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HVDC Technology for Power Transmission

13 December 2023 | Technical Topic Webinar

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EIT Lecturer

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Introduction - Presenter

Dr. Imtiaz Madni

EIT Lecturer

- Imtiaz specializes in electrical engineering and power systems.
- Proficient in designing, modeling, and simulating power systems.
- Experienced in documentation, installation, commissioning, and testing.
- Successfully delivered projects in Australia and globally.
- Possesses strong research, analytical, and problem-solving skills.
- Background includes generating innovative ideas to enhance electrical systems performance.
- Provides leadership and management in streamlining standardized operation and maintenance procedures.
- Expertise in creating documents such as estimations, specifications, electrical drawings.
- Ensures inspection and testing are conducted in compliance with Australian and international standards.

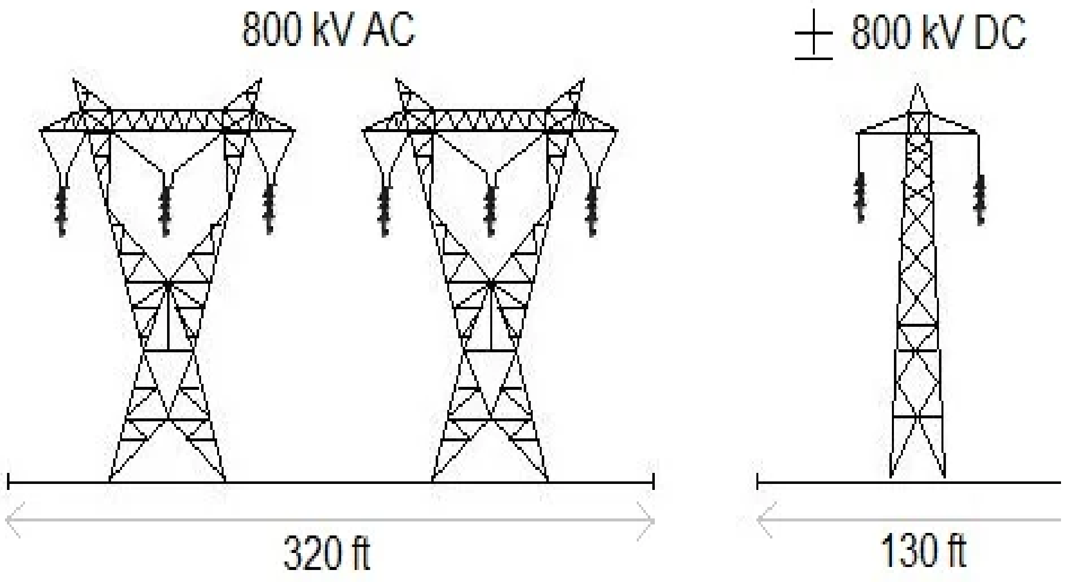
HVDC Transmission

- High-voltage dc power transmission (HVDC) use is growing across a variety of applications.
- One of the main growth drivers is renewable energy.
- HVDC interconnects between geographically dispersed wind and/or solar farms can help mitigate the effects of variable energy generation levels by providing a means for averaging the various changing power outputs.
- HVDC is already used to bring hydropower from remote generation sites to urban centers.
- AC transmission lines can only interconnect synchronized AC networks. HVDC is often used to connect unsynchronized AC power networks.

DC vs AC

- DC systems developed by the Edison's company could not transmit the power more than a couple of kilometers.
- As the transmission distance increases, voltage drops significantly due to the I^2R loss.
- With the development of AC, it became very easy to change the voltage levels of AC power using transformers.
- Power could now be transferred over longer distances using AC, by stepping up the voltage level for transmission and stepping down again for utilization.

Improvements In DC System

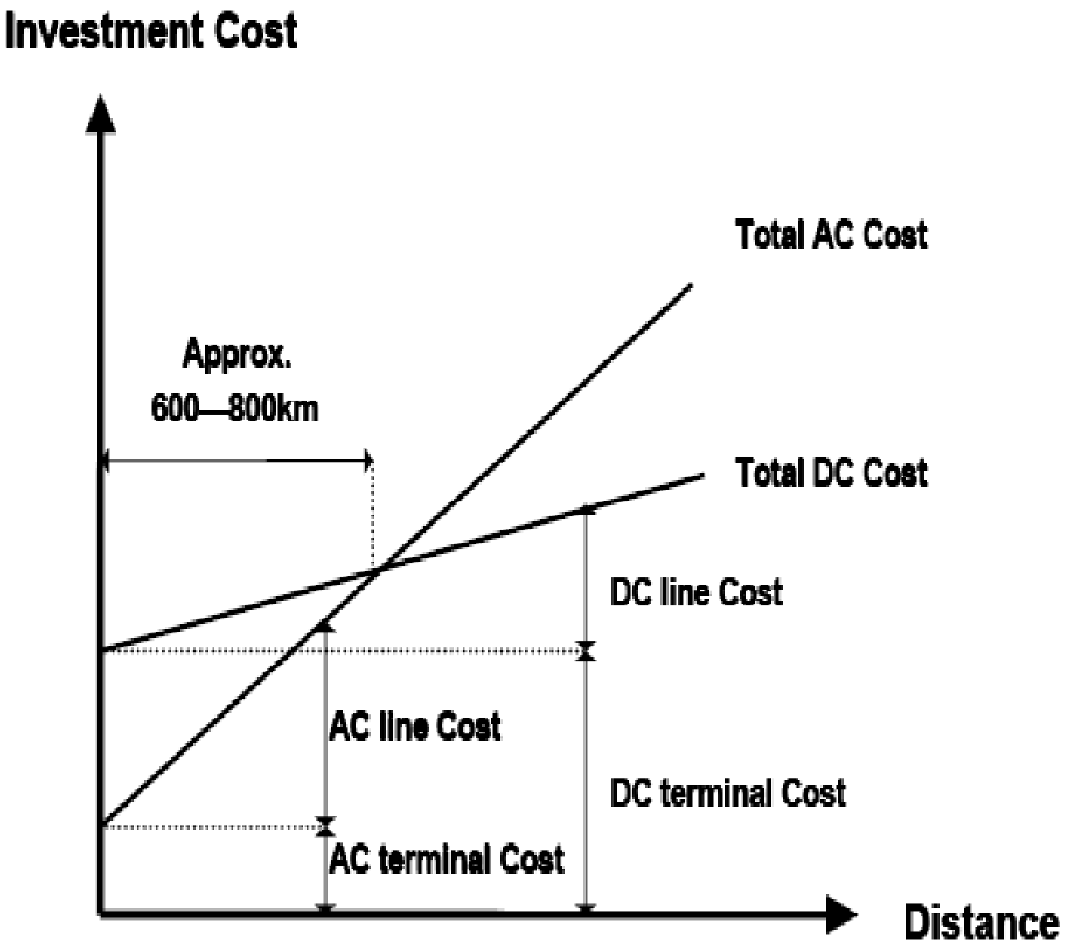


- A major problem that Edison could not solve was how to increase the transmission voltage of DC for transmitting the power over longer distances.
- With the development of mercury arc valves, it became easier to convert the power between AC and DC.
- The AC power could now be converted into DC after stepping up the voltage using a transformer and, at the end of the transmission line, it could be converted back into AC for stepping down.
- This made High Voltage DC transmission technically feasible.
- Today, HVDC technology is used as a highly efficient alternative for a huge amount of electric power transmission and for interconnecting power grids with different frequencies.

Comparison Of HVAC And HVDC Transmission

Investment cost:

- DC transmission requires fewer conductors than AC transmission - 2 conductors per DC circuit whereas three conductors per 3 phase AC circuit.
- HVDC allows line supporting towers to be smaller and, hence, requires lesser right-of-way.
- HVDC transmission line would cost lesser than an HVAC line.
- However, the terminal converter stations in HVDC are much more expensive which are not required for HVAC transmission.
- Over a specific distance, called as break-even distance, HVDC line becomes cheaper than HVAC.
- The break-even distance for overhead lines is around 600 km and for submarine lines it is around 50 km.

