10th IERE webinar on High Voltage Direct Current (HVDC)
– HVDC Technology for the New Generation Power Grid –

Introduction

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Outline

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- DC and AC
- Classification of DC Voltage
- Characteristics of DC and AC Transmission
- Cost Comparison of DC and AC Transmission
- Basic Configuration of HVDC System
- Pole Configuration of HVDC System
- LCC and VSC
- Two-terminal HVDC and Muti-terminal HVDC
- Background, Applications and Technical Challenges
- Conclusion

DC and AC

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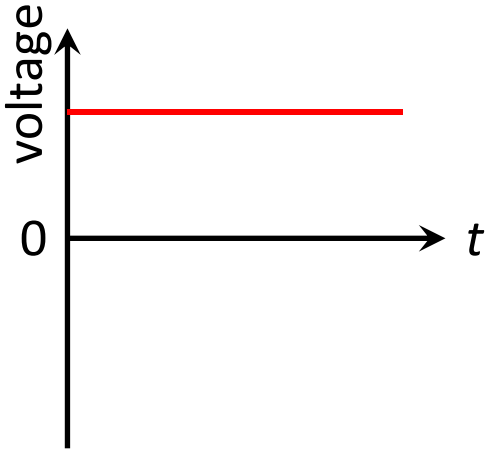
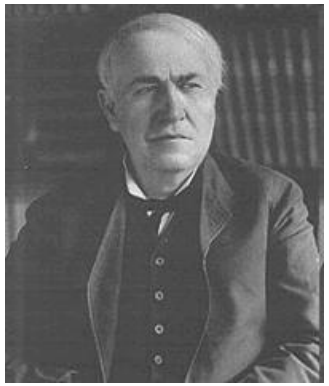
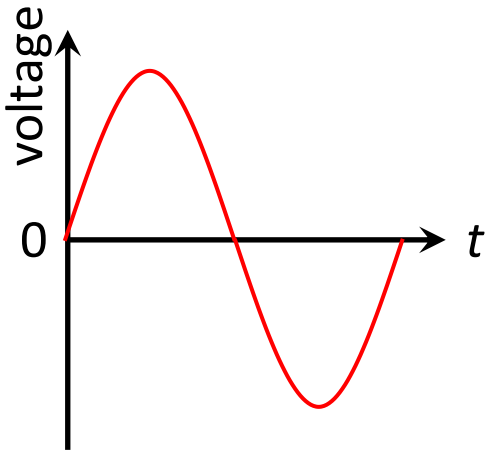
- In the late 1880s, Edison proposed the commercialization of power supply using DC, while Tesla proposed power supply using AC.
- At that time, AC became the global standard because voltage conversion was easy, while DC was difficult to step up or step down in voltage.
- In recent years, with the advancement of power electronics technology and the expansion of renewable energy, DC has once again come into the spotlight.

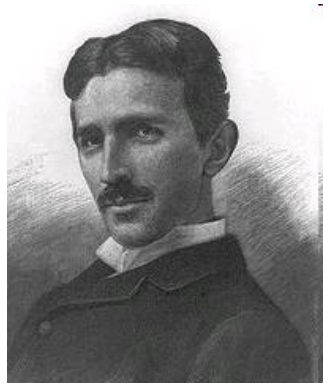




T. Edison

- Power supply using DC began commercially in 1882.

