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* MODULE 3.

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* Control of HVDC link

* Desired Control features

- Control system should not be sensitive to normal variation in voltage & frequency of ac supply.
[Variation in V & f is due to load changes]

- Control should be fast, reliable & easy

- It should have continuous operating range from full rectification to full inversion

- Control should be such that it should require less reactive power [α is maintained (10-20°) & not ↑ because cos Ø ↓ & Reactive Power req ↑]

- Under steady state conditions, valve should be fired symmetrically.

- Control should be such that it should control max current in the link & limit the fluctuation of current

- Power should be controlled independently & smoothly which can be done by controlling the current and/or the voltage simultaneously in the link.

- Control should be such that it can be used for protection of line & converter.
[In case of any abnormal operation voltage at two ends is ↓ so that the I in link becomes zero]
Because we dont have CB to disconnect the ckt as in AC

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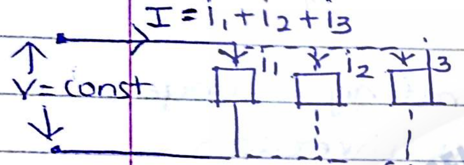
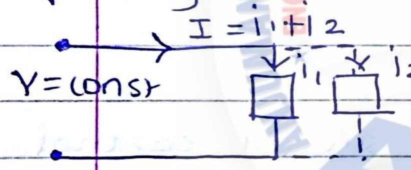
* Constant Voltage vs Constant Current Operation

Constant Voltage

(1) In this mode, loads are connected in parallel.



(2) If any load is to be replaced, it can be disconnected easily without impacting constant voltage.



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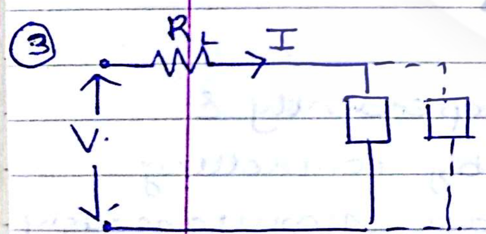


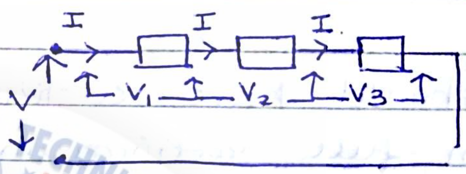
loss $= I^2 R_L$

here value of 'I' varies as per the load requirement

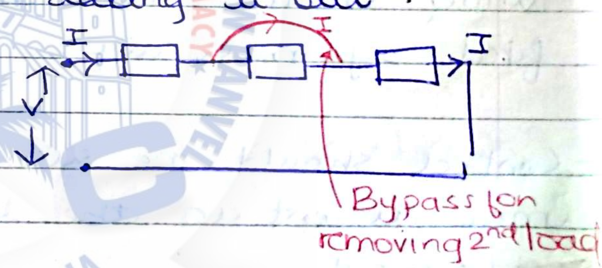
$\therefore \downarrow$ loss.

Constant Current.

(1) In this mode, loads are connected in series



(2) If any load is to be replaced, we have to bypass the load before taking it out.



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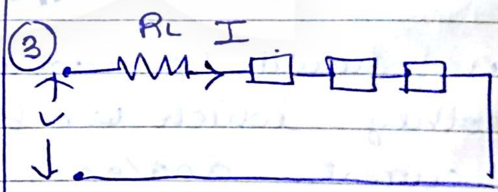

loss $= I^2 R_L$

here value of 'I' is constant so the power loss is constant

$\therefore \uparrow$ loss.

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④ Corona loss $\propto V^2$ V of line is fixed ∴ Corona loss = constant	④ 'V' of the line is varying, ∴ corolona loss is varying.
⑤ Constant voltage is to be maintained constant at PCC of ac system $R_{ac} > R_{dc}$ & impacts Power loss	⑤ $R_{dc} < R_{ac}$ which also impacts power loss ~~jersued~~.
⑥ In ac system the presence of line impedences reduce the SC currents & that is 5-6 times the rated value but there is ~~deeee~~ CB who will trip the ckt automatically	⑥ In dc system, the line has a small resistance & hence SC current is more & nearly 20-30 times that of rated value So by making I constant the max current is limited to rated current. Hence HVDC link is operated in constant current mode.