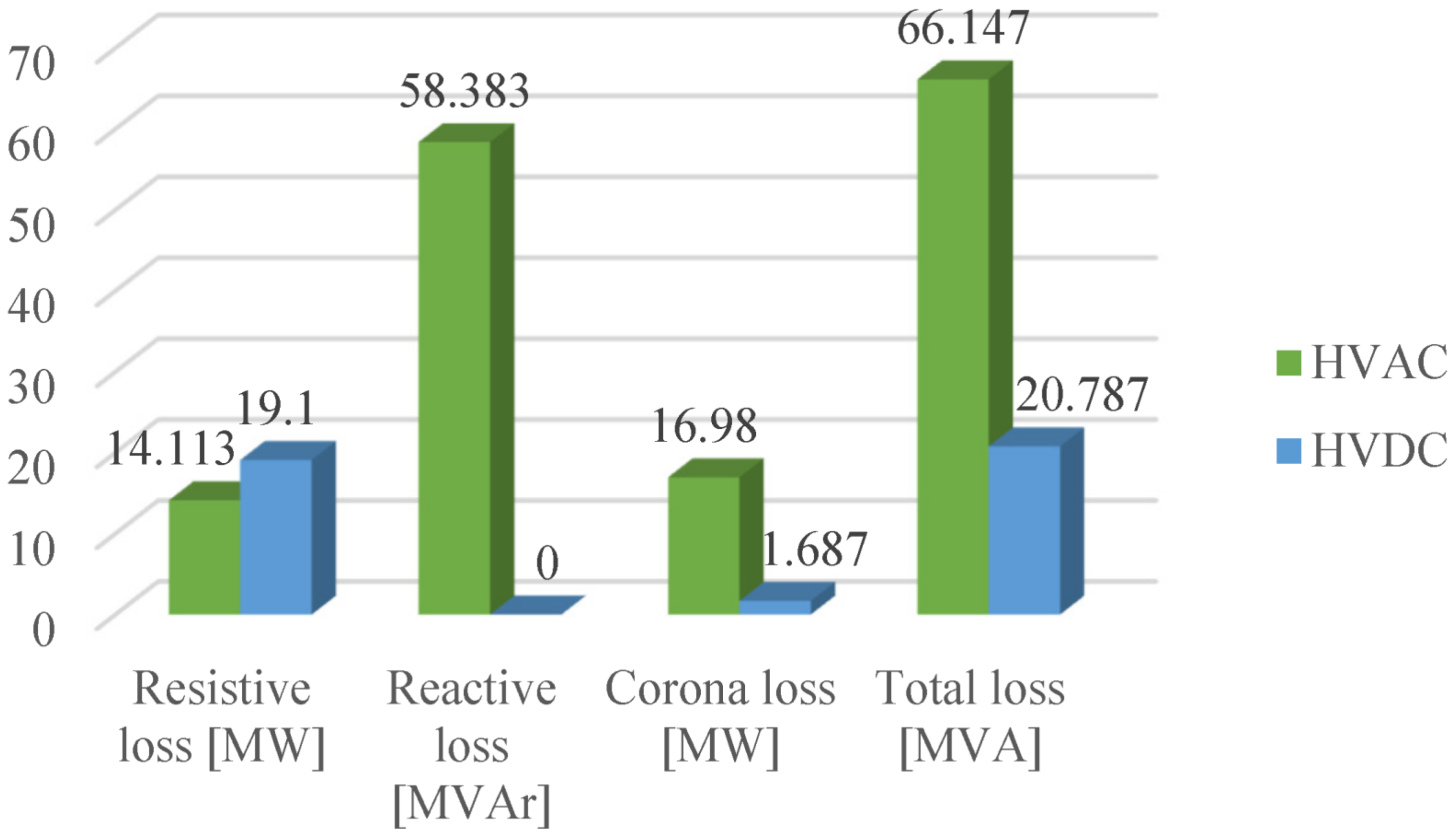


Comparison Of HVAC And HVDC Transmission

Losses:

- Corona loss is caused by the ionization of air molecules near the transmission line conductors. The corona does not spark across lines, but rather carries current (hence the loss) in the air along the wire.
- Skin effect is absent in DC. Also, corona losses are significantly lower in the case of DC.
- An HVDC line has considerably lower losses compared to HVAC over longer distances.

1000 MW power at 500 kV voltage and stretch 640 km in distance



Comparison Of HVAC And HVDC Transmission

- **Controllability:**

Due to the absence of inductance in DC, an HVDC line offers better voltage regulation. Also, HVDC offers greater controllability compared to HVAC.

- **Asynchronous interconnection:**

AC power grids are standardized for 50 Hz in some countries and 60 Hz in other. It is impossible to interconnect two power grids working at different frequencies with the help of an AC interconnection. An HVDC link makes this possible.

- **Interference with nearby communication lines:**

Interference with nearby communication lines is lesser in the case of HVDC overhead line than that for an HVAC line.

- **Short circuit current:**

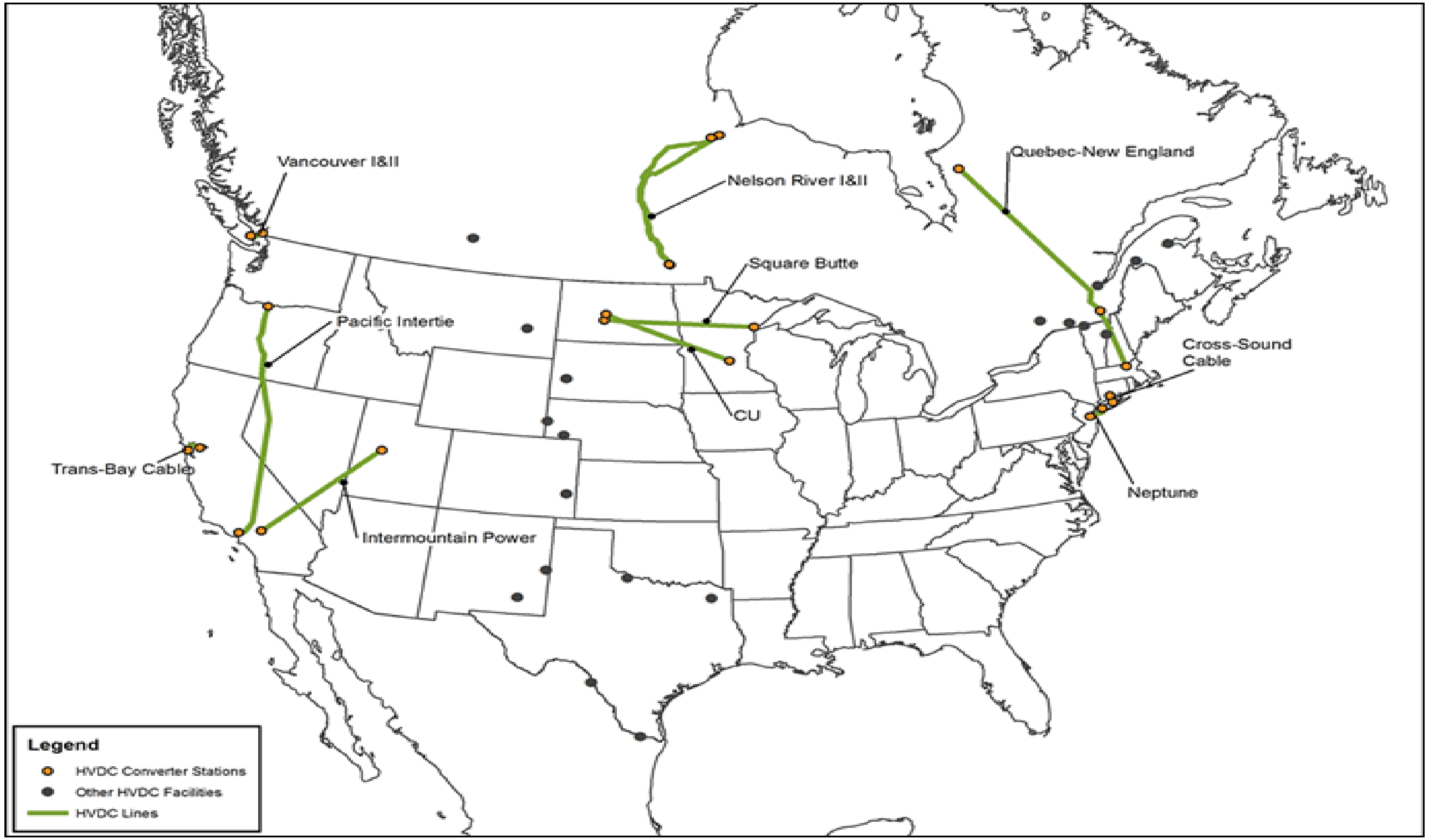
In longer distance HVAC transmission, short circuit current level in the receiving system is high. An HVDC system does not contribute to the short circuit current of the interconnected AC system.

History of HVDC

- The development of direct current (DC) transmission dates to the 1930's in Sweden and in Germany and has been a proven technology since the first major installations in 1954.
- Over the last 40+ years, DC projects have shown to offer significant electrical, economic, and environmental advantages when transporting power across long distances.
- Early commercial installations included one in the Soviet Union in 1951 between Moscow and Kashira, and a 100 kV, 20 MW system between Gotland and mainland Sweden in 1954.
- The longest HVDC link in the world is currently the Xiangjiaba–Shanghai 2,071 km (1,287 mi), ±800 kV, 6400 MW link connecting theXiangjiaba Dam to Shanghai, in China.
- Early in 2013, the longest HVDC link will be the Rio Madeira link in Brazil, which consists of two bipoles of ±600 kV, 3150 MW each, connecting Porto Velho in the state of Rondônia to the São Paulo area, where the length of the DC line is 2,375 km (1,476 mile).

HVDC Transmission Projects

- Currently there are more than 20 DC transmission facilities in the United States and more than 35 across the North American grid as indicated in the map below.



HVDC Transmission Projects

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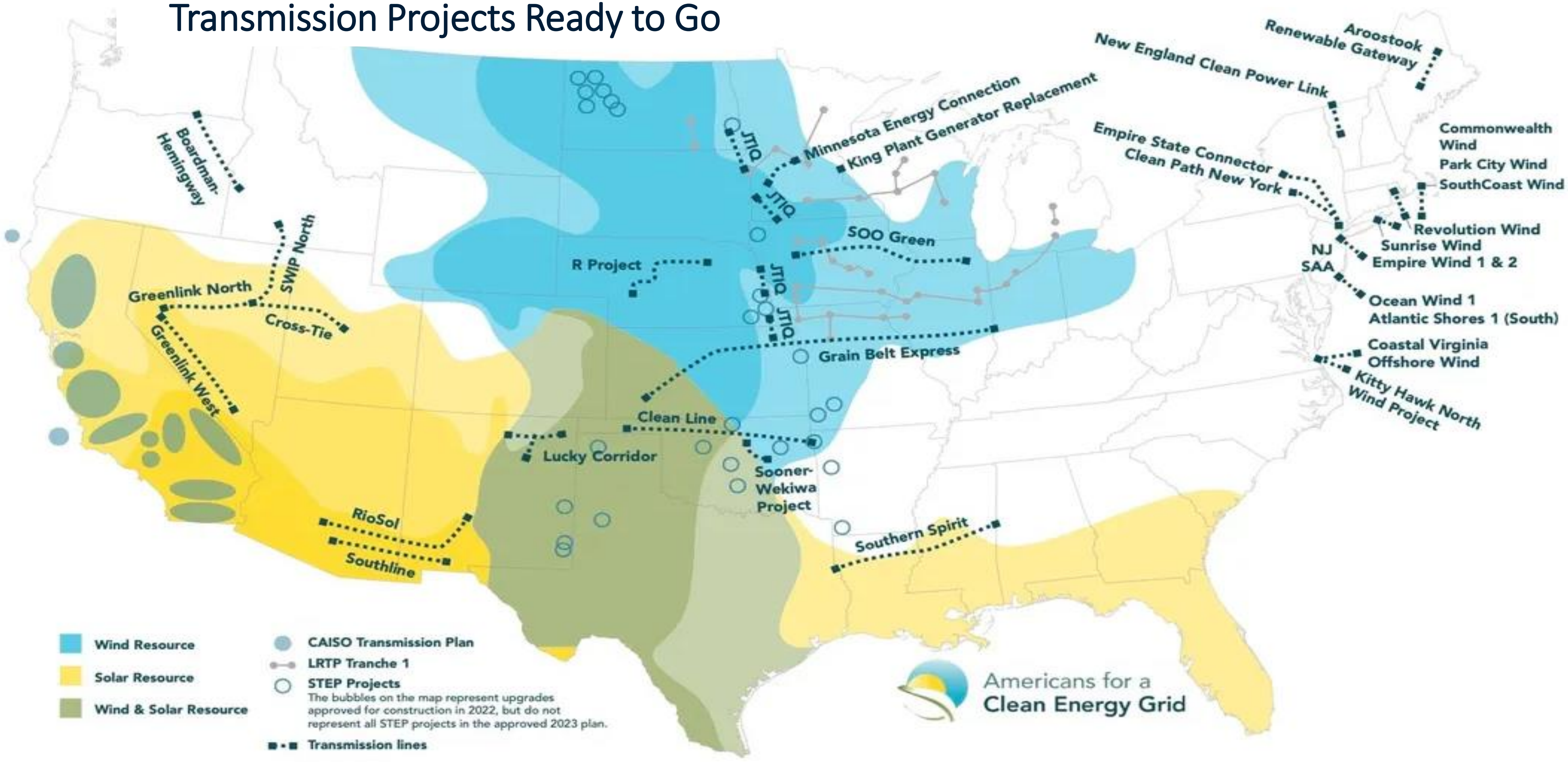
Transmission Projects Ready to Go