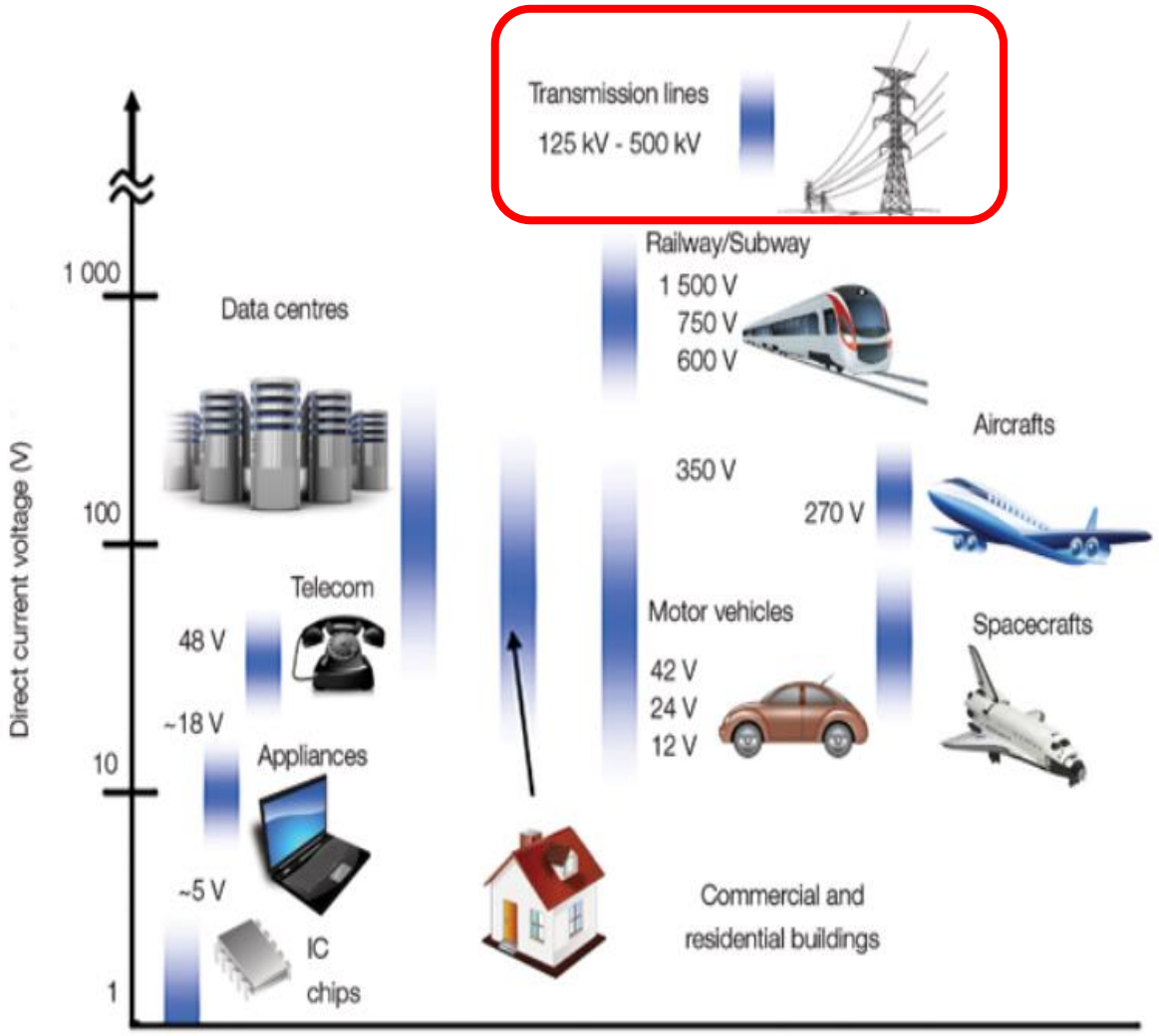




N. Tesla

- Power supply using AC was proposed in 1884.
- Long-distance AC transmission was put into practical use in 1896.

Classification of DC Voltage



IEC Technology Report : "LVDC : electricity for the 21st century"

Classification of DC Voltage by IEC

Classification	DC	AC
High Voltage	> 1,500 V	> 1,000 V
Low Voltage	≤ 1,500 V	≤ 1,000 V
Extra-low Voltage	≤ 120 V	≤ 50 V

- **HVDC**
  - High Voltage Direct Current
  - Vdc ≥ around 30 kV
    (or Vdc ≥ 100 kV to 200 kV)
- **MVDC**
  - Middle Voltage Direct Current
  - 1,500 V < Vdc < around 30 kV
- **LVDC**
  - Low Voltage Direct Current
  - ≤ 1,500 V

