Highgate Converter Overview

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VELCO

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IEEE PES

Highgate Converter

Abstract

- Introduction to HVDC
- Background on Highgate
- Operation and Control schemes of Highgate

Why Use HVDC?

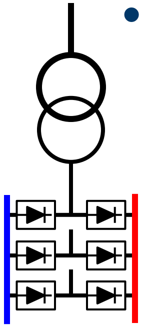
- Fast and accurate control of power transfer not dependent on system angles
- Interconnection between asynchronous systems
  - Frequency and Voltage independent
- Provides isolation from system disturbances in other system
- To transmit large bulk power over a long distance
  - Losses proportional to current squared
  - AC systems also have reactive power & losses
  - Long AC systems use series capacitors to automatically compensate vars
    - This can cause sub-synchronous resonance which can harm machines
    - Line breakers need to have higher ratings for transient recovery voltage
  - DC terminals also have real and reactive power losses but they occur only at the injection points and can be more easily compensated
  - Loss savings for and Cost savings DC vs. AC line losses occurs at long distances

Basic Principle

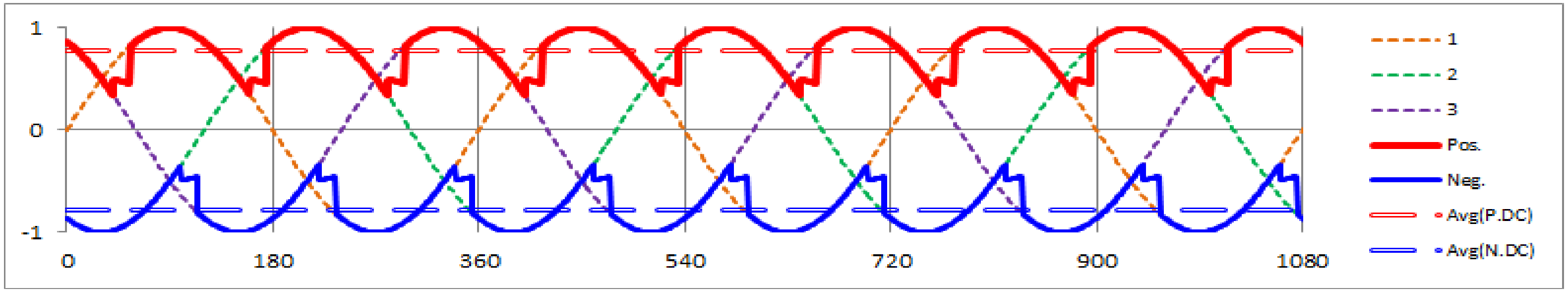
- AC is converted into DC (Rectifier Side)
- DC is then converted into AC (Inverter Side)
- Both use controlled electronic switches (Thyristors) to allow current to flow in a controlled fashion
  - Thyristors turn on (allow current flow) occurs due to a gate pulse and can be delayed but naturally turn-off when current tries to reverse
- By adjusting firing delay angles of the Thyristors, we can control the magnitude of DC voltage of the rectifier and inverter.
  - The difference of the DC voltages impacts the magnitude of current and power flow →Idc=(Vrect-Vinv)/Rdc →Pdc=Vdc*Idc
  - The polarity (which side is higher) controls the direction of power flow
  - The converter transformers determine magnitude of the voltage on the dc side and therefore the maximum possible DC voltage
- Harmonics are produced because of the 12-pulse current steps compared to sinusoidal currents

Basic Principle

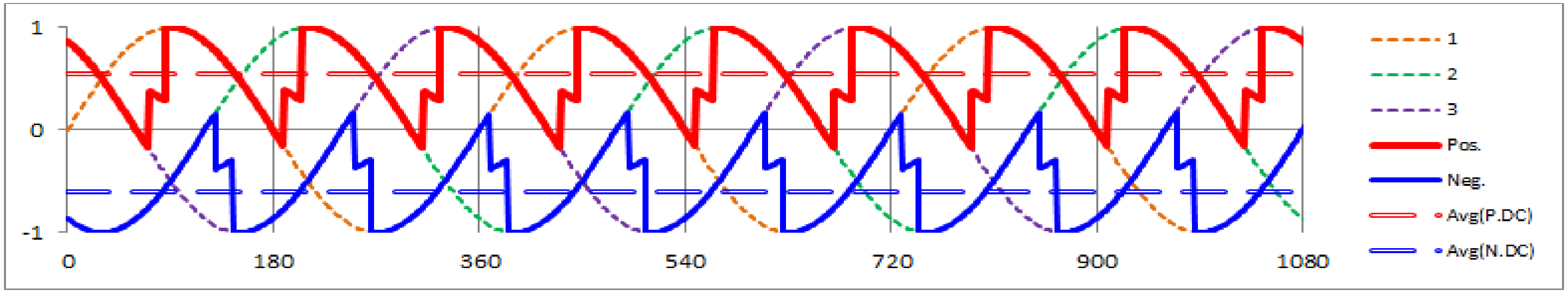
Waveform examples – Rectifier (AC to DC)



