HVDC Control
and Requirements

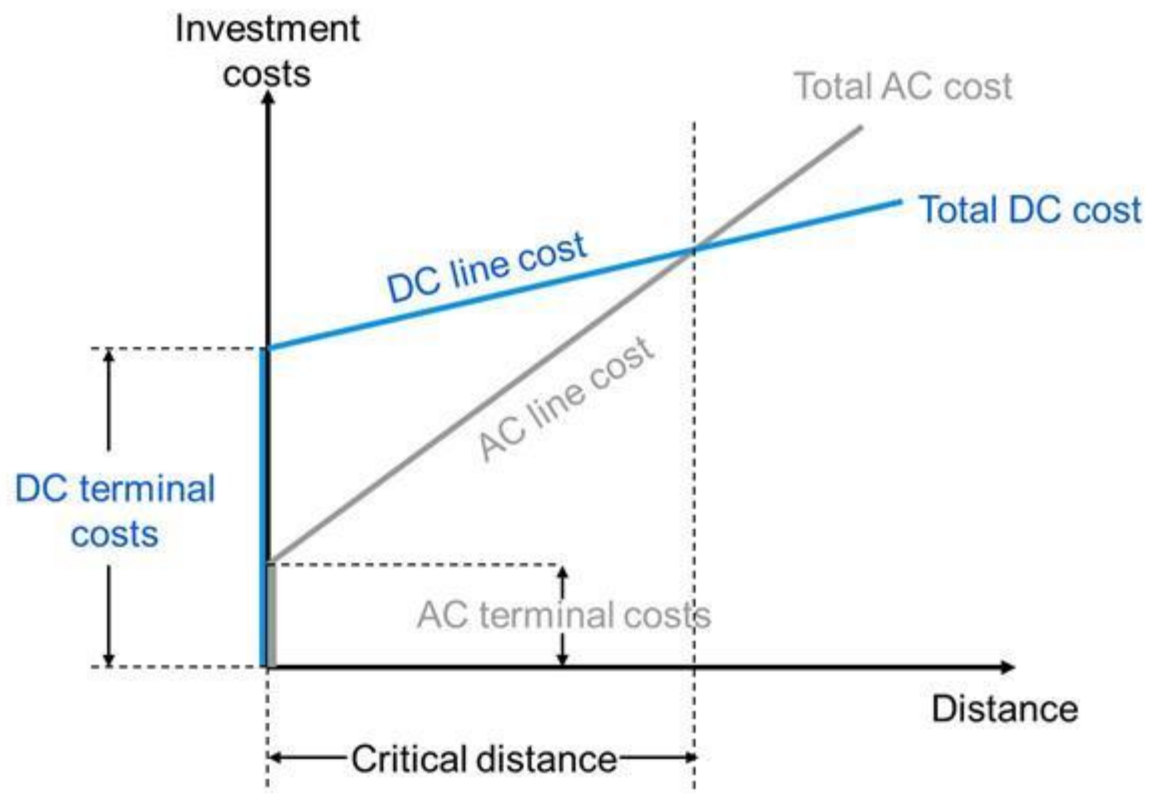
Contents

Advantages of HVDC

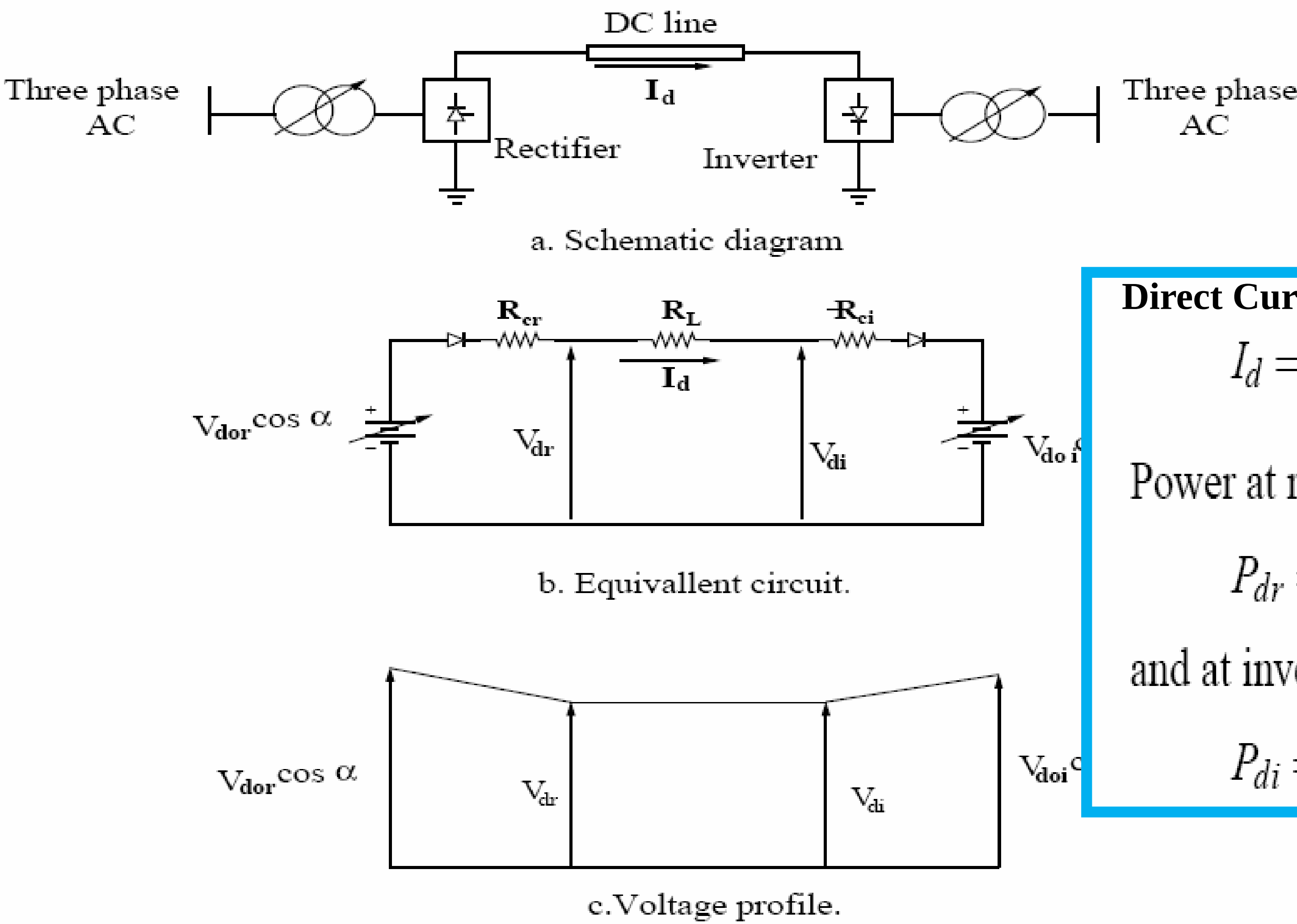
Following major advantages compared to equivalent double circuit AC line

1. Better controllability
2. Better overall economy
3. Right of way requirement half
4. Lower Transmission loss
5. No increase in Short circuit level