HVDC Technical Advantages

No Skin Effect:

- In HVDC transmission current distributes uniformly over the cross section of the conductor. Hence no loss due to skin effect is encountered. For the same current carrying capacity HVDC lines have lesser cross section compared to ac HV lines.

Lower Transmission Losses:

- HVDC transmission requires only two conductors. Therefore, the power loss in dc line will be lesser compared to ac line.

Good voltage Regulation:

- In dc lines voltage drop does not exist due to inductive reactance. Voltage Regulation will be better in HVDC transmission.

Surge Impedance Loading:

- Long EHV lines are loaded to less than 80% of natural load. No such condition is applicable in HVDC transmission.

HVDC Technical Advantages

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No Line Loading Limit:

- The permissible loading limit on EHV AC lines are limited by the transient stability limit and the line reactance to almost one third of the thermal rating of the conductors. No such limit exists in the case of HVDC line.

Lesser Coronal Loss and Radio Interference:

- Corona Loss directly proportional to frequency. Therefore, in DC line corona loss will be lesser compared to AC line.

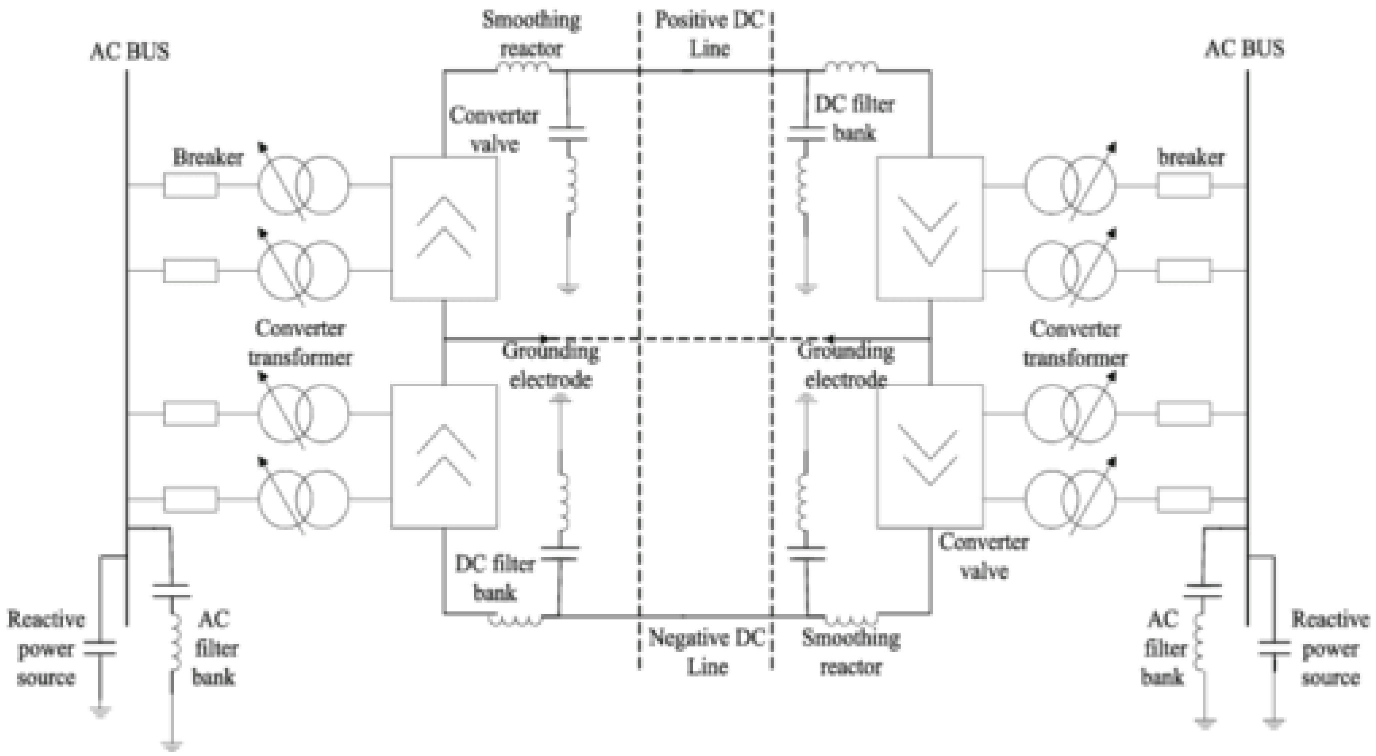
Higher Operating Voltages:

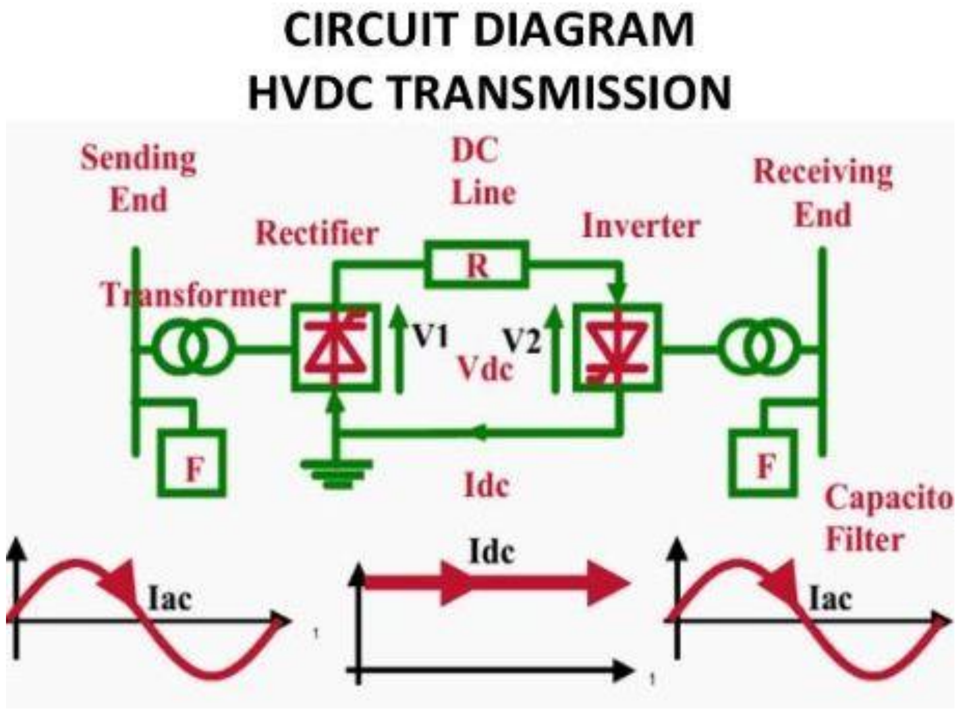
- Design of Insulation of the conductors for high voltage transmission lines depends on the switching surges but not on lightning surges. The level of switching surge will be lesser in DC line compared to AC line. Hence less insulation is required in DC line.

Reactive Power Compensation:

- Unlike AC line DC line does not require any reactive power compensation devices. This is because of the absence of charging currents and power factor operation.