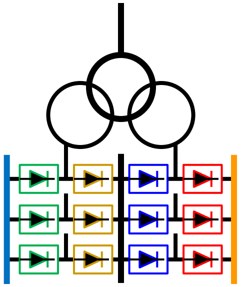
- 6 pulse, 10° firing angle (15° offset, thyristor off delay)

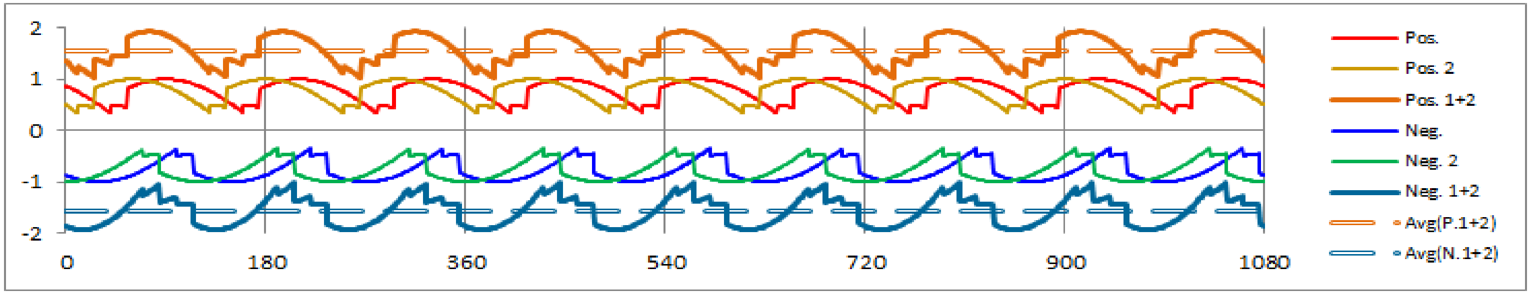


- 6 pulse, 40° firing angle, lower DC (and MW)



