



Experience of HVDC projects
Role of Cigre B4 on Energy Decarbonization

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OUTLINE

1. HVDC Overview

- 1.1 Summary of HVDC Projects world wide
- 1.2 Continental Map of HVDC Projects

2. HVDC Projects with similar characteristic to Chile HVDC Project

- 2.1 Point to Point HVDC projects with similar rating and transmission distance to Kimal-Lo Aguirre HVDC Project in Chile
- 2.2 Multi-terminal DC projects

3. Technical Requirements and Challenges of Kimal-Lo Aguirre HVDC Project

4. Role of Cigre SC B4 on energy decarbonization

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1.1 Summary of HVDC Projects

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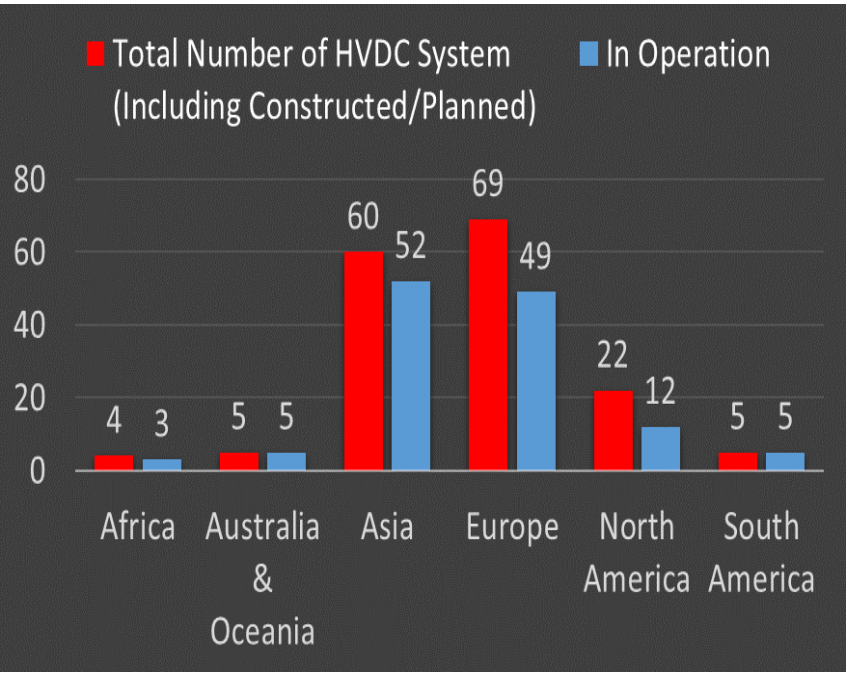
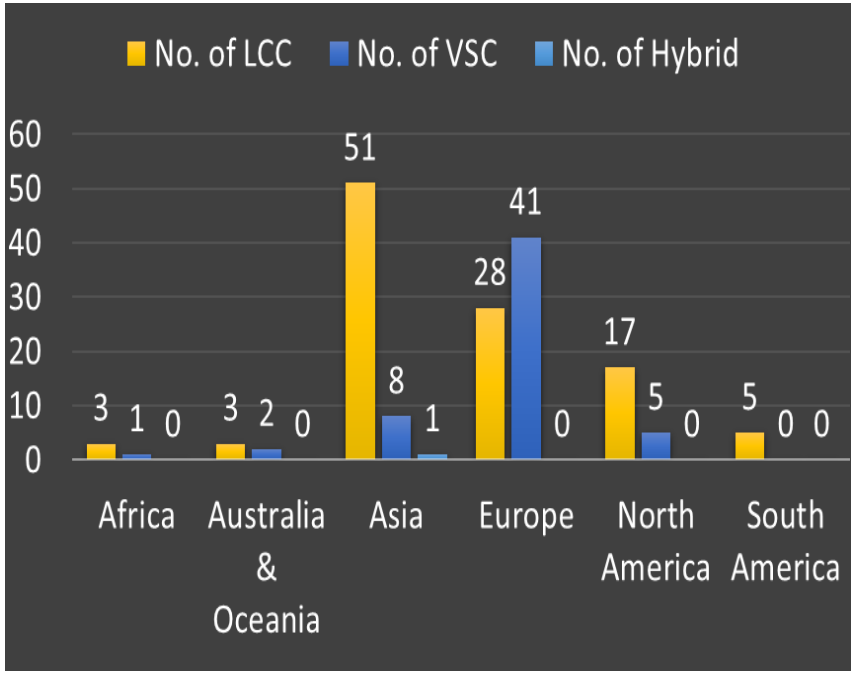
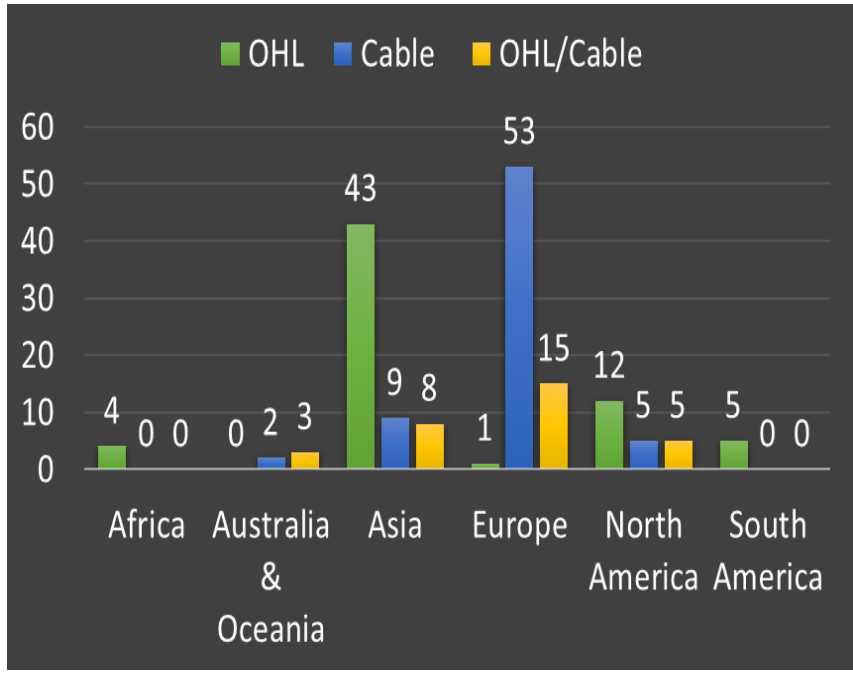
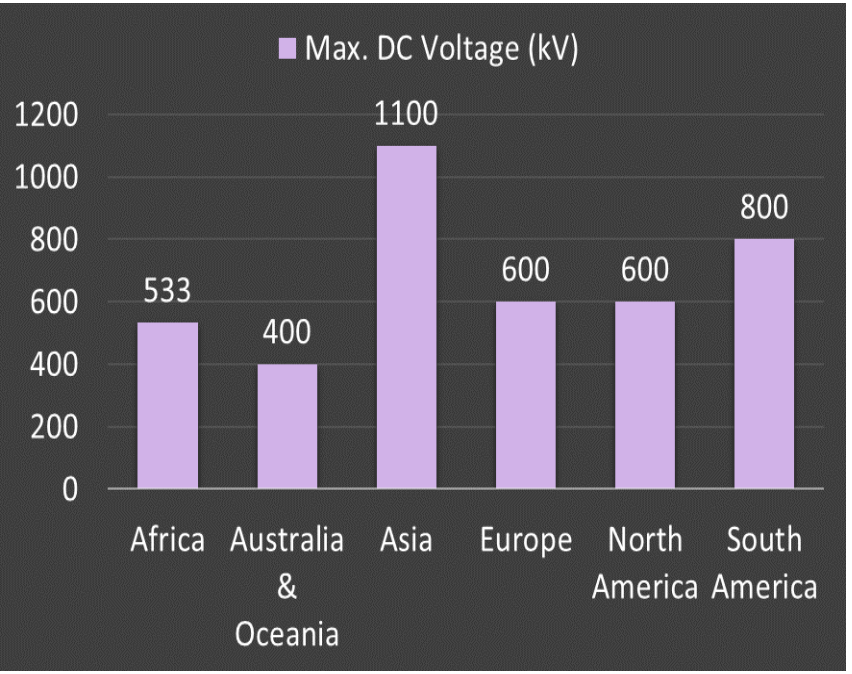
SUMMARY OF HVDC SYSTEMS