HVDC Transmission Components & Working



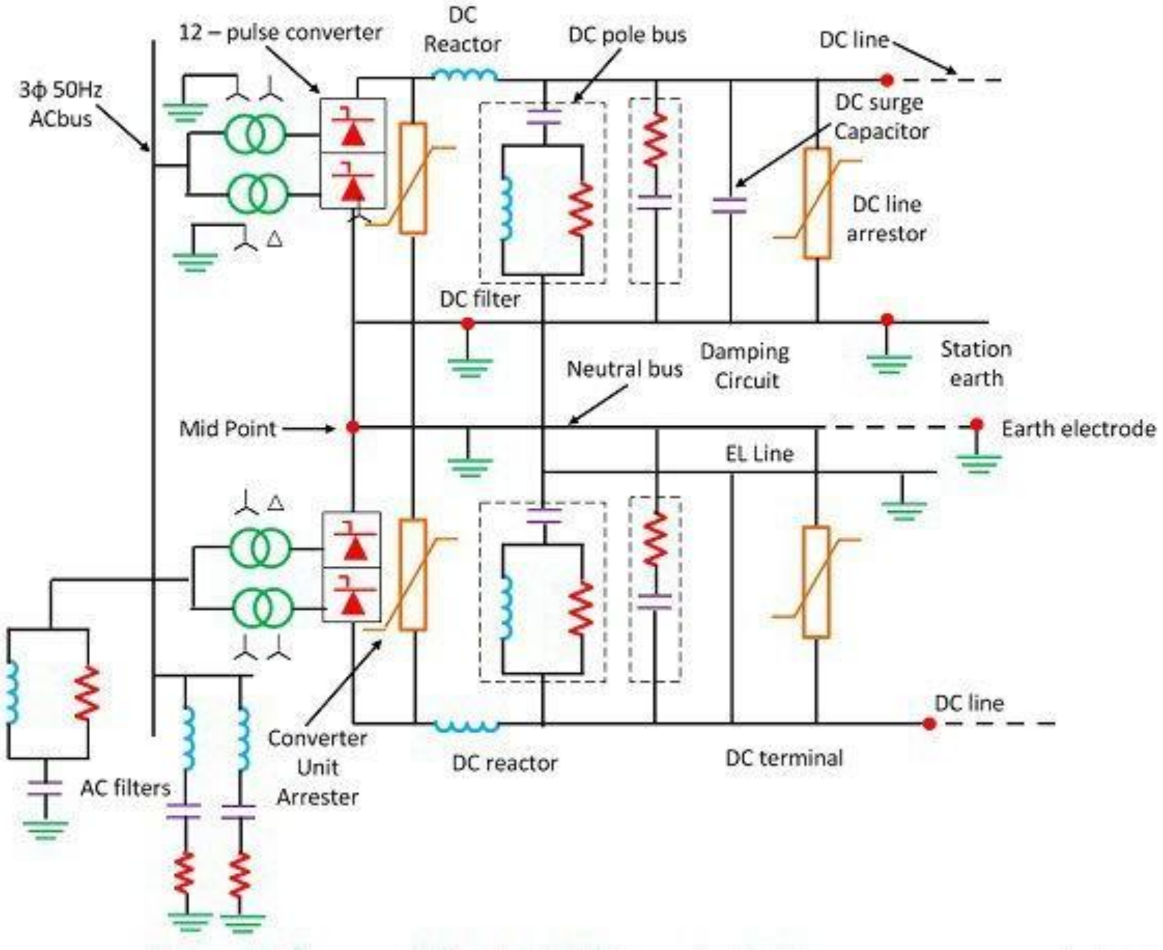


HVDC Transmission Components & Working

- HVDC transmission utilizes converter stations at either end of the system.
- A mercury arc valve or solid-state valve (thyristor) is used for the conversion of AC and DC current.
- The valve at the beginning of the system converts alternating current to HVDC, the HVDC travels to the next location through a cable.
- The valve at the end of the system converts the HVDC back to alternating current.

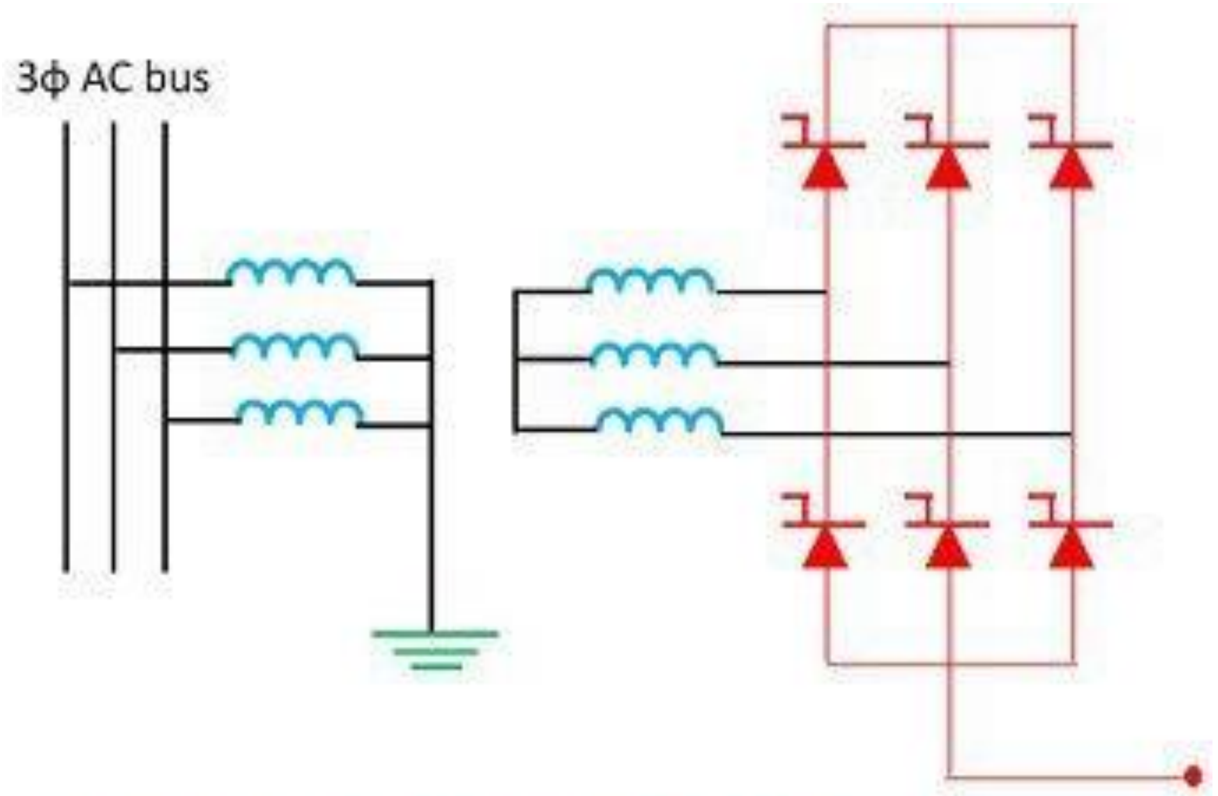
HVDC Converter Station

- The terminal substations which convert an AC to DC are called rectifier terminal while the terminal substations which convert DC to AC are called inverter terminal.
- Every terminal is designed to work in both the rectifier and inverter mode.
- Therefore, each terminal is called converter terminal, or rectifier terminal.
- A two-terminal HVDC system has only two terminals and one HVDC line.



HVDC Converter Unit

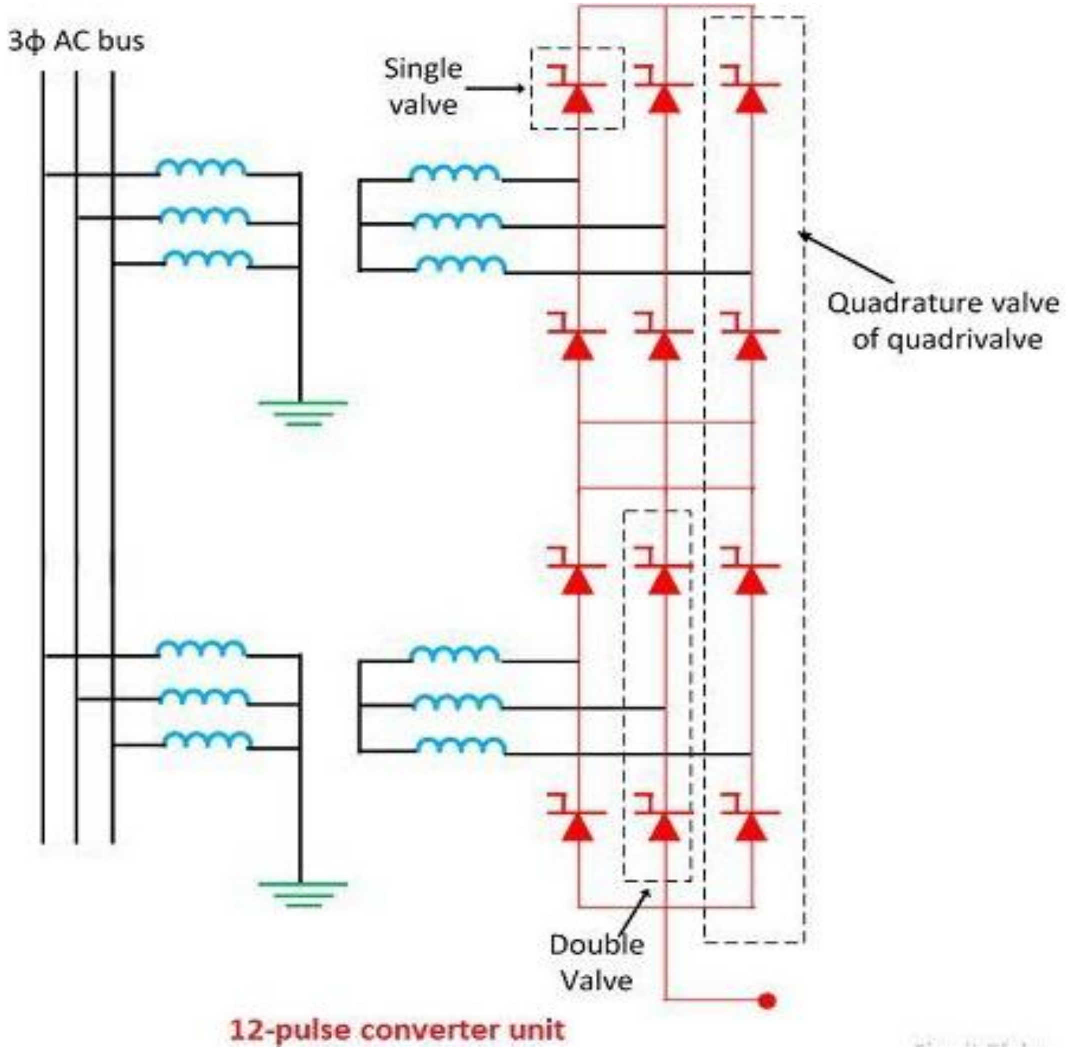
- The conversion from AC to DC and vice versa is done in HVDC converter stations by using three-phase bridge converters.
- This bridge circuit is also called Graetz circuit.
- In HVDC transmission a 12-pulse bridge converter is used.
- The converter obtains by connecting two or 6-pulse bridge in series.



6-pulse converter unit (Graetz Circuit)

HVDC Converter Valves

- The modern HVDC converters use 12-pulse converter units.
- The total number of valves in each unit is 12.
- The valve is made up of series connected thyristor modules.
- The number of thyristor valve depends on the required voltage across the valve.
- The valves are installed in valve halls, and they are cooled by air, oil, water or freon.

