Indonesia Nusantara Renewable Grid: HVDC Subsea Cables

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Outline

- Nusantara grid
- Nusantara Renewable Energy
- Updated technologies
- Case Sumatra-Java
- Case Sumatra-Peninsular
- Case Java-Bali
- Case: template solution for RE
- Solution
- Conclusion

Nusantara Grid (interconnection)

- Purposes:
  - security of supply
  - economical efficiency
  - environmental satisfaction
- Feasibility requirement
  - Technical aspect
  - Economical aspect
  - Legal aspect
- Technologies:
  - HVAC;
  - HVDC:
    - LCC
    - VSC
  - Subsea Cable;
    - OF
    - MI
    - Extruded/XLPE

Tol Listrik Nusantara (Indonesia Supergrid) ref[1]

Indonesia Supergrid

ref[1]

Interkoneksi Jawa-NTB-NTT

VSC-HVDC Jabar-Sumbawa
VSC-HVDC Flores-Sumba
VSC-HVDC Flores-Timor
HVAC Sumbawa-Flores

Di Pulau Jawa, terminal bisa ada di Jatim, Jateng, dan Jabar

ref[2]

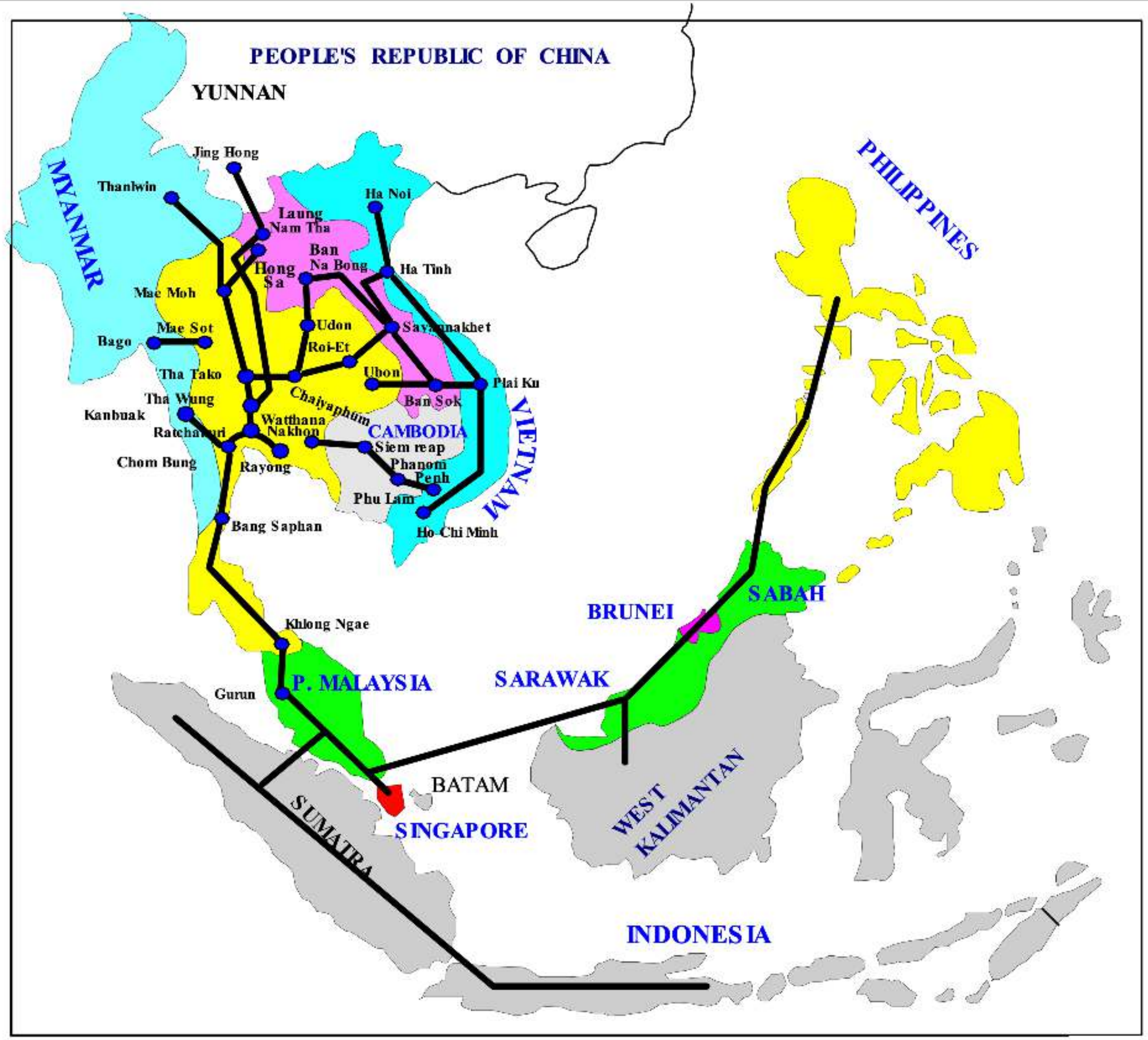
Table 20 Status of Interconnection Projects in Southeast Asia

	Projects	Status
1	Peninsula Malaysia – Singapore	Operating synchronously since 1985 under zero electricity exchange Improve system resilience due to larger combined size and short time transfer during emergency
2	Peninsula Malaysia – Thailand	
	Bukit Keteri – Sadao	In operation since 1981 with power transfer capability up to 80 MW
	Gurun – Khlong Ngae (HVDC)	Project in progress and targeted for completion in 2000
3	Sarawak – Peninsula Malaysia (submarine cable HVDC 500Kv and HVAC 275 kV)	This project originally planned to transmit to Peninsula Malaysia 2100 MW of electricity from a 2400 MW Bakun hydropower project in East Malaysia. However the Bakun project has been scaled down for domestic consumption due to financial crisis that hit ASEAN region recently and the interconnection project has been deferred indefinitely
4	Sumatra, Indonesia – Peninsula Malaysia (submarine cable)	Project aimed for bi-directional electricity flow. MOU has been signed by both parties for the development of a mine power plant in Sumatra, Indonesia Funding is the constraint for project implementation (private participation as an alternative)
5	Batam, Indonesia – Bintan, Indonesia – Singapore – Johore, Malaysia	Seeking sponsors for financing the study
6	Sarawak, Malaysia – West Kalimantan, Indonesia (150 kV, 250 MW overhead line)	Implementation being prepared with options for the private participation
7	Sabah, Malaysia – Philippines	Seeking sponsors for financing the study
8	Sarawak, Malaysia – Brunei – Sabah Malaysia (275 kV overhead line)	Pre-feasibility study completed and seeking sponsors for financing the feasibility study
9	Thailand – Lao PDR	
	Nam Ngum Dam	In operation since 1972. Currently, the generating capacity is around 150MW and about half of the power generated is exported to Thailand.
	Xe Set Hydro power	In operation since 1991 with the capacity of 45 MW. Most of the power generated are exported to Thailand.
	Hongsa – Mae Moh	No progress has been reported.
	Ban Na Bong – Udon Thani	Discussed in details in the section "GMS Interconnections"
	Savannakhet – Roi Et	
	Boloven – Ubol Ratchathani	
10	Viet Nam – Lao PDR	Possibility of inclusion of interconnection between Thailand – Myanmar, Thailand – South China, Viet Nam – Cambodia
	Central Viet Nam – Central Lao PDR	
		Discussed in details in the section "GMS Interconnections"
	Central Viet Nam – Southern Lao PDR	
11	Thailand – Myanmar	New project – details of the project will be studied by the relevant power authorities/ utilities Discussed in details in the section "GMS Interconnections"
12	Viet Nam – Cambodia	New project – details of the project will be studied by the relevant power authorities/ utilities Discussed in details in the section "GMS Interconnections"
13	Lao PDR – Cambodia	New project – details of the project will be studied by the relevant power authorities/ utilities
14	Thailand - Cambodia	New project – details of the project will be studied by the relevant power authorities/ utilities

Sources: Biyaem, *et al* (1998)
Chonglertvanichkul, P., (2000)
Jaafar, Z., (1999)

ref[2]

Figure 28 Southeast Asia Power Interconnection Projects



Source: Chonglertvanichkul, P., (2000b)

ref[11]

Asia Pacifik Super Grid

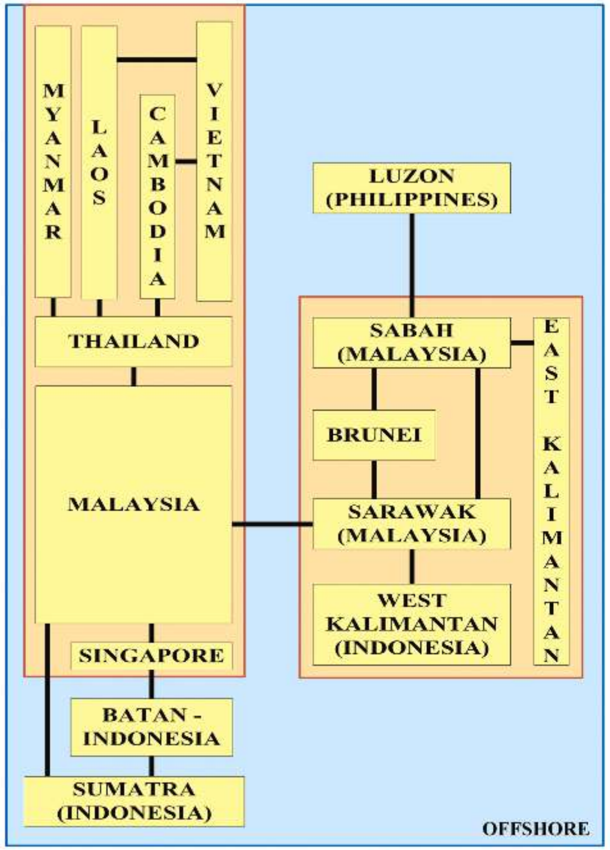


Fig. 2. ASEAN super grid [11].