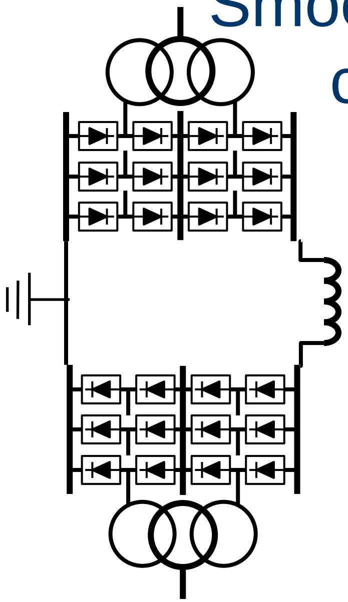
- 12 Pulse, 10° firing angle

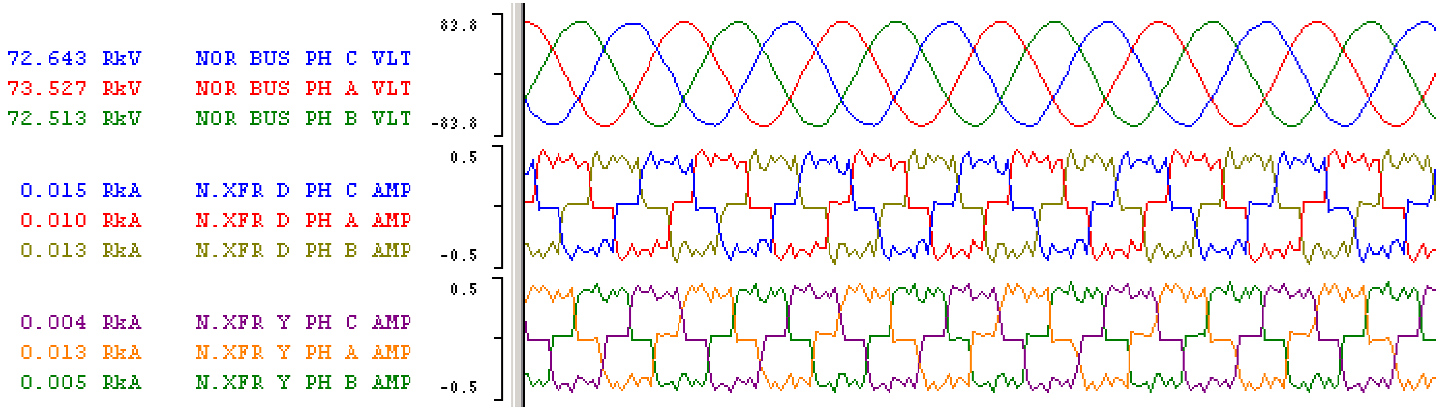




Back-to-Back Converters

- Monopolar HVDC connections
- No DC Transmission Line (just a bus)
- Both converters are located at the same site
- Utilize 12-pulse converter units on both the Rectifier and Inverter sides
- Valves can be located in one Valve hall – Option Smoothing Reactor reduces negative sequence coupling





HVDC Review

- What are the reasons HVDC is utilized?
  - Direct accurate Control of power transfer
  - Interconnections between Asynchronous systems
  - Provides isolation from system disturbances
  - Transmission of Bulk power of Long Distances
  - No restrictions on cable length while AC Cables must be less than ~40 km
- The terms Rectifier & Inverter refer to what functions?
  - A Rectifier converts AC to DC
  - An Inverter converts DC to AC
  - Either converter can be either rectifier or inverter
- Firing Angle has what impact on the DC and Power Flow?
  - Adjusting the firing delay angle adjusts the magnitude of the DC voltage
  - Magnitude and polarity of the DC voltage affects the magnitude and direction of Power flow

Background
of the Highgate Converter

- 225 MW BTB Interconnection between Hydro Quebec and VELCO (both 60 Hz but Asynchronous)
- Commissioned in 1985
- Recognized as the fastest constructed HVDC Substation from Drawing Board to Commissioning
- Continuous Capacity of 225 MW rated (up to 40°C)
- Limited to 218 MW due to HQ System until fall of 2014
- North AC bus is connected to the HQ System (120kV)
- South AC bus is connected to the VELCO system (115kV)

Basic Ratings of the Converter

- Continuous Capacity of 225 MW rated (up to 40°C)
  - North to South
  - Requires transformer cooling fans and pumps
  - Requires 4 cooling towers in-service
    - 5th tower added for redundancy, does not increase power transfer rating
- Maximum Direct Voltage - 56 kV
- Minimum Direct Voltage - 32.5 kV (20 MW)
- Maximum Direct Continuous Current - 4061 A

- Continuous Capacity of 170 MW rated (up to 40°C)
  - South to North (System not converter constraint)

Cooling System

- 2 closed loop systems separated by dual heat exchangers
- Fine water (De-ionized, Pure Water) cools the valves
- Raw water (Propylene Glycol/water) mixture cools the fine water
- Redundancy in the controls
- Redundancy of pumps, motors and fans and heat exchangers.

New Pump Cooling Equipment

Harmonic Filter Banks and additional Capacitor Banks

- Symmetric filter configuration each side (North & South)

- 2 – 11th/13th filter (22 / 20 MVAR)
- 1 – HP 25th filter (22 / 20 MVAR)
- 1 – 3rd/27th filter (11 / 10 MVAR)
- Provides harmonic filtering and VAR support for the converters

- 3 – 20 (22) MVAR
- 1 – 10 (11) MVAR
- Extra VAR support is needed to avoid drawing vars from the ac systems on both sides (helps maintain voltage)

Power Control Mode

Keeps DC power equal to the Power Order given by the operator

- The power order is given by the Operator
- DC Current is controlled to keep ordered power constant
  Idc = Pdc/Vdc
- The power order is set in MW (20 to 225 MW)
- The power ramp rate is set in MW/min (1 to 30 MW/min)
- Power modulations are available if enabled