Characteristics of DC and AC Transmission

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Item	DC Transmission	AC Transmission	Remark
Number of Conductors (Overhead Line, Cable)	✓ 2(main and return lines)	✗ 3 (three-phase lines)	DC has lower lost
Long-Distance Transmission (Cable Transmission)	✓	✗ * system stability * Ferranti effect	DC is advantageous for cable transmi-ssion
Transmission Capacity	✓ * thermal constraint	✗ * thermal constraint * reactive power losses * skin effect	
Insulation Design	✓ low	✗ high	
Transmission Efficiency	✓ high	✗ low	
Voltage Conversion	✗ not easy	✓ easy (transformer)	
AC/DC converter	✗ required	✓ not required	
Circuit Breaker	✗ not easy	✓ easy (zero crossing)	

Cost Comparison of DC and AC Transmission

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▶ AC/DC Converters

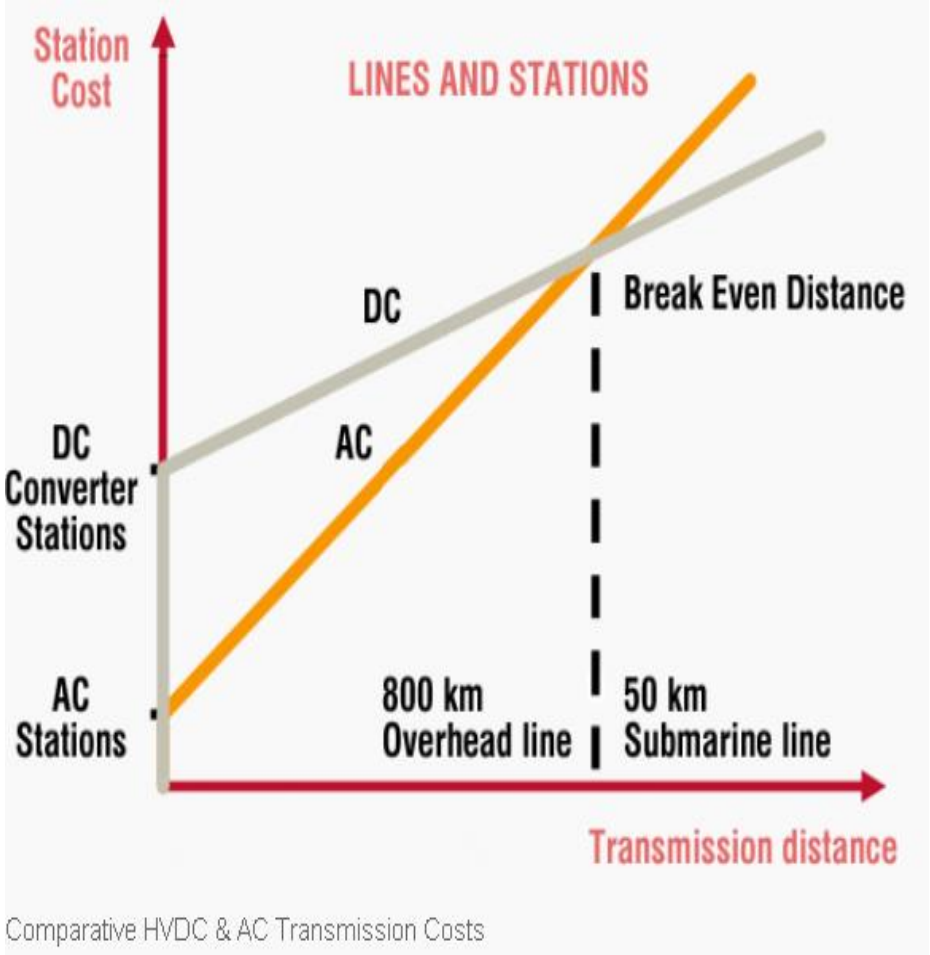
In HVDC transmission, converter stations are required for system interconnection regardless of the transmission distance.