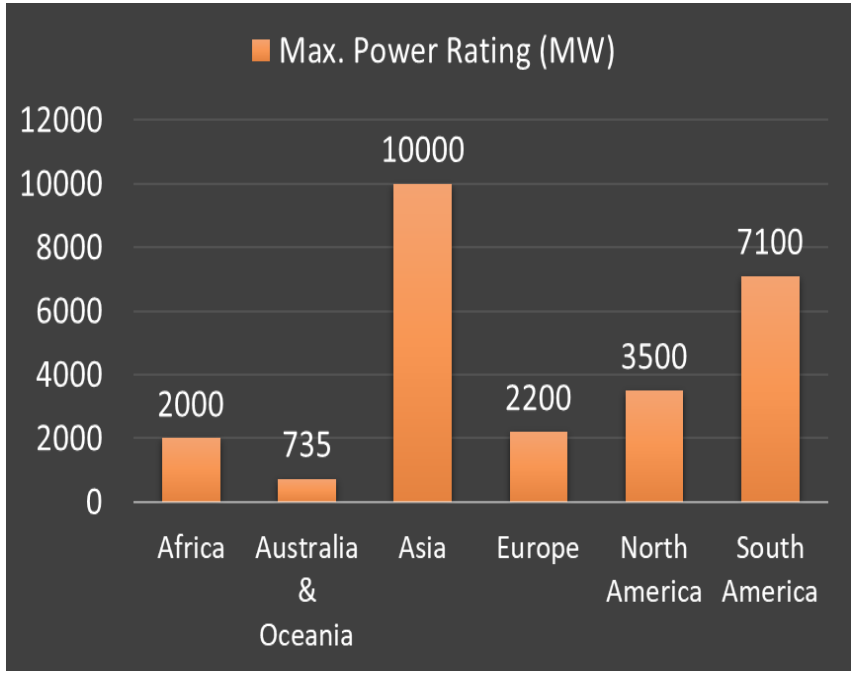
Description	Africa	Australia Oceania	Asia	Europe	North America	South America	Total
No. of HVDC Systems	4	5	60	69	22	5	165
In Operation	3	5	52	49	12	5	126
Refurbished/Upgraded	2	2	1	3	3	0	11
No. of LCC	3	3	51	28	17	5	107
No. of VSC	1	2	8	41	5	0	57
No. of Hybrid (LCC+VSC)	0	0	1	0	0	0	1
No. of Multi-Terminal	0	0	4	1	1	0	6
Voltage Level (kV)	350-533	80-400	30-1100	9-600	150-600	600-800	2-1100
Power Rating (MW)	300-2000	180-735	18-10000	3-2200	312-3500	3150-7100	3-10000
OHL (No./max km)	4/1700	n.a.	43/3333	1/10	12/1362	5/2439	65/3333
Cable (No./max km)	n.a.	2/176	9/134	53/740	5/248	n.a.	69/1928
OHL+Cable (No./max km)	n.a.	3/611	8/451	15/623	5/1135	n.a.	31 6.6-1100/7-570

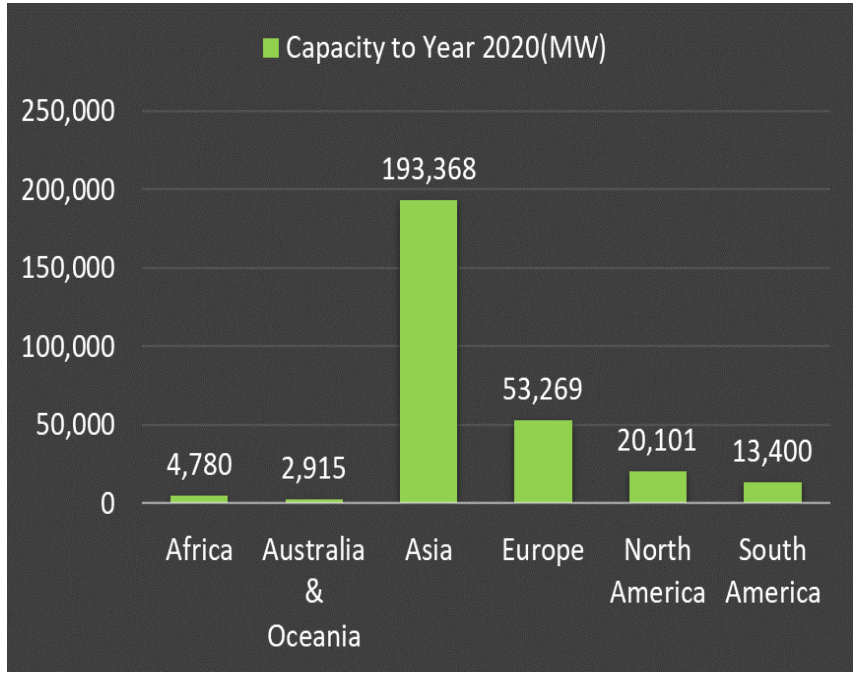

Total Number of HVDC System (Including Constructed/Planned)
In Operation
80
60
40
20
0
4 3
5 5
60 52
69 49
22 12
5 5
Africa
Australia & Oceania
Asia
Europe
North America
South America


No. of LCC
No. of VSC
No. of Hybrid
60
50
40
30
20
10
0
3 1 0
3 2 0
51 8 1
28 41 0
17 5 0
5 0 0
Africa
Australia & Oceania
Asia
Europe
North America
South America