AC & DC Transmission cost



HVDC Transmission link



Direct Current

$$I_d = \frac{V_{dor} cos\alpha - V_{doi} cos\gamma}{R_{cr} + R_L - R_{ci}}$$

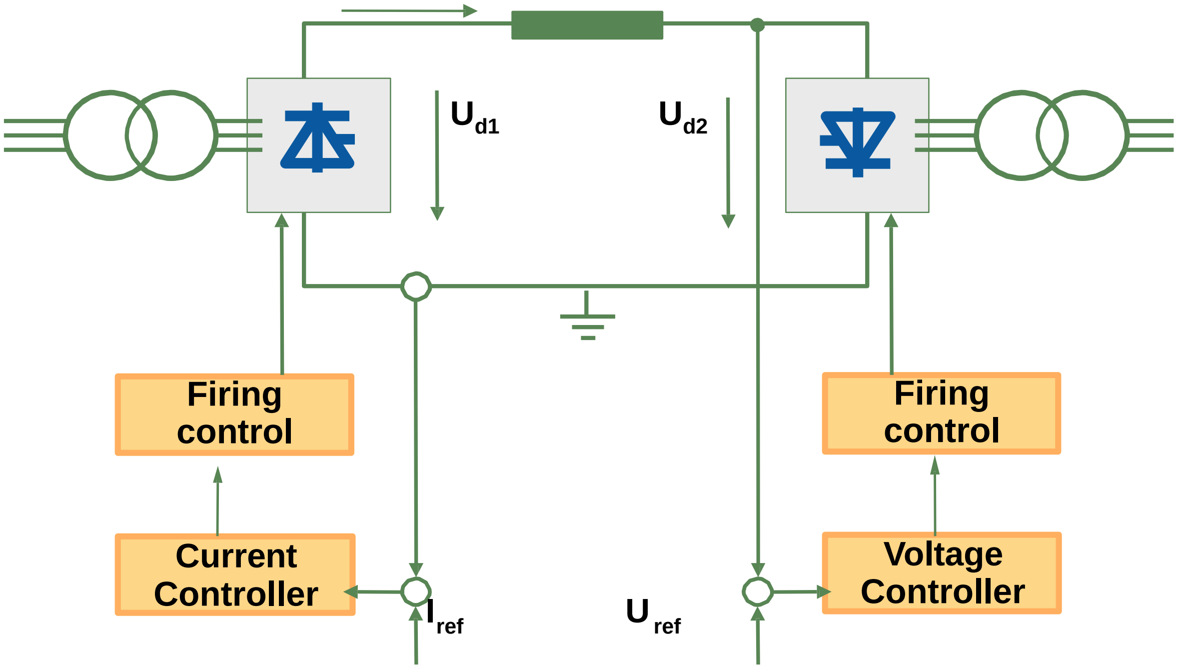
Power at rectifier terminals

$$P_{dr} = V_{dr} I_d$$

and at inverter terminals

$$P_{di} = V_{di} I_d = P_{dr} - R_L I_d^2$$

Control System



Actual converter control steady-state characteristics

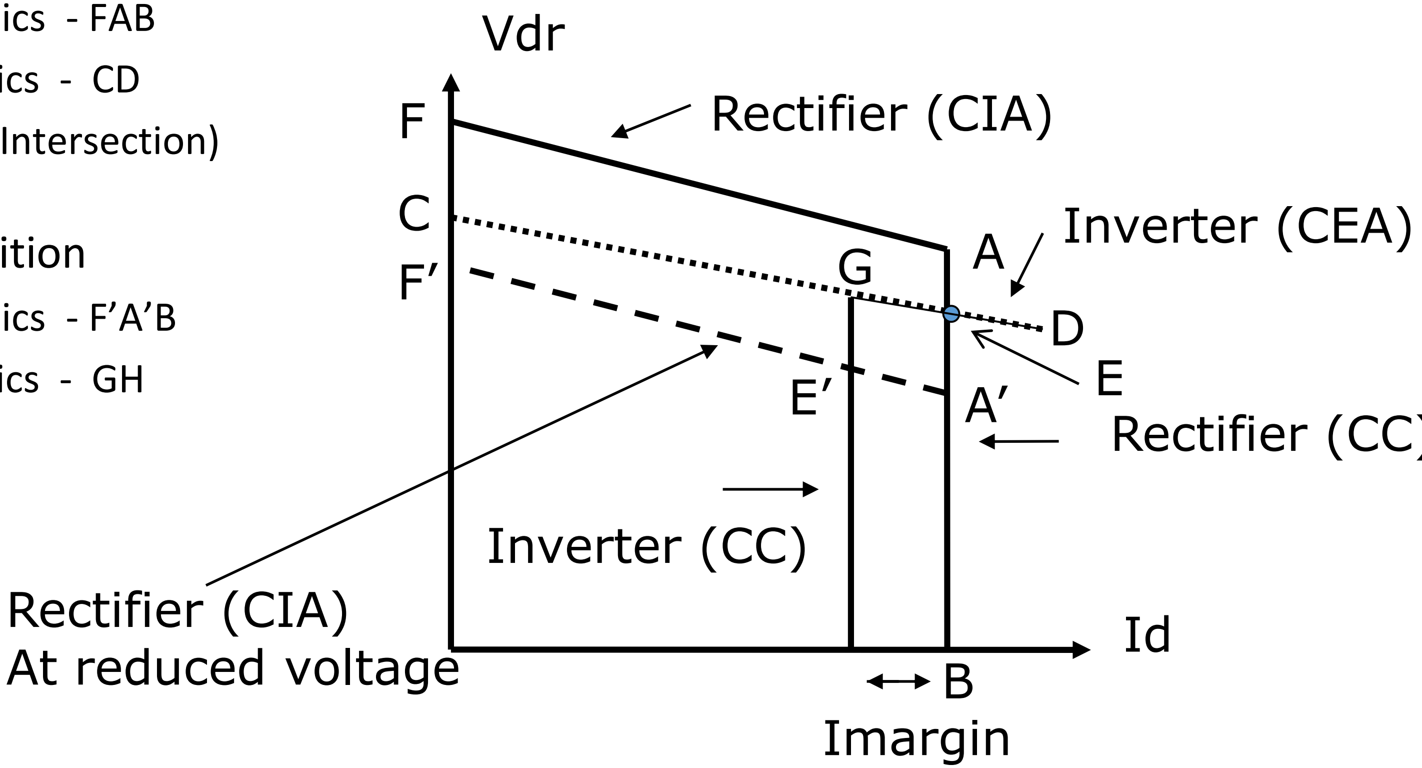
Inverter Terminal Voltage including voltage drop in line $V_d = V_{doi} cos\gamma + (R_L - R_{ci}) I_d$