▶ Transmission Efficiency

HVDC transmission offers higher transmission efficiency and becomes more economical as the transmission distance increases.

▶ Power System Stability and Reactive Power Supply

As the transmission distance increases, HVAC transmission requires reactive power compensation to keep power system stability and to compensate AC cable charging current.



Comparative HVDC & AC Transmission Costs

Analysing the Costs of High Voltage Direct Current (HVDC) Transmission (6 August 2014)

Basic Configuration of HVDC System

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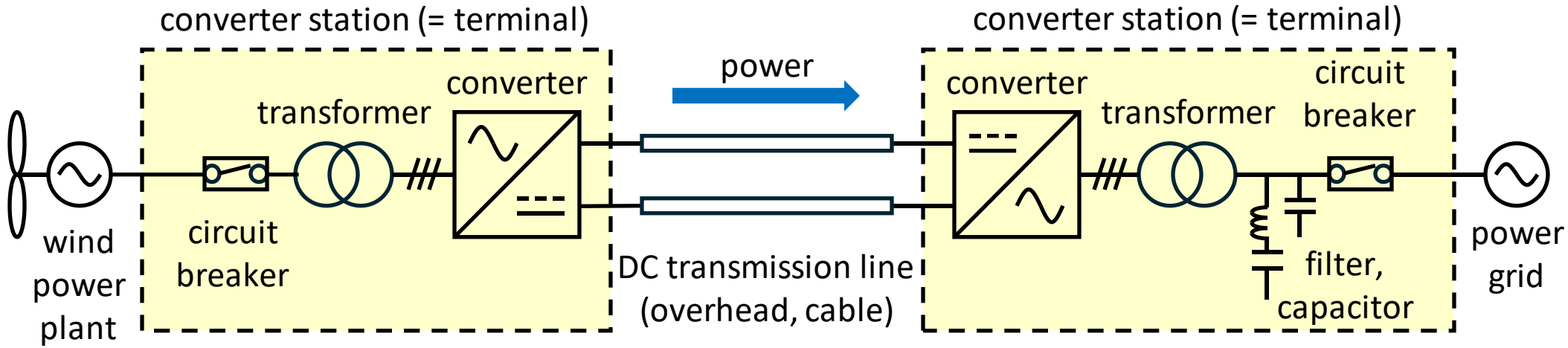
▶ An example of power transmission from wind power plant to a power grid



▶ AC/DC converters

Using power semiconductor devices, power is converted from AC to DC at the sending terminal and from DC to AC at the receiving terminal.

▶ DC transmission lines

Overhead line, underground cable, or submarine cable

▶ Control and protection equipment

Converter control and protection panels, AC circuit breakers, etc.

▶ LC filters & capacitors

Harmonic absorption and reactive power compensation

Pole Configuration of HVDC System

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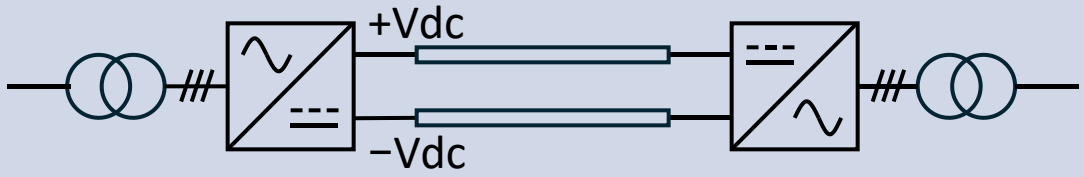
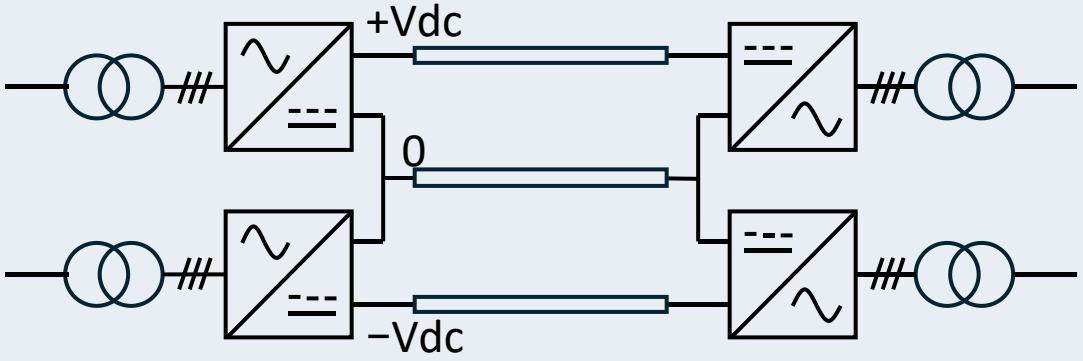
Name	Configuration	Remarks
Symmetric Monopole		▶ Simple configuration ▶ Configuration with two DC cables ▶ The entire system shuts down in the event of a DC line fault
Bipole		▶ Configuration with three DC cables ▶ Can continue operation at half output even in the event of a DC line fault ▶ Requires approximately twice the foot-print and building size compared with a symmetric monopole of the same capacity

