Main Project Data	
Customer	POWERGRID
Commissioning year	Bipole-1; 2017 Pole-3; 2019, Pole-4; 2020
Technology	LCC
Configuration	Parallel Bipole
Power rating	6,000 MW
DC voltage	±800 kV
Length of DC OHL	1,367 km
Length of DC sub cable	-
Length of DC U/G cable	-
Customer benefit	Controllable, economical long-distance transmission
Application	Bulk transmission of thermal generation



The SouthWest Link

Main Project Data	
Customer	Svenska Kraftnat
Commissioning year	2020
Technology	VSC
Configuration	Dual Independent Symmetrical Monopoles
Power rating	2 x 720 MW
DC voltage	± 300 kV
Length of DC OHL	60 km
Length of DC sub cable	-
Length of DC U/G cable	190 km
Customer benefit	Long underground cable power transmission
Application	Reducing energy cost differential



France – Italy Link (FIL)

The longest HVDC land cable connection (190 km)

Main Project Data

Customer	RTE - Terna
Commissioning year	2021
Technology	VSC
Configuration	Dual Independent Symmetrical Monopoles
Power rating	2 x 600 MW
DC voltage	±320 kV
Length of DC OHL	-
Length of DC sub cable	-
Length of DC U/G cable	190 km
Customer benefit	Regional interconnection without overhead lines
Application	Interconnection between country networks



Converter Station at Grande-Ile



Grande-Ile Converter Station (France)



Piosasco Converter Station (Italy)



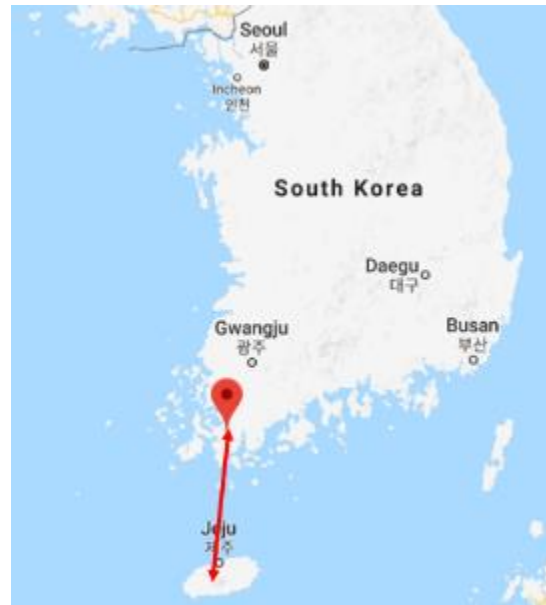
Converter station at Piosasco



Mainland – Jeju #1 HVDC Link Upgrade



Main Project Data	
Customer	KEPCO
Commissioning year	2019
Technology	LCC
Configuration	Bipole
Power rating	300 MW
DC voltage	±180 kV
Length of DC OHL	-
Length of DC sub cable	101 km
Length of DC U/G cable	-
Customer benefit	Bi-directional power flow to accommodate increased renewables, improved reliability
Application	Island-Mainland interconnection



