



# **Electrical Power Transmission & Distribution (DI03000101)**

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# **UNIT-3**

## **HVAC & HVDC**

### **SYSTEMS**

# ECONOMICAL CONSIDERATION IN THE CHOICE OF SYSTEM VOLTAGE

## Basic Economic Principle

- **Conductor cost**
  - Increasing transmission voltage **reduces conductor cost**
  - higher voltage lowers current for the same power, allowing the use of thinner conductors and lighter supporting structures.
- **Equipment costs**
  - **equipment costs rise** with voltage
  - transformers, insulators, switchgear, and lightning arrestors costs increase rapidly as voltage rises.

# **FACTORS AFFECTING TRANSMISSION VOLTAGE**

- **Power to be transmitted**
- **Length of transmission line**
- **Generation voltage**
- **Conductor size & cost**
- **Insulation & Equipment costs**
- **Efficiency**
- **Future growth**

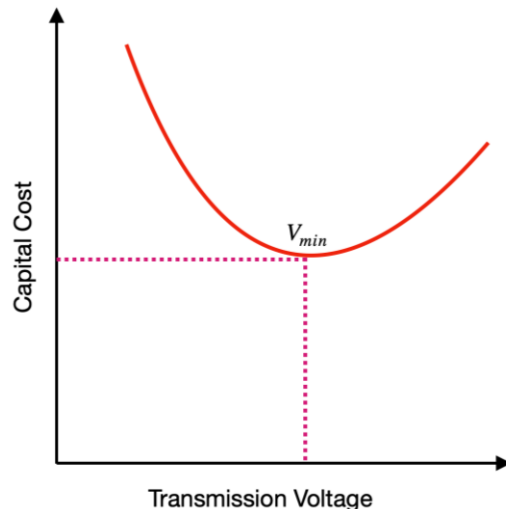
# SELECTION OF ECONOMICAL TRANSMISSION VOLTAGE

$$V = 5.5 \sqrt{0.62l + \frac{3P}{150}}$$

$V$  = line voltage in kV

$l$  = line length in km

$P$  = per-phase maximum power in kW



## TRANSMISSION LINE VOLTAGE SELECTION

SHORT



UNDER 50 km

UP TO **5 MW**

**11-33 kV**

MEDIUM



50-150 km

UP TO **50 MW**

**66-132 kV**

LONG



OVER 150 km

OVER **100 MW**

**220 kV+**

VERY LONG



OVER 500 km

OVER **1000 MW**

or **HVDC**

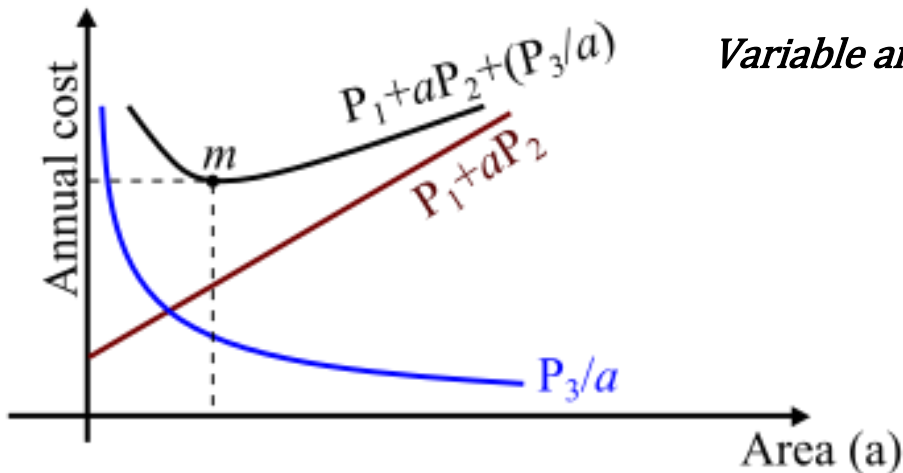
# SELECTION OF ECONOMICAL CONDUCTOR SIZE

**Kelvin's Law** states that the most economical conductor size is achieved when the total annual cost is minimum.

- Annual charges on capital cost (interest, depreciation, installation of conductors and supports).
- Annual cost due to energy wasted ( $I^2R$  losses in conductors).

$$Y = P_1 + P_2a + \frac{P_3}{a}$$

$$P_2a = \frac{P_3}{a}$$



*Variable annual charge = Annual cost of energy wasted*

# CONDUCTOR SELECTION

## Current Carrying Capacity:

- Conductor must safely carry the intended load current without overheating

## Voltage Drop:

- Lower resistance (larger size) reduces voltage drop along the line, improving system performance

