Topics

• Line Commutated Converter - LCC
• Effective short Circuit Ratio - ESCR
• Configurations and operating modes
• Conversion principles
• Reactive power
• Capacitor Commutated Converter – CCC
• Converter arrangements
• Converter station layout and equipment
• Control & protection
• Questions?
HVDC technology
Line Commutated Converters - LCC

HVDC Classic

- Current source converters (CSC)
- Line-commutated converter (LCC) with thyristor valves
- Requires ~50% reactive compensation (35% HF)
- Converter transformers
- Minimum short circuit capacity > 2 x Pd, > 1.3 x Pd with capacitor commuted converter (CCC)
Short Circuit Ratio
What’s the deal?

- Commutation performance
- Voltage stability
- Dynamic performance
- Dynamic overvoltage, DOV
- Low order harmonic resonance, \( f_{res} = f_1 \sqrt{S/Q} \)
- Rule of thumb – ESCR > 2 LCC, > 1.3 CCC;
  where \( ESCR = \frac{(S_N + S_G + S_{SC} + S_{WF} - Q)}{P_{DC}} \)

\[ f_{res} = f_1 \sqrt{S/Q} \]
HVDC in bipolar operation

Single 12p CSC per pole with metallic return switching

- MRTB – metallic return transfer breaker, used for switching from ground return to metallic return
- GRTS – ground return transfer switch, used for switching from metallic return to earth return in preparation for restarting pole (NRTS for systems with continuous metallic neutral)
- BPS – bypass switch, used to provide metallic return path
- NBS – neutral bus switch, used to commutate spill current from healthy pole for neutral bus fault
- NBGS – neutral bus ground switch, used to help clear faults on electrode line (or metallic neutral
HVDC monopolar earth return operation
Temporary during emergencies or maintenance

\[ I_{dp1} = I_g \]

- DC disconnect, closed
- DC disconnect, open
- DC breaker, closed
- DC breaker, open
HVDC monopolar metallic return operation

During converter outages or degraded line insulation

\[ I_{dp1} \]

\[ I_g = 0 \]
Commutation in a controlled bridge

Rectifier operation

\[ U_d = U_{di0} \cos \alpha - \frac{3}{\pi} X_c I_d \]

\[ U_{di0} = \frac{3\sqrt{2}}{\pi} U_v \]
Reactive power characteristics

LCC

- Converter stations appear as a reactive load, i.e. lagging power factor
- Both rectifier and inverter operation exhibit lagging power factor, i.e. current lags voltage
- Lagging power factor is due to phase control and commutating reactance
- Typically reactive power demand = 55% of station rating at full load
- Reactive power compensation – typically 35% of station rating from ac filters the balance from shunt banks
- Shunt reactors sometimes used at light load to absorb excess from filters

HVDC Classic:
Reactive compensation by switched filters and shunt capacitor banks
Conventional HVDC technology

**LCC and CCC**

- CC located between converter transformers and thyristor valves - reduces transformer rating, increases valve voltage rating
- CC provides part of the commutation voltage and reactive support. Reduces probability for commutation failure for remote faults
- CC location reduces bank exposure to ac network faults, simplifies commutation capacitor protection, reduces MOV energy
- Reduces amount of shunt compensation, raises ac network resonance frequency, reduces dynamic overvoltage, lowers minimum ESCR
- Reduces variable O&M with shunt bank switching and transformer LTC operations
CCC principles of commutation

Inverter operation

- Commutation Margin, $\gamma$
- Apparent Margin $\gamma_{ac}$
- Commutation margin increases with $+\Delta I_d$ or $-\Delta U_{ac}$
HVDC converter arrangements

HVDC Classic
- Current source converter
- Line commutated
- Thyristor valves
- Thyristor modules
- Electrically triggered
Layout of bipolar HVDC station
± 500 kV, 3000 MW
HVDC converter station
6400 MW, ± 800 kV with series converters
Thyristor Valve Installation
Layout of HVDC quadruple thyristor valve

- Quadruple valve
- Thyristor module
- Reactor
- Saturable Reactor Module
- Thyristor Module = 9 thyristor positions
- TCU Derivative
- Feeding Resistor
- Feeding Capacitor
- DC Grading Resistor
- Thyristor
- Damping Resistors
- Damping Capacitors
- TCU Derivative
- Thyristor Control Unit
- TCU
HVDC thyristor module