Mainland – Jeju#1 HVDC Link
300MW, DC ±180kV



H450 Valve Installed in Converter Station



XXXXXXXX



KEPCO and Grid Solutions Joint Venture

- Dismantling, Installation and Commissioning
- Site management
- AC Protection

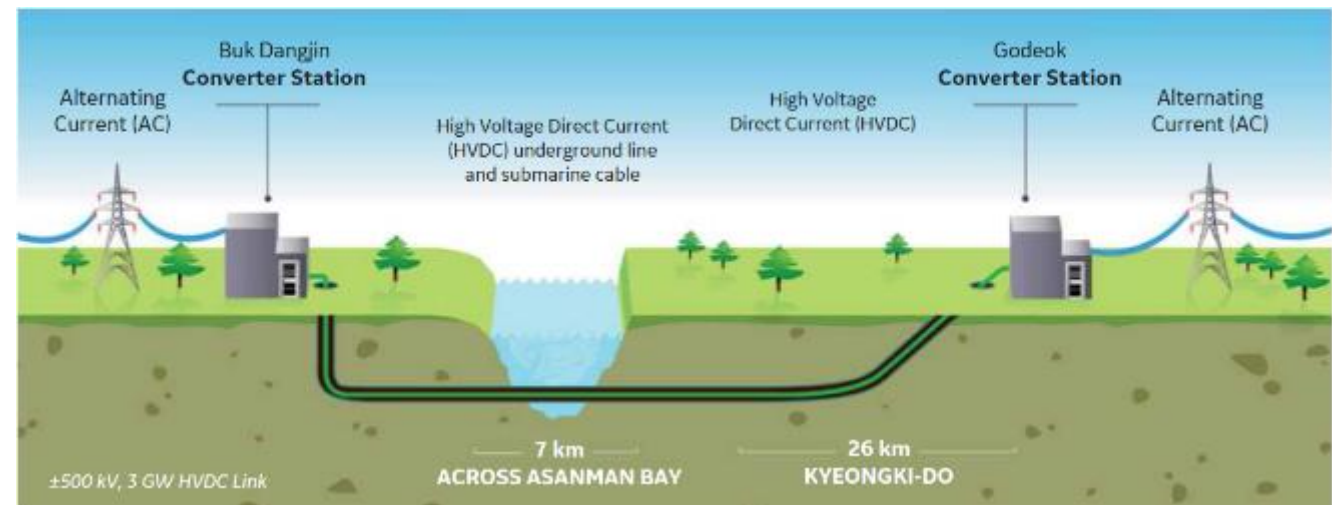


- Valves, Cooling, SA, DCCT
- Series V control system
- System studies
- Training

Buk-Danghin – Godeak HVDC Link (Phase 1/2)