## Short-circuit Rating:

- Sufficient size needed for fault conditions

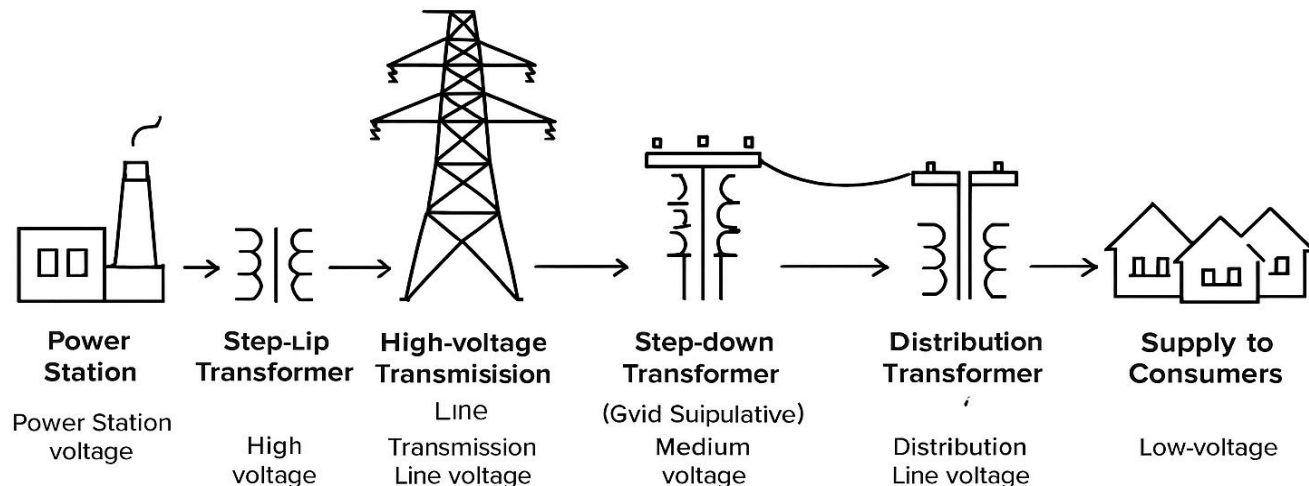
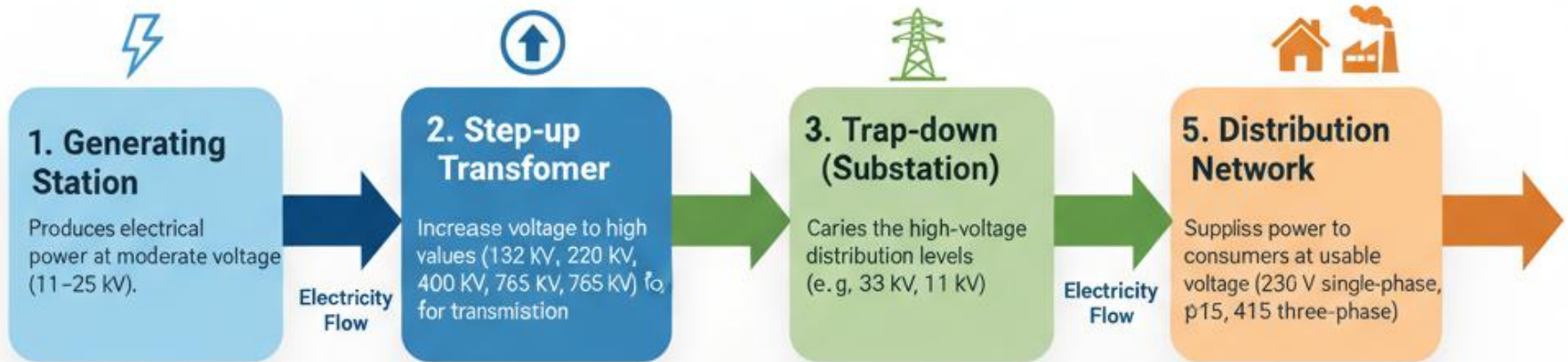
## Mechanical Strength:

- Larger sizes may be required in overhead lines for mechanical reliability

## Material and Installation Cost:

- Larger conductors increase both material and supporting infrastructure cost.

# HVAC TRANSMISSION



# ADVANTAGES OF HVAC

## Efficient Long-Distance Transmission

- High voltage reduces current, which minimizes  $I^2R$  losses (power loss due to resistance).
- HVAC systems can transmit power over hundreds of kilometers efficiently.

## Easy Voltage Transformation

- Using transformers, voltage can be easily stepped up for transmission and down for distribution.
- This flexibility is a major reason why HVAC is widely used.