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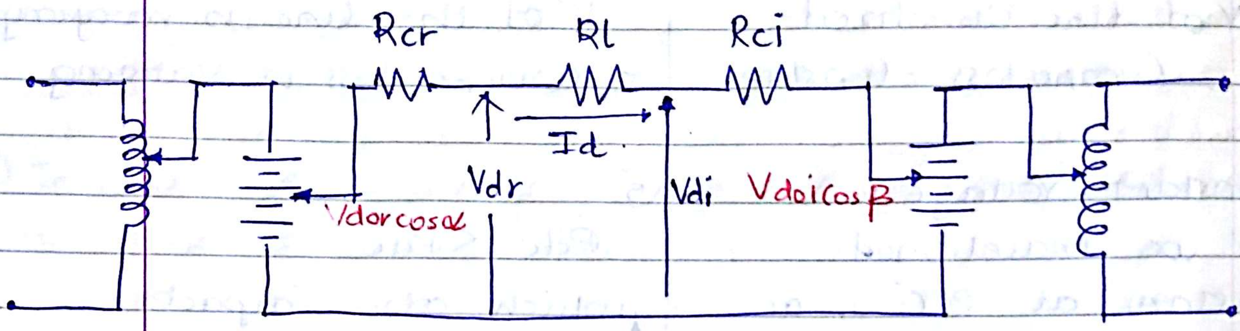
* HVDC link can be represented as;



• Eq ckt of HVDC link

- $I_d = \dfrac{V_{dor}\cos\alpha - V_{doi}\cos\beta\,(\text{or } \gamma)}{R_{cr} + R_L \mp R_{ci}}$

- For maintaining safe commutation margin, γ is used as control variable instead of β.

[$V_{di} = V_{doi}\cos\beta + R_{ci} I_d$
$V_{di} = V_{doi}\cos\gamma - R_{ci} I_d$]

- From above it is clear that for inverter operation we can operate in 'β mode' or 'γ mode'. We can either decide β instant or γ instant.

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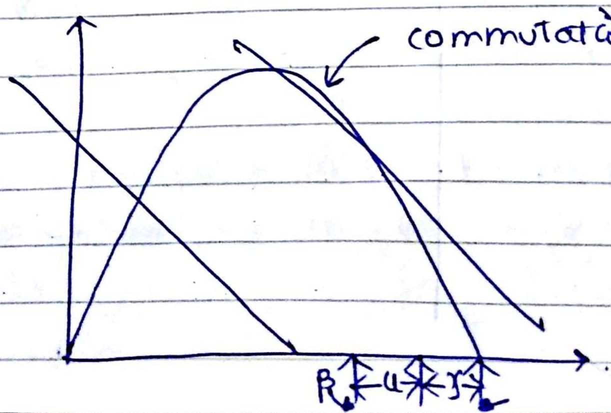

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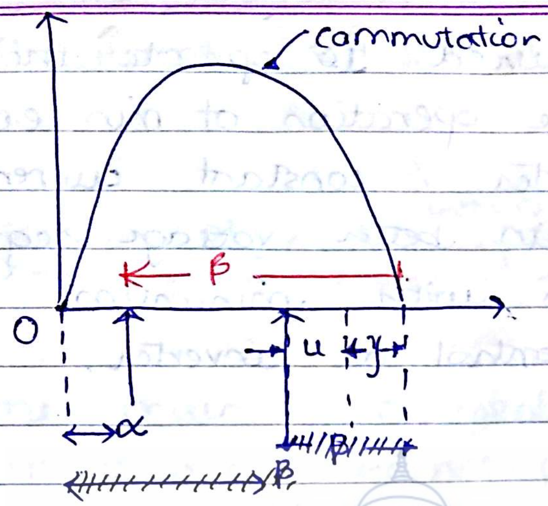

It is always preferred to use inverter end with 'γ' control. Reason being, if 'γ' is not maintained a certain degree, voltage may reverse before the completion of successful commutation.

- It is therefore desireable to have γ fixed at 5°–10° to avoid commutation failure & 'u' & 'β' is varied accordingly.

- The problem of using 'γ' control is that we have a -ve resistance (-Rci) which introduces stability issues.

- To control power in two terminal 'dc link' it is desirable to have current control in one converter & voltage control in 2nd converter. The increase of power in the link can be achieved by.
    - Reducing α which will improve P.F
    - Increasing 'γ or β' which will worsen the P.F & higher loss in valve snubber ckt.