Normal voltage condition

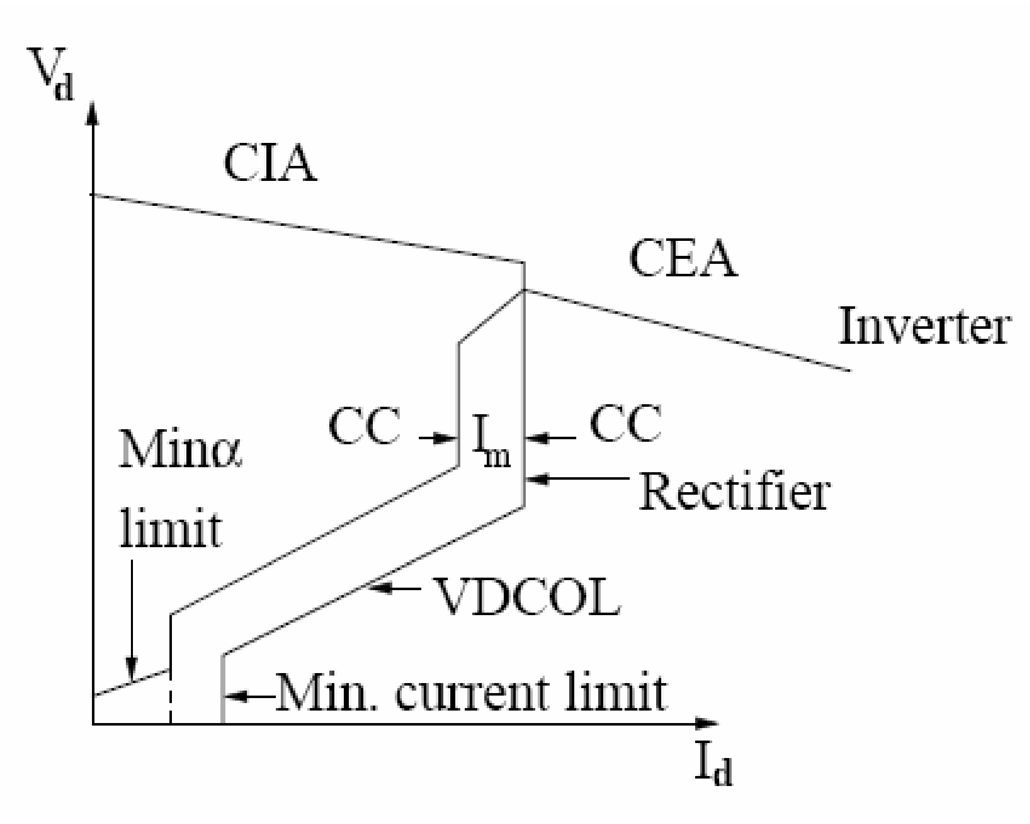
- Rectifier characteristics - FAB
- Inverter characteristics - CD
- operating point is E (Intersection)

Reduced voltage condition

- Rectifier characteristics - F'A'B
- Inverter characteristics - GH
- operating point is E'