## Established Infrastructure

- HVAC systems have been in use for over a century.
- Components like transformers, circuit breakers, insulators, and protection systems are well-developed and readily available.

## Cost-Effective

- Compared to HVDC (High Voltage Direct Current), HVAC systems are cheaper to install and maintain for shorter distances.
- No need for expensive converter stations unless switching to DC.

# ADVANTAGES OF HVAC

## Three-Phase Power Compatibility

- HVAC supports three-phase power, which is ideal for industrial loads and balanced power distribution.
- It allows for rotating machines (motors, generators) to operate efficiently.

## Simpler Switching and Protection

- HVAC systems use AC circuit breakers, which are simpler and more economical than DC breakers.
- Protection schemes like relays and fuses are well-established for AC systems.

## Reactive Power Control

- HVAC systems allow for reactive power compensation using capacitors and inductors.
- This helps in voltage regulation and power factor improvement.

## Interconnection of Grids

- HVAC systems make it easier to interconnect multiple power stations and substations.
- This improves grid stability and allows power sharing between regions.

# DISADVANTAGES OF HVAC

## Transmission Losses

- **Reactive Power**
- **Power Factor**
- **Skin Effect**
- **Corona Effect**
  - **Power Loss**
  - **Audible Noise and Radio Interference**
  - **Ozone Production**

## Voltage Regulation and Stability

- **Voltage drops occur due to resistance, inductance, and capacitance**
- **Stability problems arise due to phase angle differences in three-phase AC systems at high distances, resulting in potential system instability and the need for careful management.**

# DISADVANTAGES OF HVAC

## Infrastructure and Costs

- large, heavy towers, making infrastructure costlier and bulkier compared to HVDC towers.
- The cost of better insulation materials increases

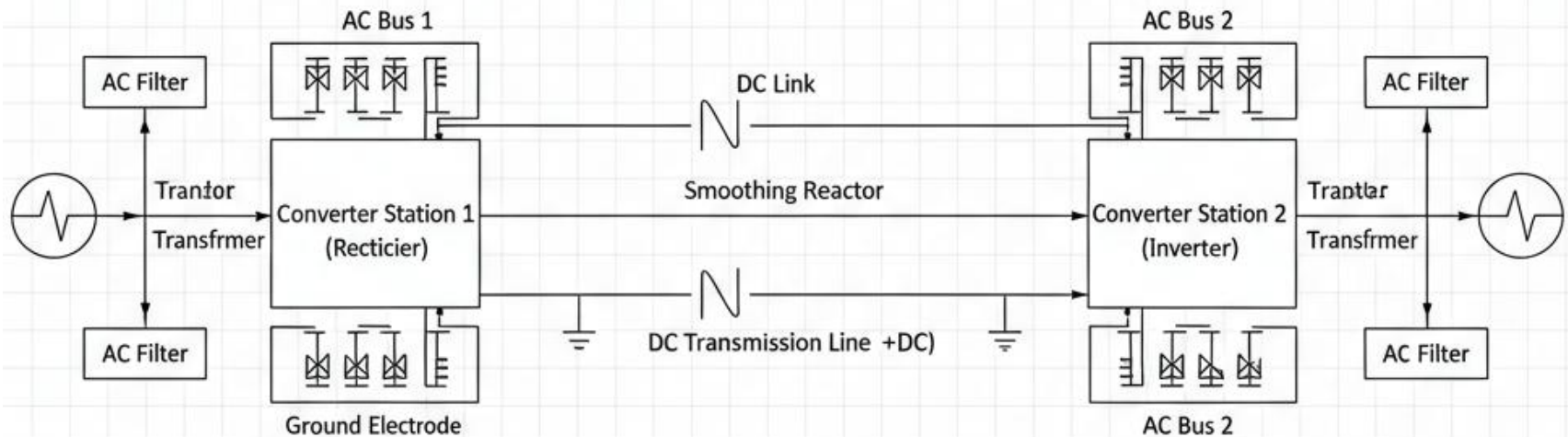
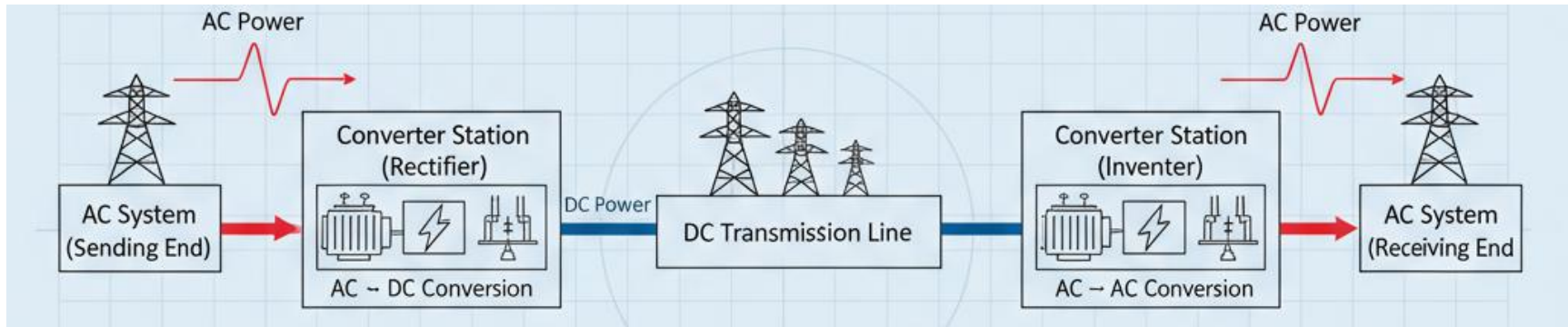
## Limitations Regarding Long-Distance and Power Transmission