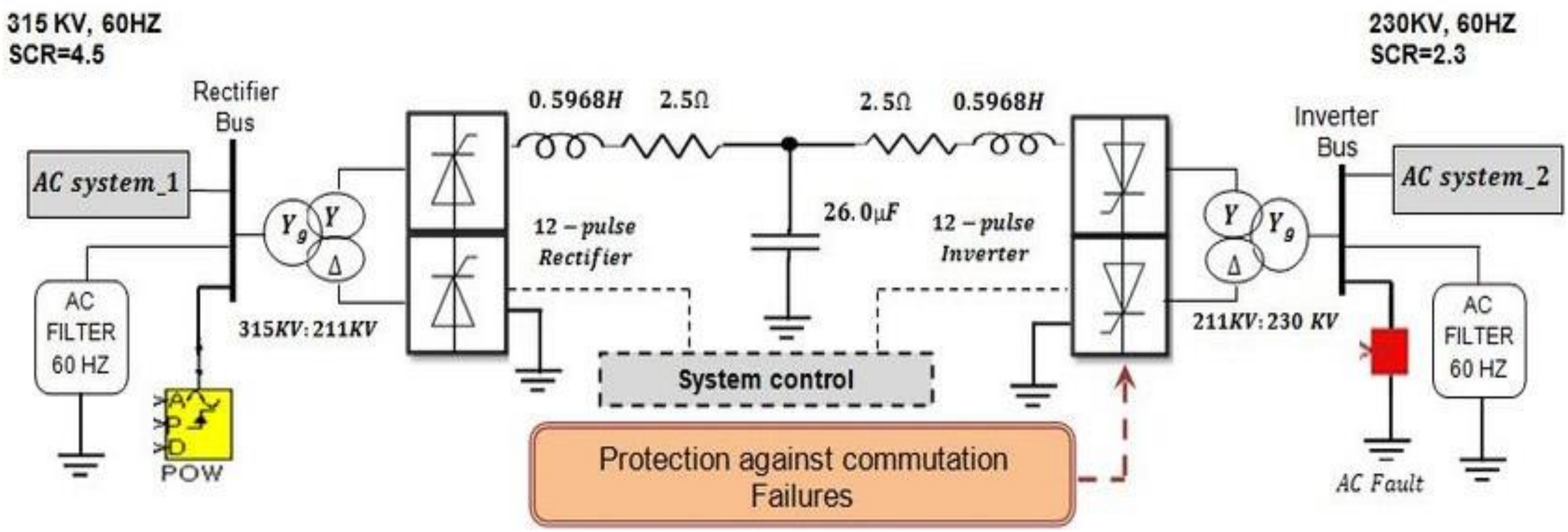


HVDC Converter Transformer

- The converter transformer converts the AC networks to DC networks or vice versa.
- They have two sets of three phase windings.
- The AC side winding is connected to the AC bus bar, and the valve side winding is connected to valve bridge.
- These windings are connected in star for one transformer and delta to another.
- The AC side windings of the two, three phase transformer are connected in stars with their neutrals grounded.
- The valve side transformer winding is designed to withstand alternating voltage stress and direct voltage stress from valve bridge.

World's first 1,100 kV HVDC transformer

HVDC Converter Transformer



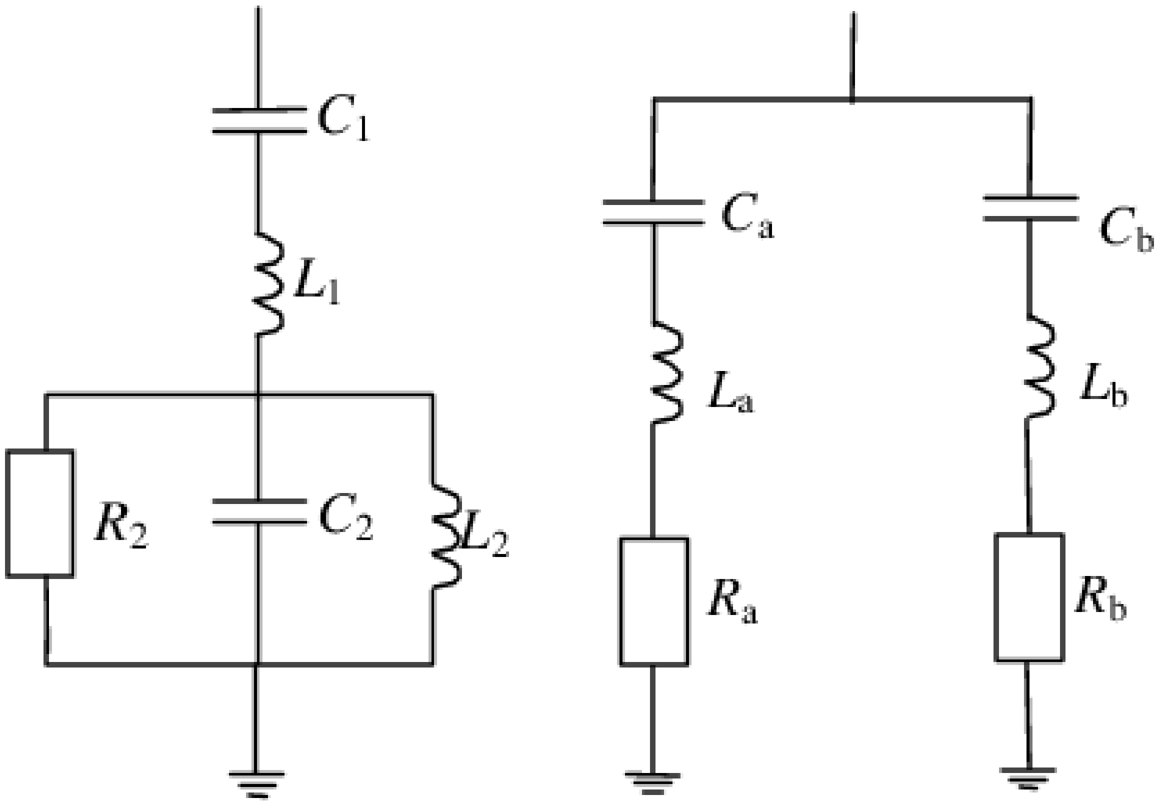
HVDC Transmission Filters

- The AC and DC harmonics are generated in HVDC converters.
- The AC harmonics are injected into the AC system, and the DC harmonics are injected into DC lines.
- The harmonics have the following disadvantages.
    1. It causes the interference in telephone lines.
    2. Due to the harmonics, the power losses in machines and capacitors are connected in the system.
    3. The harmonics produced resonance in an AC circuit resulting in over voltages.
    4. Instability of converter controls.

HVDC Transmission Filters

AC Filters

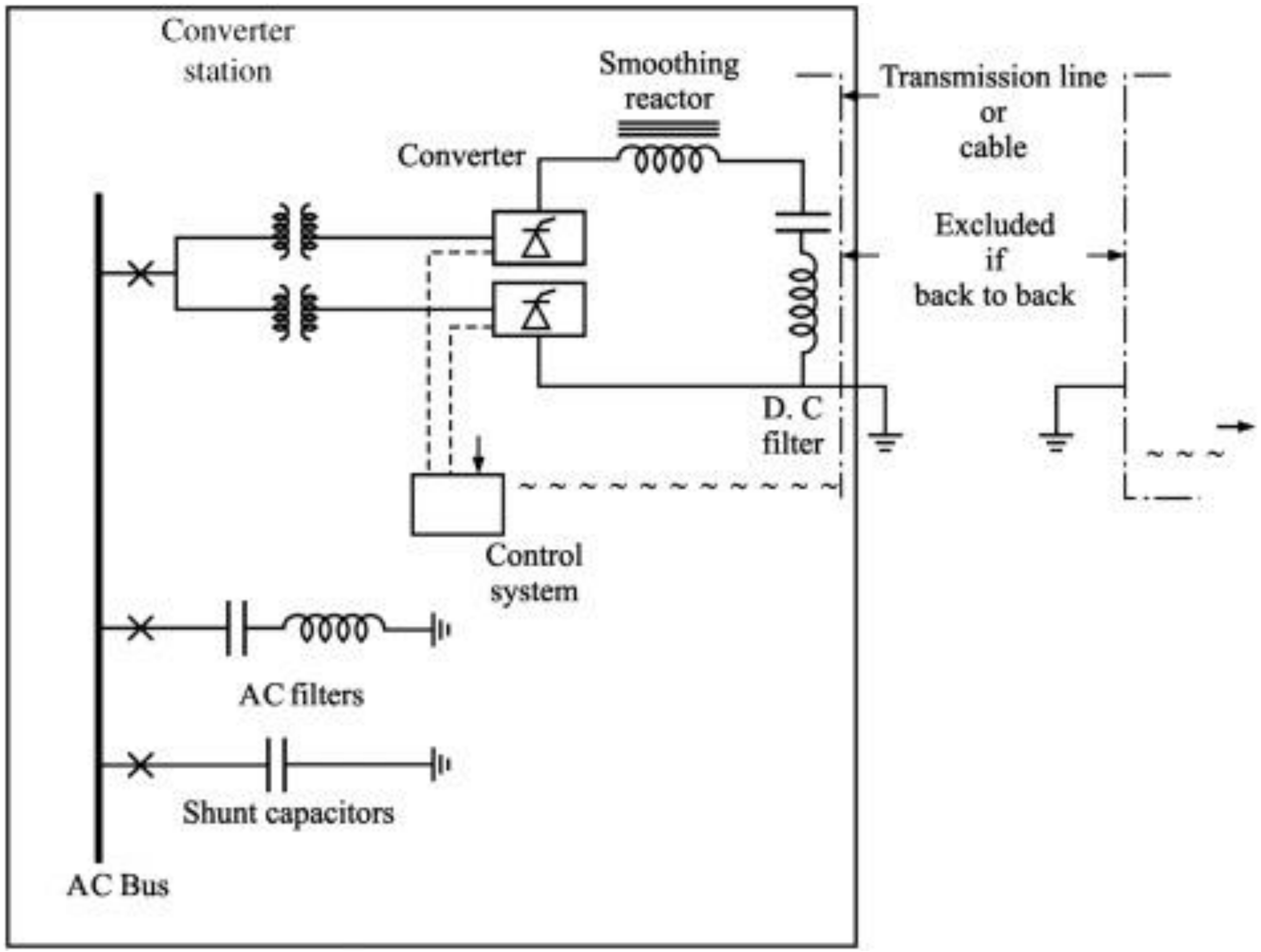
- The AC filters are RLC circuit connected between phase and earth.
- They offered low impedances to the harmonic frequencies.
- Thus, the AC harmonic currents are passed to earth.
- Both tuned and damped filters are used.
- The AC harmonic filter also provided a reactive power required for satisfactory operation of converters.