Current Control Mode

Operates to maintain constant current regardless of the DC Voltage fluctuations

- The current order is entered by the operator
- The current order is set in A (360 to 4050 A)
- The ramp rate is set in A/min (1 to 500 A/min)
- Power modulations are available if enabled

Note VELCO only uses Current control under test mode

Highgate Converter Initial Review

- The facility was commissioned when and to connect who?
  - The facility was commissioned in 1985 to bring power from Hydro Quebec into VELCO's system
- What are critical components for achieving the full rating?
  - At least 4 out of the 5 radiator towers
  - Transformer fans and pumps available
- Does the outdoor cooling liquid in the Radiators enter the valve hall to cool the Thyristors?
  - No, the cooling system has 2 loops, Raw water (Propylene Glycol/water) between the radiators and the heat exchanger & Fine water (De-ionized, Pure Water) between the heat exchangers and the valves
- What are the 2 functions the Filter shunt Capacitor banks perform?
  - The filter capacitors absorb harmonics and provide VAR/Voltage support. The regular capacitors are primarily for VAR/Voltage support.

Starting the Converter

Permissions / Steps

- At least 1 of redundant protection and control systems available/healthy for each system.
- Tap changer starts in tap position 31 (highest ratio - lowest dc side voltage)
- AC busses initially isolated by breakers
- Valve hall grounds need to be removed

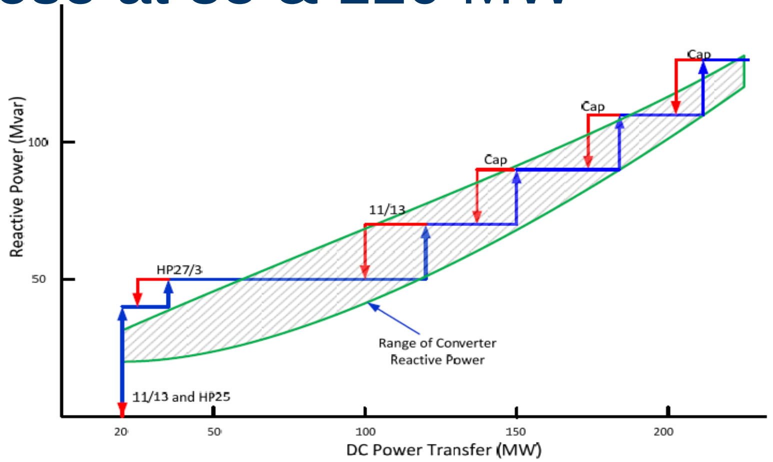
- Once energized with breakers:
- Tap changers move to regulate dc side transformer voltage to starting condition
- Minimum filters must be available
- Thyristors still blocked but available to de-block
- Converter Ramp Order and Power Order values cannot be changed yet

- The converter firing pulses will be Deblocked (i.e. released) – starts at 20 MW
- Minimum filters needed for filter performance are automatically connected at deblock

Starting the Converter

Ramp and Filter/Capacitor Switching

- System operator selects Ramp Order & Power Order
- Automatic AC voltage on both sides to a setpoint is provided by adjusting converter var absorption. This can be increased at low power by lowering the dc voltage reference and by firing angle control and by switching in and out filters/capacitor banks
- Additional minimum filters will close at 35 & 120 MW
- Capacitor banks will connect or disconnect automatically to maintain desired voltages



Switching of Ac Filters and Shunt Capacitors to meet Converter Reactive Needs

Stopping the Converter

- Emergency Stop
  - Block thyristor firing pulses
  - Trip & lockout main breakers
- Normal Stop
  - Ramp down
    - System operator selects ramp order
    - and power order of 20 MW
    - With ramp, filters will open at 100 & 25 MW or with voltage control
    - Other capacitors will open with voltage control
  - Issue Block Command
    - Blocks thyristors
    - Trips minimum filters
  - Operator may manually open main breakers

Changing of Power Direction

- Automatic Sequence
  - Ramp to Min Power Order
  - Block Converters (The minimum filters remain connected)
  - Reverse Rectifier/Inverter designations
  - Restart the Converters. Due to different firing angles the dc voltage is reversed, current flows in same direction
  - Ramp to new Power Order

Runbacks

- Power Modulated Voltage Controller (PMVC) Runbacks
  - Utilizes a PID Function to constrain DC power transfer if the AC systems cannot maintain voltage above a set-point DC transfer is controlled so AC voltage does not go too low (maximizes energy throughput)
- Voltage Runbacks
  - When enabled and voltage below set-point for a given time:
  - Quick MW ramp down until voltage is acceptable or MW minimum met
- Frequency Limiter Runbacks (North only)
  - When enabled and outside frequency band:
  - Ramp speed proportional to frequency deviation

