Advantages of HVDC

Why HVDC rather than HVAC?

- Long distances make HVDC cheaper
- Improved link stability
- Asynchronous link
- Right-of-way for an AC Line designed to carry 2,000 MW is more than 70% wider than the right-of-way for a DC line of equivalent capacity.
Technical Considerations

- Bulk transmission of Power at voltages up to 800kV
- Back-to-back HVDC converters are used to connect two AC systems with different frequencies – two regions where AC is not synchronized
- Submarine Cable Transmission
- Transmission at reduced voltage
- Inherent Overload Capability
Economical Considerations

Comparison

<table>
<thead>
<tr>
<th></th>
<th>HVDC</th>
<th>HVAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terminal Cost</td>
<td>higher</td>
<td>lower</td>
</tr>
<tr>
<td>Line Cost</td>
<td>lower</td>
<td>higher</td>
</tr>
<tr>
<td>Right-of-Way Cost</td>
<td>lower</td>
<td>higher</td>
</tr>
</tbody>
</table>

Conclusion

HVDC is more economical for transmission distances longer than the break-even distance.

If capitalisation of losses and right-of-way cost are included in the cost comparison, the break-even distance is further reduced.
Example Losses on Optimized Systems for 1200 MW
Economical Considerations

Capitalised Losses / Break-Even-Distance

- Break-even-distance
- AC terminals
- AC line
- DC line
- DC terminals
- DC losses
- Total DC cost
- Total AC cost

Transmission distance

Costs
Economical Considerations

Right-of-Way

Typical Transmission Line Structures for approx. 2000 MW

- 60m ± 500 kV DC
- 110 m 2 x 500 kV AC
### Comparision of Losses - Case Study

<table>
<thead>
<tr>
<th>Parameter</th>
<th>HVDC System</th>
<th>AC System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>±500 kV</td>
<td>400kV (1D/C+1S/C)</td>
</tr>
<tr>
<td>Power</td>
<td>2250 MW</td>
<td>2250 MW</td>
</tr>
<tr>
<td>Line Configuration</td>
<td>Quad Bersimis</td>
<td>Quad Moose</td>
</tr>
<tr>
<td>Line Length</td>
<td>970 km</td>
<td>970 km</td>
</tr>
<tr>
<td>Losses</td>
<td>135 MW (inc terminal losses)</td>
<td>216 MW</td>
</tr>
<tr>
<td>Capitalisation of diff with 97% Availability and 60% utilisation); tariff @10 cents</td>
<td>USD 41 million</td>
<td></td>
</tr>
</tbody>
</table>
Technical Considerations

- **Typical HVDC Short-Time Overload Characteristics**

Graph showing overload characteristics at 20°C and 40°C ambient temperatures over time.
Inherent Continuous HVDC Overload vs. Ambient Temperature

- Overload in pu
- With redundant cooling
- Without redundant cooling

Ambient Temperature in Degree Celsius
HVDC Long Distance Transmission Systems

**Monopolar**
- Terminal A
- Transmission Line
- Terminal B

**Bipolar**
- Terminal A
- Transmission Line
- Terminal B
- Pole 1
- Pole 2
HVDC Cable Transmission Systems

- **HVDC Classic Bipole**
  - Pole 1
  - Pole 2
  - Terminal A
  - Terminal B

- **HVDC PLUS Symmetrical Monopole**
  - Pole 1
  - Pole 2
  - Terminal A
  - Terminal B

Cable Systems
- Submarine Cable Systems
- Land Cable Systems
HVDC Back-to-Back Links

- Back-to-Back

Technical Reasons
- Different System Frequencies
  \( f_1 \neq f_2 \)
- Different System Controls
  \( \Delta f_1 \neq \Delta f_2 \)
- Exchange of low Power compared to the Size of the interconnected AC Systems
- Prevention of cascading Disturbances
  ("Firewall")
HVDC Long Distance Transmission Systems

Multi Terminal

Terminals in Parallel

Terminals in Series
Basic HVDC Single Line Diagram

- DC OH Line
- Thyristor Valves
- Smoothing Reactor
- DC Filter: DT 12/24
- DC Filter: DT 12/36
- Converter Transformer
- 400 kV AC Bus
- AC Filters, Reactors
- DC Filter: DT 12/24
- DC Filter: DT 12/36
- Thyristor Valves
- Smoothing Reactor
- Converter Transformer
- 400 kV AC Bus
- AC Filters