- The power transmission capacity of HVAC lines is limited for very long distances (>500 km);
- HVAC systems cannot provide asynchronous interconnections

## Maintenance and Reliability Issues

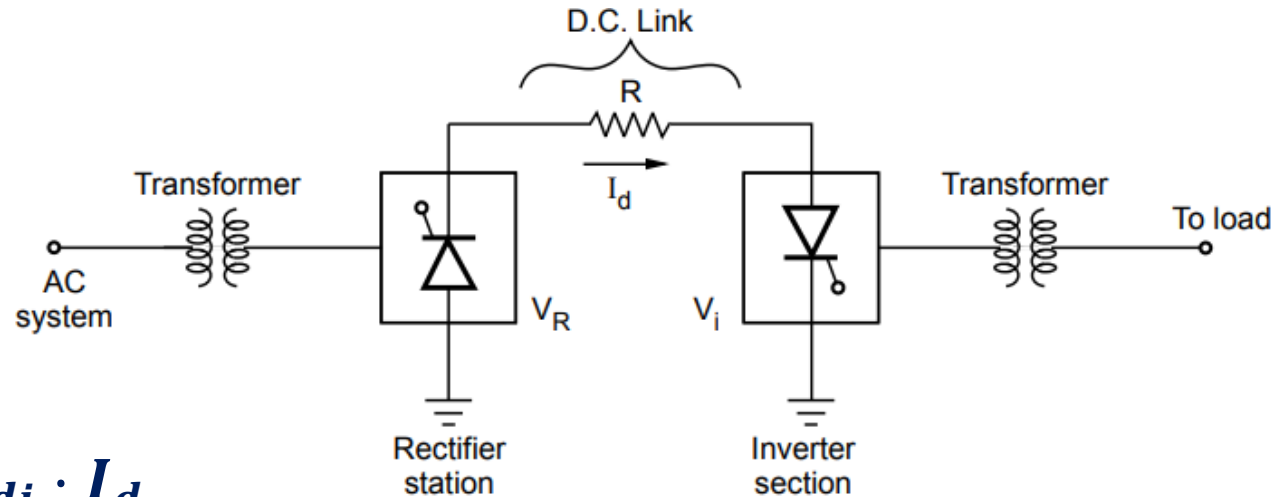
- require more maintenance due to the complexity of compensating equipment and larger infrastructure.
- Reliability is typically lower for HVAC compared to HVDC under challenging environmental and operational conditions.

# HVDC TRANSMISSION



Line Diagram-HVDC

# HVDC POWER TRANSFER



$$P_d = V_{di} \cdot I_d$$

$$I_d = \frac{V_{dr} - V_{di}}{R_l + R_c}$$

$$P_d = V_{di} \cdot \left( \frac{V_{dr} - V_{di}}{R_l + R_c} \right)$$

- $V_{dr}$ : DC voltage at the rectifier station
- $V_{di}$ : DC voltage at the inverter station
- $R_l$ : Resistance of the DC transmission line
- $R_c$ : Equivalent commutating resistance

# ADVANTAGES OF HVDC

**No reactive power issues**

HVDC eliminates reactive power losses and the need for compensation equipment, supporting maximum transmission capacity.

**No skin or proximity effect:**

DC transmission avoids losses due to the skin effect and proximity effect that occur in AC transmission, further increasing efficiency and reliability.

**Easy asynchronous interconnection:**

HVDC links can interconnect power networks running at different frequencies or voltages, providing grid flexibility and stability.

**Fast and precise control:**

HVDC systems can precisely regulate power flow, enhance grid stability, and help integrate renewable energy sources (like offshore wind and solar) into grids across continents or regions.

