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, \( f_{\text{res}} = f_1 \sqrt{S/Q} \)
- Rule of thumb – ESCR > 2 LCC, > 1.3 CCC;
  where ESCR = \( (S_N + S_G + S_{\text{SC}} + S_{\text{WF}} - Q)/P_{\text{DC}} \)
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

$I_{dp1} = I_g$
HVDC monopolar metallic return operation
During converter outages or degraded line insulation

Commutation in a controlled bridge
Rectifier operation

\[ U_j = U_{\text{ao}} \cos \alpha - \frac{3}{\pi} X_d I_d \]
\[ U_{\text{ao}} = \frac{3 \sqrt{2}}{\pi} U_r \]
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 \(+ \Delta Id\) or \(- \Delta Uac\)

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

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

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

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 HVDC 12-pulse converter

- AC side current harmonics: \( f_h = 12n \pm 1 \), i.e. 11\(^{st}\), 13\(^{th}\), 23\(^{rd}\), 25\(^{th}\), . . .
- Typical ac filter performance criteria: THD < 1.5\%, \( D_i < 1\% \), TIF < 45
- DC side voltage harmonics: \( f_h = 12n \)
- Typical dc filter performance criteria: \( I_{eq} < 250\)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

Harmonic number
Impedance (ohms)

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 week 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 M\(^{\text{1/2}}\) 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