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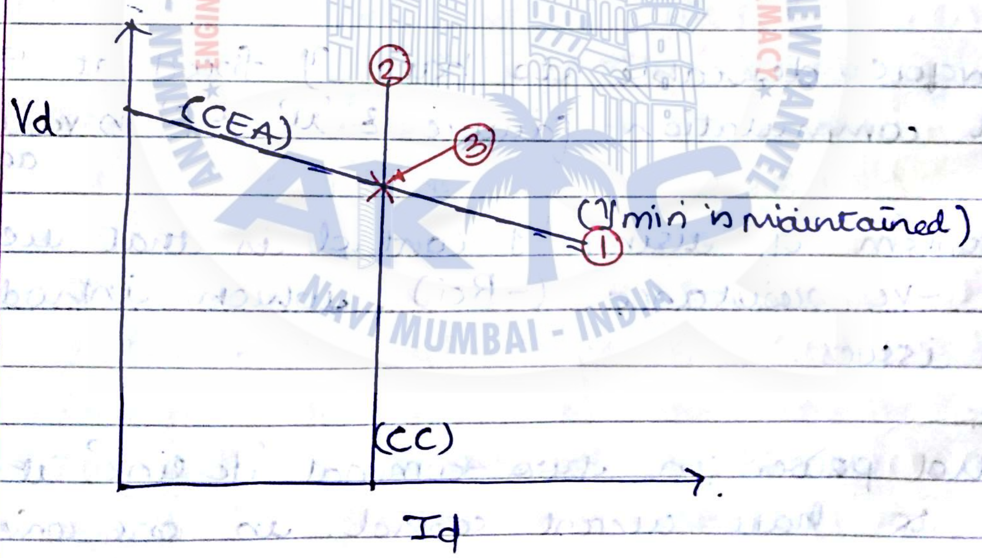
- Therefore it is required to operate the inverter at minimum 'γ'. The operation of min extinction angle at the inverter & constant current control at rectifier results in better voltage regulation than the operation with minimum 'α' at rectifier & current control at inverter.

- To avoid commutation failure it is economical to operate inverter at constant extinction angle (CEA) control.

- Characteristics of controller. (Ideal)



① Characteristic to be maintained by inverter end is called Constant Extinction angle Control (CEA) where γ is not varied much & so we get only a slight slope.

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(2) Constant current (CC) control is employed at rectifier end

(3) The intersection pt is the actual operating of the dc link.

- However the main problem of CEA control is the -ve resistance characteristics of the converter which makes it difficult to operate stably if connected in weak AC system.

- Under normal condition, rectifier operates at constant current control (CC) control & inverter at constant extinction angle (CEA) control.

- With this control let us examine the effects of AC voltages on dc link current.

- Increase in rectifier voltage: Current in link will be increased. To control the current in rectifier end, controller will increase the delay angle(α) while inverter end controller will maintain constant extinction angle (CEA). Decrease in 'α' will worsen the P.F & generally is controlled upto some fixed angle & thereafter Tap changer is used.

We know that;

$$I_d = \frac{V_{dor}\cos\alpha - V_{doi}\cos\beta(\text{or }\gamma)}{R_{cr} + R_L \pm R_{ci}}$$

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∴ If rectifier end voltage ↑ → V_{dor} ↑ → I_d ↑

The rectifier acts in constant current mode & makes

$\alpha \uparrow \rightarrow \cos\alpha \downarrow \rightarrow (V_{dor}\cos\alpha)\downarrow \rightarrow I_d \downarrow \rightarrow \cos\phi \downarrow$

This means 'α' is to varyed upto a certain range only beyond which cos ϕ becomes poor.

- Now if 'α' is changed to max value, yet 'I_d' has not become rated then 'OLTC' comes into picture to vary rectifier voltage.

- If 'OLTC' variation is insufficient, then the inverter side 'OLTC' has to be varied to vary V_{doi}

• <u>Decrease in Rectifier voltage:</u>

- $V_{dor}\downarrow \rightarrow I_d\downarrow \rightarrow \cos\alpha\uparrow \rightarrow \alpha\downarrow$ (so α_{min} has to maintained)

- If α_{min} has reached & $I_d \neq$ constant rated value, then 'OLTC' operates to change rectifier voltage.

So the characteristics become.

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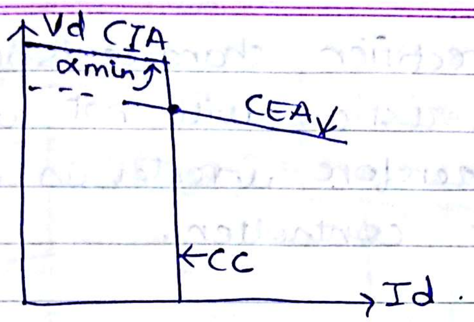

- Increase in inverter voltage:

- Current in the link will be reduced & to maintain constant current in the link, angle α will be reduced to αmin which is req. for the complete firing of the valve. If still current in link is less than the reference current, the tap changer is to be operated to increase the A.C voltage at the rectifier.

- Decrease in Inverter Voltage:

- DC current in the link will be increased. Rectifier end controller will increase the delay angle α. Decrease in 'α' will worsen the P.F & is generally controlled up to certain angle & thereafter tap-changer is used. (α is maintained 10-20°).

