HVDC Control

LCC Reactive power characteristics

- Operates at lagging power factor
- Both rectifier and inverter operation
- Due to phase control
- Typically reactive power demand = 55\% of station real power rating at full load
- $Q_{\text{comp}}$: typically 35\% of station rating: ac filters plus shunt banks
- Shunt reactors sometimes used at light load to absorb excess from filters
Short Circuit Ratio

- Commutation performance
- Voltage stability
- Dynamic performance
- Dynamic overvoltage
- Low order harmonic resonance,
- Rule of thumb – ESCR > 2 for LCC
- ESCR = (S_N + S_G + S_SC + Q)/P_{DC}

Control Principles

- Two independent control inputs at each terminal
  - Firing angle → fast
  - AC voltage → slow (LTC)
- Synchronized firing with PLL
- Fast control loop for firing commands
- Somewhat slower for regulator
Control Principles

- One terminal controls DC voltage (fast)
- One terminal controls DC current (slower)
  - Current order from higher order power command
- Communication enhances performance
- Required for start up or major changes
  - Power flow reversal

Simplified Circuit
Static Characteristics

- Alpha min for rectifier
  - Disturbance
- Gamma min at inverter
  - Commutation failure
- VDCOL

Measurements

- DC voltage and current
- AC voltage
- Remote end current or voltage
- Operator commands
Station Control

- Bipole power order
- Frequency control/limits
- AC voltage control
- Reactive power

Bipole Control

- Pole power orders
- Power limits
- Pole balancing
Pole Control

- Pole power
- Firing angles, limits
- Phase limits
- Static characteristics
- Tap changer
- SSR damping
- Power Swing damping
- Pole protection

Power Control

- Operator sets power demand
- Compare to measured control
- Set current or voltage order
  - Within limits
- Can integrate offset to power order with frequency slope characteristic
- Can add power modulation control
- SSR damping
DC Faults with LCC

- DC faults
  - One end will not feed the fault
  - Use converter control to reverse voltage polarity
    - Reverses current direction
    - Starves Fault
  - Smoothing reactor slows rate of rise of current
- AC faults
  - Load rejection
  - Commutation failure

VSC Control Loops

- VSCs using PWM and MMCs can control two variable independently
- Control was done in synchronous dq frame to improve response
- Inner current regulators and out control
- Current cross coupling term may have small effect
- Impact on ac systems
Outer Controls Available With VSC

- Control Power Flow on DC Link
  - Control DC Voltage (at one end)
  - Control DC Current (at other end)

- Converters Can Control AC Side Voltage or Reactive Power
  - Relatively Fast Control
  - An equivalent to lower voltage ride through

- Power Oscillation Damping

Real/Reactive Power Output

P-Q Diagram

Operating Area

HVDC VSC Operating Range
AC Fault Behavior

- Controls will have a huge impact
- Converter topology some effect
  - Most topologies are ungrounded
  - Transformer may be Yg-Δ (delta faces converter)
    - Some variation with vendors

Inner Controls

- Most schemes use inner current regulators
  - Fact acting, protect devices from excess currents
  - Possibly 2 sets, one each for pos and neg sequence
Impact of Inner Controls

- Converter will limit current for ac faults
  - Same current for variety of fault locations
  - A little different in older schemes
- Doesn’t vary much with converter topology
- Generally fairly balanced currents
- Try to support local voltage
  - Current at leading power factor
- Some reports of impact on distance protection

Source: L. He, C.C. Liu, “Effects of HVDC Connection for Offshore Wind Turbines on AC Grid Protection,” 2013 IEEE PES General Meeting
DC Fault Behavior

- Converter topology poses problem
- Diodes form uncontrolled path
  » Known since 1980’s
- Pole to pole versus pole to ground

Clearing DC Faults

- To date, no systems use DC breakers for this problem
- Siemens proposed IGBTs in old HVDC plus designs
- Full bridge based MMCs can block dc fault currents
  » Doubles device count and increases losses
  » So schemes use half-bridges
- Rely on ac side breakers to interrupt dc fault current – point to point systems
AC System Impact

- AC system will see dc fault current
  - Will most often look like phase to phase fault
  - Possibly 3 phase depending on breaker response time
- Followed by load (or source) rejection since dc power transfer will go to zero
  - Will not see temporary overvoltages as with LCC

Circuit Interruption Options

- Multiterminal HVDC Grids will need DC breakers
  - Possibly as little as 2 ms response needed
- Lack of DC breakers (at least fast ones)
  - BPA test, metallic earth return breakers
  - IGBTs in line (point to point better)
    - Drawbacks: ratings, losses and they don’t truly “open” and “isolate”
  - Recent developments HVDC breakers
Multiterminal HVDC Systems

- Multiterminal Connection Options
- Controls
- Mixing LCC and VSC
  - Full bridge MMC
  - DC/DC converters