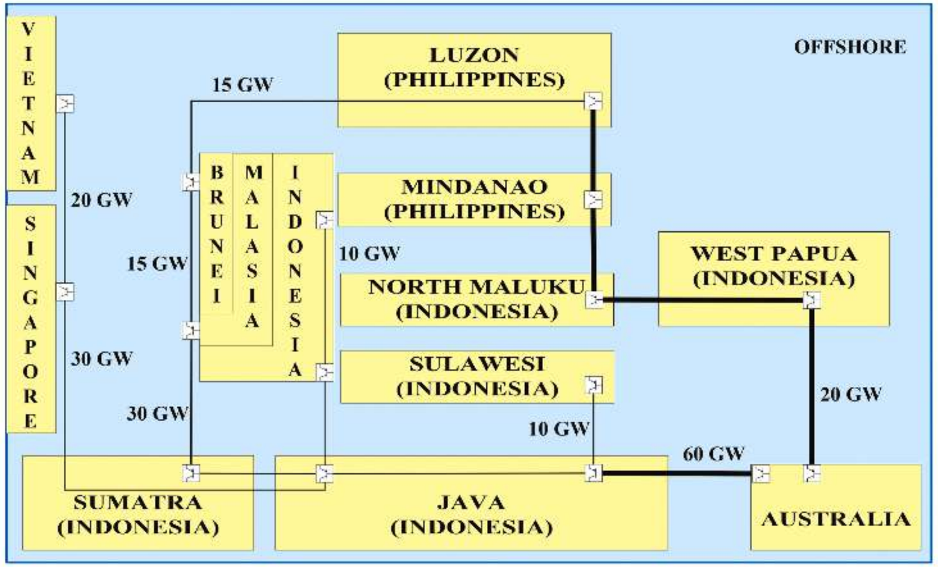


Fig. 3. Indonesia -Australia HVdc interconnector in 2050 by Refs. [3].

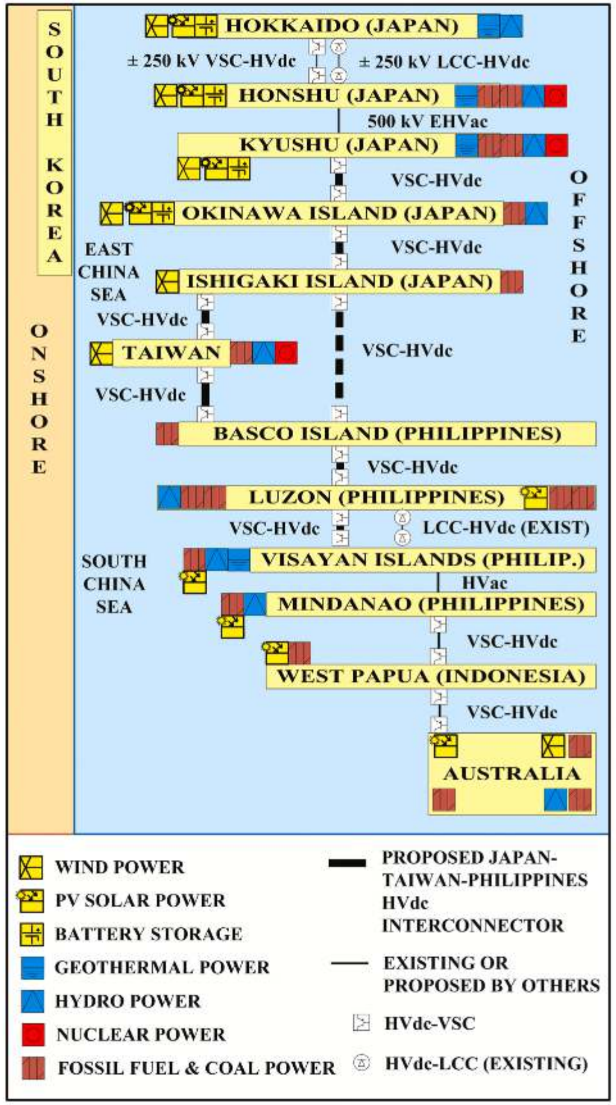
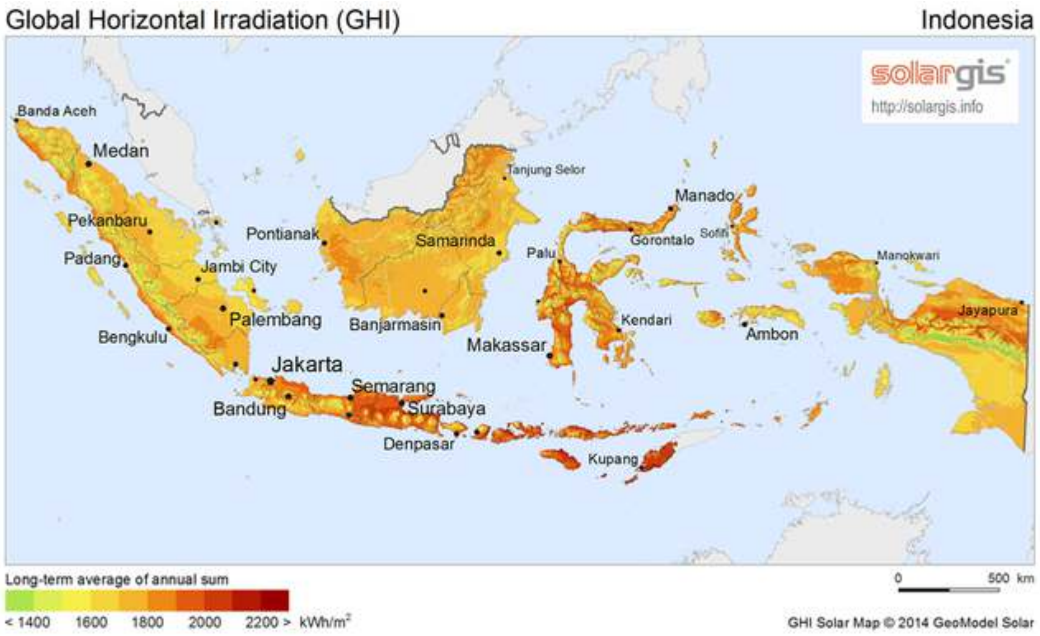


Fig. 5. Japan-Taiwan-Philippines interconnector linked to the Australia-Indonesia-Philippines Interconnector.

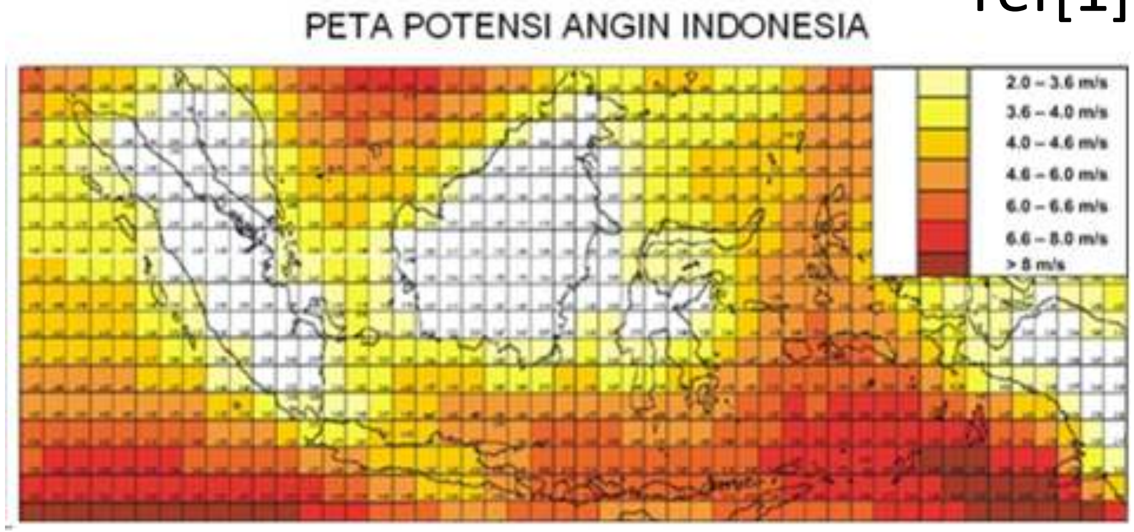
Nusantara Renewable Energy

- Hydro
- Geothermal
- Wind
- PV
- Main issues:
  - Capacity
  - Location of sources vs load center
  - Archipelago
  - Intermittent energy
  - Tropical climate
- Related to technology solution → offshore technology

ref[1]

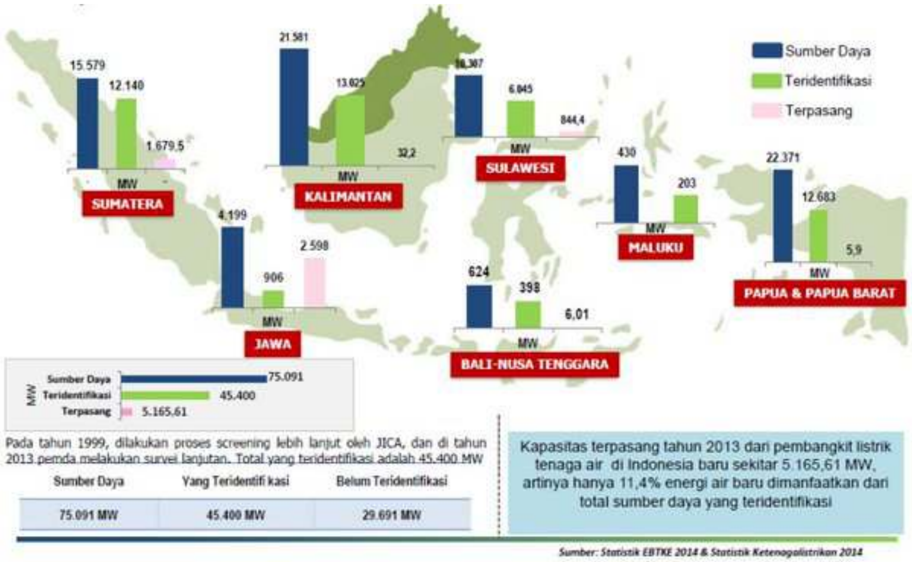


Global Horizontal Irradiation (GHI)
Indonesia
solargis
http://solargis.info
Banda Aceh
Medan
Pekanbaru
Padang
Pontianak
Jambi City
Samarinda
Tanjung Selor
Manado
Palu
Gorontalo
Sofifi
Manokwari
Palembang
Banjarmasin
Bengkulu
Makassar
Kendari
Ambon
Jayapura
Jakarta
Semarang
Surabaya
Bandung
Denpasar
Kupang
Long-term average of annual sum
< 1400 1600 1800 2000 2200 > kWh/m²
0 500 km
GHI Solar Map © 2014 GeoModel Solar