Highgate Converter 2nd Review

- What are some of the required starting conditions of the converter?
  - At least 1 of redundant protection and control systems available/healthy for each system.
  - Transformer Tap changer in position 31 (highest ratio - lowest LV or DC voltage)
  - AC busses initially isolated by breakers
  - Valve hall grounds need to be removed
  - Once transformers are energized with breakers:
  - Tap changers move to regulate LV/dc to starting value, HV must remain within band
  - Minimum filters available
  - Thyristors available to de-block
- What are the 3 runback schemes?
  - Power Modulated Voltage Control
  - Voltage Runbacks
  - Frequency Runbacks

Temporary Blocking

- Special Control Sequences to allow the converter to ride through faults on North & South lines
- There are no Operator inputs or adjustments to the North or South Temporary block sequences
- Separate Temporary Block sequences are provided on the North side and the South sides

Temporary Blocking
initiation & actions

Initiated by a serious voltage drop for a given time

- Retards firing angle of the rectifier to reduce DC Current toward zero
- Blocks the faulted-side converter with Bypass Pair
- Opens faulted-side Main Breakers, but leaves filters and shunts connected
- Switches the control mode of the unfaulted-side DC converter to AC overvoltage control mode
- Deblocks the faulted-side converter as an Inverter the unfaulted-side as a Rectifier (if not already that way)
- After dc voltage is established, fires a bypass on the faulted-side side and circulates current through bypass pairs in the faulted-side as needed to control overvoltage as the unfaulted-side AC Bus to 1.1 pu
- Maintains the above condition until the faulted-side AC voltage recovers
- If not recovered within a given timeframe , the converter will trip

Temporary Blocking
Recovery

- If the ac voltage recovers, the dc system will automatically be restored back to pre-fault power order
  - Firing angle of the unfaulted-side converter is retarded to bring DC current to zero and the converter is blocked
  - The faulted-side Main breakers are re-closed
  - Power direction is restored to the pre-fault state (rectifier/inverter designations during temporary block may need to be reversed)
  - The pole controls rapidly restore the pre-fault power by adjusting firing angles (no ramping)

Temporary Blocking
additional initiation

Other than voltage other initiating signals may include:

- Transfer trip signals from other substation protection systems
- Status indications from other substations for low system strength determination

Likewise both voltage recovery and removal of any other initiating condition need to occur to allow recovery from temporary block condition

There are some conditions where due to harmonics the system may not be able to restore previous conditions and will instead trip if those conditions are determined by the control system

Offline Capacitor Bank Switching

- Used when Converter offline for extended outage
- Request for using the capacitor banks for addition MVAR support to the system
- Allows the use of five of the capacitor banks
    - (3) 20 MVAR banks and (2) 10 MVAR banks for a total of 80 MVARs,

Offline Capacitor Bank Switching

Mode of operation/switching:

- Verify that the Converter is stopped
- Open the Main breaker
- Place the Filter control to Manual
- Open the converter Transformer high-side disconnect
  - Need person on site to confirm disconnect is open
- Enable the Cap bank control
- Close the Main breaker
- Dispatch the desired cap/filter banks

Offline Capacitor Bank Protections

- If voltage is above High voltage limit
  - Sequential tripping of capacitor banks
  - Stops when below High voltage limit
- If voltage is above Very-High voltage limit
  - Faster sequential tripping of capacitor banks
  - Reverts to slower sequential tripping (High voltage mode) when below Very-high voltage limit

Highgate Converter Final Review

- Does the converter trip during a line fault?
  - Generally not unless the ac voltage stays low for a long time. Trick question, some breakers will at least trip temporarily but the system will resume where it left off if the ac voltages recover in time. Otherwise the system will trip if the AC system voltage remains low or some other protection conditions exist
- Other than voltage what other initiating conditions may cause a temporary block?
  - Transfer trip from other substations
  - Status from other substations that in combination can be determined to be a low short circuit condition
- Can the north & south capacitor banks be used when the converter is offline?
  - Only the capacitors on one side have been set up in the control system for independent ac bus voltage control while offline

QUESTIONS / ANSWERS