- Decrease in converter Voltage:

- It will decrease the DC current. To maintain this current, 'α' is to be decreased but limited to αmin & then tap changer is to be used to increase the current.

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If further decreased rectifier characteristics fall below & CEA characteristic will not intersect & Id will be zero. Therefore inverter is also equipped with constant current controller.

* Slope of α, β & γ characteristics

- **What is Vd?**

$V_d = V_{dor} \cos\alpha - (R_{cr} + R_L) I_d$ (Here RL is added to rectifier side arbitarily)

$V_d = V_{doi} \cos\beta + R_{ci} I_d$

$V_d = V_{doi} \cos\gamma - R_{ci} I_d$.

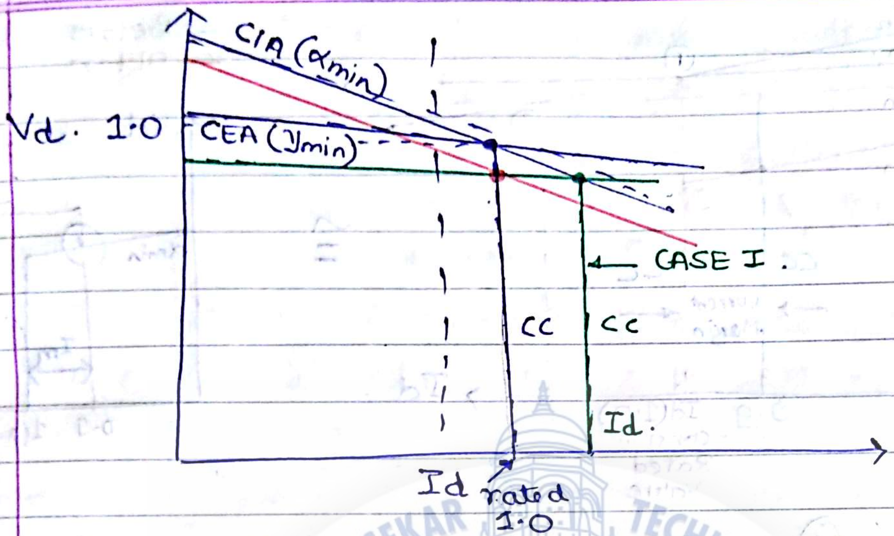
- **Constant advance angle control (β)**

- If a higher value of β is used to avoid commutation failure, the power factor will be poor. (Hence we never use this method)

- **Constant Extinction Angle (CEA) Control (γ)**

- The value of β is calculated for fixed value of γ using following relation

$$I_d = \frac{\sqrt{3} E_m}{2\omega L} (\cos\gamma - \cos\beta)$$



• From above, it is clear that αmin slope is more due to RL added to Rcr & γmin slope is comparitively less

- Intersection of γmin & αmin slope is the pt of rated current flow in ckt

CASE I : If inverter voltage drops down as shown, the current in the link (Id) will increase (∵ CEA characteristic falls) (Green line)
However, by controlling 'α' or rectifier voltage' we can have the operating pt shifted to maintain constant rated current (Red line)

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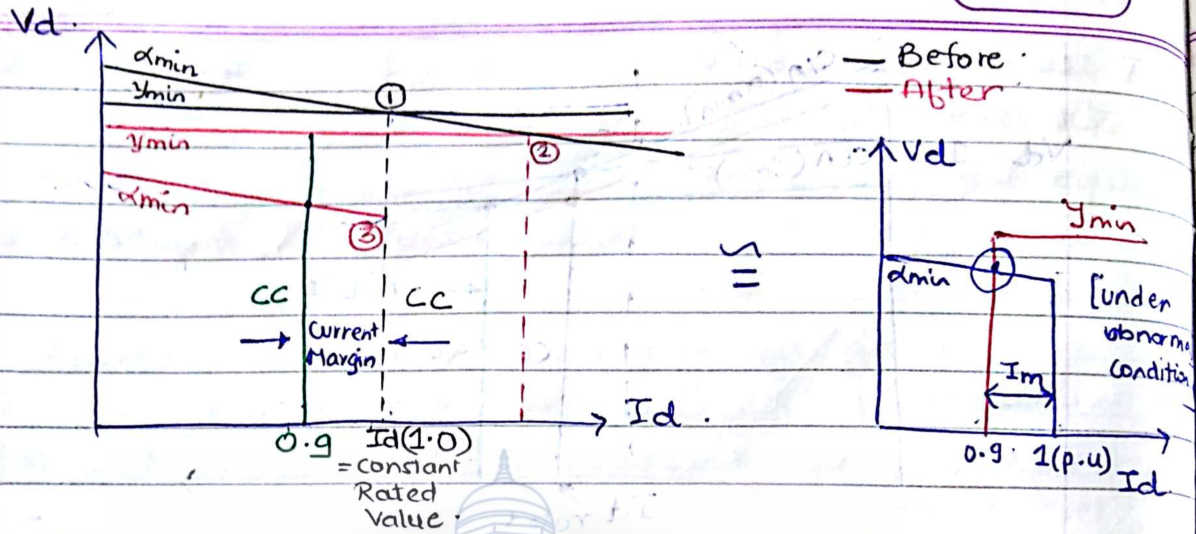

In above fig, ① indicates intersection of CIA(αmin) and CEA (γmin) Characteristics to maintain constant rated current 'Id'.