# ADVANTAGES OF HVDC

## **Lower transmission losses:**

**HVDC transmission has significantly less loss than HVAC, especially over long distances (typically over 600 km for overhead lines, much less for underground or submarine cables).**

## **Efficient long-distance transmission:**

**HVDC is preferred where large amounts of power must be sent over vast distances. Losses can be as low as 2–3%, compared to 5–10% for HVAC.**

## **Less need for conductors and towers:**

**HVDC lines require fewer conductors and smaller towers, reducing overall infrastructure and land costs.**

# DISADVANTAGES OF HVDC

## **Expensive converter stations:**

HVDC requires costly converter stations at both ends for AC-to-DC and DC-to-AC conversion, making the system uneconomical for short distances.

## **Complicated conversion and operation:**

Operating and maintaining HVDC stations involves complex technology, specialized equipment, and trained personnel.

## **Harmonic generation:**

Converters produce harmonics on both AC and DC sides, necessitating expensive filtering and smoothing equipment.

## **Limited transformer capability:**

Transforming voltage levels in DC is difficult and must be performed on the AC side; DC does not support transformer action directly.

# DISADVANTAGES OF HVDC

## **Difficult fault isolation:**

Circuit-breaking and fault isolation in HVDC systems—especially multi-terminal setups—is technically challenging and more expensive than in AC systems.

## **Low overload capacity:**

HVDC converter stations typically have limited short-term overload capability compared to AC systems.

## **Maintenance complexity:**

HVDC systems require higher maintenance for insulation and more spare, often system-specific, parts; they are less standardized than AC grids.

## **Control complexity:**

Power flow and system expansion, especially for multi-terminal and grid interconnection projects, demand advanced controls and high system coordination.

## **No easy voltage change for distribution:**

DC is not easily adaptable for distribution or sub-transmission because voltage level adjustment must occur on the AC side prior to conversion.

# MAJOR HVDC CONFIGURATIONS

## Monopolar HVDC System

Single conductor, earth/sea return  
Advantages: Cost-effective, expandable  
Disadvantages: Earth return issues, reliability concerns

## Bipolar HVDC System

Two conductors, opposite polarity  
Neutral grounding, flexible operation  
Advantages: High reliability, reduced earth current, suitable for long distance  
Disadvantages: Higher cost, insulation complexity

## Homopolar HVDC System

Two/more conductors, same polarity  
Always uses earth as return  
Advantages: Lower insulation cost, higher current capacity  
Disadvantages: High earth current, limited usage

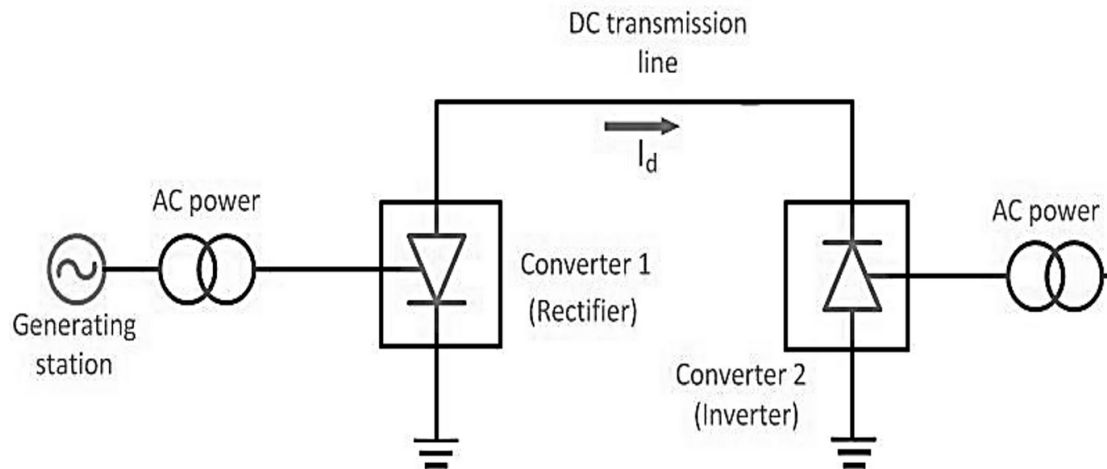
## Back-to-Back HVDC System

No transmission line, rectifier and inverter in same station  
Used for interconnecting asynchronous grids  
Advantages: Grid interconnection, compact design  
Disadvantages: Not suitable for long distance transfer

## Multiterminal HVDC System (MTDC)

More than two converter stations  
Flexible power exchange, scalable  
Complex control and protection

# MONOPOLAR HVDC SYSTEM



- **Single conductor (pole):** Usually negative polarity (-) is chosen to minimize corona discharge and radio interference.
- **Return path:** Either ground or metallic return conductor.
- **Terminals:** Two converter stations (rectifier at sending end, inverter at receiving end).