- Thyristors
- Capacitors
- Heat sinks
- Cooling tubes
- Resistors
- Compression springs
- TCU
- Current connector

Diagram showing protective firing, recovery protection, monitoring, and normal firing.
Valve Cooling System

- Single circuit system
- Outdoor dry, liquid-to-air coolers for valve heat dissipation
- Same base design for HVDC, HVDC Light and SVC
- High reliability – redundant pumps, coolers, control, monitoring and protection
- Designed for ease of maintenance – redundancy permits repair or replacement of parts without requiring a converter or pole outage
Transformer Converter Interface HVDC

- Match valve voltage with system AC-side
- Provide impedance to limit the short circuit current to the valve
- Galvanically separate the AC- and DC-side (takes place inside transformer, between AC and DC winding) making it possible to connect the converters in series
- Converter transformers also carry harmonics, phase shift provides some harmonic cancellation
- MVA rating and transport limitations determine configuration
Harmonic Filters
Conventional HVDC12-pulse converter

- AC side current harmonics: $f_h = 12n \pm 1$, i.e. $11^{th}, 13^{th}, 23^{rd}, 25^{th}, \ldots$
- Typical ac filter performance criteria: THD $< 1.5\%$, $D_h < 1\%$, TIF $< 45$
- DC side voltage harmonics: $f_h = 12n$
- Typical dc filter performance criteria: $I_{eq} < 250\text{ma}$
- Typically 35% of station rating in installed ac filters
- Harmonics diminish with increasing harmonic number
Filter types

Bandpass filter

High-pass filter

Double-tuned filter
HVDC classic control principles

- Two independent variables at each terminal – firing angle, ac voltage
- Control of firing angle is fast, control of ac voltage is slow (LTC)
- One end assigned to voltage control, the other end to current control
- Higher level power control calculates current order – no need for speed for normal dispatch but can be fast for pole loss compensation or runback
- Current (or voltage) order converted to firing angle and sent to control pulse generator
- CPG synchronized to ac voltage via PLL for equidistant firing
Firing angle limits and VDCOL

- Firing angle limits – alpha min for rectifier operation, minimum commutation margin for inverter operation
- Minimum firing voltage for rectifier operation for disturbances
- Voltage dependent current order limiter for controlling dynamic reactive power demand during start-up and disturbance recovery
- VDCOL time constants – fast for decreasing voltage, slower for increasing voltage
- VDCOL up time constant speed dependent on system strength
Rio Madeira HVDC Project Challenges

Complex Customer structure
Technology
  – Very weak network in NW Brazil.
  – Advanced technical solutions
    • Capacitor Commuted Converters – Replaces 2 Synchronous machines
    • Large three winding transformers (Largest HVDC transformers so far)
    • Deep hole electrodes

Logistics
  – Transport of transformers on river. Limited period of enough water in river
  – Brazilian Custom Clearance
Rio Madeira HVDC Project

ABB Araraquara Converter station (right) and Ahlstrom station in the middle
Rio Madeira HVDC Project

Porto Velho Bipole quadruple valves
Rio Madeira HVDC Project

Araraquara Bipole double valves
Rio Madeira HVDC Project

Porto Velho Back to Back station
Rio Madeira HVDC Project

Porto Velho Back to Back
NorthEast – Agra (NEA800), India

- Power: 6000/8000* MW * continuous overload
- DC-voltage: ± 800 kV
- Transmission: 1728 km
- Three-station multi-terminal bipole with OH-lines, parallel-connected 12-pulse converters
- In-service: 2014-15

**Diagram**

- **Bipole 1** to **Bipole 2**
  - Bipole 1: Agra to Alipurduar via Pole 1 and Pole 2
  - Bipole 2: Agra to Biswanath Chariali via Pole 3 and Pole 4
  - +/- 800 kV
  - Total transmission distance:
    - Bipole 1: ~1296 km
    - Bipole 2: ~432 km

[Map showing the transmission network from Agra to Alipurduar and Biswanath Chariali]
Questions?