- ② Indicates that when inverter end voltage drop & thus CEA characteristic drop, 'Id' increases tremendously.

- ③ Now suppose rectifier voltage ~~is~~ also drops off so the αmin characteristics reduce 'γmin' & 'αmin' do not intersect.

- Solution is that the inverter should have a current control such that the characteristic now look like as shown in green.

- Current margin is introduced which is 10% of rated value.

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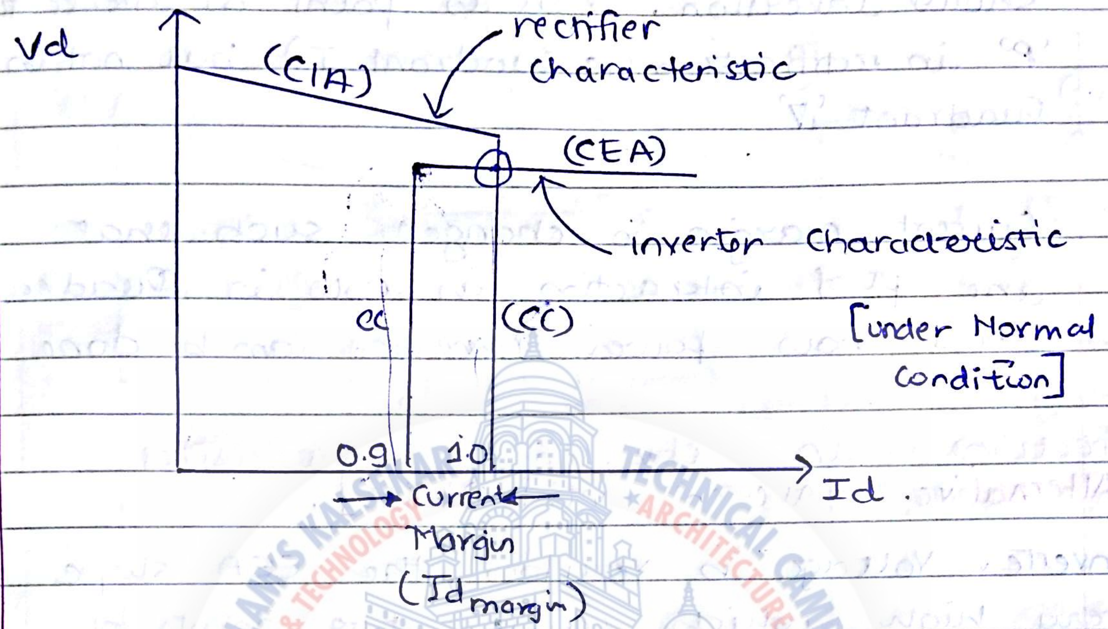
- So the characteristic now looks like



- We have the following complete characteristics

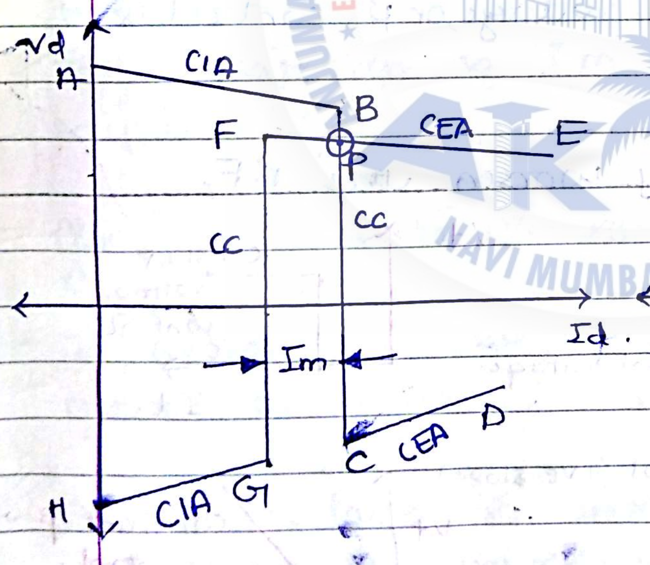


Fig: Controller Characteristics.