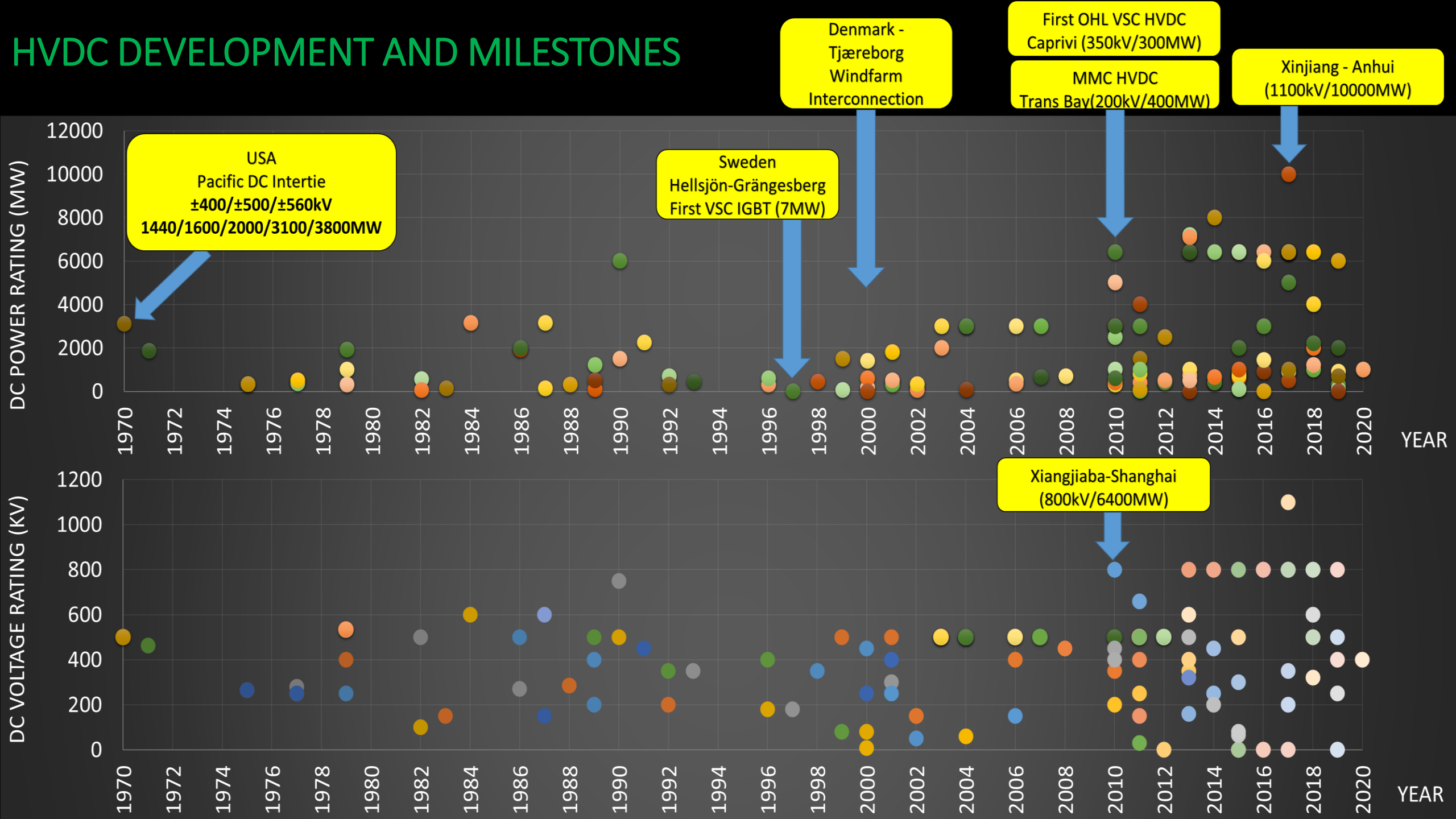

OHL
Cable
OHL/Cable
60
50
40
30
20
10
0
4 0 0
0 2 3
43 9 8
1 53 15
12 5 5
5 0 0
Africa
Australia & Oceania
Asia
Europe
North America
South America


Max. DC Voltage (kV)
1200
1000
800
600
400
200
0
533
400
1100
600
600
800
Africa
Australia & Oceania
Asia
Europe
North America
South America


Max. Power Rating (MW)
12000
10000
8000
6000
4000
2000
0
2000
735
10000
2200
3500
7100
Africa
Australia & Oceania
Asia
Europe
North America
South America


Capacity to Year 2020(MW)
250,000
200,000
150,000
100,000
50,000
0
4,780
2,915
193,368
53,269
20,101
13,400
Africa
Australia & Oceania
Asia
Europe
North America
South America

HVDC DEVELOPMENT AND MILESTONES



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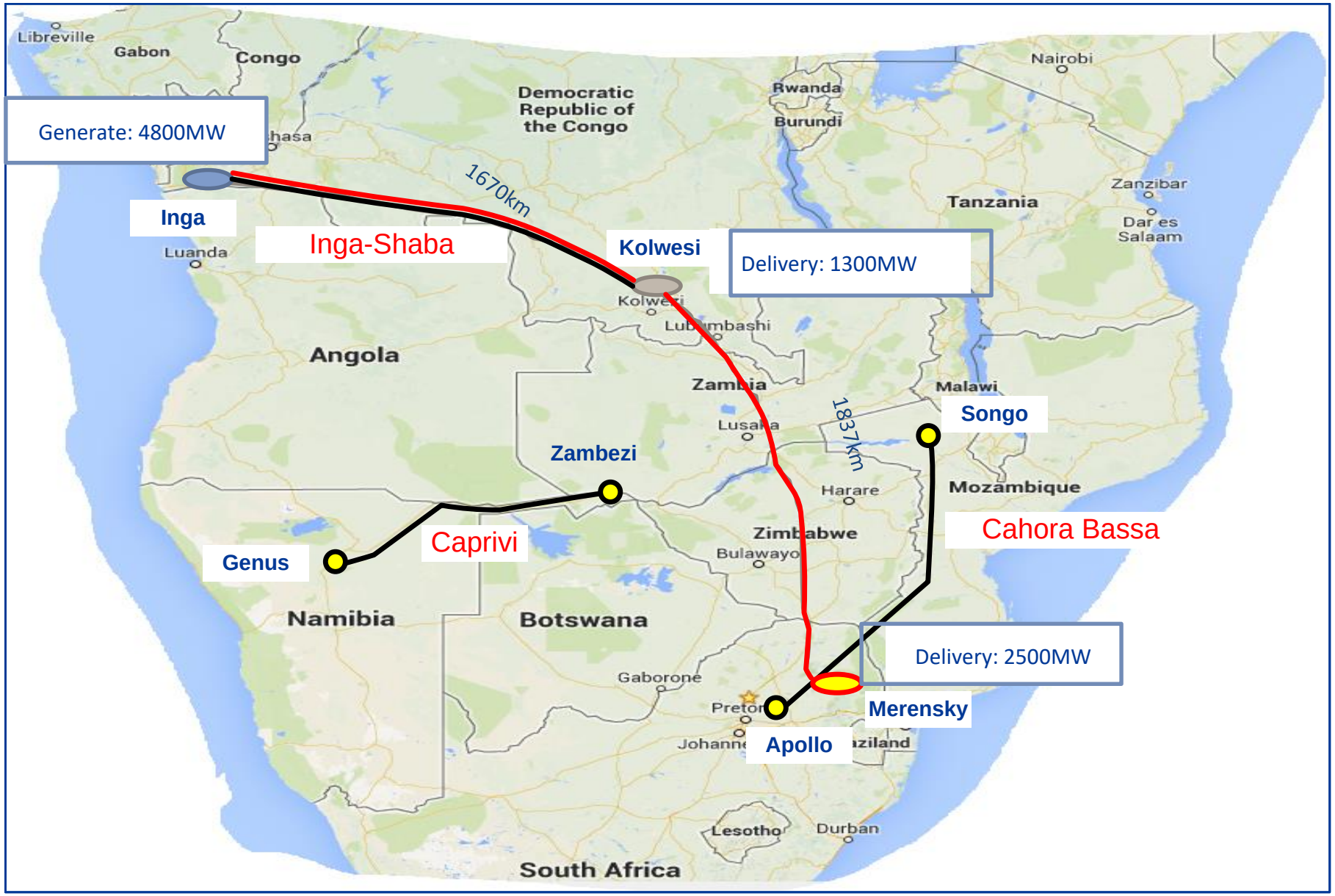
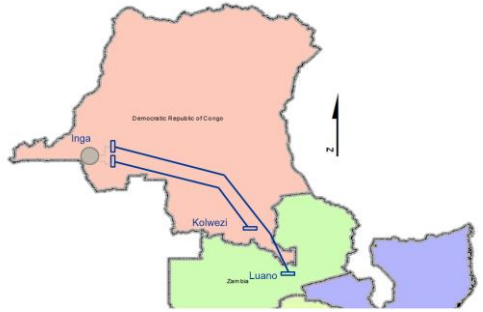
1.2 WORLD MAP OF HVDC