PETA POTENSI ANGIN INDONESIA
2.0 – 3.6 m/s
3.6 – 4.0 m/s
4.0 – 4.6 m/s
4.6 – 6.0 m/s
6.0 – 6.6 m/s
6.6 – 8.0 m/s
> 8 m/s

PETA PERSEBARAN SUMBER ENERGI PANAS BUMI
D I Aceh 17 Lokasi
Sumatera Utara 16 Lokasi
Riau 1 Lokasi
Sumatera Barat
Jambi 8 Lokasi
8 Lokasi
16 Lokasi
Sumatera Selatan
Bengkulu
Lampung 13 Lokasi
Kalimantan Timur
Kalimantan Barat
3 Lokasi
Kalimantan Tengah
Kalimantan Selatan
Sulawesi Utara
Gorontalo 2 Lokasi
Sulawesi Tengah
Maluku 15 Lokasi
2 Lokasi
Irian Jaya
Sulawesi Tenggara 13 Lokasi
Sulawesi Selatan 16 Lokasi
DKI Jakarta
5 Lokasi Banten
Jawa Tengah 14 Lokasi 3 Lokasi
Jawa Barat
6 Lokasi
Jawa Timur
Nusa Tenggara Barat
Timor Timur
Yogyakarta
Bali
Nusa Tenggara Timur 18 Lokasi
40 Lokasi
1 Lokasi
11 Lokasi
5 Lokasi
TOTAL : 251 LOKASI



Sumber Daya
Teridentifikasi
Terpasang
15.579
12.140
1.679,5
MW
SUMATERA
21.581
13.025
32,2
MW
KALIMANTAN
10.387
6.045
844,4
MW
SULAWESI
430
203
MW
MALUKU
22.371
12.683
5,9
MW
PAPUA & PAPUA BARAT
4.199
906
2.598
MW
JAWA
624
398
6,01
MW
BALI-NUSA TENGGARA
MW
Sumber Daya 75.091
Teridentifikasi 45.400
Terpasang 5.165,61
Pada tahun 1999, dilakukan proses screening lebih lanjut oleh JICA, dan di tahun 2013 pemda melakukan survei lanjutan. Total yang teridentifikasi adalah 45.400 MW
Sumber Daya
Yang Teridentifi kasi
Belum Teridentifikasi
75.091 MW
45.400 MW
29.691 MW
Kapasitas terpasang tahun 2013 dari pembangkit listrik tenaga air di Indonesia baru sekitar 5.165,61 MW, artinya hanya 11,4% energi air baru dimanfaatkan dari total sumber daya yang teridentifikasi
Sumber: Statistik EBTKE 2014 & Statistik Ketenagalistrikan 2014

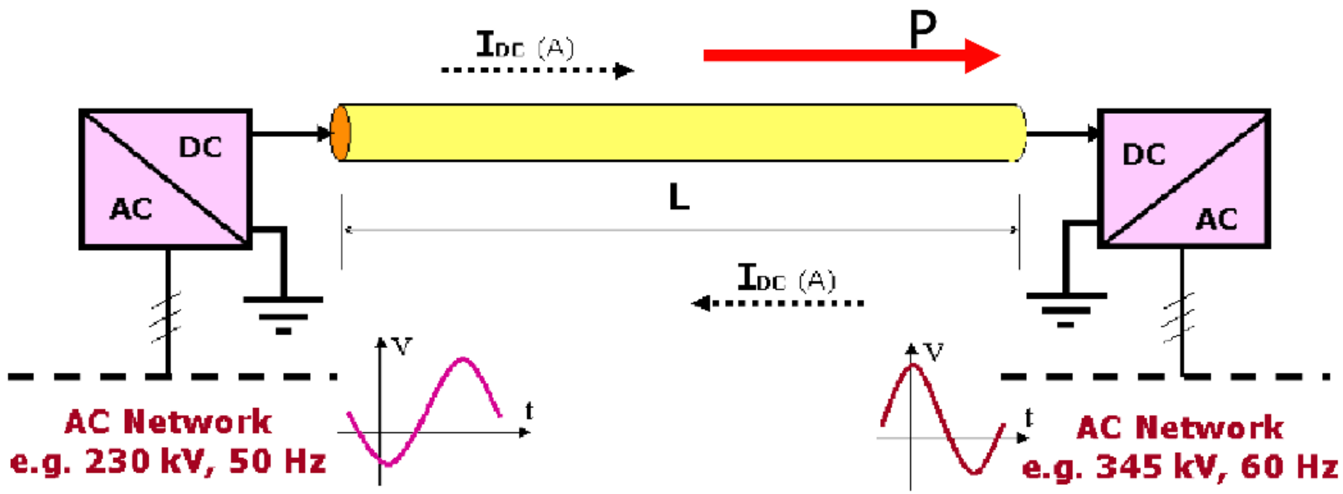
Updated technologies

- Driver/Qualification: Power, Voltage > opt Cost
- HVDC: LCC (Less Losses, mature) vs VSC(weak sys, Q, reverse current)
- HVDC cable: OF(environment), MI, XLPE (space charge)

ref[3]

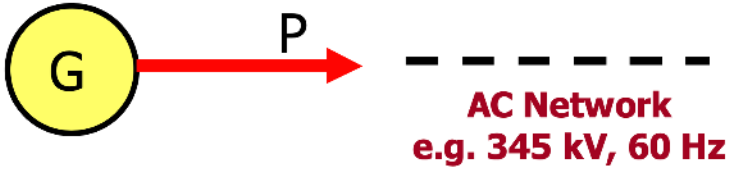
AC-DC CONVERSION

Systems are operated in AC; therefore DC transmission shall be associated with AC-DC Converter Stations at both ends.



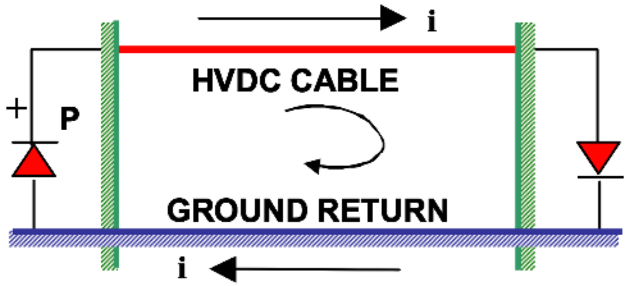
The two networks are not required to be syncronised; they can have different frequency and voltage.

The system, overall, acts like a Generating Power Station that is injecting power into the receiving network.



ref[3]

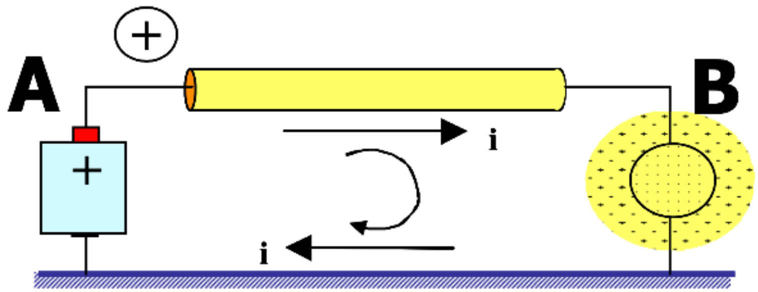
LINE COMMUTATED CONVERTER



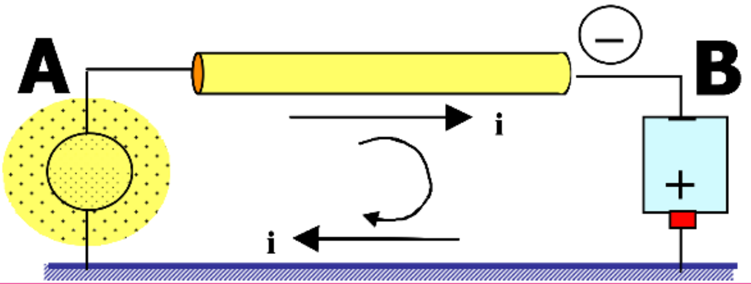
Conventional High-Power Converters use Tyristors (controlled Diodes): the current flows in one direction only and the polarity reversed Line Commutated Converter (LCC).

Therefore, when the power flow is reversed, also the polarity on the HVDC cable is reversed: here an example:

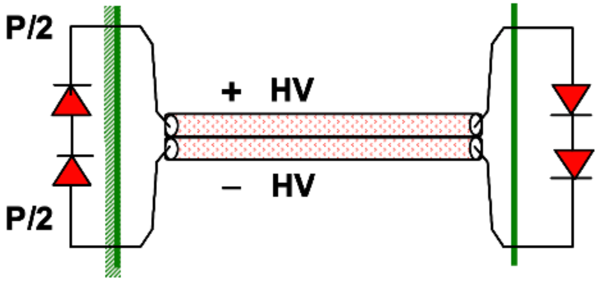
Transferring power from side A to B, clockwise direction of current, cable is at positive voltage (+)



Transferring power from side B to A, to keep same direction of current, cable is at negative voltage (-)



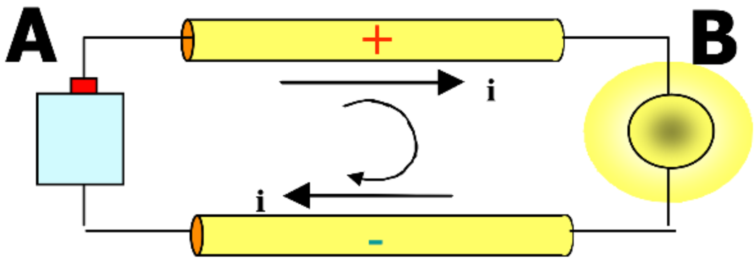
VOLTAGE SOURCE CONVERTERS



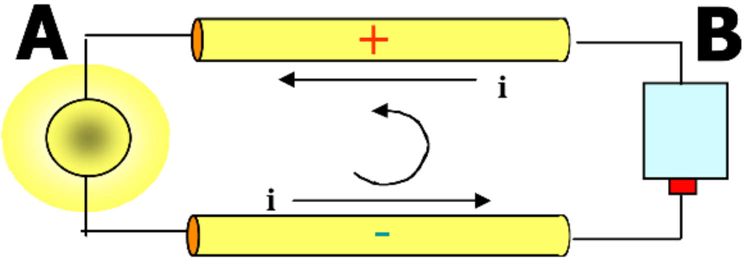
The New Generation of Converters (**VSC – Voltage Source Converters**) use use IGBT Transistors. The AC voltage is 'built' as liked; there are no constraints on current direction and therefore there is no necessity to reverse the polarity when the power flow is reversed