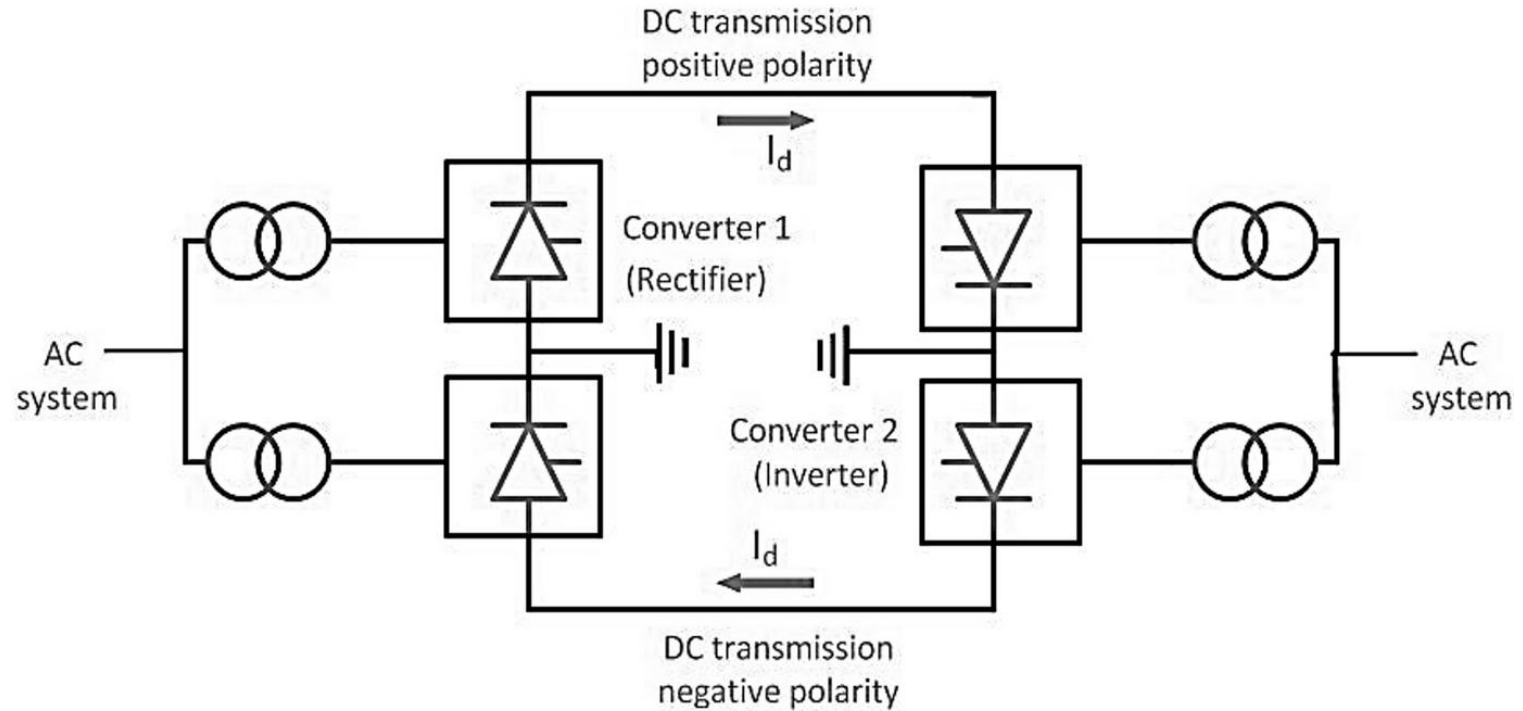
## Typical Voltage Rating:

±500 kV (negative pole used in monopole).

## Typical Power Rating:

Up to 600–1000 MW per pole.