HVDC Transmission Filters

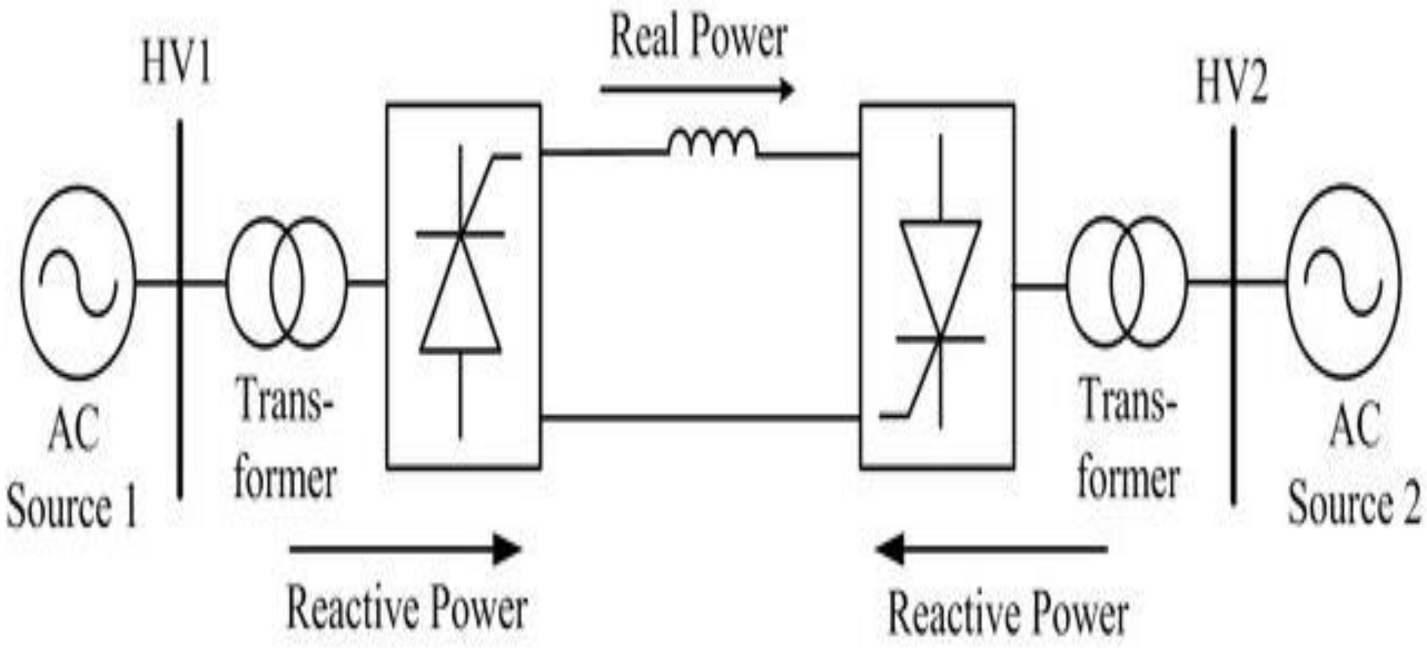
DC Filters

- The DC filter is connected between the pole bus and neutral bus.
- It diverts the DC harmonics to earth and prevents them from entering DC lines.
- Such a filter does not require reactive power as DC line does not require DC power.



HVDC Transmission Reactive Power Source

- Reactive power is required for the operations of the converters.
- The AC harmonic filters provide reactive power partly.
- The additional supply may also be obtained from shunt capacitors synchronous phase modifiers and static var systems.
- The choice depends on the speed of control desired.



HVDC Transmission Smoothing Reactor

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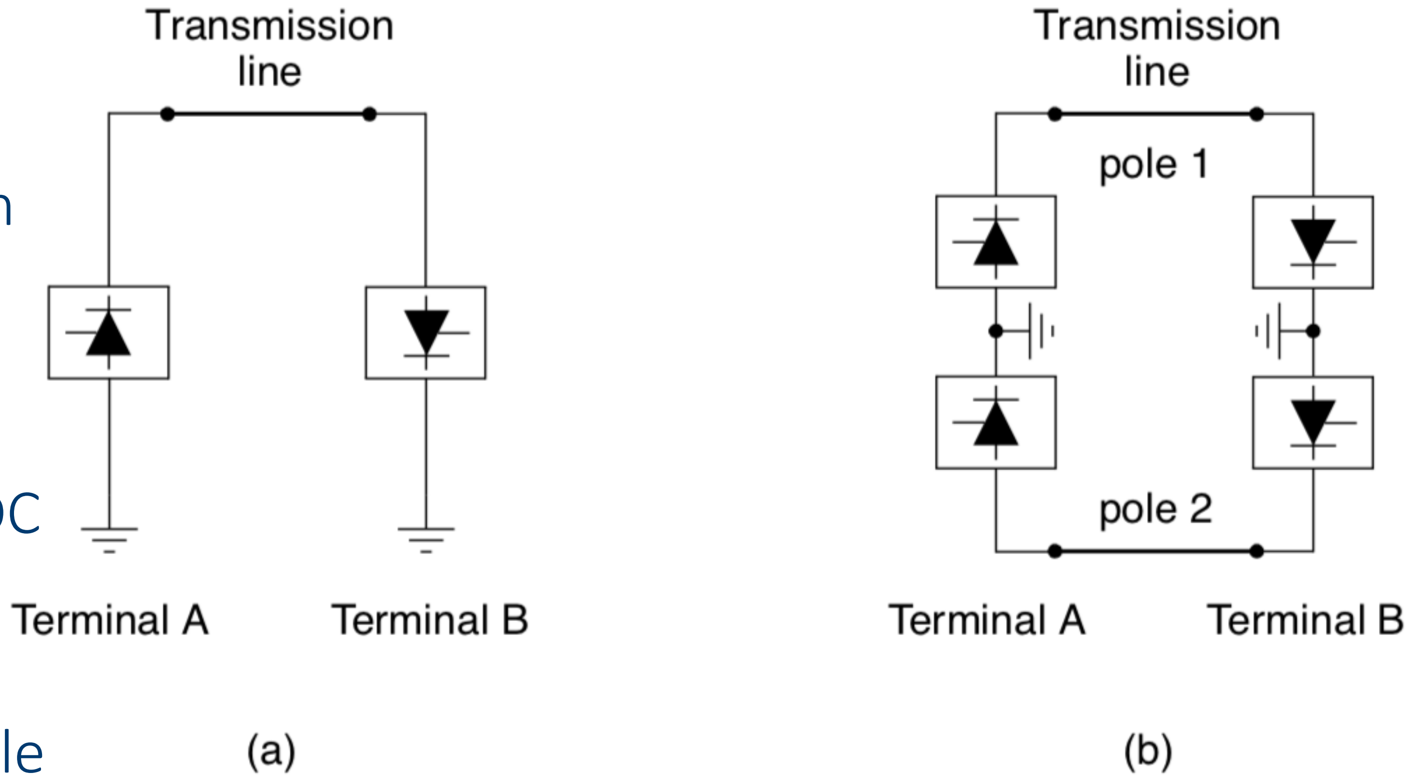
- Smoothing reactor is an oil filled oil cooled reactor having a large inductance.
- It is connected in series with the converter before the DC filter.
- It can be located either on the line side or on the neutral side.
- Smoothing reactors serve the following purposes.
  - They smooth the ripples in the direct current.
  - They decrease the harmonic voltage and current in the DC lines.
  - They limit the fault current in the DC line.
  - Consequent commutation failures in inverters are prevented by smoothing reactors by reducing the rate of rising of the DC line in the bridge when the direct voltage of another series connected voltage collapses.
  - Smoothing reactors reduce the steepness of voltage and current surges from the DC line. Thus, the stresses on the converter valves and valve surge diverters are reduced.

HVDC Transmission System Pole

- The HVDC system pole is the part of an HVDC system consisting of all the equipment in the HVDC substation.
- It also interconnects the transmission lines which during normal operating condition exhibit a common direct polarity with respect to earth.
- The word pole refers to the path of DC which has the same polarity with respect to earth.
- The total pole includes substation pole and transmission line pole.