LCC and VSC

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Item	LCC (Line-Commutated Converter)	VSC (Voltage Source Converter)
Power Device Type	thyristor	IGBT
Gate Turn on/off	gate turn on	gate turn on and off
Power Device Rating	high voltage, large current short-circuit withstand capability	high voltage, large current
AC Grid Voltage	required	not required black-start capable
Harmonic Filters	required	not required
Controllability	not flexible	flexible
Reactive Power	not controllable, must be compensated	controllable
System Configuration and Cost	simple, lower cost	complicated, higher cost
Footprint	requires a larger footprint (with filters and capacitors)	requires a smaller footprint (without filters and capacitors)
Technological Maturity	matured	in progressing

Two-terminal HVDC and Muti-terminal HVDC

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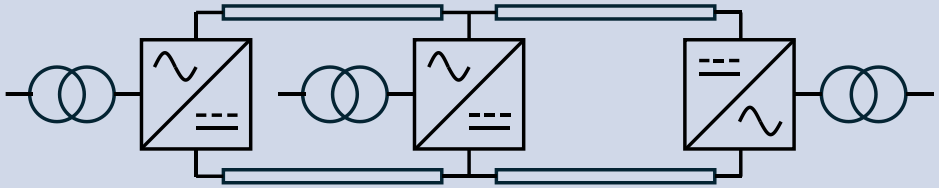
Item	Two-terminal HVDC System	Multi-terminal HVDC System
Typical Circuit		
Basic Configuration	one sending and one receiving converter station	three or more converter stations connected to a common DC network
System Complexity	simple configuration and control	complex control and coordination required
Converter Control	simple DC voltage/power control	coordinated DC voltage and power control among terminals
Protection	easy fault isolation	difficult fault isolation requires DC circuit breakers
Reliability	stops if one converter has a failure	power can be rerouted through other terminals
Applications	long-distance, submarine, back-to-back	DC grids, offshore wind integration
Technology Maturity	well-established and proven	still evolving and developing

Background, Applications and Technical Challenges

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▶ Background of HVDC Installation

- Growing demand for long-distance, large-capacity power transmission
- Integration of renewable energy sources

▶ Application Examples

- Long-distance bulk power transmission
- Submarine cable systems
- Offshore wind power integration
- International interconnection for power trading and reserve sharing

▶ Technical Challenges

- Multi-terminal HVDC control and protection
- Fast DC circuit breakers
- Grid-forming control to support AC system stability
- Multi-vendor interoperability

Conclusion

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- This presentation provides a brief overview of HVDC configurations, advantages, and classifications.
- The background, application examples, and technical challenges have also been explained.
- HVDC is a key technology for the renewable energy age. HVDC also enables efficient and flexible power transmission.
- R&D will continue on multi-terminal HVDC, DC circuit breakers, and interoperability.
- HVDC will become the backbone of future power networks.