Therefore, when the power flow is reversed, the direction of current is reversed but the polarity of the HVDC cables is the same: here an example:

Transferring power from side A to B, clockwise direction of current, one cable is at positive (+) and one at negative (-) voltage

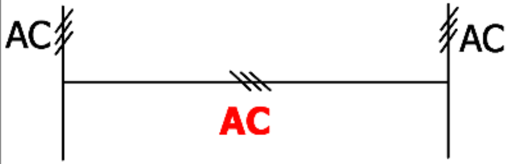


Transferring power from side B to A, to keep same polarity of cables but with anticlockwise direction of current



ref[3]

Some Considerations on Transmission Systems

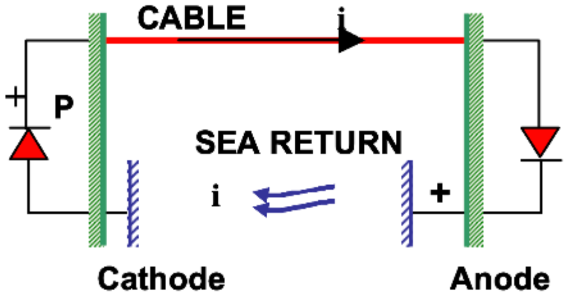
Transmission Solution	Advantages	Drawbacks/Limitations
	Simple No maintenance High Availability	Heavy cable Length (50-150 km) Rigid connection/Power control Require reactive compensation High short circuit currents
	Less no. of cables, lighter No limits in length Low cable and conv. Losses Power flow control Very high transmiss. power	Needs strong AC networks Cannot feed isolated loads Polarity reversal Large space occupied Special equipment (trafo, filters)
	Can feed isolated loads (oil platforms, wind parks, small islands, etc.), medium power Modularity, short deliv.time Small space and envir.impact No polarity reversal Standard equipment	Higher conversion losses Limited experience Limited power

ref[3]

TYPICAL HVDC CONFIGURATIONS

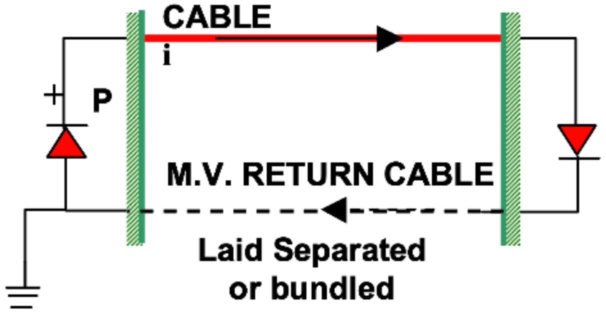
MONOPOLE

(Majority of Old Systems: SA.CO.I; ITA-GREECE; Fennoskan; Baltic Cable)

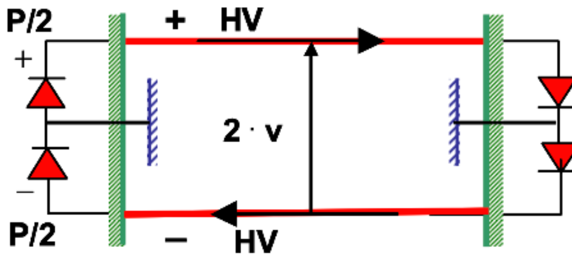


MONOPOLE (WITH METALLIC RETURN)

(Hokkaido-Honshu 1; Moyle; SVE-POL; Basslink; Neptune)

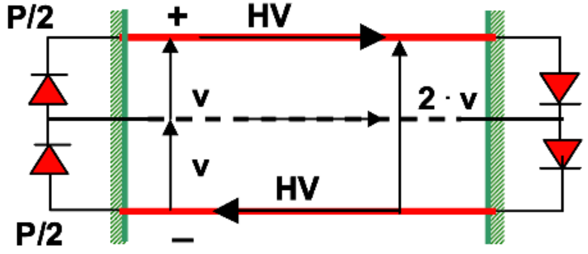


BIPOLE WITH EMERGENCY ELECTRODES



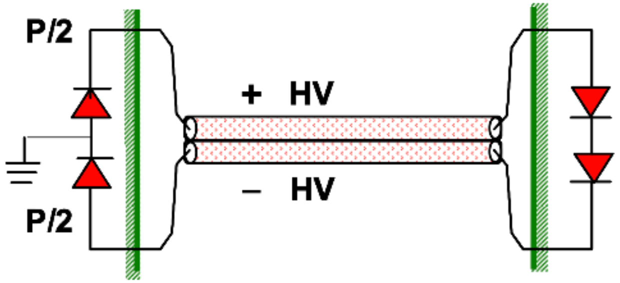
(Cook-Strait; Vancouver 1; Skagerrak; Haenam-Cheju)

BIPOLE WITH METALLIC RETURN



(Hokkaido-Honshu 2; Gotland 2)

BIPOLE WITHOUT METALLIC RETURN



(Cross Channel; Nor-Ned; Transbay)

ref[4]

Table 3: Comparison between HVDC transmission technology options

HVDC Converter Types		LCC	VSC
Switching Device		Mercury Arc (1950s – 1970s)	IGBT (1990s – Present)
		Thyristor (1970s – Present)	
Commutation (Frequency Range)		Line Dependent (50-60 Hz)	Self-Commutated (up to few kHz)
Station Power Loss [15, 54, 117]		0.6%-0.8%	~ 1%
Power-Flow Reversal Mechanism		Voltage Polarity Reversal (slow, causes more current stress)	Current Direction Reversal (Fast, adds more reliability)
Network Strength Dependency		Dependent (expensive added equipment in weak grids) [58]	Largely Independent
Converter Station Footprint		Larger	Smaller (40-50%) [75]
Inherent VAR Consumption		50-60% of rated MW	None, and can support reactive power to AC grid
Reactive/Filtering Equipment Requirements		High (Expensive)	Low
Inherent VAR control and Grid Support		No	Yes
Inherent AC Grid Black-Start Capability		No	Yes
Fault Handling Capability	**AC Side**	Lower (Line-Frequency Dependent)	Higher (MVAR Support/Black Start)
	DC Side	Higher (DC Reactor/SC failure)	Lower (High di/dt rate)
AC & DC Side Harmonics Level		Higher	Lower
Market Share (# of Projects) [27]	**(1954-2018)**	81%	19%
	(2010-2018)	70%	30%
Available Rating Combinations*	**Max**	12,000 MW/ ±1,100 KV	2,000 MW [118]/ ±500 kV [15] (525 kV [119]*)
	Average	2,000 MW/ ±400 kV	580 MW/ ±220 kV
Common Applications		High-Power, Long Distance	Offshore/Cable-based Projects
Multi-Terminal HVDC Suitability		Limited	Highly Suitable
Stations Cost (at High Ratings)		Lower	Higher

*Current maximum VSC voltage is ±500 kV at Skagerrak 4 project [15], which will be taken over by NordLink in 2020 with ±525 KV [119].

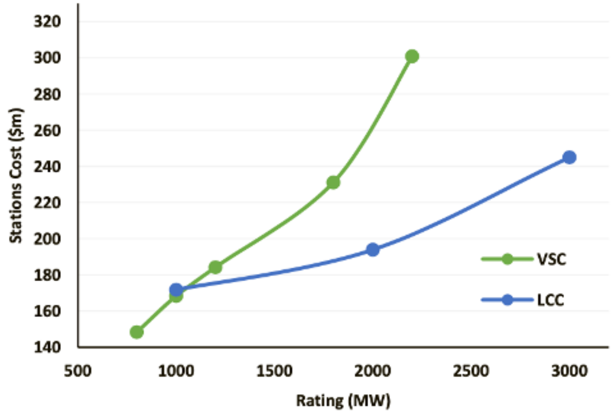
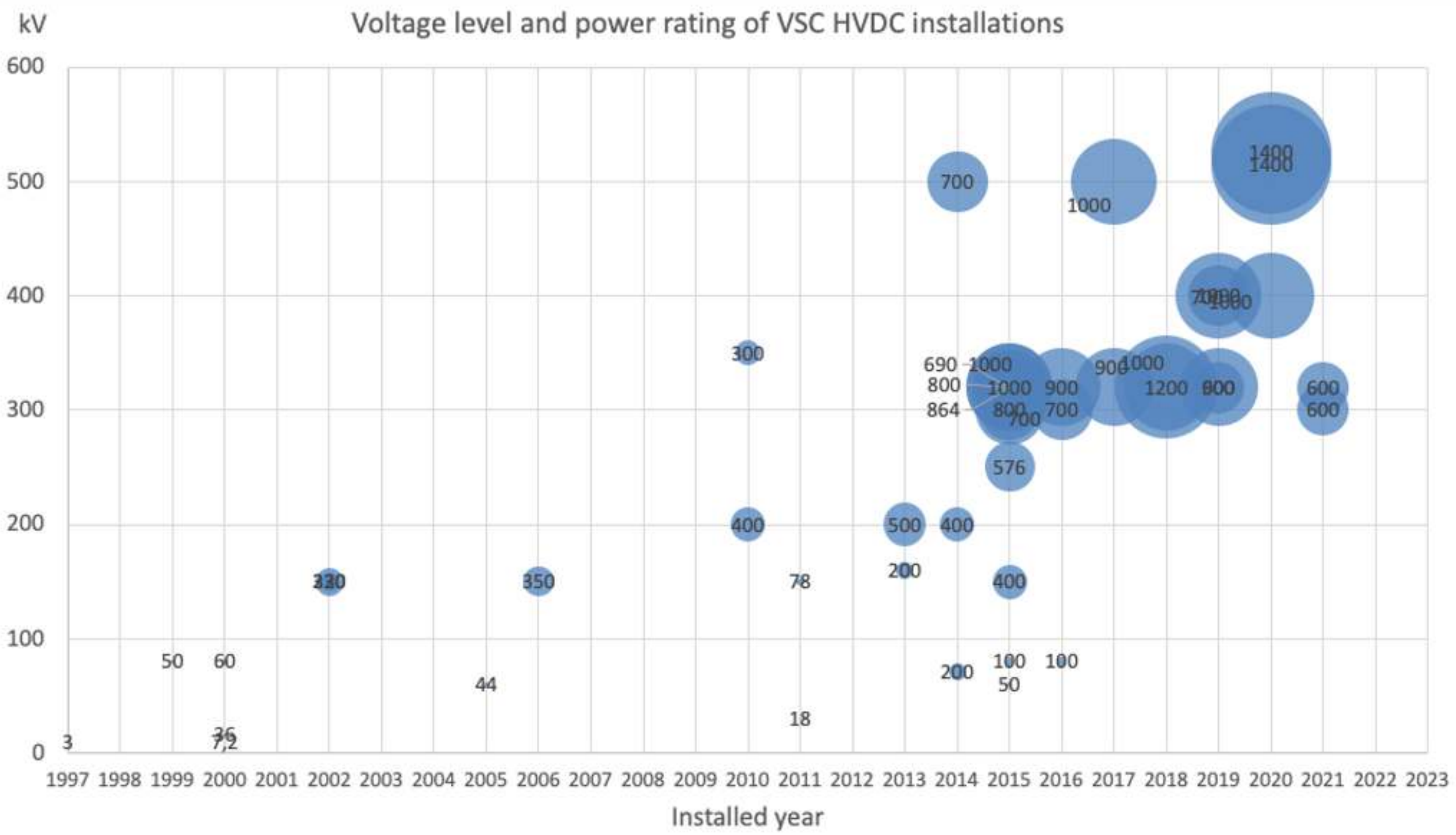