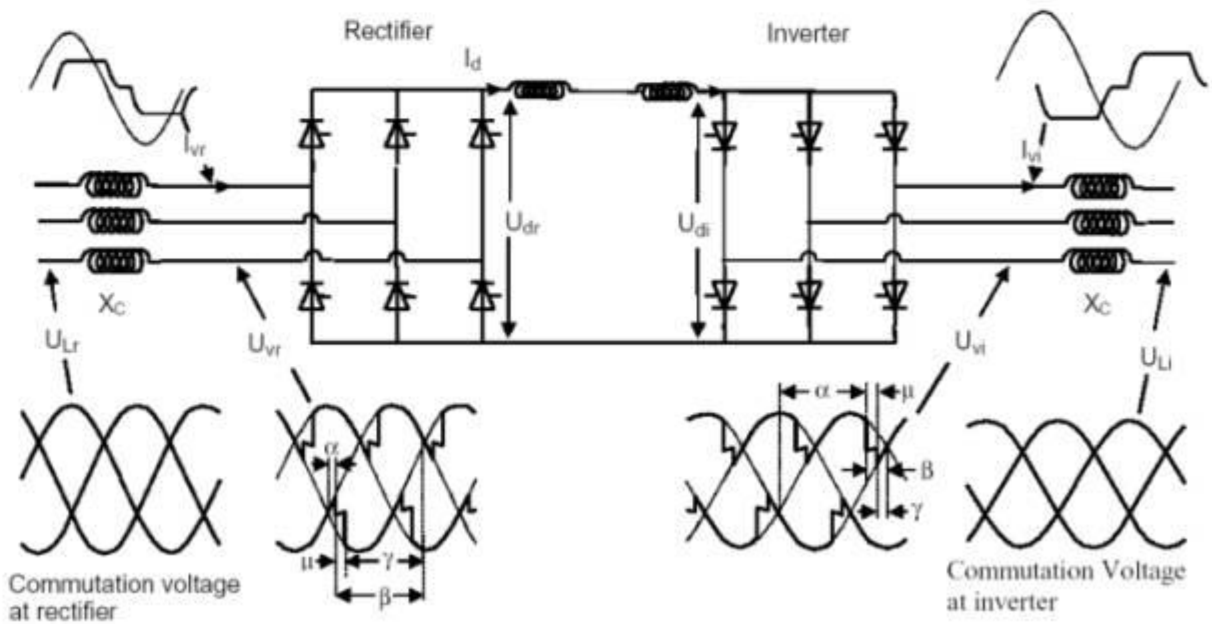


Steady-state V-I characteristic with VDCOL

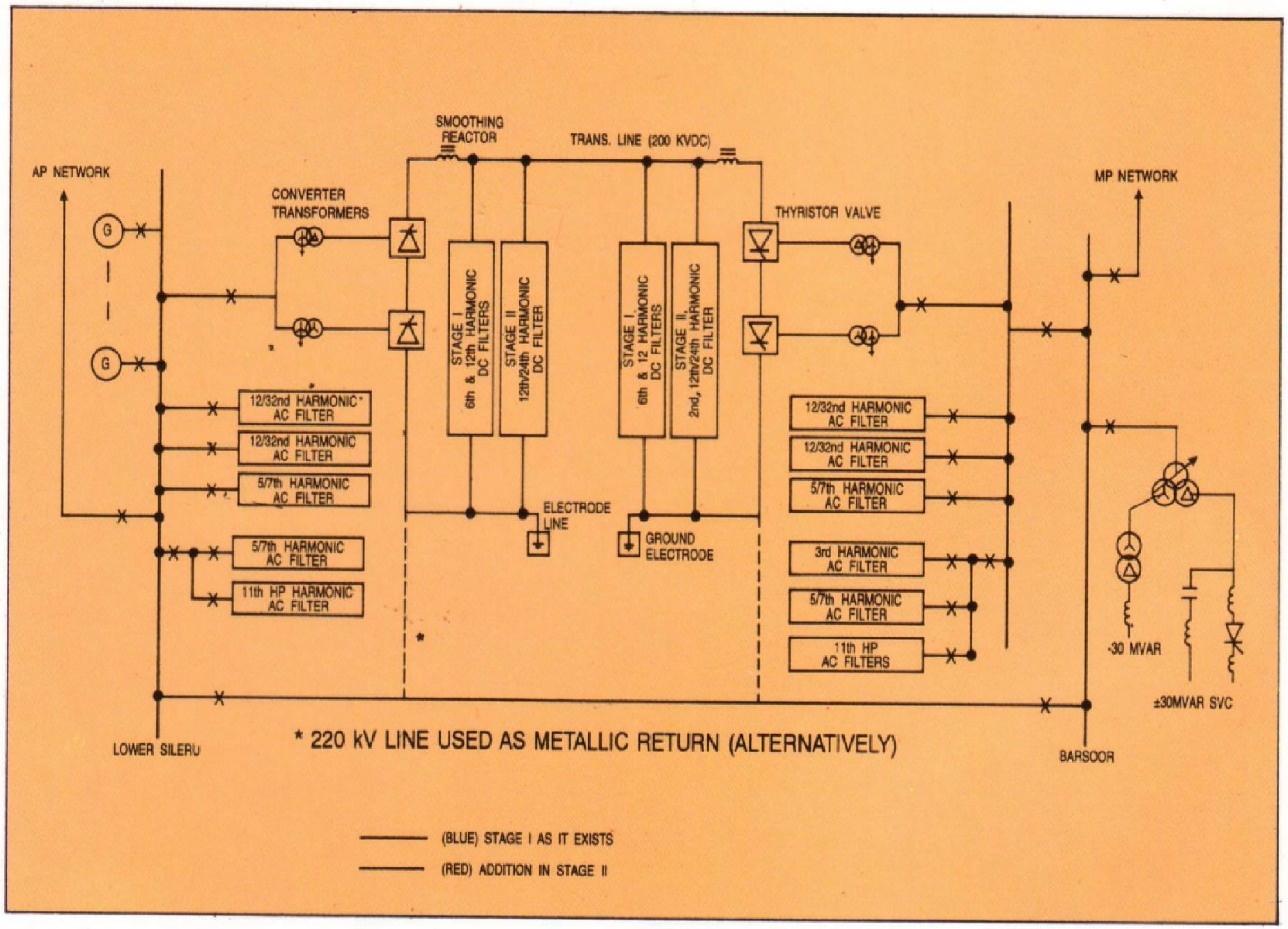


- VDCOL Characteristic is a function of AC voltage (or) direct voltage.
- Minimum α-limit for inverter
- Minimum current limit for rectifier