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Modes of Operation

Bipolar

Bipolar DC OH Line

Thyristor Valves

Smoothing Reactor

Current

Converter Transformer

400 kV AC Bus

AC Filters, Reactors

DC OH Line

Smoothing Reactor

Thyristor Valves

Converter Transformer

400 kV AC Bus

AC Filters
Modes of Operation

Monopolar Metallic Return

- DC OH Line
- Thyristor Valves
- Converter Transformer
- Smoothing Reactor
- Current

400 kV AC Bus
AC Filters, Reactors

400 kV AC Bus
AC Filters
Modes of Operation

Monopolar Metallic Return

- Thyristor Valves
- Converter Transformer
- Smoothing Reactor
- DC OH Line
- 400 kV AC Bus
- AC Filters, Reactors

SIEMENS
Modes of Operation

Monopolar Ground Return
Overall Layout of HVDC station
Isometric view – Conventional Bipolar HVDC
Example HVDC “Classic”
Key Components of HVDC
Bipolar HVDC Terminal

1. AC Switchyard
2. AC Filters
3. Transformers
4. Converter Valves
5. Smoothing Reactors and DC Filters
6. DC Switchyard
HVDC Terminal Requirements

**AC Switchyard**
Connects the Terminal to the AC System

**AC Filters, Capacitor Banks**
Reactive Power Supply
Filter harmonic Currents

**Converter Transformers**
Obtain the AC Voltage needed for the required DC Voltage
Obtain 12-Pulse Operation (Star and Delta Connection)
Allow for Series Connection of 6-Pulse Bridges
HVDC Terminal Requirements

**Thyristor Valves**
Convert AC to DC and vice-versa
Connect 6-Pulse Bridges in Series for required DC Voltage

**Smoothing Reactors and DC Filters**
Smoothen the DC Current
Avoid Resonance with DC Line
Limit Interference caused by DC Side Harmonics

**DC Switchyard**
Achieve required DC Side Transmission Configuration
Main Equipments

- Thyristor Valves
- Valve Cooling
- Converter Transformer
- Smoothing Reactor
- DC Switches
- AC Filters
- DC Filters
- PLC Filter
- Ground Electrode
Thyristor Valves

- The rectification and inversion process is carried out by the thyristor valves

- Housed inside the valve halls
Thyristors

- Thyristor Technology with direct Light-Triggered Thyristors
- Rated Voltage up to 800 kV
- Rated Current more than 3,000 A
- Free from Oil and exclusive Use of Flame-retardant self-extinguishing Materials ⇒ Reduced Fire-Hazard
- Efficient and Corrosion-free Water Cooling
- Excellent Seismic Performance
Direct Light Triggered Thyristor LTT

High Reliability

- 80 % less Electronic Components
- Direct Laser Light-triggered Thyristor
- Thyristor Blocking Voltage: 8 kV
- Thyristor Wafers:
  - 4" for currents up to 2,200 A
  - 5" for currents up to 3,700 A
Comparison of Electrical with Direct Light Triggering

**ETT**
Triggering and Monitoring Functions

- **voltage detection**
- check-back signal
- auxiliary power logic
- electric gate pulse
- protective gate pulse
- optical trigger signal

Valve Base Electronics with low power LED

**LTT**
Firing and Monitoring System conveniently from the Ground to Thyristor Potential

- **voltage detection**
- check-back signal
- optical gate pulse

Valve Base Electronic with high power laser
Parallel Water Cooling

The Siemens Design of the Valve-Cooling Circuit with Parallel-Water Cooling has been in Operation for more than 30 Years

- It provides all thyristors with the same cooling water temperature
- Electrolytic currents are minimized by the use of grading electrodes
- Careful choice of materials allows operation without de-oxygenizing equipment
- None of these systems had corrosion problems

Diagram:
- a Thyristor
- b Heat Sink
- c Piping
- d Manifold
Valve hall
Valve hall
Thyristors Valves - Module Layout
Air Blast Cooler

[Diagram of an air blast cooler showing fluid in and out flow paths]
Valve Hall-External View
East-South Interconnector II, India, 2003

SIEMENS
Converter Transformer

- Provide the AC voltage for the converter
- Subject to DC voltage and currents on the Valve side.
- Can be two winding or three winding depending on MVA rating and size
- Subject to special tests such as DC withstand, polarity reversal and heat run test with harmonic currents taken into account
Winding Arrangement

Core

R-Regulating Wdg
L- Line Wdg
V-Valve Wdg
Winding arrangement

Core  
R-Regulating Wdg
L- Line Wdg
V-Valve Wdg
V  L  R
Converter Transformer
Converter Transformer
Converter Transformers

400 MVA 1-ph / 3-w

354 MVA 1-ph / 3-w
Smoothing Reactor

- Removes ripples from DC voltage
- Limits rate of rise of current in case of DC line faults
- Limits higher order harmonics in DC line
- Limits possible resonance at fundamental and 2nd harmonic frequencies
HVDC Smoothing Reactor