Figure 11: LCC and VSC stations cost evolution with rating based on actual data from [105].

ref[8]



Voltage level and power rating of VSC HVDC installations
kV
Installed year

ref[3]

BASIC REQUIREMENTS OF SUBMARINE CABLES

- **Long continuous lengths**
- **High level of reliability with practical absence of expected faults**
- **Good abrasion and corrosion resistance**
- **Mechanical resistance to withstand all laying and embedment stresses**
- **Minimized environmental impact**
- **Minimized water penetration in case of cable damage**

ref[3]

KEY POINTS TO CONSIDER WHEN SELECTING A SUBMARINE CABLE

- **Power to be Transmitted**
- **Route Selection - Seabed Geology, Thermal Resistivity of Seabed**
- **Length of Cable**
- **Water Depth**
- **Protection Requirements - Burial Depth, Fishing Activity, Marine Activity**
- **Security of Supply**
- **Environmental Considerations**
- **Economic Viability**

Mechanical Protection – Armour Design

- SINGLE ROUND WIRE ARMOUR
  (it covers the vast majority of the submarine installation requirements, including windmill applications)
- DOUBLE ROUND WIRE ARMOUR (uni-directional)
- DOUBLE ROUND WIRE ARMOUR (contra-directional)
- ROCK ARMOUR
- PLASTIC COATED WIRES
- STEEL TAPE ARMOUR PLUS WIRES
- DOUBLE STEEL STRIP ARMOUR
- NON-MAGNETIC ARMOUR

ref[4]

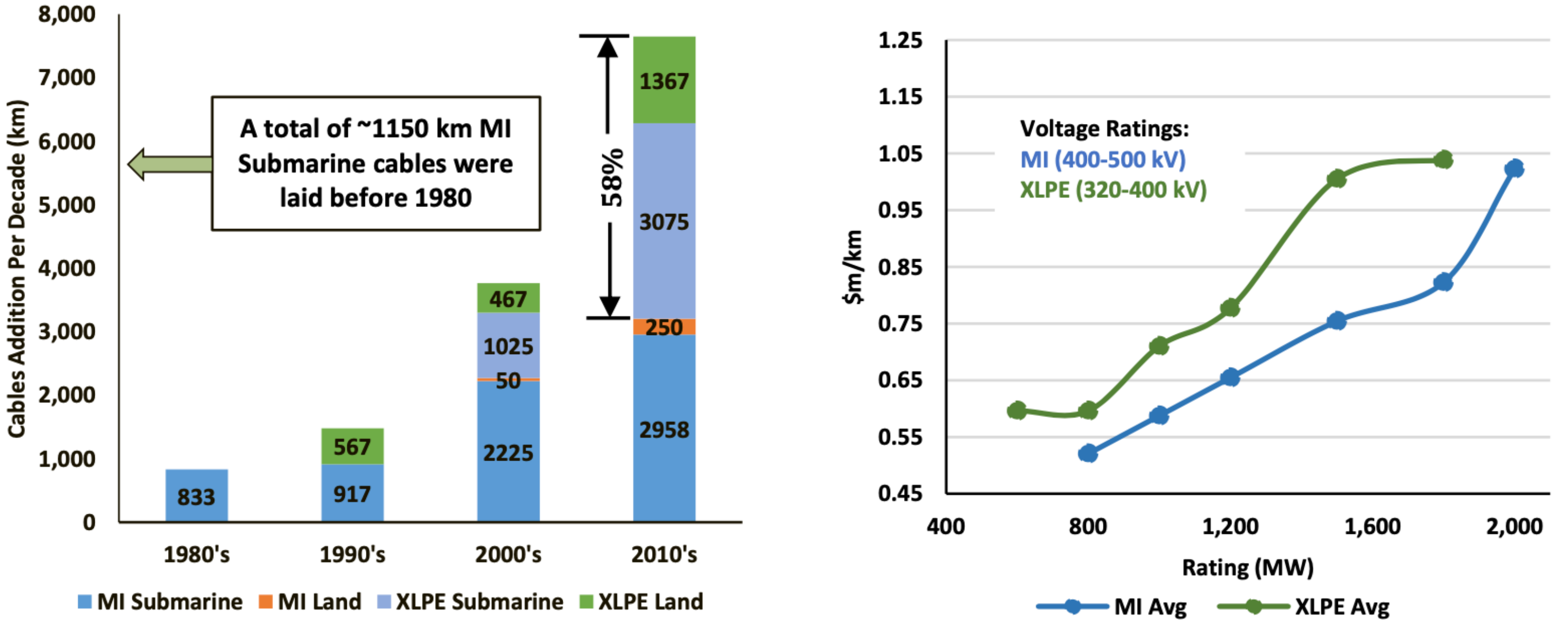
Table 4: Comparison between XLPE and MI DC cables technology.

Cable Type	Mass Impregnated (MI)	Extruded (XLPE)
Insulation Type	Paper insulated/Oil filled	Polymer (cross-lined polyethylene)
First Use for HVDC	1954	1999
HVDC Applications	LCC & VSC	Mainly VSC (limited suitability for LCC due to voltage reversal)*
Mechanical Weight/Installation	Higher/Harder	Lower/Easier
Maximum Rating (Project-Based)	2,200 MW/±600 kV (Western Link) [137]	2,000 MW/±320 kV** (INELFE) [118]
Longest Distance	580 km (NorNed) [127]	400 km (NordBalt) [147]

* Special types of XLPE cables are rarely used in LCC projects (e.g. the ±250 kV Hokkaido-Honshu link in Japan) [146, 148].

** NEMO Interconnector commissioned in 2019 uses 400 kV XLPE cables manufactured by JPS of Japan [151]. ABB has also recently manufactured 525 kV XLPE cables that should be soon in service [39].

ref[4]



(a) (b)

Figure 17: XLPE and MI cables comparison: (a) DC cables length up to 2020 [149]. (b) average costs comparison of ~400 kV cables at different ratings, excluding installation which is easier/cheaper for XLPE cables [105].

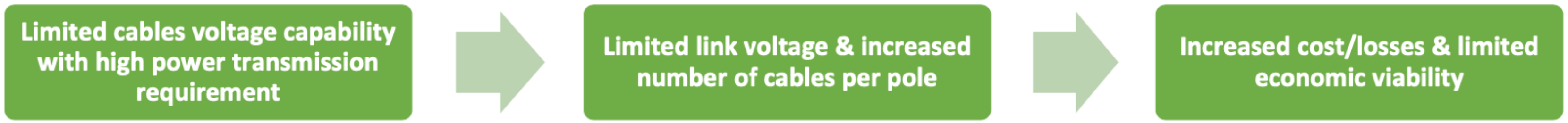
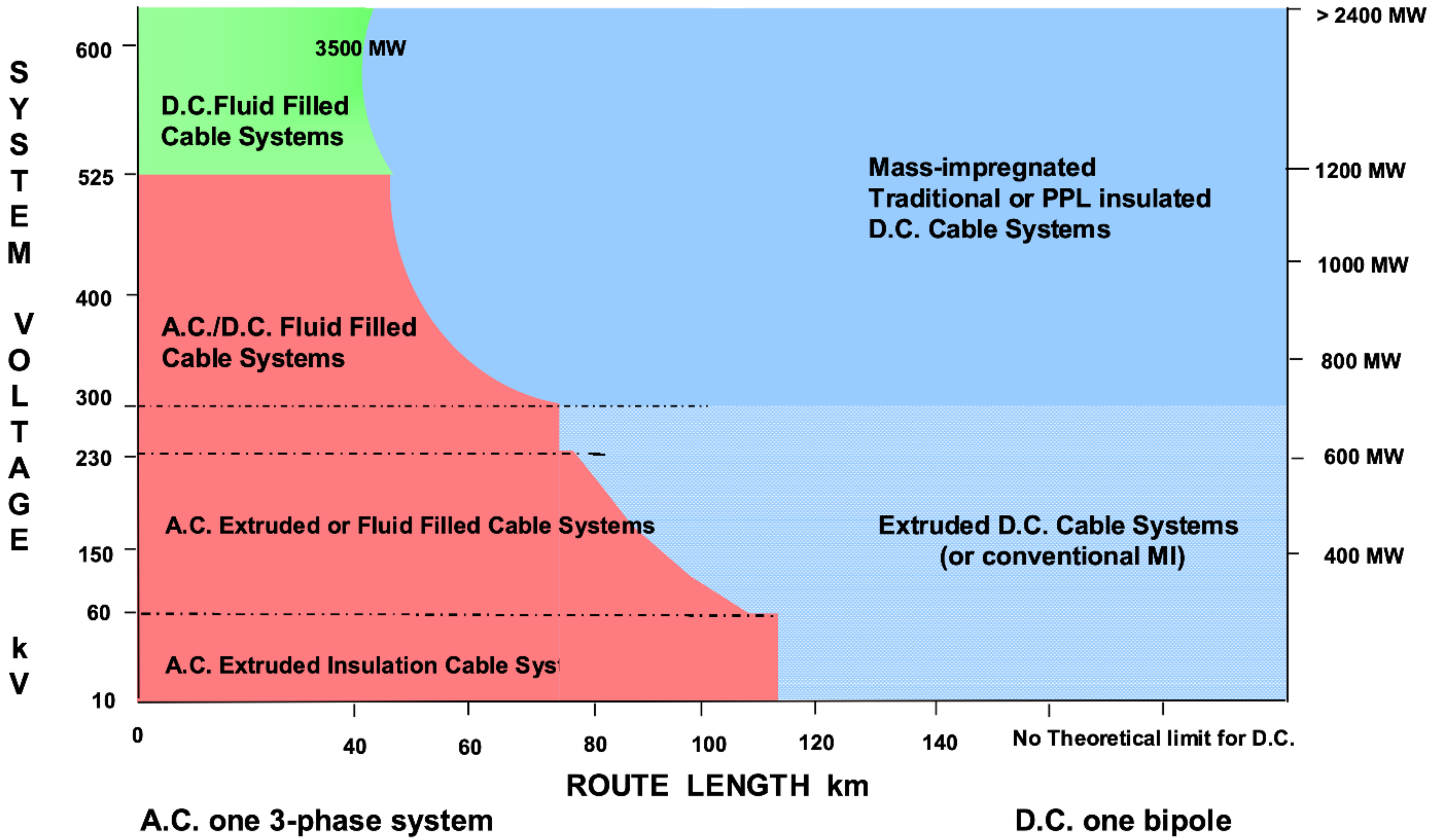