# BIPOLAR HVDC SYSTEM

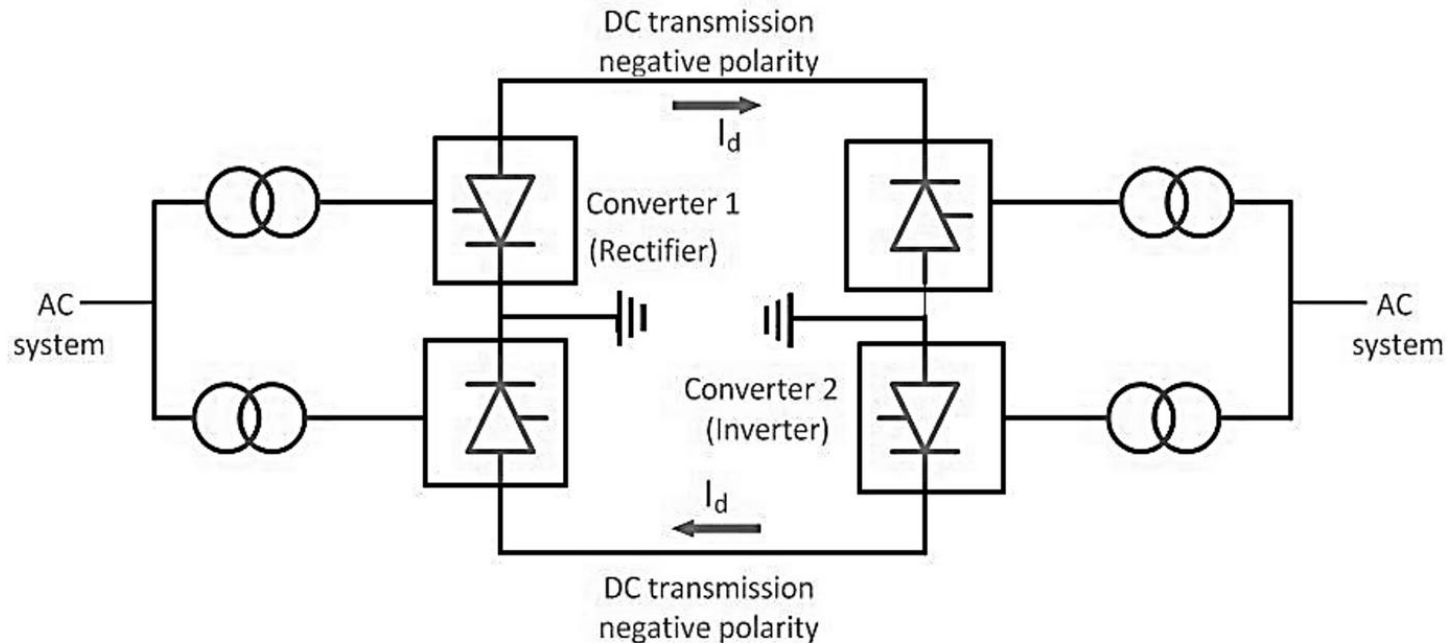


- **Two conductors:** One at positive polarity, one at negative polarity.
- **Neutral grounding:** Usually via electrodes at converter stations.
- **Optional metallic return/ground return:** Used in case of emergency when one pole is out of service.

**Typical Voltage Rating:**  $\pm 500$  kV to  $\pm 800$  kV

**Typical Power Rating:** 1,500 MW – 6,000 MW (per line)

# HOMOPOLAR HVDC SYSTEM

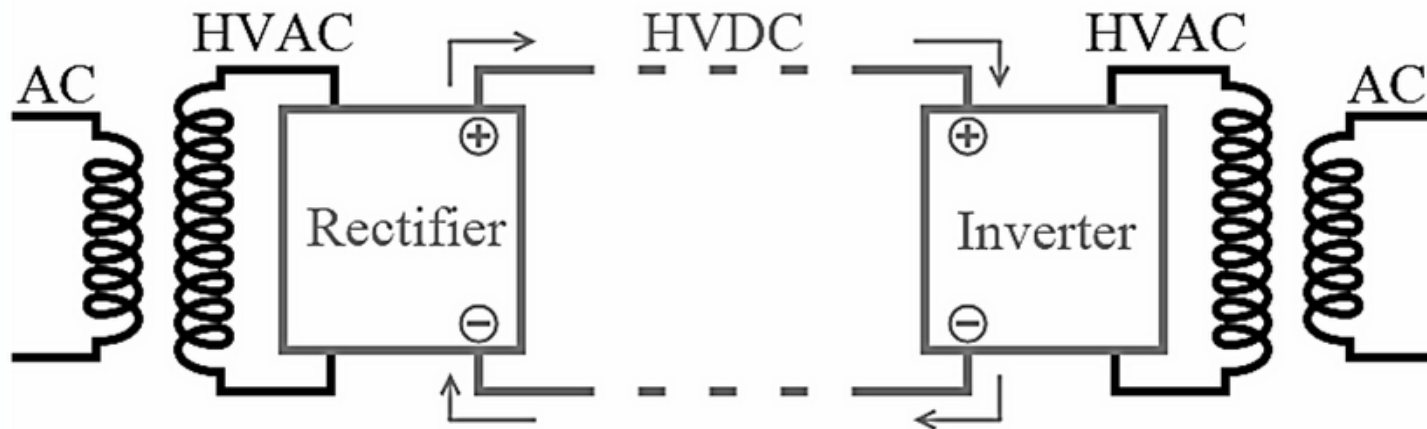


- **Two (or more) conductors** at the **same polarity** (typically negative, to reduce corona discharge and radio interference).
- **Earth (ground) return path** is always used.
- Voltage levels are lower than bipolar systems but the total current carried is higher.