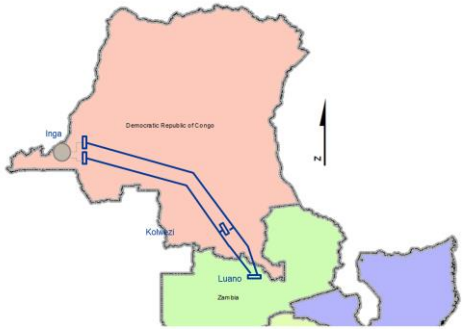
AFRICA HVDC



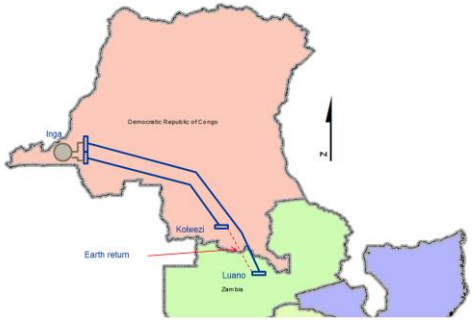
Two Independent



Three-terminals



Split Pole



ASIA HVDC

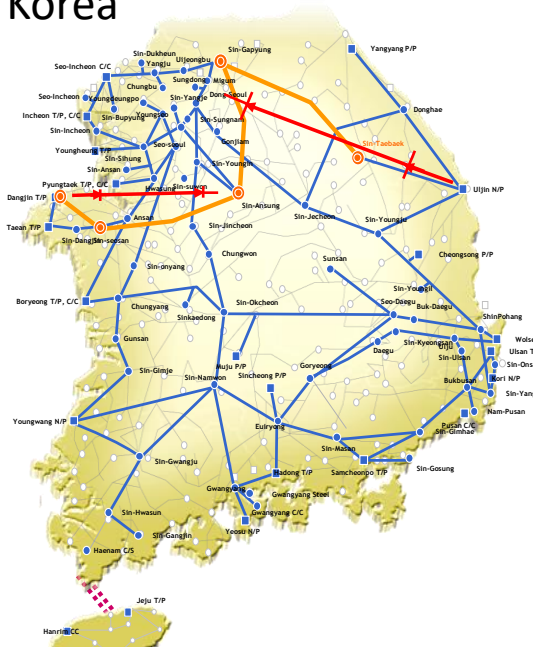
China ongoing DC Projects:

1. Zhangbei 525kV VSC HVDC Grid
2. Wudongde LCC/VSC Hybrid HVDC Project – 8000MW/±800kV
3. Behaitan LCC/VSC Hybrid HVDC Project

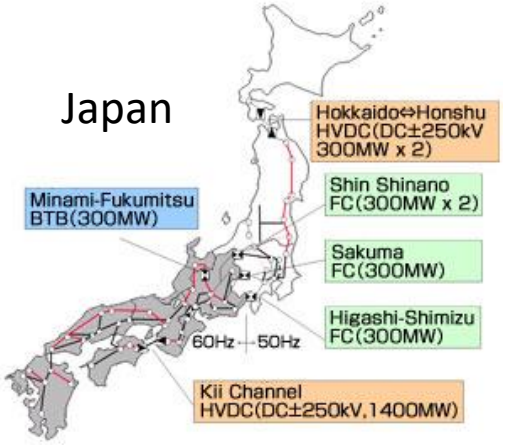
China

India

Korea



Japan



EUROPE HVDC

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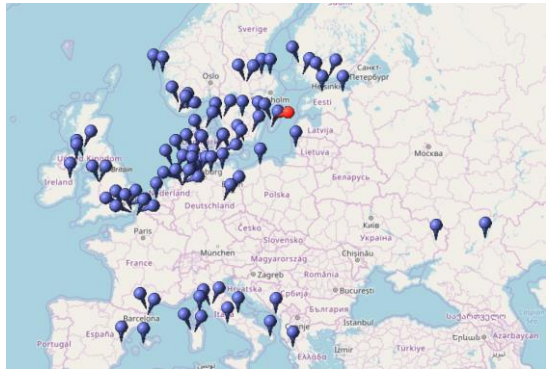
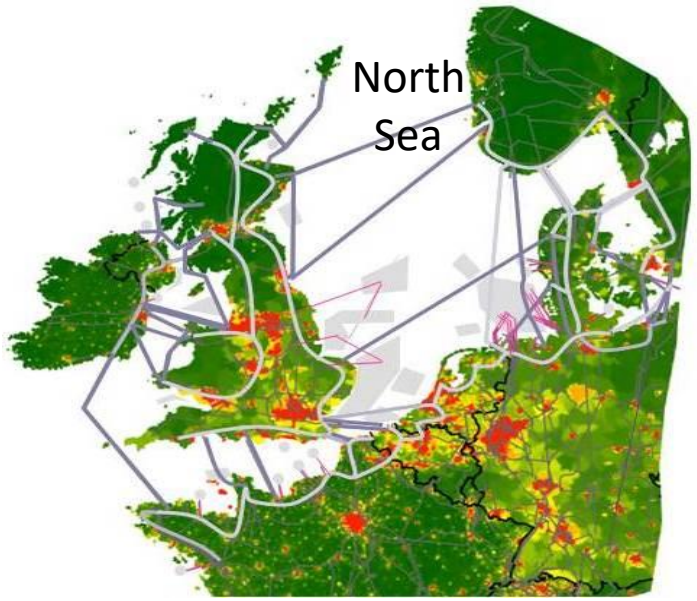


North Sea DC Projects:

1. More 900MW 320kV offshore hvdc projects as planned (Germany).
2. 1400MW 320kV offshore HVDC projects (UK)
3. Feasibility study on 2GW Offshore wind farm integration operated at 525kV in Netherland and German.