Figure 15: Qualitative summary of the limited power transfer capacity of DC cables.

ref[3]

AC vs. DC - TRANSMISSION OPTIONS



ref[3,10]

Cable Technologies

Technologies	Technology Availability 2020	2025	2030
Mass Impregnated HV DC Cables, ±600 kV	9	9	9
Extruded HV DC Cables, ±320 kV	7 [1)]	9	9
Extruded HV DC Cables, ±525 kV	5	7	9
Extruded HDVC Cables, ±600 kV	3	5	7

TABLE 4.3 Limits of Offshore Transmission Systems (Available)

System	Voltage Rating	Power Rating
DC submarine cable mass-impregnated	Up to ± 500 kV	Up to 2500 MW per system
DC submarine cable extruded	Up to ± 525 kV	Up to ±2650 MW per system
AC submarine cable	Up to 275 kV	Up to 400 MVA per three-phase cable
Offshore DC converters (VSC)	Up to ± 320 kV	Up to 1200 MW per converter

Reference: "Table 4.1 Summary table of the technologies and the respective TRL levels"; ENTSO-E TYNDP 2018 Technologies for Transmission System.
In this table, Technology Readiness Levels (TRL) are defined as follows:

- TRL 9 – actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)
- TRL 8 – system complete and qualified (some smaller improvements need to be done still)
- TRL 7 – system prototype demonstration in operational environment
- TRL 5 – technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
- TRL 3 – experimental proof of concept

1) Note: As extruded cables ±320kV have been in operation since 2013, their technical availability in 2020 is considered to increase to TRL8 (not anymore at TRL7, which is stated in the table above)

ref[10]

Current Rating 2016

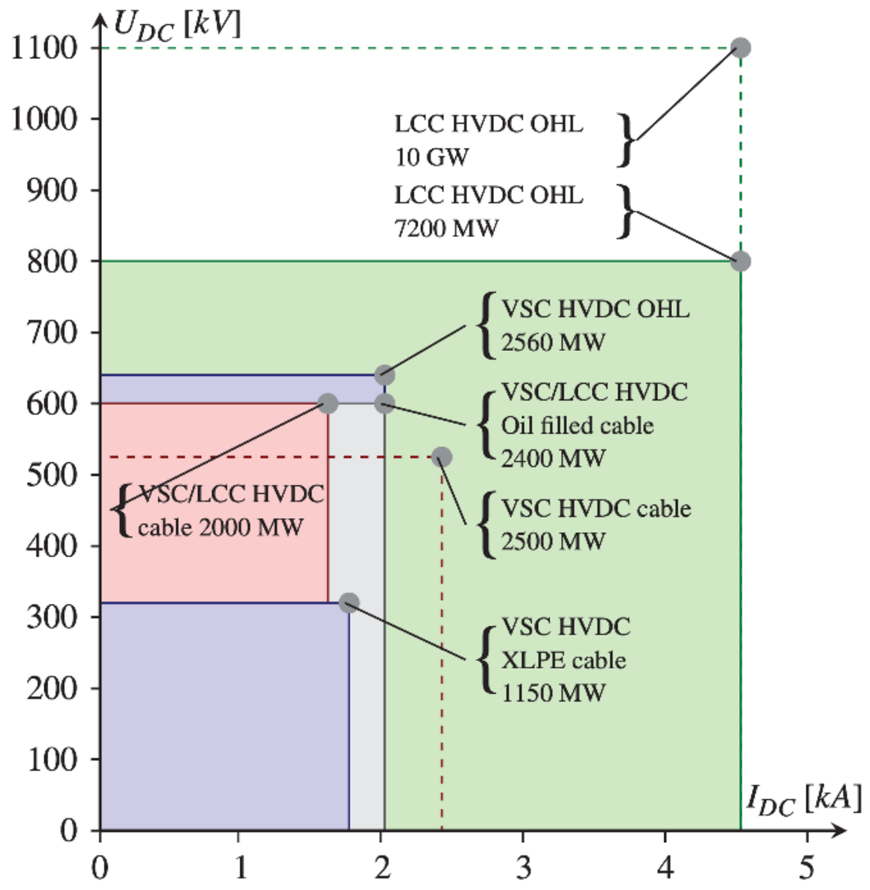


Figure 4.1 Current possible ratings for HVDC systems (U_{DC} refers here to the pole voltage, in a bipolar or symmetrical monopole setup, $P = 2 \cdot U_{DC} \cdot I_{DC}$) [2]. The dashed curves indicate announced maximum rates for LCC and VSC HVDC, respectively.

Google Chrome

ref[4]

Table 6: Summary of the medium term horizon for main HVDC transmission system components.

System Component		Medium-Term Technology Outlook	Likely Impact
HVDC Converters	LCC	Maintaining its position as the main OH UHVDC power transfer technology	Pushing the maximum power transmission limit in Asia beyond 12,000 MW at ±1,200 kV [220]
	VSC	Available at higher ratings beyond 650 kV at lower normalized costs and station losses [105]	Playing vital role in MTDC development, increasing interconnected markets share and RES utilization (expected 65% of new HVDC projects by 2020 [75])
HVDC Cables	MI	Higher rating availability (750 kV at 3,000 MW per bipole by 2030 [105])	Pushing the maximum rating limits for projects with UG/submarine cable sections, yet with overall diminishing market share compared to XLPE
	XLPE	Higher rating availability (650 kV at 2,600 MW per bipole by 2030 [105])	Expanding its market share dominance , parallel to VSC technology progress and fuelled by the need to construct new MTDC links connected to offshore wind farms
DC Grid Protection	DCCB	Moving from MV prototyping stage to HV implementation around 2030 [220]	Accelerating DC grids implementation. Leading to increased MTDC networks share, increased security of supply and enhanced RES utilization
	VSC Based MMC	Enhanced control algorithms for DC fault-blocking at higher ratings [87]	

Collectively, Table 7 summarizes several renewable grid penetration targets from major international markets. HVDC links are essential to achieve these targets due to their vital role in long-distance transmission from remote large-scale renewable sources to load centres.

Table 7: Renewable energy targets in main global markets.

Market		Renewable Energy Target (E/P)*	Target Year
Europe		32% (E) [233] 15% (EU member states capacity interconnection) [7]	2030
China		770 GW (P) [234, 235] (37%-39% of total capacity in 2020 [1, 235])	2020
India		227 GW (P) [236] (48% of total capacity in 2022 [1])	2022
Russia		4.5% (E) [237]	2024
Brazil		45% (E) [226, 238]	2030
GCC Countries		80 GW (P) [239]	2030
Africa**		50% (E) [229]	2030
USA***	**New York**	50% (E) [240]	2030
	California	50% (E) [240]	2030

* E/P is used to distinguish (E)nergy generation from (P)ower generation capacity targets.

** This number is based on achieving individual existing national RES penetration targets by 2030 [229].

*** No nationwide target is set, yet IRENA estimates a potential of reaching 27% (E) of RES generation by 2030 with appropriate investment in interconnection infrastructure, in addition to renewable incentives [241].

ref[13]