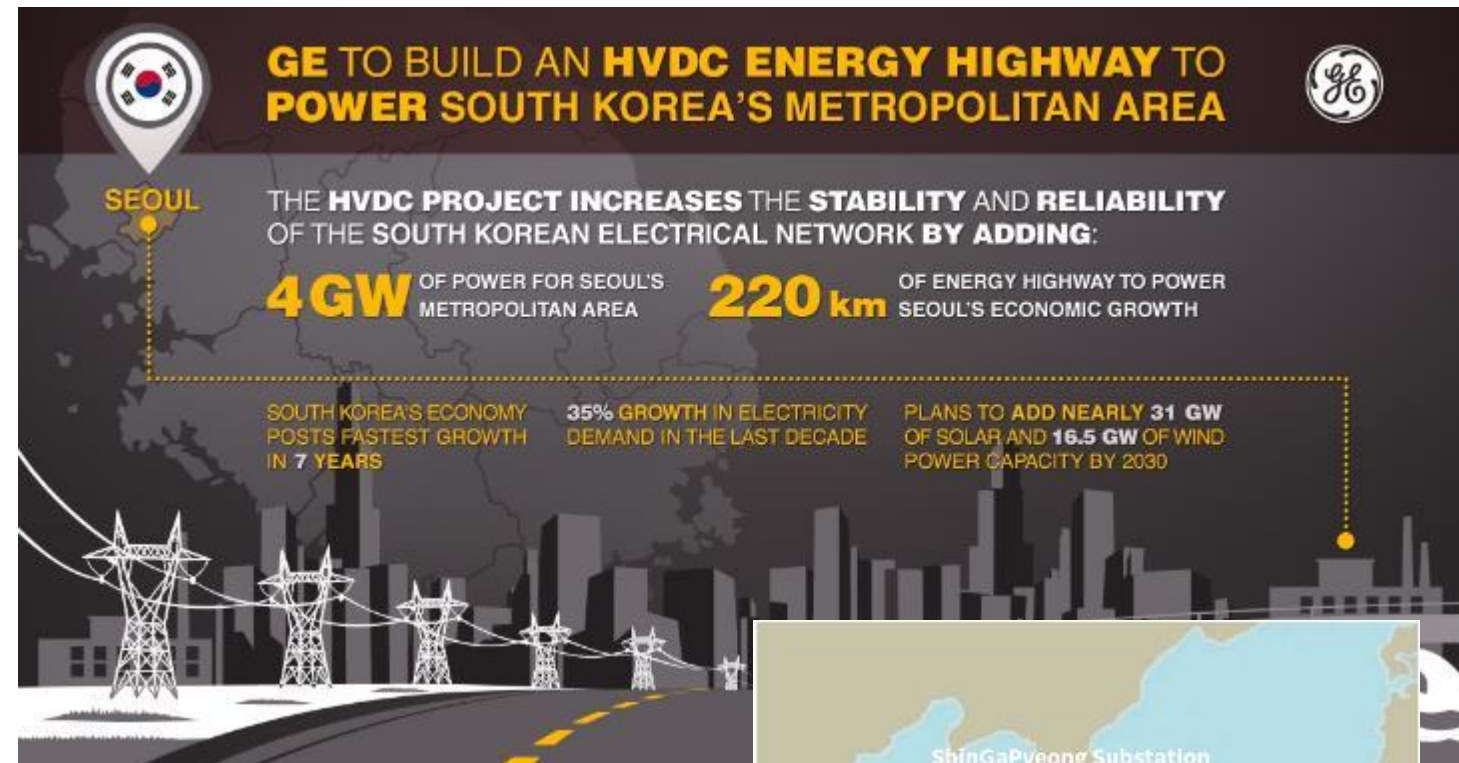


Main Project Data	
Customer	KEPCO
Commissioning year	2020 (pole 1) / 2024
Technology	LCC
Configuration	Bipole
Power rating	3,000 MW
DC voltage	± 500 kV
Length of DC OHL	-
Length of DC sub cable	7 km
Length of DC U/G cable	26 km
Customer benefit	Energy security to highly industrialized area of Godeak without overhead lines
Application	Bulk power transmission



Eastern Power (EP) HVDC Link

Main Project Data	
Customer	KEPCO
Commissioning year	2027 (customer delay)
Technology	LCC
Configuration	Bipole w/Metallic Return
Power rating	4,000 MW
DC voltage	±500 kV
Length of DC OHL	220 km
Length of DC sub cable	-
Length of DC U/G cable	7 km
Customer benefit	Supply of low-cost energy to load center
Application	Bulk transmission



GE TO BUILD AN HVDC ENERGY HIGHWAY TO POWER SOUTH KOREA'S METROPOLITAN AREA

THE HVDC PROJECT INCREASES THE STABILITY AND RELIABILITY OF THE SOUTH KOREAN ELECTRICAL NETWORK BY ADDING:

4 GW OF POWER FOR SEOUL'S METROPOLITAN AREA

220 km OF ENERGY HIGHWAY TO POWER SEOUL'S ECONOMIC GROWTH

SOUTH KOREA'S ECONOMY POSTS FASTEST GROWTH IN 7 YEARS

35% GROWTH IN ELECTRICITY DEMAND IN THE LAST DECADE

PLANS TO ADD NEARLY 31 GW OF SOLAR AND 16.5 GW OF WIND POWER CAPACITY BY 2030



220 km energy corridor from Donghaean on the East coast, to Shingapyeong near Seoul metropolitan area

Where Is The Technology Going ?

HVDC Market Evolution

Significant Growth in HVDC Installed Base

- Radial Offshore
- Onshore Point-Point
- Strong Push Towards VSC

Convergence towards Standards ?

- VSC Technology
- Ratings and Configurations
 - Monopole : ± 320 kV / 1200-1600 MW
 - Monopole : ± 400 kV / 1200-1800 MW (Mainly in US)
 - Bipole : ± 525 kV / 2000-2400 MW
- “Market Pull” Towards Higher VSC Ratings To Match LCC
 - Higher Current Ratings (~ 4 kA, ~ 10 GW)
 - Requires Different Approach From Existing MMC



Future Activities HVDC



Closer Proximity of HVDC Radial Links, Increases potential for HVDC Interconnection:

- Differing Owner Ambitions Developers + Utilities + ISOs
- Influenced by Commercial, Political, Reliability, ...

Technology Readiness for Interconnection:

- Cigre Guidelines, No DC Grid “Standards”
- Additional Work Needed for DC Breakers, DC-DC Converters, DC Fault Current Limiters, DC C&P, FB Converters,
- Europe Building Multiterminal HVDC And “Energy Islands”
- Interoperability - InterOPERA Initiative in Europe
 - Similar facilities in N America ?
- NY State AC-Side Mesh between Offshore Windfarms
 - NJ, NE States Following
 - Floating Offshore HVDC for CA, ME, ...
- DOE Investing in Development of Supply Chain, Technologies, Multi-Terminal, Interoperability, etc.





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