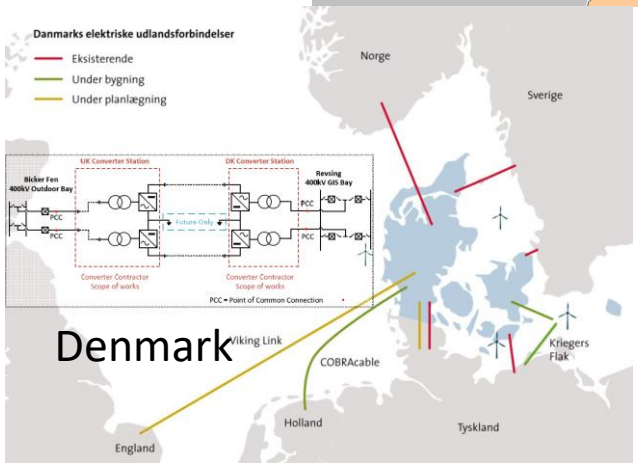
Johan Sverdrup Phase 1
- 100 MW +/- 80 kV
- VSC two-level
- 200 km
- Commisioning 2019

Norway

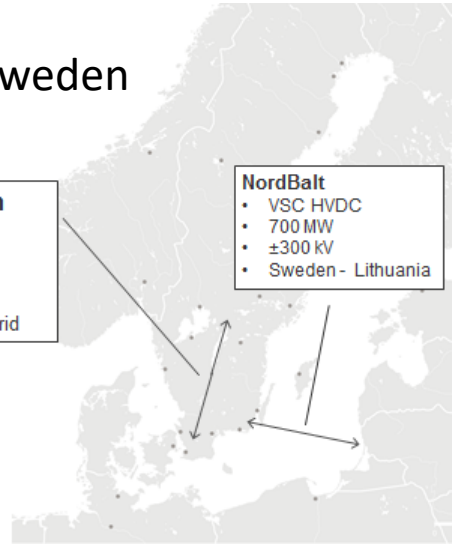
North Sea Link (NSL)
- 1400 MW +/- 515 kV
- VSC Converters
- Bipole
- Suldal in Norway – Newcastle area in England
- 722 km
- Commissioning 2021

NordLink
- 1400 MW +/- 525 kV
- VSC Converters
- Bipole
- Tonstad in Norway – Wilster in Germany
- 571 km cable + 53 km OH-line
- Commissioning 2019

UK



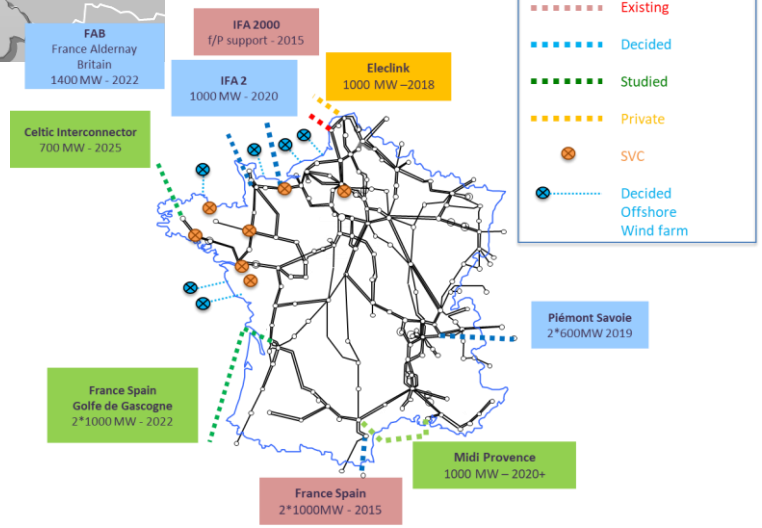
Sweden



SydVästlänken
- VSC HVDC
- 2 Parallel Links
- 720 MW
- ±300 kV
- Within 400 kV grid

NordBalt
- VSC HVDC
- 700 MW
- ±300 kV
- Sweden - Lithuania

France



NORTH AMERICA HVDC

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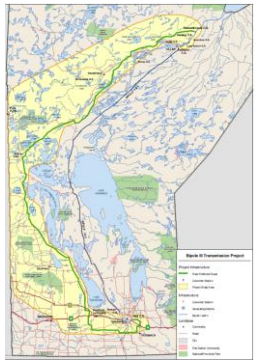
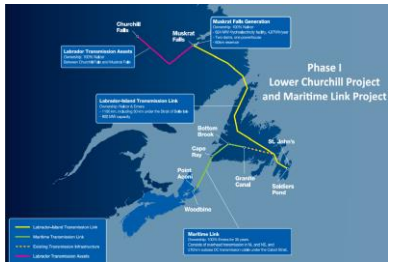


Nelson River Bipole III

- HVDC link between Keewatinohk to Riel, Manitoba, Canada
- ± 500 kV, 2300 MW Bipole LCC scheme, OHL
- ~ $4.6B (CND)
- Route length: 1384 km
- Present status: Under construction.
- Planned in–service by July 2018

2015/2016 East HVDC
West HVDC
NELSON RIVER BIPOLE III 2018
Square Butte 1977 (500 MW)
1991 Quebec – New England (2000 MW)
Nelson River 1971 (1620 MW)
Coal Creek 1979 (1000 MW)
1989 McNeill (150 MW)
Nelson River II 1978-1985 (1800 MW)
1985 Miles City (200 MW)
Chateauguay (1000 MW) 1984
Eel River 1972 (320 MW)
2003 Rapid City DC (200 MW)
NPCC
MRO
Madawaska 1985 (350 MW)
Highgate (200 MW) 1985
1970 PDCI (3100 MW)
WECC
RFC
Ridgefield (660 MW) 2013
2010 Transbay VSC
SPP
Cross Sound Cable (300 MW) 2002
1986 IPP (2400 MW)
2014 Mackinac (200 MW)
SERC
Neptune (600 MW) 2007
2005 Lamar (210 MW)
1984 Blackwater (200 MW)
TRE
FRCC
1984 Oklaunion (200 MW)
Stegall (110 MW) 1977
Welsh (600 MW) 1998
Sidney 200 MW 1988
1983 Artesia (200 MW)
Eagle Pass 2000
Sharyland 2007