Typical voltage/current waveforms



Typical HVDC main circuit equipments

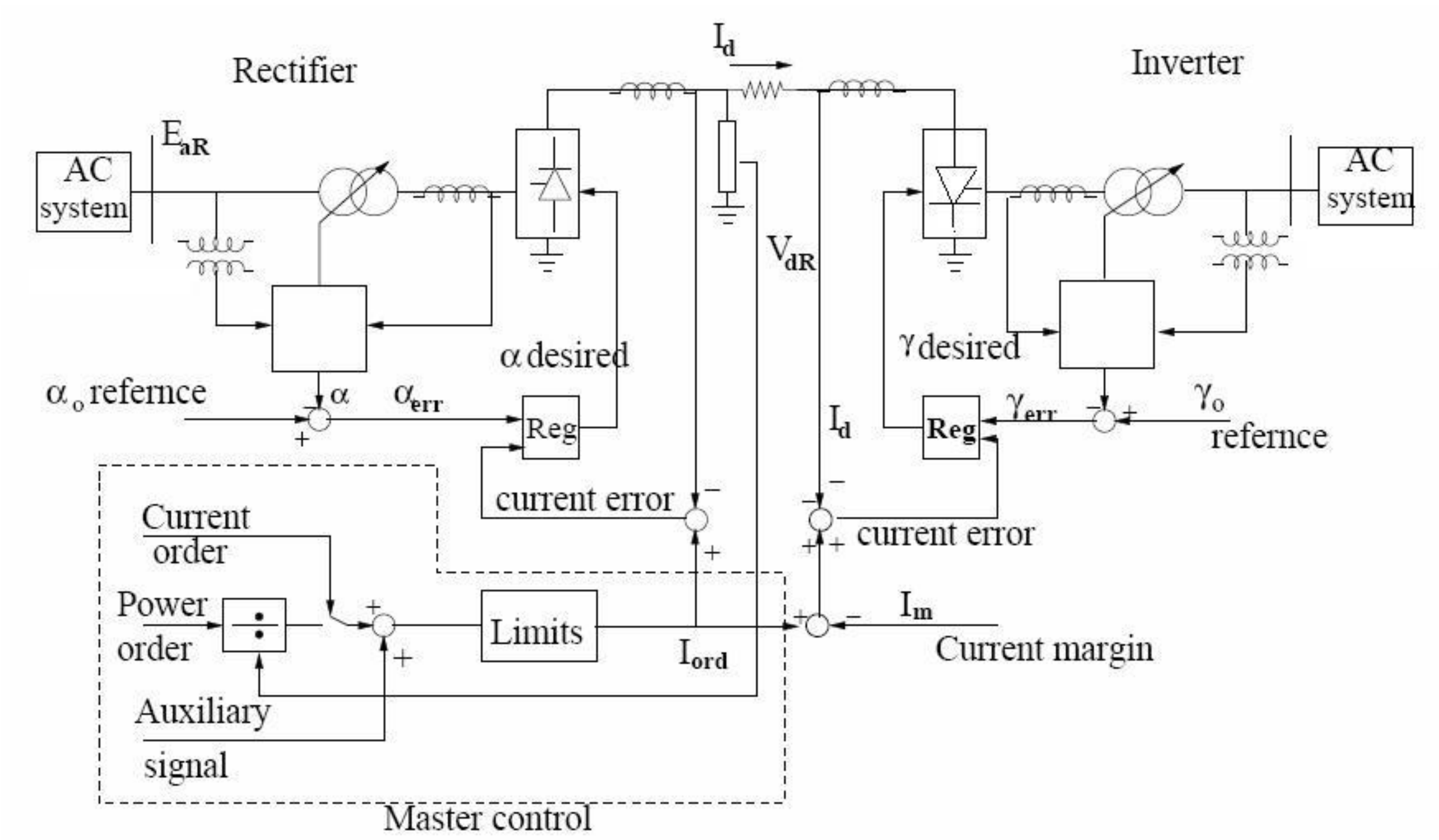


NHVDC (Stage I & II) Block Diagram

HVDC Control

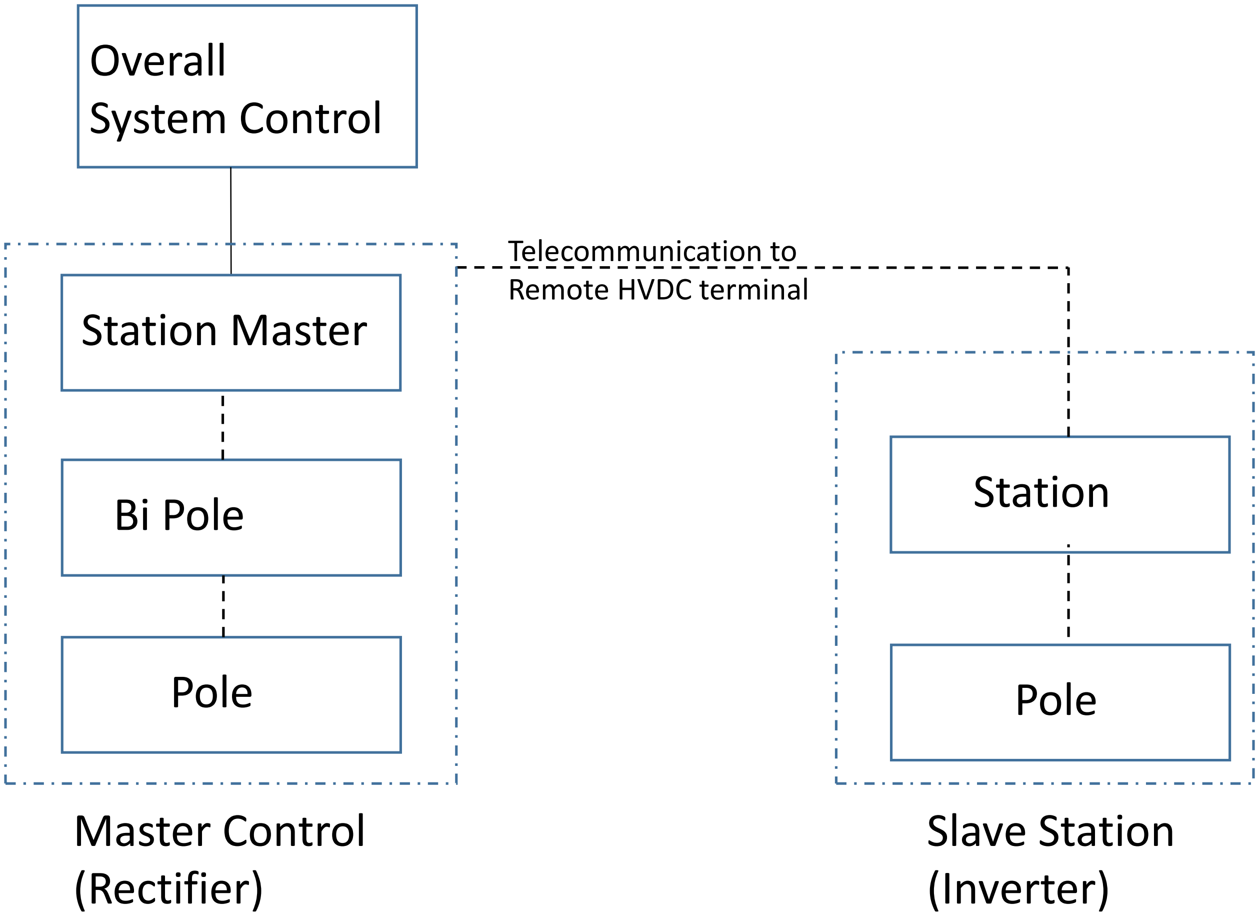
- To send firing pulses to thyristor valves in order to keep DC power at ordered level
- Prepare HVDC system for start up & shutdown

Basic Control Scheme



Typical HVDC Mimic Control Panel

HVDC system controls Hierarchy



Typical design targets for HVDC Availability & Reliability

- Energy Availability : >99%

- No. of Pole Outages: <8 per year

- No. of Bipole Outages: <0.2 per year

Design Methodology

- No single contingency within the converter stations should cause shut down of Bipole
- To achieve this, redundancy is built into the following:
    - Control and protection system
    - Redundant thyristors in Thyristor valves
    - Redundant AC Filters sub-banks
    - Circuit Breakers by using one & half breaker schemes
    - Auxiliary power supplies
    - Valve Cooling systems

Modes of Control

- ❑ Basic operator selectable control modes :
  - Power control mode
  - Current control mode
- ❑ Higher level control modes :
  - Frequency control
  - AC system stabilization

Modes of Control (Cont’d)

Operation modes

1. Normal/Reduced direct voltage
2. Reactive power exchange (by RPC)
3. AC voltage control (by RPC)

HVDC controls

- Current order is set by operator at master controller
- Current order is coordinated with inverter using check back concept through telecomm.
- To maintain Iref(Rect) > Iref(Inv), at rectifier
  - Current order increase is immediately passed to CC
  - Current order decrease , it waits until check back signal receives from Inverter
- Without telecommunication
  - Current order at master, can ramp up or down
  - Inverter *current tracking function* follows the actual current through a smoothing time constant
- Iref and Uref are set by Bipole control level

Station Master Control

Tasks

- Power and current balancing among all terminals
- Power ramping
- Power loss compensation
- Co-ordination during and after fault recovery

Equipped with

- Bipole power control
- Reactive power control
- Master sequences and local station sequences