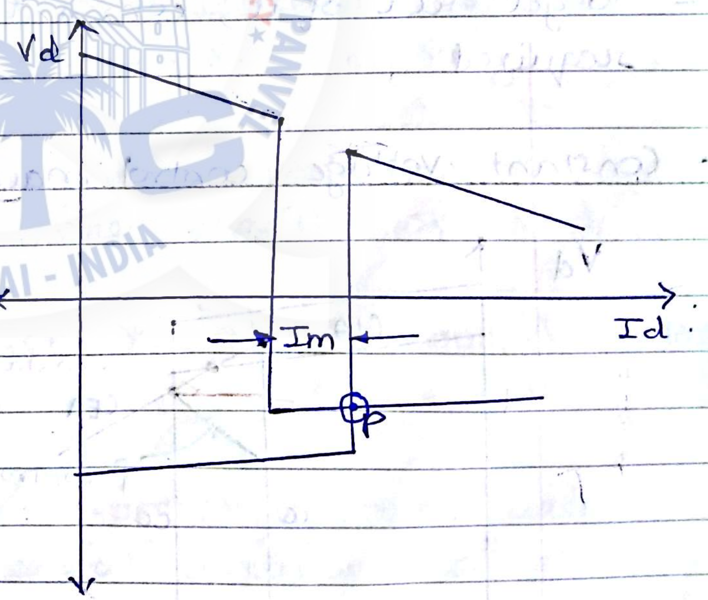


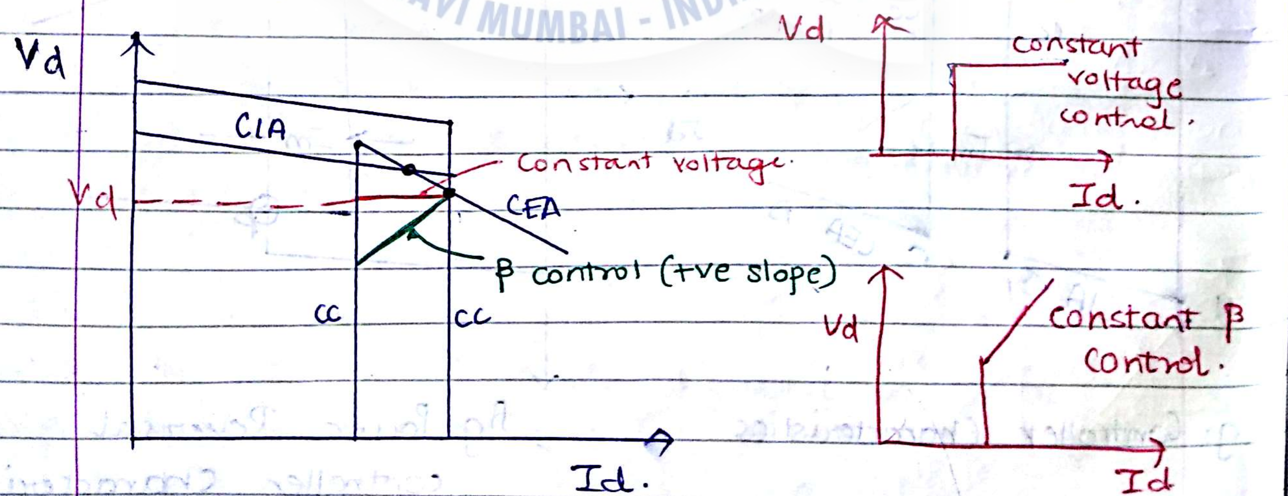
fig: Power Reversal controller characteristics.

fig ① : Quadrant 'I' shows rectification & Quadrant 'IV' shows inversion. There is point of intersection 'P' in rectification (ie Quadrant I) but not in Quadrant 'IV'

fig ② : Current margin is changed such that the pt of interaction is now in Quadrant 'IV'. Thus now power reversal can be done.

* Correction in inverter characteristics [Alternative inverter control Modes].

- If inverter voltage is very low, the CEA slope is very high which causes two points of intersection which will cause mal-operation. Here Mode Stablization is used to avoid multiple operating pts.
- To get rid of it, constant voltage, or β control is required
- Constant voltage control may worsen the P.F.