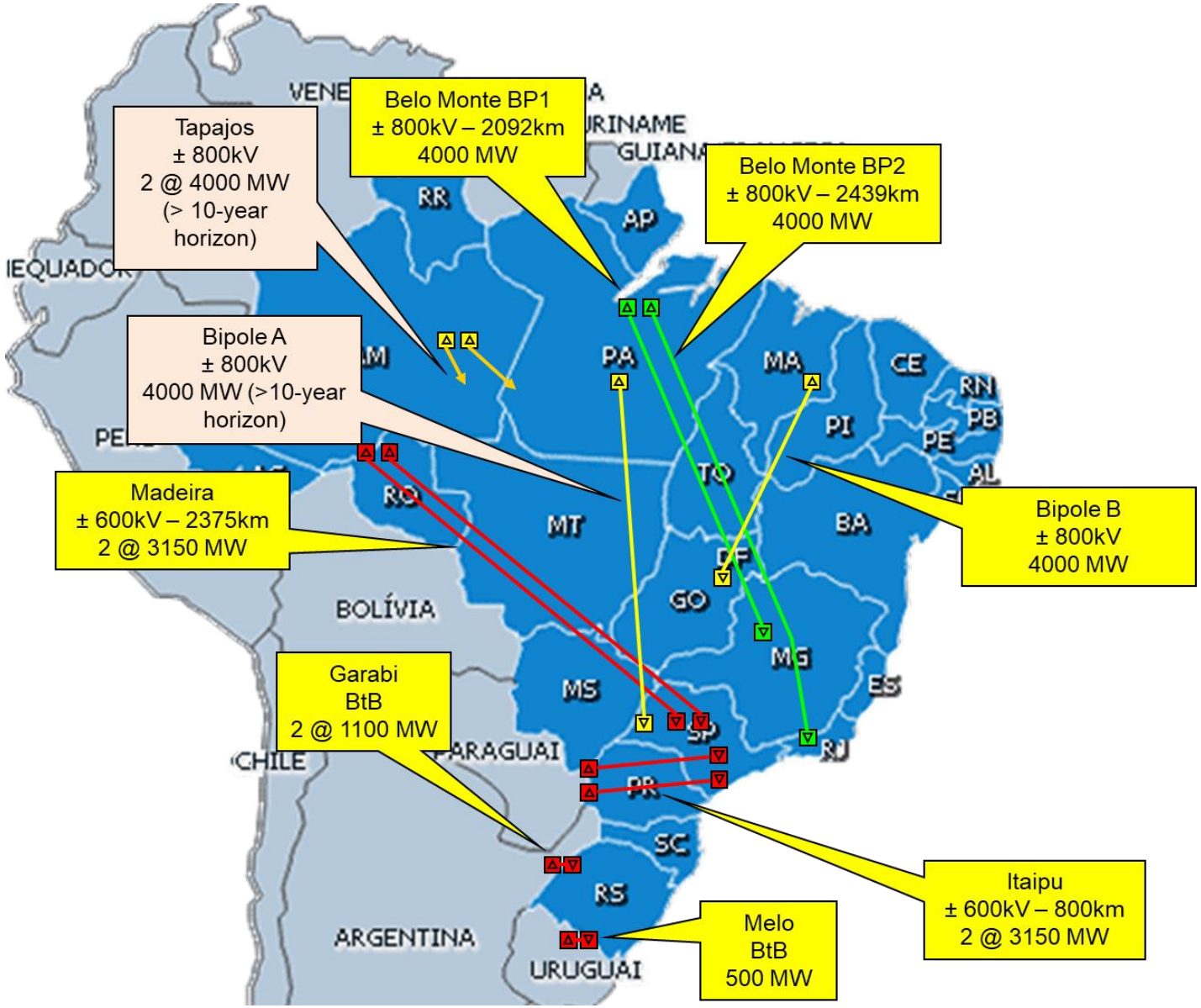
Labrador-Island Link (LIL)

- HVDC link from Muskrat in Labrador to Soldiers Pond in Newfoundland
- ±350 kV, 900 MW Bipole LCC scheme, OHL/Cable
- Route length: 1100/35km
- Present status: Under construction.
- Planned in–service by 2017/2018

Maritime link

- HVDC link from Bottom Brook in Newfoundland to Woodbine in Nova Scotia
- ±200 kV, 500 MW VSC scheme, OHL/Cable
- Route length: 470/170km
- Present status: Under construction.
- Planned in–service by 2017

SOUTH AMERICA HVDC



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2.1 POINT TO POINT HVDC PROJECTS WITH SIMILAR TRANSMISSION RATING AND DISTANCE TO CHILE KIMAL-LO AGUIRRE HVDC PROJECTS

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POINT TO POINT HVDC PROJECTS WITH SIMILAR TRANSMISSION RATING AND DISTANCE TO CHILE HVDC PROJECT

No	Name	Location	Length OHL/Cable (km)	kV	MW	Year	Type
1	Pacific DC Intertie	USA	1362	500	3100	1970	LCC
2	Nelson River Bipole 1	Canada	1835	463.5	1854	1971	LCC
3	Cahora Bassa	Mozambique	1420	533	1920	1979	LCC
4	Nelson River Bipole 2	Canada	940	500	2000	1978-1985	LCC
5	Itaipu 2	Brazil	805	600	3150	1987	LCC
6	Talcher-Kolar	India	1450	500	2000	2003	LCC
7	Three Gorges - Changzhou	China	890	500	3000	2003	LCC
8	Three Gorges - Guangdong	China	940	500	3000	2004	LCC
9	Guizhou - Guangdong I	China	980	500	3000	2004	LCC
10	Three Gorges - Shanghai	China	1060	500	3000	2006	LCC
11	Guizhou - Guangdong II	China	1200	500	3000	2007	LCC
12	Hulunbeir - Liaoning	China	920	500	3000	2010	LCC
13	Hubei - Shanghai	China	970	500	3000	2011	LCC
14	Mundra - Haryana	India	960	500	2500	2012	LCC
15	Nelson River Bipole 3	Canada	1324	500	2000	2018	LCC
16	Ethiopia–Kenya HVDC	Ethopia/Kenya	1045	500	2000	Ongoing	LCC