Oil immersed Design

270 mH
500 kV DC
3,000 A

Air-Core Design

150 mH
500 kV DC
1,800 A
Smoothness Reactor

Inductance: 250 mH (two coils @ 125 mH)
Rated voltage: 500 kV dc
Rated current: 2000 A dc
Siemens HVDC Transmission
Supplies in India

Converter Transformer and Valve Hall – Talcher Station (ESI - II)

AC Harmonic Filters – Talcher Station (ESI - II)
High Speed DC Switches

Switches to commutate direct current (MRTB, MRS, HSNBS, HSGS)

Metallic Return Transfer Breaker (MRTB) and Metallic Return Switch (MRS)

Use of standard SF₆ circuit breakers
MRTB & GRTS

\[ I_d = I_{d1} + I_{d2} \]
Operation of the MRTB is as follows:

1. As the contact S opens, and develops an arc voltage, it generates an oscillation in the circuit L, C, and S at the natural frequency of the loop which is known and part of the design.

2. As the current in S decreases by being shunted to the L and C branch, the arc voltage of S increases due to its negative current voltage characteristic.

3. A current oscillation is set in L and C which grows in magnitude with time until its magnitude equals the current to be interrupted creating a current zero in S allowing it to extinguish and recover.
Bipolar and Monopolar metallic return is the normal mode of Operation

Why and when Ground Return?

Permanent fault on one Pole conductors of DC line. Scheduled maintenance for major work of DC line.
TYPICAL LAYOUT OF ELECTRODE STATION

Ground Electrode
Ground Electrodes Effects

- Local Effects (Upto < 1 km)

- Safety of Humans and Animals

- High temperature rise of Ground and drying of soil.

- Remote Effects (may be upto 50 Km and beyond)

- Potential rise can cause DC current flow in transformer Neutrals

- Corrosion of buried metallic objects.
Design Requirements

Local Electrode parameters.

- Ground Electrode resistance $\leq$ 0.3 $\Omega$
- Touch Voltage $\leq$ 40 Volts
- Step Voltage $\leq$ 6 Volts
- Current Density $\leq$ 0.5 A/m²
- Temperature on the surface of sub-electrode: $\leq$ 100 °C.

Remote Effects.

The Ground potential rise and electric field shall decay fast and shall be negligible (few Volts) within 15-20 kms of electrode site.
DC Yard
Auxiliary Systems-HVDC

- Auxiliary Power
- LT Power System
- DG Set
- DC Power/UPS
- Air Conditioning/Ventilation
- Fire Fighting/Detection
- Illumination
- PA System
- Valve Cooling System
- Oil Filtration System
- Service Water
- Telephone & PA System
Auxiliary Power Sources

- Usually two 33kV/11kV sources
- DG Set connected on LT bus
- Voltage Variation: ±10%
- Frequency Variation: ±5%
Typical Aux Power Scheme for HVDC Station

FROM ICT1, 400/132/33 kV, 200 MVA TRF TERTIARY;

FROM ICT2, 400/132/33 kV, 200 MVA TRF TERTIARY;
Valve Hall Ventilation Requirements

- Inside DB temperature 50°C ± 2°C
- Inside R.H. 43% ± 5%
- Clean room to ISO class 7 as per ISO 14644-1:1999
- Positive pressure – 3mm of water column
- Dedicated one running and one standby AHU
- Supply air through high efficiency filters to main desired clean room condition
Fire Protection - Stages

- Fire Prevention
- Fire Detection
- Fire Fighting
- Smoke Evacuation
Fire Protection - Design Aspects

Fire Prevention

- Separated areas
- Design of equipment
- Maintenance
Fire Protection - Choice of Material

Fire Protection Walls
- Dry Composite Transformer Wall Bushing
- Minimised Inflammable Materials
- Dry Composite Wall Bushing
Fire Protection - Detection

- valve hall
- transformers
- control / service building
- indication / control system
Fire Protection - Transformers

- Buchholz Relays
- VESDA Detectors
- Air Sampling Tubes
- Ultra Violet Detectors
- Infra Red Sensors
Fire Protection - Control Rooms

Optical Smoke Detectors
Ionisation Smoke Detectors
Fire Protection Walls
CO₂ Fire Fighting
Fire Fighting

Technology and Installations

- deluge system
- carbon dioxide (CO₂)
- hydrants
- portable fire extinguishers
Fire Protection - Deluge System

Selective Initiator of Transformer and Valve fire fighting

Deluge System

Hydrant System (if required)