HVDC Transmission Types

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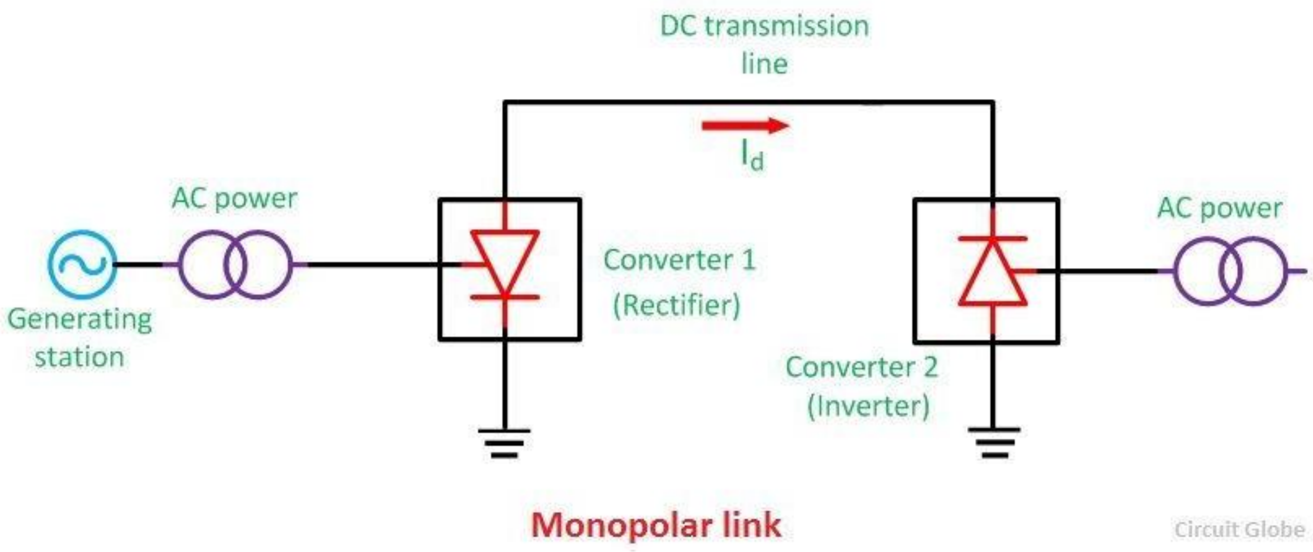
- HVDC Configuration
  - Monopole
  - Bipolar
  - Back-to-Back
  - Multi-terminal System
  - Tripolar

HVDC Transmission Types

<u>Monopolar Link</u>

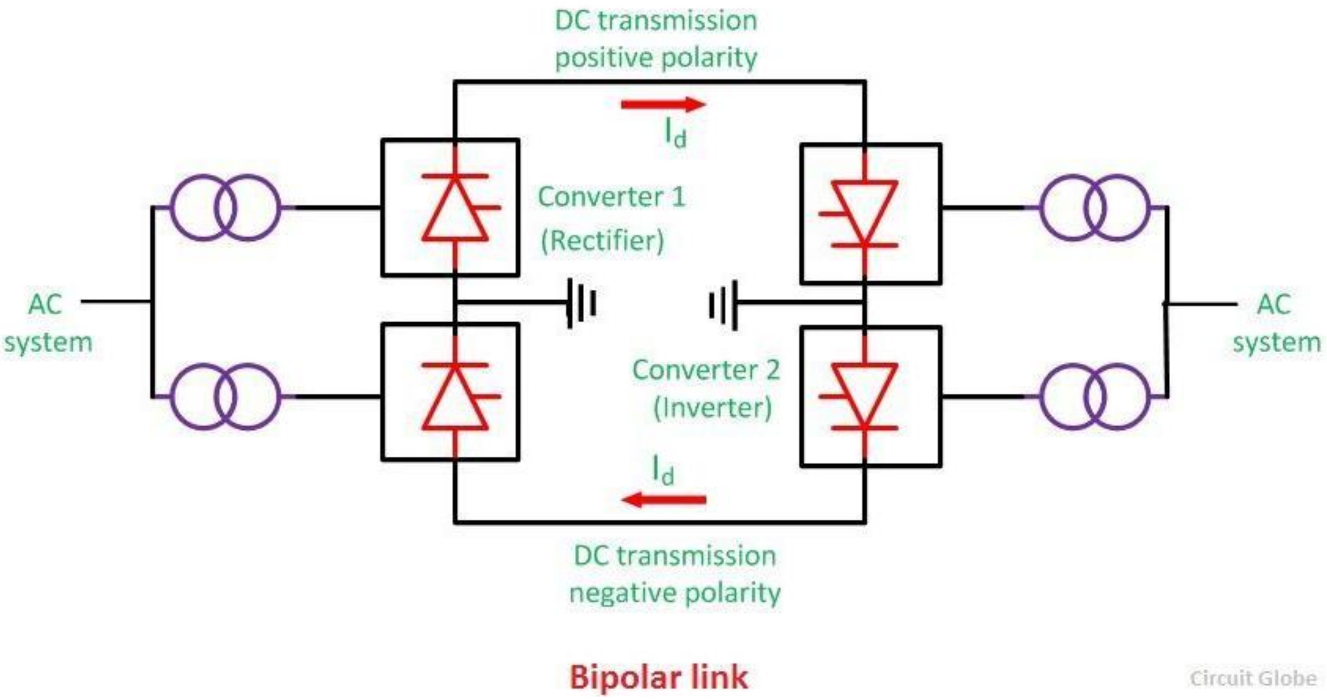
- It has a single conductor of negative polarity and uses earth or sea for the return path of current.
- Sometimes the metallic return is also used.
- In the Monopolar link, two converters are placed at the end of each pole.
- Earthing of poles is done by earth electrodes placed about 15 to 55 km away from the respective terminal stations.
- But this link has several disadvantages because it uses earth as a return path.
- The monopolar link is not much in use nowadays.



HVDC Transmission Types

Bipolar Link

- The Bipolar link has two conductors one is positive, and the other one is negative to the earth.
- The link has converter station at each end.
- The midpoints of the converter stations are earthed through electrodes.
- The voltage of the earthed electrodes is just half the voltage of the conductor used for transmission the HVDC.

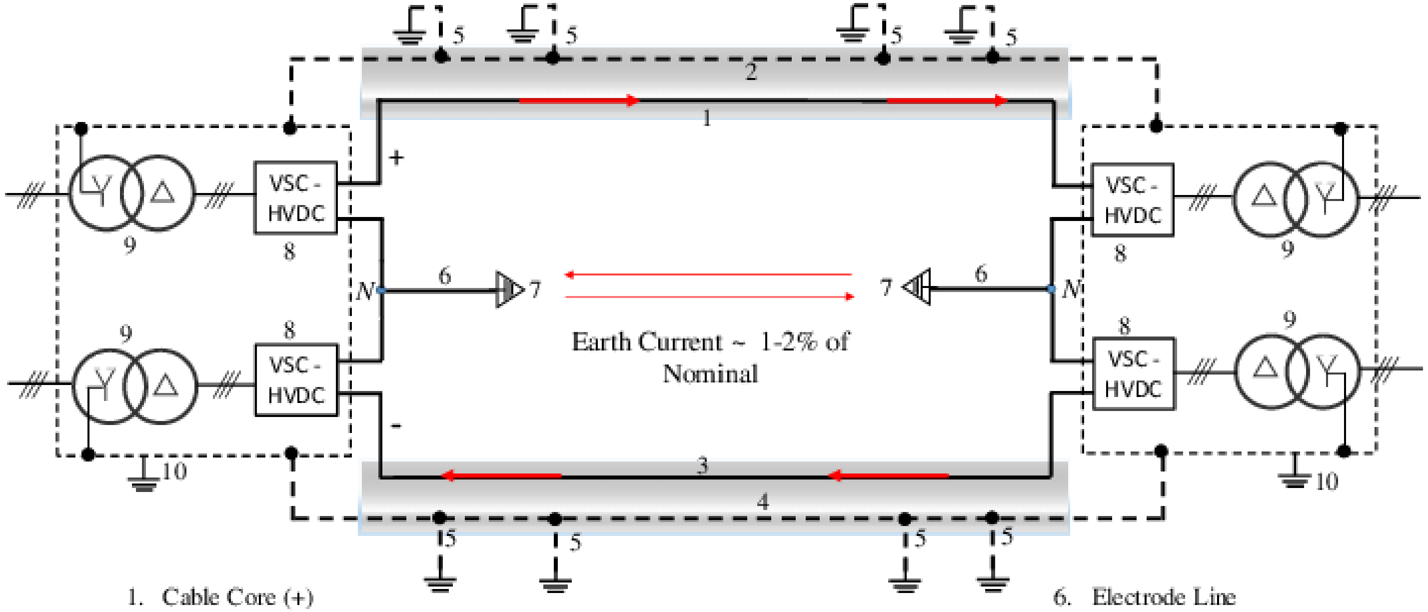


HVDC Transmission Types

Bipolar Link

- The most significant advantage of the bipolar link is that if any of their links stop operating, the link is converted into Monopolar mode because of the ground return system.

- The half of the system continues supplies the power. Such types of links are commonly used in the HVDC systems.



1. Cable Core (+)
2. Cable Sheath (+)
3. Cable Core (-)
4. Cable Sheath (-)
5. Sheath Bonding to Earth
6. Electrode Line
7. Earth Electrode
8. VSC-Convertor (MMC)
9. Convertor/Interface Transformer
10. Station Earthing Grid

HVDC Transmission Types

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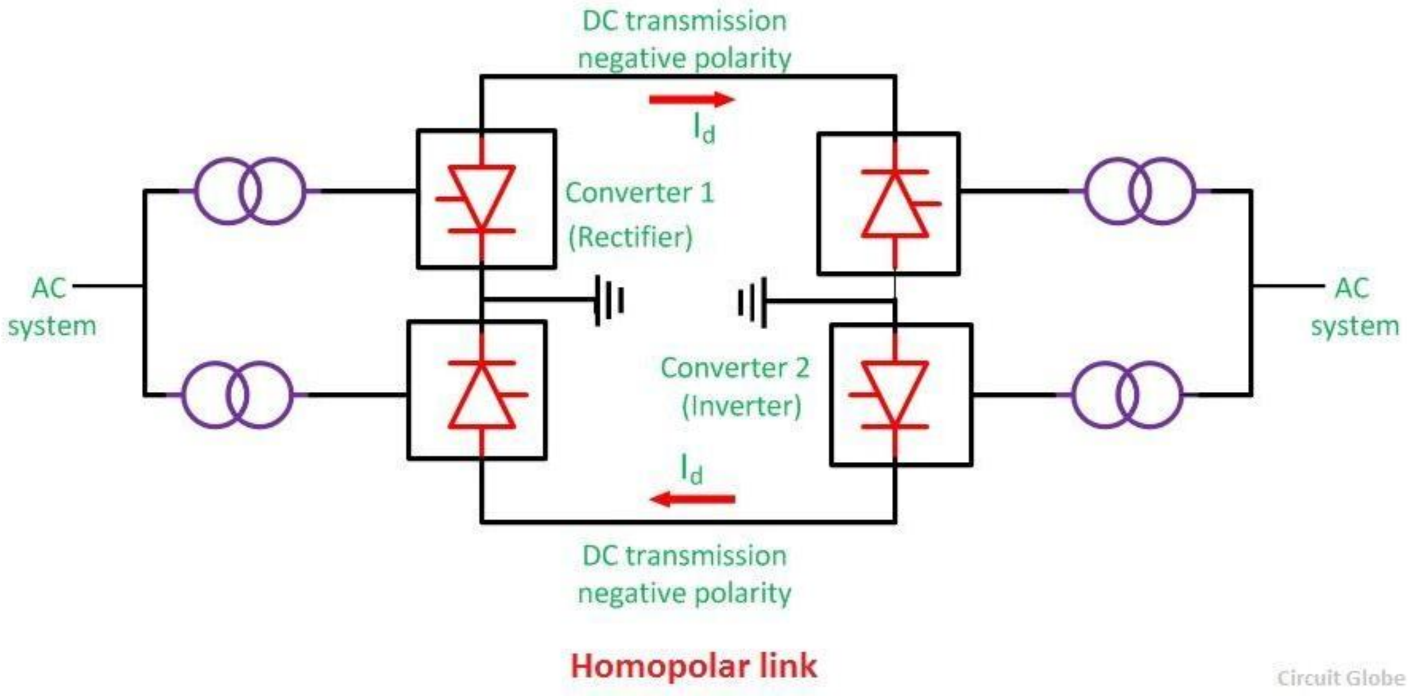
Homopolar Link