Bipole Power Control

$$Iref = \Pr ef\,(BiPole) \big/ UdBipole$$

- Power order calculator for scheduled power
  - Both are in P mode
  - One in P mode, other in I mode
  - Both in P mode, one pole becomes current limited

- Power Order Calculator for AC stability power

- Active at both converters, inverter does not have P controller but by telecommunication
  - Frequency control
  - AC System stabilization modulation
  - Small signal modulation

Bipole Power Control (Cont'd)

- Current Balance Control: PI controller at Rectifier, becomes active Igr>dead band (2A)
- Pole power capability : $P_{cap_{P1}} = U_{ref_1} \times I_{\max Pole1}$
- During reduced voltage operation, the pole current limit (POLE Imax) is reduced according to a characteristics to match converter capability at higher firing angles
- Tap changer control in reduced voltage operation
  - Automatically brought to highest tap derived from increased firing angle
- Reduced short circuit level
  - Caused by disconnected lines or loss of generators
  - Can produce transient stresses e.g. over voltage or repeated communication failures during or after change of power

Pole Level Control

- Rectifier mode
  - Current control : Controls dc current to Iref
  - DC Voltage control : Upper voltage limit control e.g. 2.5% above normal
- Inverter mode
  - DC Voltage control
  - Current control : Controls dc current to Iref-Imargin(0.1 p.u)
  - Extinction angle control : Controls γ to γmin.
- AC System voltage reduction causes inverter γ controller to take over from voltage control to avoid commutation failure

Tap Changer Control

- To keep the ordered α, γ and Udc at the targeted values determined by VARC
- No-load control : when converter blocked or station is in open line test mode
- Angle Control (γ or α)
- Voltage control (Ud)
- Udio Control:- Controls Udio to 1.0 pu. Under reduced V operation, it change from 1.0 pu to 0.8 pu

Additional Contract Requirements

- Frequency control
- AC System Stabilisation
- DC Current response
- DC Power Order Change
- Pole Blocking
- Reactive Power Control

Typical Frequency Control Requirement

- Power flow changes through the transmission to control the frequency of one region provided the frequency of the other grid does not deviate specified band(i.e. 48.5 Hz to 51.5 Hz)

- Possible to set any where between 48.5 Hz to 51.5 Hz in steps of 0.05 Hz

- Also possible to set the frequency band by setting lower limit and upper limit to a value between 48.5 Hz to 51.0 Hz. While trying to meet the frequency target the frequency band shall not be deviated for more than 0.01 Hz

- Automatic activation of frequency controller

- The frequency control shall also be possible even with the communication system out of service. But, the extent of control may be limited by the dead band at the other end

Typical AC System stabilization Requirement

- Utilize fast control action to suitably stabilize the AC system by rapidly increasing or decreasing the power flow transiently above or below the ordered value in response to AC system stabilizing control signals
- Small signal modulation shall be allowed even when HVDC telecontrol facilities are not in service
- HVDC transmission system shall be able to continue operation with reduced ac bus bar voltages
- Able to continue operating without blocking of converters with ac bus voltage reduced for a period of 1 sec followed by voltage recovery to 85%
    - To 30% of nominal during three phase fault
    - To zero on one phase during single line to ground fault

Typical Response Requirements

DC Current Response

When operating at any DC power transfer level between minimum and maximum rated power levels, pole dc current shall respond

- Within 30 msec. for current order changes not exceeding the margin
  - a)Current order step from (1-x) pu to 1.0 pu
  - b)Current order step from 1.0 pu to (1-x) pu, applied immediately after the step of (a) has settled
  - c)Current order step from 1.0 pu to (1-x) pu
  - d)Current order step from (1-x) pu to 1.0 pu applied immediately after the step of (c) has settled

  x = current margin – tolerance of measuring/ control circuits
- Within 70 msec. for current order changes exceeding the margin

  x= 0.5 for above cases

Typical Response Requirements (Cont'd)

DC Power order change

- When operating between minimum and rated power
  - Power controller shall respond to either a step increase or a step decrease in dc power order such that 90% of the ordered change is achieved within 150 milliseconds of power order change at the rectifier end

Typical Response Requirements (Cont’d)

Pole Blocking

- Ability of control system to increase power up to the 5-second overload rating on one pole following reduction in power on other pole

- When increase or reduction in power transfer of a healthy pole is required due to power reduction or increase on a pole
  - 90% of the dc power transfer required shall be achieved within 80 milliseconds of the faulted pole changing power

Typical Reactive Power Control Requirements

- Controlled quantity to be either AC bus voltage or reactive power exchange with AC system

- It shall not require any reactive element switching for dc power flow changes of around 5% of current power level in either direction since the last switching operation had taken place

- Switching necessary to maintain the AC bus voltage from 380-420 kV and the frequency shall be from 49.0-50.5 Hz is permissible for smaller than 5% change in transmitted power

Thank

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