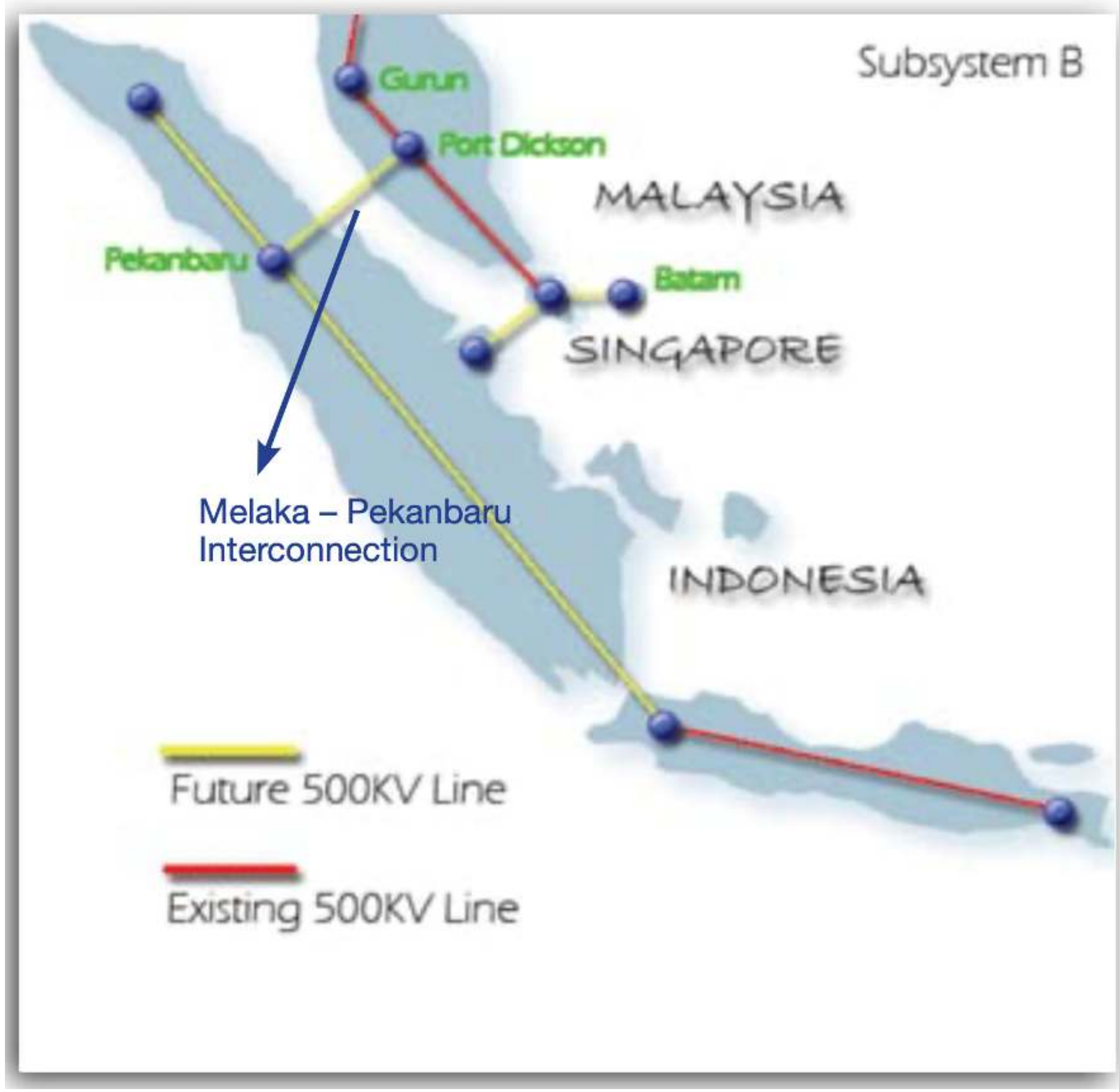
Case Sumatra-Java

- Solution: HVDC LCC Bipole ± 500 kV, 3000 MW, Submarine Cable (OF,MI)
- Length ±36 kmr
- 500 kV DC OF/MI cables
- 2cct: 2 poles + 1 spare

ref[12]

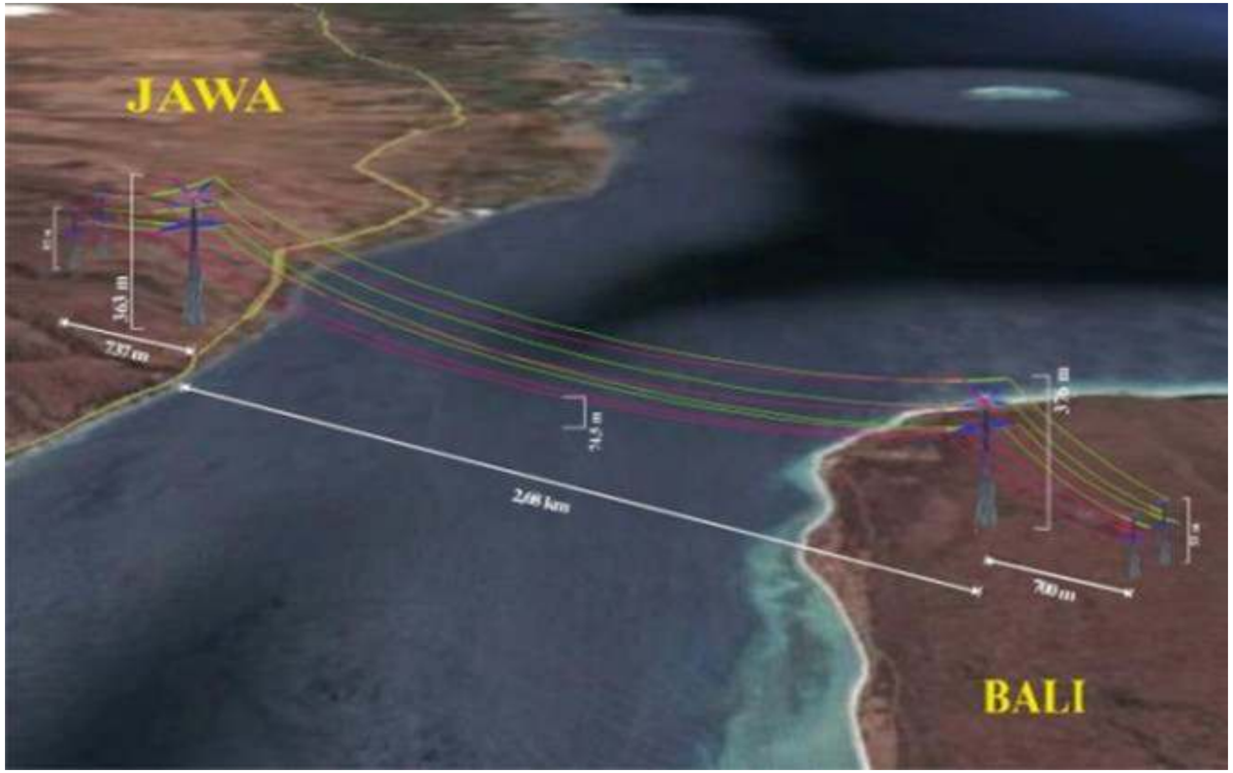
Case Sumatra-Peninsular

- Solution HVDC LCC Bipole ± 250 kV, 600 MW OHL, Submarine Cable (OF,MI)
- 2cct: 2 poles + 1 spare
- Submarine cable (52 km) Telok Gong –Rupat Island;
- Overhead transmission lines (30 km) crossing the Rupat Island;
- Submarine cable (5 km) Rupat Island - Dumai



Case Java-Bali

- Solution HVAC 500 kV, 2000 MVA, Submarine Cable (XLPE)
- Length +6 kmr
- 500 kV AC Extruded cables
- 2cct: 2x3 single core + 1 spare



Case: template solution for RE

- Point to point
- Lumped generating farm
- Power shared

ref[6]

Offshore Wind Parks

Fig. 1 Geographical division of the planned OWP into four clusters with the allocated transmission routes and NVP in the substations (stand 03.2011)

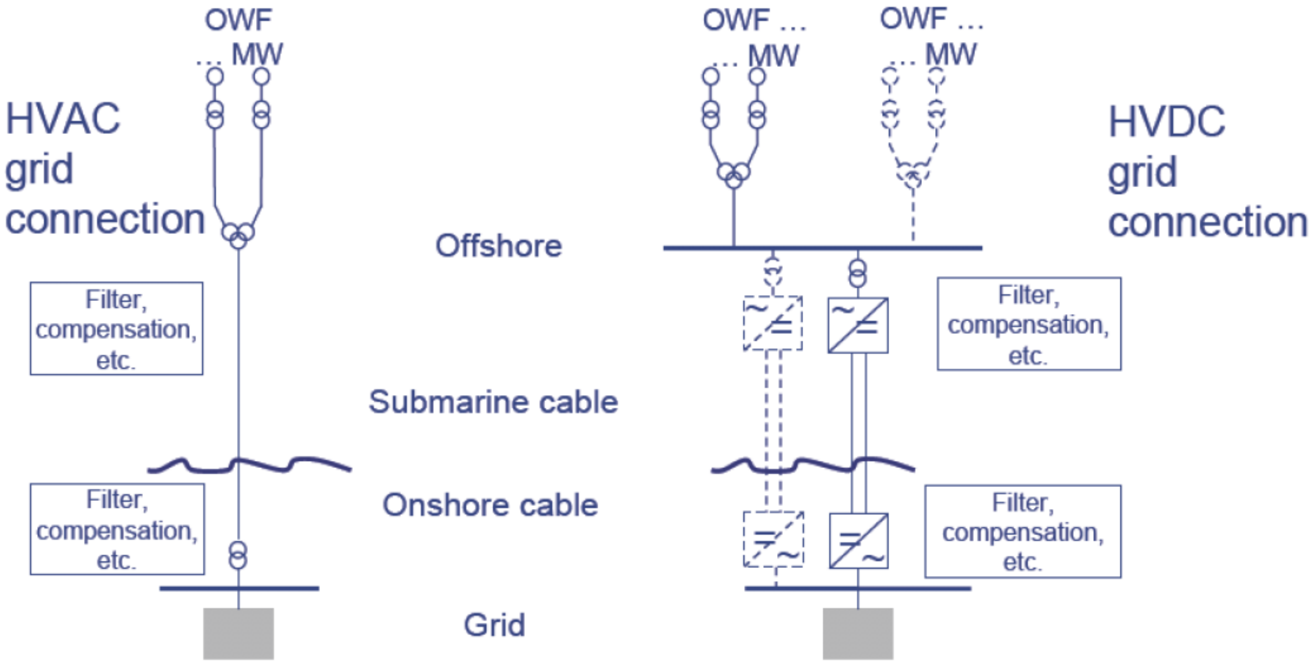


Fig. 2 Schematic representation of the technical variants of OWP grid connection; configuration as HVAC and HVDC systems

ref[6]

Offshore Wind Parks

Table 1 VSC-HVDC-based offshore wind projects in operation and in construction in Germany

Project	Transmission Capability	Length	Operation Time
BorWin1	±150 kV, 400 MW	200 km	2010
BorWin2	±300 kV, 800 MW	200 km	2015
BorWin3	±320 kV, 900 MW	160 km	2019
DolWin1	±320 kV, 800 MW	165 km	2015
DolWin2	±320 kV, 900 MW	135 km	2016
DolWin3	±320 kV, 900 MW	160 km	2018
HelWin1	±250 kV, 576 MW	130 km	2015
HelWin2	±320 kV, 690 MW	130 km	2015
SylWin1	±320 kV, 864 MW	205 km	2015
DolWin6	±320 kV, 900 MW	90 km	2023
DolWin5	±320 kV, 900 MW	130 km	2024