*Mode Stabilization

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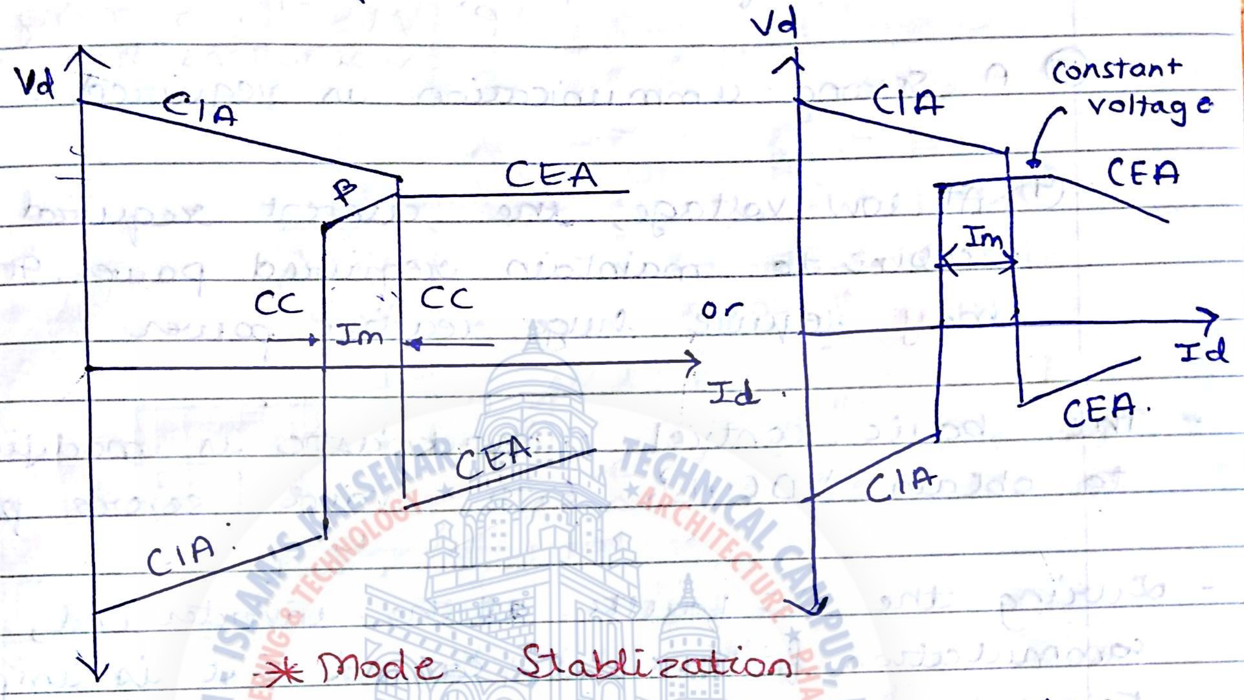
- So we use β control which changes the characteristics as follows:



* Mode Stablization

- Now suppose due to some fault, voltage at the rectifier & the inverter falls to a very low value, maintaining 'Im' then becomes very difficult

- Also the converter valves are heavily stressed.

- To avoid this we go for VDCOL (Voltage dependent current order limit)

- Always voltage or current controllers are used instead of DC power control because;

  (1) Damping factor (→ Nothing but 'R') in DC line is small, the controller may become unstable.

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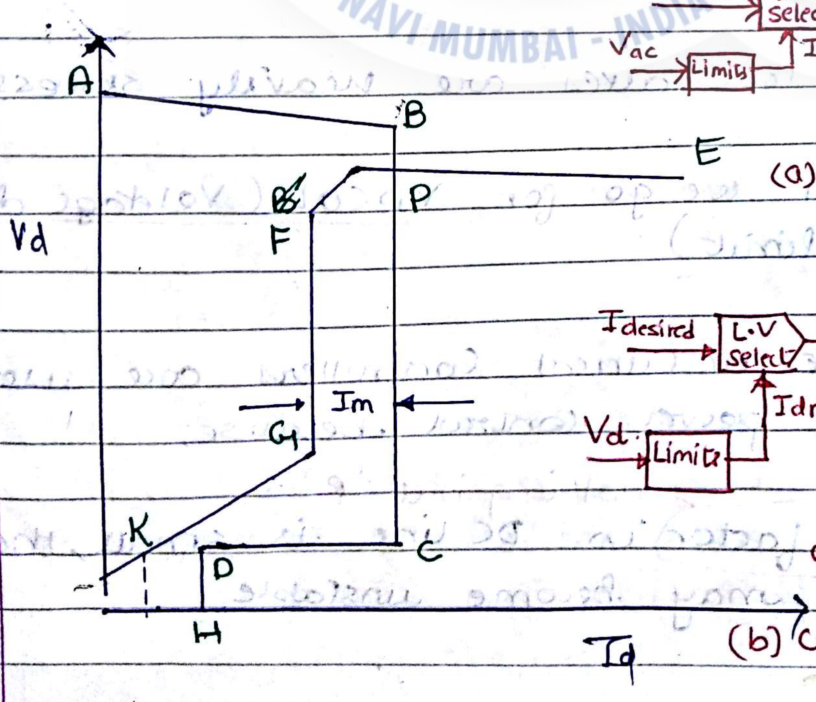
② Controlling power the ckt becomes complex & looses flexibility ($P = V_d . I_d$, for changing 'P' V_d & I_d has many combinations hence complex)