**Typical Voltage Rating:**  $\pm 250$  kV to  $\pm 500$  kV (per conductor, negative)

**Typical Power Rating:**  $> 1000$  MW (depending on number of conductors)

# BACK-TO-BACK HVDC SYSTEM

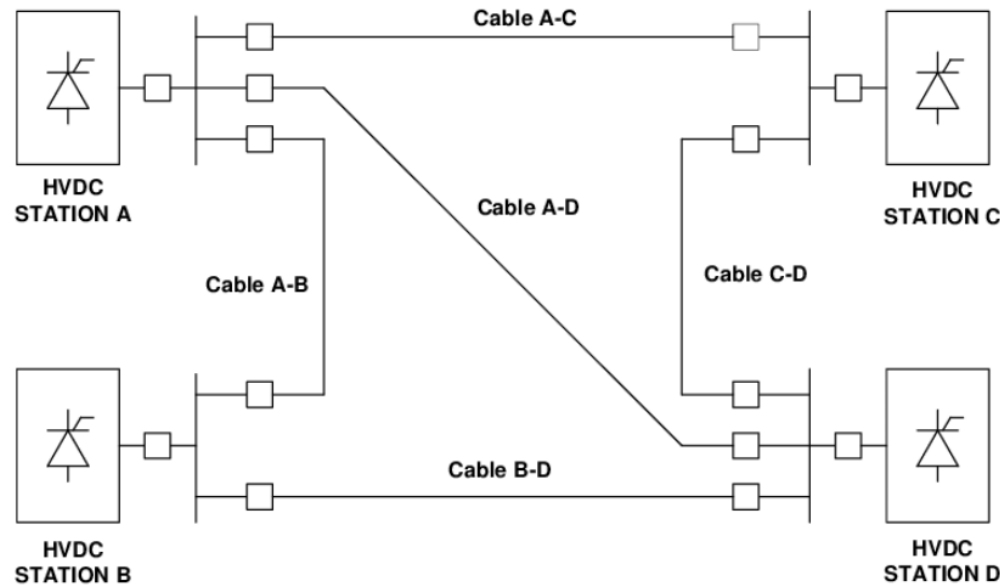


- **Two converter stations in one location:**
  - Rectifier converts AC to DC.
  - Inverter immediately converts DC back to AC.
- **No DC transmission line** (just a short DC link inside the station).
- Power ratings are usually lower than long-distance HVDC.

**Typical Voltage Rating:**  $\pm 80$  kV to  $\pm 200$  kV (lower than long-distance HVDC)

**Typical Power Rating:** 50 MW – 1,200 MW

# MULTITERMINAL HVDC SYSTEM (MTDC)



MTDC systems can be built in different **topologies**:

1. **Radial (Star) Topology** – one main station feeding multiple terminals.
2. **Series (Tapped) Topology** – converter stations connected in series along the DC line.
3. **Parallel (Meshed/Network) Topology** – multiple interconnections like an AC grid.
4. **Hybrid Topology** – combination of the above.

## Converter Stations

Rectifier (Sending end) → Converts AC to DC

Inverter (Receiving end) → Converts DC back to AC

Converter Transformers

Filters

Smoothing Reactors

Switchgear & Protection

## DC Transmission Medium

Overhead Transmission Line

Underground Cables

## Ground Return / Electrodes & Control System

Control & Protection System

## Cooling system

# COMPONENTS OF AN HVDC SYSTEM

# HVDC SYSTEM COMPARISON

Aspect	Monopolar	Bipolar	Homopolar	Back-to-Back	MTDC
Conductors	1	2 (opp. polarity)	2+ (same polarity)	None (short DC bus)	3 or more terminals
Return Path	Earth/metallic	Neutral, backup earth	Earth	Not needed	Radial, series, meshed
Reliability	Low	High	Low	High	High
Usage	Initial/stages	Long-distance/standard	Rare/experimental	Asynch grids	Emerging supergrids
Power Rating	600-1000 MW/pole	1500-6000 MW/line	~1000 MW	50-1200 MW	Variable

# HVDC SYSTEM APPLICATIONS

**Long-distance bulk transmission**

**Submarine cables/interconnections**

**Grid stability and asynchronous network linking**

**Renewable integration (wind, hydro, solar) via MTDC**

*Thank  
You*

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