Multi Terminals VSC

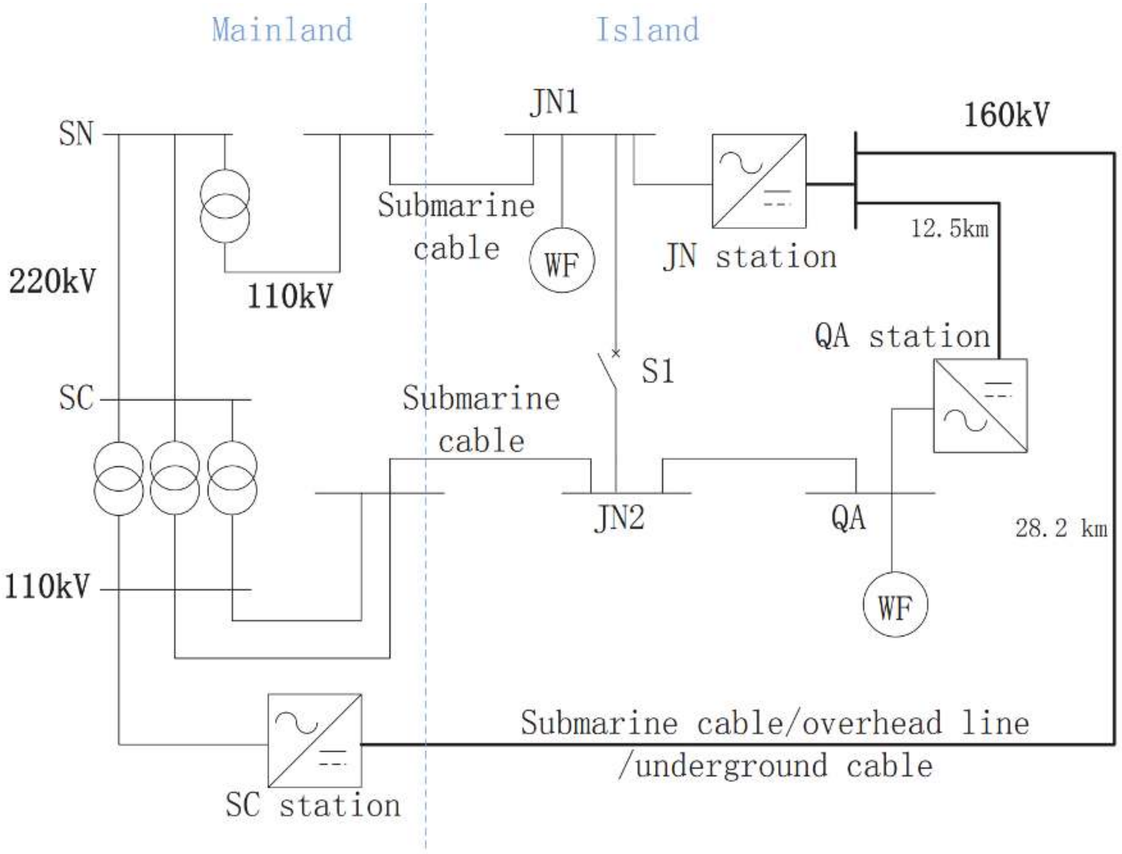
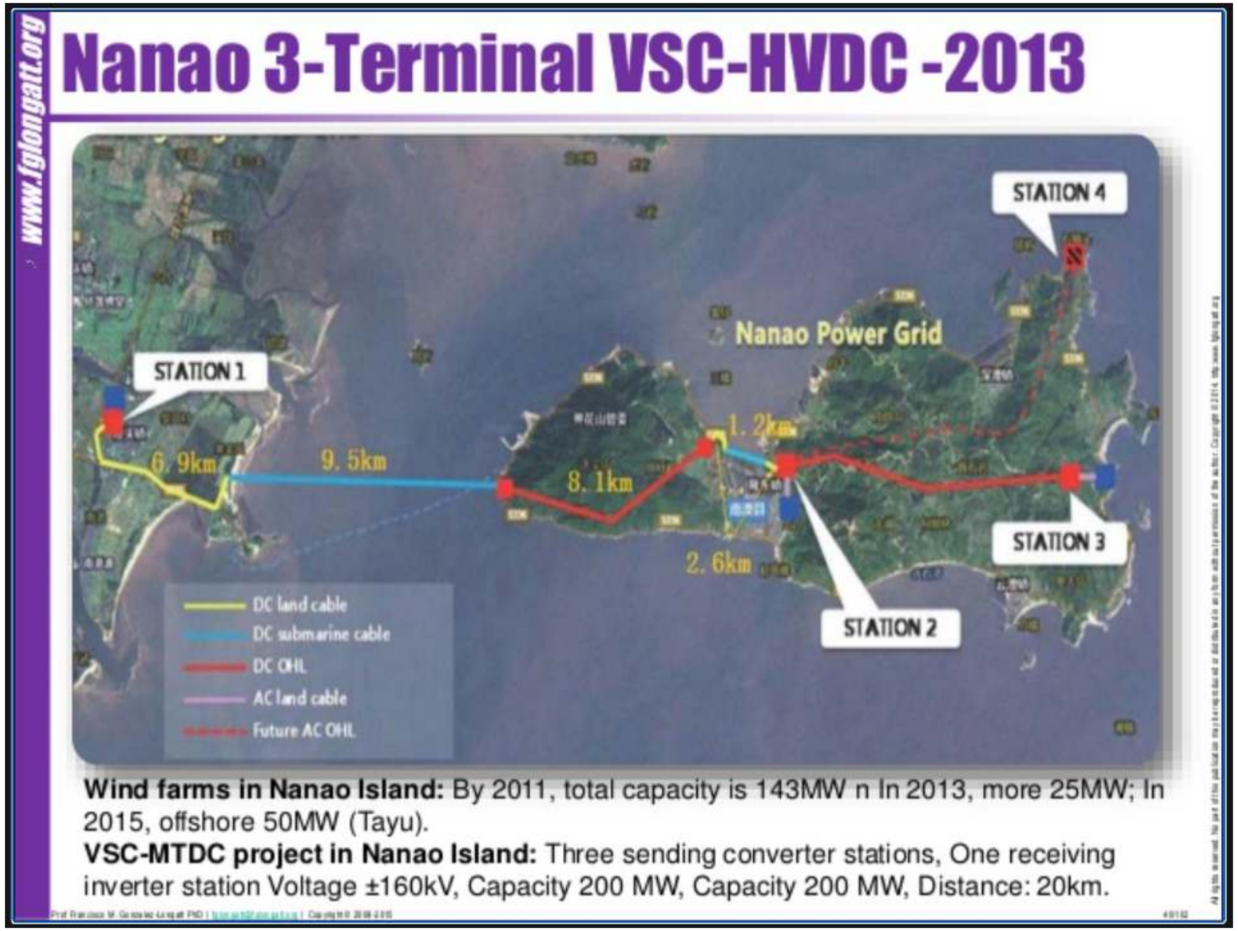


Fig. 1. Network configuration



ref[9]

Multi Terminals VSC

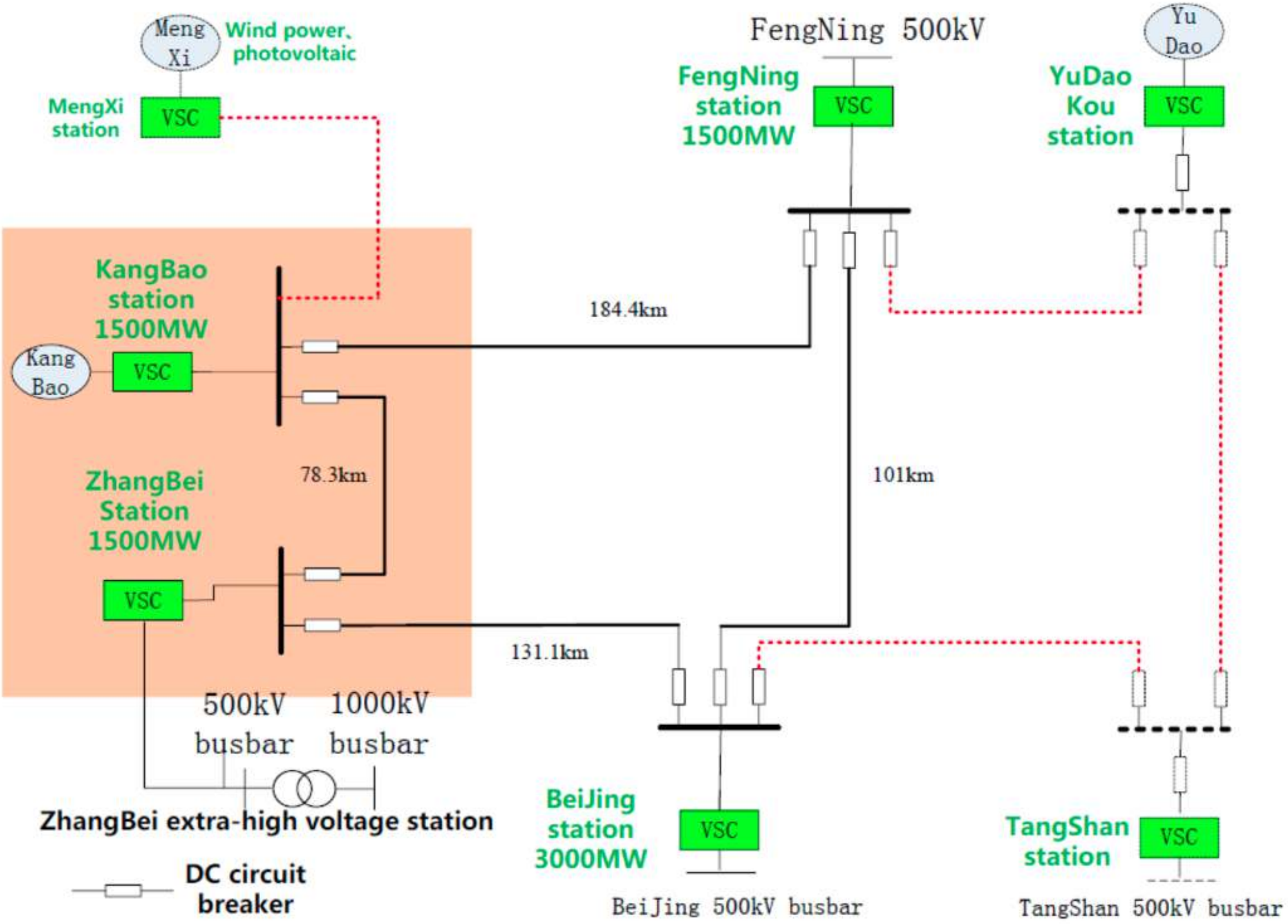


Fig. 7. HVDC grid topology in Zhangbei [23]

Solution

- Achieving the main purposes of Grid
- Selecting available technologies that meets
  - Technical requirements
  - Optimizing cost of station systems-transmissions-cables

Conclusions

- Technologies is Available for Indonesia Nusantara Renewable Grid
- Need collaboration and commitment of gov/regulator-utility-developers

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