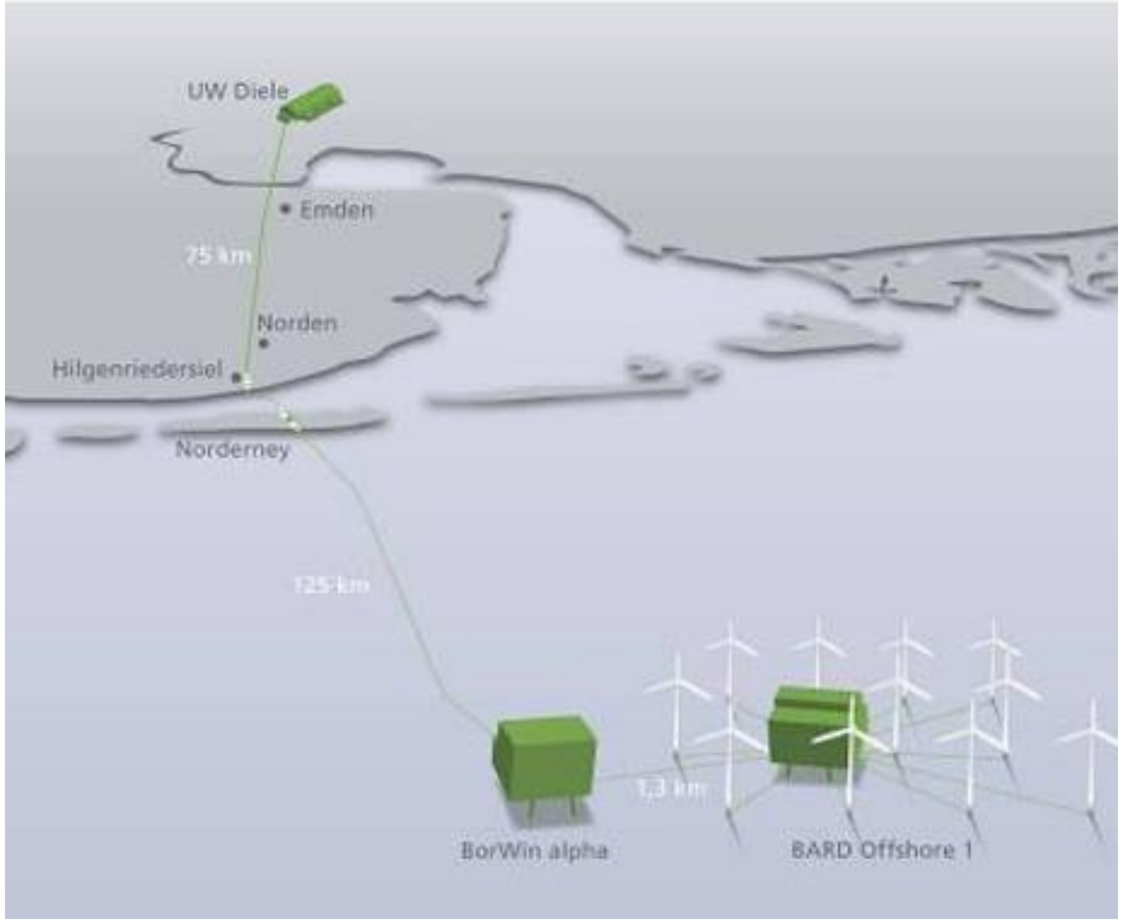
- It has two conductors of the same polarity usually negative polarity, and always operates with earth or metallic return.
- In the homopolar link, poles are operated in parallel, which reduces the insulation cost.



HVDC for Sustainable Applications

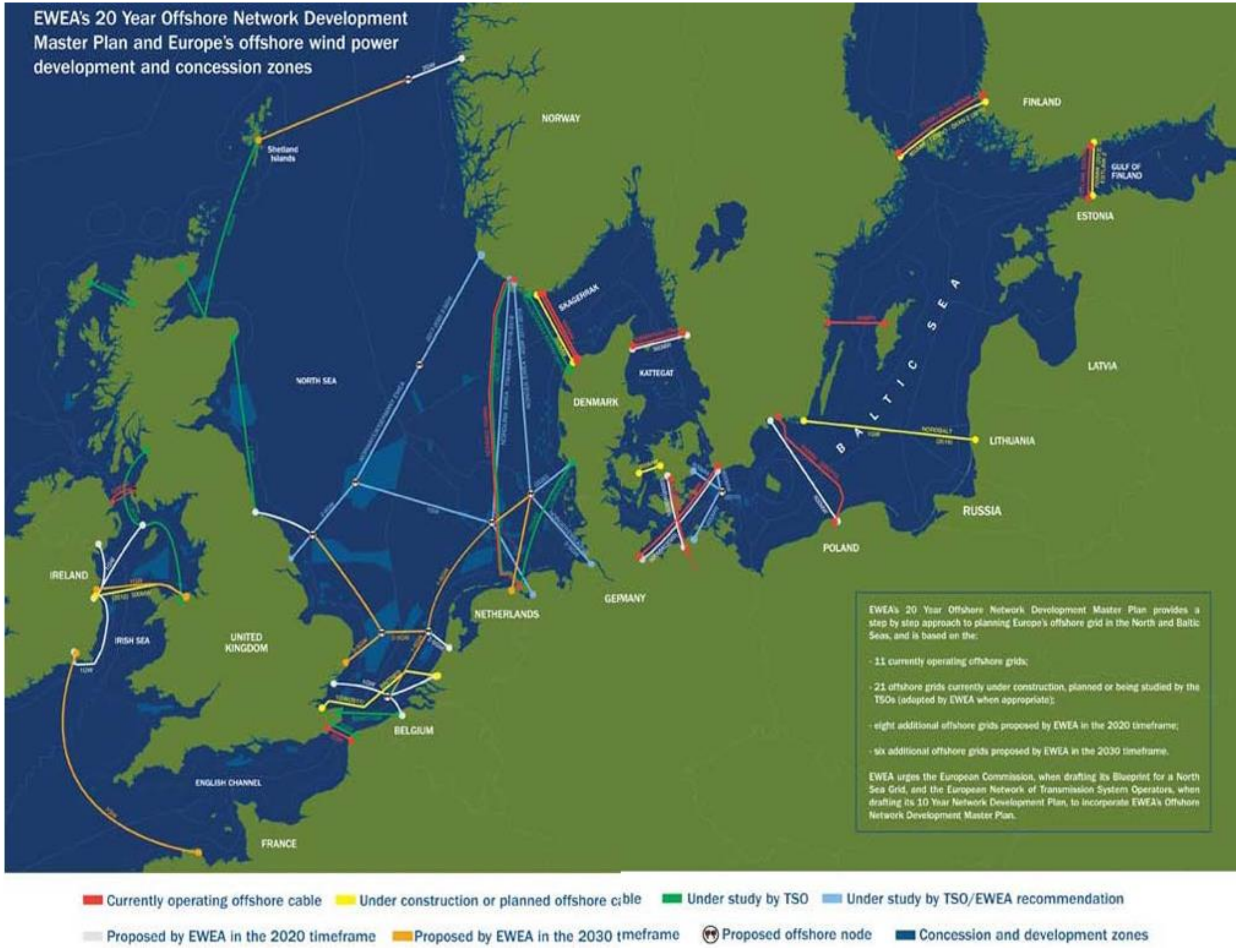
- HVDC transmission technology plays a key role in the development of our future sustainable transmission grids.
- There are several important applications where HVDC has shown to be the most advantageous alternative in the grid toolbox.
- All of them assist in reducing CO2 emission in different ways.
- The applications already delivered can be grouped as follows:
    - Bulk power transmission from large, concentrated but remote energy sources, such as large-scale hydropower plants (LCC HVDC)
    - Offshore wind farms and remote land-based wind farms, sometimes at a moderate distances from load centers but inaccessible to present HVAC grids (VSC HVDC)
    - Embedded HVDC links for improving HVAC grid performance and that consequently facilitate introduction of renewable energy into the grid (VSC HVDC)
    - National or regional grids that interconnect with one another (LCC and VSC HVDC) • Supply of electrical power from shore to oil and gas offshore platforms

HVDC for Sustainable Applications



HVDC for Sustainable Applications

Offshore DC grid as proposed by EWEA (European Wind Energy Association)



Conclusion

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- By using HVDC, transmission grids can be optimized and controlled to support the introduction of renewable generation into the grid.
- Finally, HVDC is also useful in supplying power to offshore oil and gas platforms.
- DC grids will surely add several important features for handling future sustainable power generation, but it also involves challenges.
- There are technical challenges, but the main concern is around international regulations in order to manage the grids of the future.
- Most of the basic technology required is available and the fundamental standards are being developed.
- HVDC systems ordered during 2007-2009 corresponded to connection of more than 30 GW of renewable energy.
- It is therefore safe to say that HVDC is playing a key role in the transformation of our energy systems.

Thank you!

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