Substation Engineering

HVDC Substations (Part 2)

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- High Voltage Direct Current (HVDC) Substations
- Part 2 of 3: Equipment and Converter Technologies
- Course: Substation Engineering (DI04009011)

Agenda

- Converter Technologies: LCC vs VSC
- Line Commutated Converters (LCC / Classic HVDC)
- Voltage Source Converters (VSC / Modern HVDC)
- Converter Transformers
- Thyristor Valves and Valve Halls
- Harmonic Generation and Filters (AC & DC)
- Smoothing Reactors
- Summary and Q&A

Two Generations of HVDC Technology

- LCC (Line Commutated Converter): Also known as Classic HVDC. Uses Thyristors.
- VSC (Voltage Source Converter): Also known as VSC-HVDC or Light HVDC. Uses IGBTs (Insulated Gate Bipolar Transistors).
- LCC relies on the AC grid voltage for commutation (turning off the valves).
- VSC has self-commutating capability; it can create its own AC voltage waveform.

Line Commutated Converters (LCC)

- Mature technology, capable of the highest power and voltage ratings (up to 1100 kV, 12000 MW).
- Valves can only be turned on by a gate signal; they turn off naturally when current crosses zero (requires a strong AC grid).
- Consumes significant reactive power (approx. 50% of active power transmitted).
- Requires large AC filter banks and capacitor banks for reactive compensation.

Voltage Source Converters (VSC)

- Modern technology, power ratings up to around 3000 MW.
- IGBTs can be turned on AND off via gate signals (self-commutating).
- Can operate with weak AC grids or even dead networks (black start capability).
- Independent control of active and reactive power.
- Generates fewer harmonics, requiring significantly smaller filters.

Comparison: LCC vs VSC

Feature	LCC (Thyristor)	VSC (IGBT)
Max Power Capability	Very High (>10 GW)	High (∼3 GW)
Reactive Power	Consumes ∼50%	Can generate/consume
Minimum AC Grid Strength	Strong grid required	Can operate on weak/dead grids
Footprint	Very Large (huge filters)	Compact (small filters)
Black Start Capability	No	Yes

Converter Transformers

- Act as the galvanic interface between the AC grid and the DC valves.
- Provide the necessary ungrounded AC voltage to the converter bridges.
- Typically arranged to provide a 30-degree phase shift between bridges to create a 12-pulse system.
- Subjected to severe electrical stress: combined AC and DC voltages.

Design Challenges of Converter Transformers

- DC Insulation Stress: Insulation must handle DC voltage, which distributes based on resistivity (temperature dependent), not capacitance.
- Harmonics: High harmonic currents flow through the windings, causing extra heating and requiring robust cooling.
- DC Magnetization: Even slight DC currents can saturate the transformer core, causing noise and overheating.
- Often built as single-phase units due to massive size and transport limitations.

Thyristor Valves and Assembly

- A single thyristor can only block a few kilovolts.
- Hundreds of thyristors are connected in series to withstand hundreds of kilovolts.
- Arranged in modular 'valve structures' suspended from the ceiling in the valve hall (especially for high seismic zones).
- Fired simultaneously using light pulses via fiber optics (Light Triggered Thyristors).

Harmonics in HVDC Systems

- The switching process of converters inherently generates harmonic currents and voltages.
- A standard 12-pulse LCC generates characteristic AC harmonics of order $12n \pm 1$ (11th, 13th, 23rd, 25th...).
- Generates characteristic DC harmonics of order $12n$ (12th, 24th...).
- These harmonics can cause overheating in equipment, telecom interference, and grid resonance.

AC and DC Filters

- AC Filters: Large banks of capacitors, inductors, and resistors tuned to absorb specific harmonic frequencies (e.g., 11th and 13th).
- In LCC systems, AC filters also provide the large amount of reactive power required by the converter.
- DC Filters: Located on the DC side to prevent harmonic currents from flowing down the DC line, which acts like a giant broadcasting antenna.
- VSC systems use much smaller filters due to high-frequency Pulse Width Modulation (PWM).

Smoothing Reactors

- Massive inductors placed in series with the DC line.
- Functions:
- 1. Smooth the ripple in the direct current.
- 2. Limit fault currents on the DC line.
- 3. Prevent commutation failures in the inverter.
- Typically air-core, dry-type reactors to avoid core saturation issues.

Control Systems (Brief Overview)

- HVDC control systems act in milliseconds.
- Rectifier normally controls the DC Current.
- Inverter normally controls the DC Voltage.
- Protection systems must quickly detect DC line faults and block the valves to prevent equipment damage.

Summary of Converter Equipment

- LCC uses thyristors (high power, strong grid) while VSC uses IGBTs (flexible, weak grid).
- Converter transformers face unique AC and DC stresses simultaneously.
- Valves consist of hundreds of series-connected semiconductors.
- Filters and smoothing reactors are essential to manage harmonics and maintain stable DC flow.

Next Lecture Preview

- HVDC Transmission Link Configurations.
- Monopolar Links (Ground return vs Metallic return).
- Bipolar Links and their redundancy advantages.
- Multi-terminal HVDC systems.
- Back-to-Back configurations.