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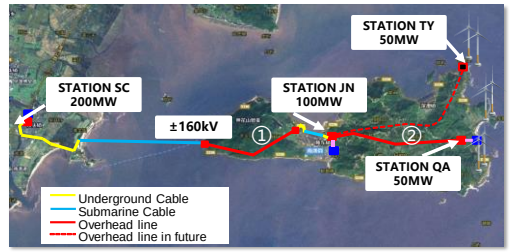
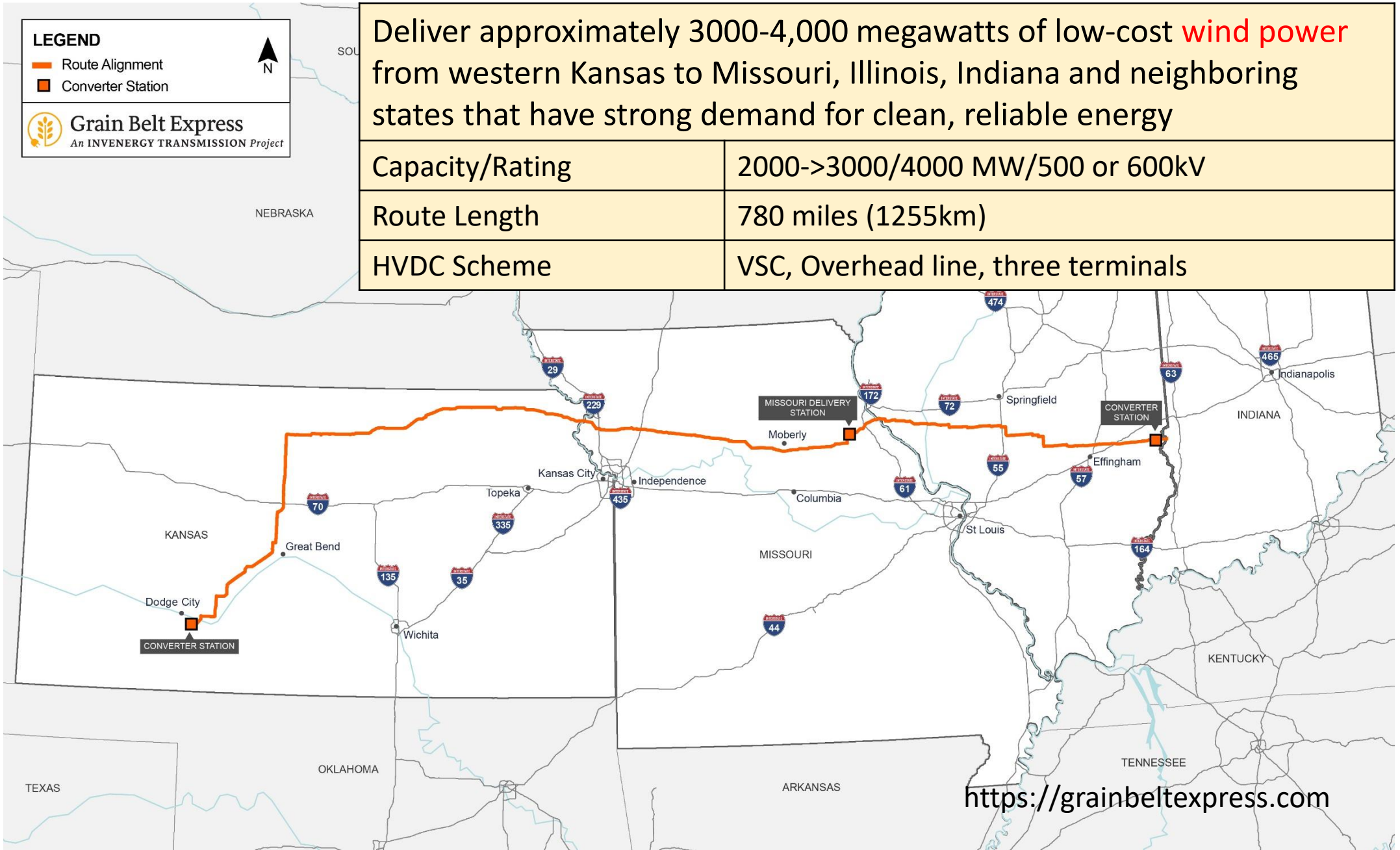
2.2 Multi-terminal HVDC Projects

RADIAL MULTI-TERMINAL DC PROJECTS

Name	Quebec-New England	SACOI	North East Agra	Nan'ao island	Zhoushan island
Country	Canada - USA	Italy - France	NE India	China	China
Technology	LCC-Bipole w/ Electrodes	LCC-Monopole w/ Electrodes	LCC-Bipole w/ Electrodes	VSC-SM (MMC)	VSC-SM (MMC)
Terminal (No.)	5->3	3	3 (4 Future)	3 (5 Future)	5 (HVDC Grid)
Rating (MW/kV)	2000/± 450	200/± 200	600/± 800	200/± 160	1000/± 200
DC Breaker	No	No	No	Mechanical	FB Hybrid
In Service Year	1986	1989	2016	2013/2017 (DCCB)	2014/2016 (DCCB)
Map					

GRAIN BELT EXPRESS CLEAN LINE IN USA

Deliver approximately 3000-4,000 megawatts of low-cost wind power from western Kansas to Missouri, Illinois, Indiana and neighboring states that have strong demand for clean, reliable energy	
Capacity/Rating	2000->3000/4000 MW/500 or 600kV
Route Length	780 miles (1255km)
HVDC Scheme	VSC, Overhead line, three terminals



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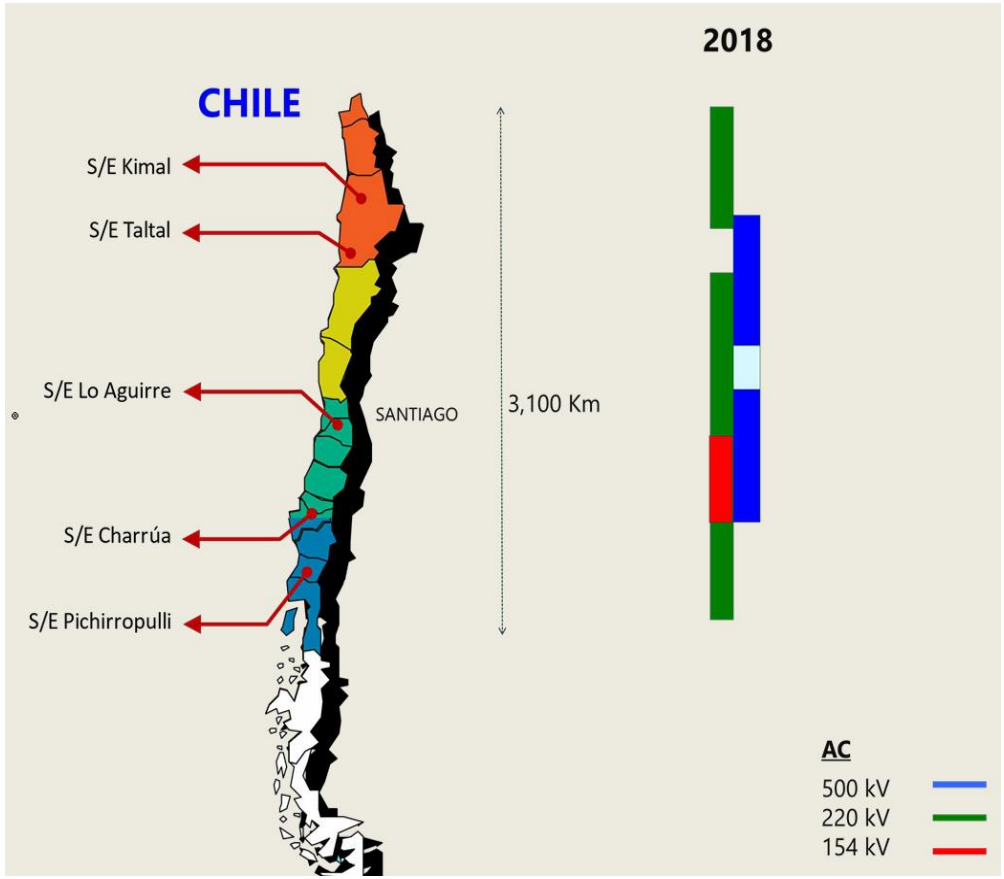
3. Technical Challenges Of Kimal-lo Aguirre HVDC Projects

TECHNICAL REQUIREMENTS AND CHALLENGES OF KIMAL – LO AGUIRRE HVDC LINK (1)



Kimal – Lo Aguirre HVDC Link

- **Primarily PV and Wind (97-99%)**
- **Likely Low SCL at sending End**
  - **Due to high Solar and Wind**
  - **Require HVDC to be able to operate at low SCL**
  - **Additional equipment to increase SCL**
- **Steady state voltage support**

  Require the addition of adequate amounts of dynamic reactive supply and/or switched reactive compensation equipment strategically placed within the ac transmission system in order to retain the capacity for voltage control and maintain power quality within normal power system operating parameters.
- **AC//DC Parallel System may cause**
  - **Voltage and angular instability due to dc block**
  - **Mutual coupling between sending and receiving end**
- **Compensation for Variability of renewable generation**

TECHNICAL REQUIREMENTS AND CHALLENGES OF KIMAL – LO AGUIRRE HVDC LINK (2)

- No HVDC system in operation that transmits sole Solar power
- Feasibility studies required to identify the most suitable technology (LCC vs. VSC)
- Conceptual engineering design studies required to prove the selected technology and define conceptual design by HVDC suppliers as initial of project execution
- Detailed engineering design studies to complete the overall design concerning rating and performance requirements
- Adding third terminal at later stage

Role and Activities of Cigre SC B4 on Energy Decarbonization

ENERGY DECARBONIZATION - REQUIREMENTS

- Renewable energy at various scales and locations are required to be transferred and integrated into the existing and future system
  - Hydro
  - Offshore wind (900MW trending up to 2GW)
  - Onshore wind (growing from a few hundred to greater than 2GW)
  - Distributed PVs
  - Large concentrated Solar power
  - Hybrid Wind/Solar power
- Rapid growing renewable energy and penetration inherently bring many technical challenges that complicate the performance characteristic and operation of power systems.
- Resilient systems is required to ensure the reliable, stable, flexible, controllable and economic renewable energy regulation and exchange.

DC & PE - ENABLING TECHNOLOGY FOR RESILIENT SYSTEM

Role of HVDC

- Long distance transmission and system
- Power transfer of Renewable energy
- Enhanced power system operation with system integration through HVDC
- System support provided by FACTS at both transmission and distribution

Copyright: Siemens

Two Parallel Technology Paths

- Mature and Growing Thyristor based LCC HVDC
- Developing and Growing IGBT and IEGT based VSC HVDC

Copyright: Siemens/Infineon

WHAT DOES CIGRE SC B4 DO?

Scope of B4

- HVDC systems
- PE based device such as SVC, STATCOM, UPFC, TCSC for AC system enhance including voltage regulation, reactive power compensation, power quality improvement
- DC converters for energy storage
- DC system and PE device in distribution (New initiation by Cigre)

B4 Structure

Members

Activities

- Very well diversified members from manufacturers, utilities, transmission system operators (TSOs), distribution system operators (DSOs), consultants and research institutes.
- Advisory groups for B4 strategic planning, DC & FACT RAM survey, compendiums, website, newsletter etc.
- WG/JWGs deliver Technical brochure covering various aspects of DC and PE as well as Green books

Promotive Activities

- Recruiting young engineers and women engineers to participate in its activities (NGN and WIE).
- Webinar/Tutorials/Workshop at Cigre event both at international and national level
- Newsletters

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TECHNICAL BROCHURES

80 TBs (1987 – 2020)

- 2-3/year
- https://b4.cigre.org/GB/publications/sc-b4-technical-brochures

Covering all aspects of DC and PE

- Technologies
  - LCC/VSC
  - P2P/Multi-terminal/DC Grid
- DC system/PE equipment
- Planning/feasibility
- System performance, impact/interaction, modelling
- DC system/PE device testing
- Equipment testing
- Operation and maintenance (O&M)
- Upgrade and life extension
- DC and FACTS RAM Performance
- HVDC compendium
- Environmental
- Economics

ACTIVE WORKING GROUP

AG/WGs	Title
B4.AG01	Strategic advisory group
B4.AG03	Communication and website
B4.AG04	HVDC/FACTS System performance
B4.64	Impact of AC System Characteristics on the Performance of HVDC schemes
B4.69	Minimizing loss of transmitted power by VSC during Overhead line fault
B4.70	Guide for Electromagnetic Transient Studies involving VSC converters
B4.71	Application guide for the insulation coordination of Voltage Source Converter HVDC (VSC HVDC) stations
B4/B1/C4.73	Surge and extended overvoltage testing of HVDC Cable Systems
B4.74	Guide to Develop Real Time Simulation Models (RTSM) for HVDC Operational Studies
B4.75	Feasibility Study for assessment of lab losses measurement of VSC valves
B4.76	DC-DC converters in HVDC Grids and for connections to HVDC systems
C2/B4.38	Capabilities and requirements definition for Power Electronics based technology for secure and efficient system operation and control
B4.77	AC Fault response options for VSC HVDC Converters
B4.78	Cyber Asset Management for HVDC/FACTS Systems
B4.79	Hybrid LCC/VSC HVDC Systems
C6/B4.37	Medium Voltage DC distribution systems
C4/B4.52	Guidelines for Sub-synchronous Oscillation Studies in Power Electronics Dominated Power Systems
B4/A3.80	HVDC Circuit Breakers- Technical Requirements, Stresses and Testing Methods to investigate the interaction with the system
B4.81	Interaction between nearby VSC-HVDC converters, FACTs devices, HV power electronic devices and conventional AC equipment
B4.82	Guidelines for Use of Real Code in EMT Models for HVDC, FACTS and Inverter based generators in Power Systems Analysis
B4. 83	Flexible AC Transmission Systems (FACTS) controllers' commissioning, compliance testing and model validation tests
B4. 84	Feasibility study and application of electric energy storage systems embedded in HVDC systems
B4. 85	Interoperability in HVDC systems based on partially open-source software
B4/A3.86	Fault limiting technologies for DC grids
B4.87	Voltage Source Converters (VSC) HVDC responses to disturbances and faults in AC systems which have low synchronous generation.
TF B4/B1.88	Insulation coordination procedure for DC cable systems in HVDC stations with Voltage Source Converters (VSC)
B4.89	Condition Health Monitoring and predictive maintenance of HVDC Converter Stations
B4.90	Operation and maintenance of HVDC and FACTS Facilities
B4.91	Power-electronics-based transformer technology, design, grid integration and services provision to the distribution grid
B4.92	STATCOMs at Distribution Voltages

Thank you