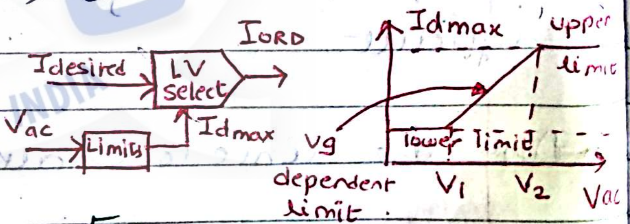
③ A strong communication is required.

④ At low voltage, the current required is excessive to maintain required power. It may require huge reactive power.

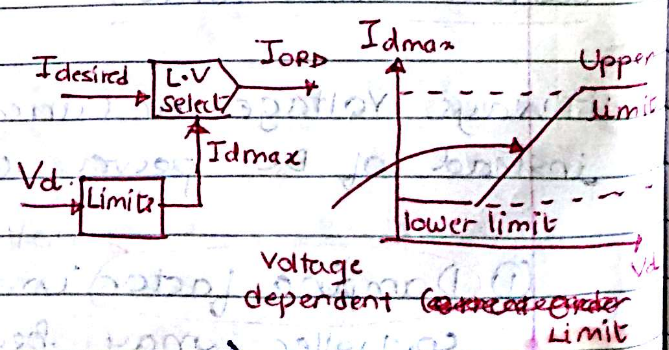
- The basic control characteristic is modified to obtain 'VDCOL' & to avoid severe problems.

- During the AC faults at the inverter end, commutation failure is caused & it is important to reduce the stress on inverter valves which can be achieved by a low voltage dependent current order limit (VDCOL) to rectifier control characteristics.





(a) Current limit as function of Alternating voltage



(b) Current limit as a function of direct Vg.

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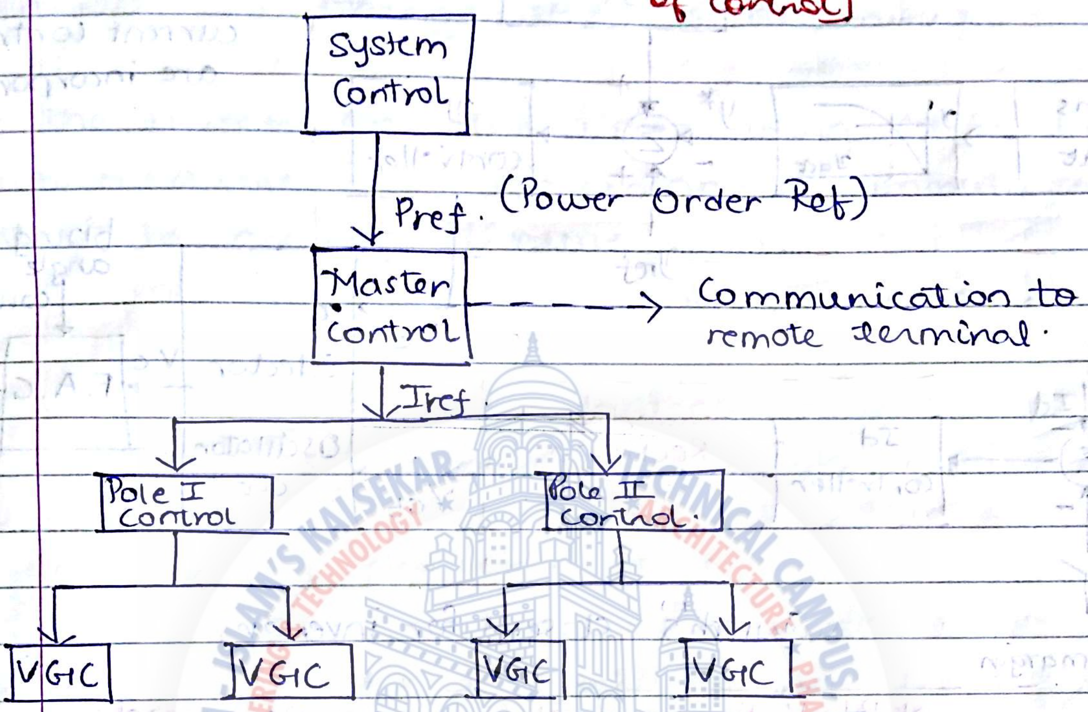
* Valve Group Control (VGC) [Hierarchy of different levels of control]

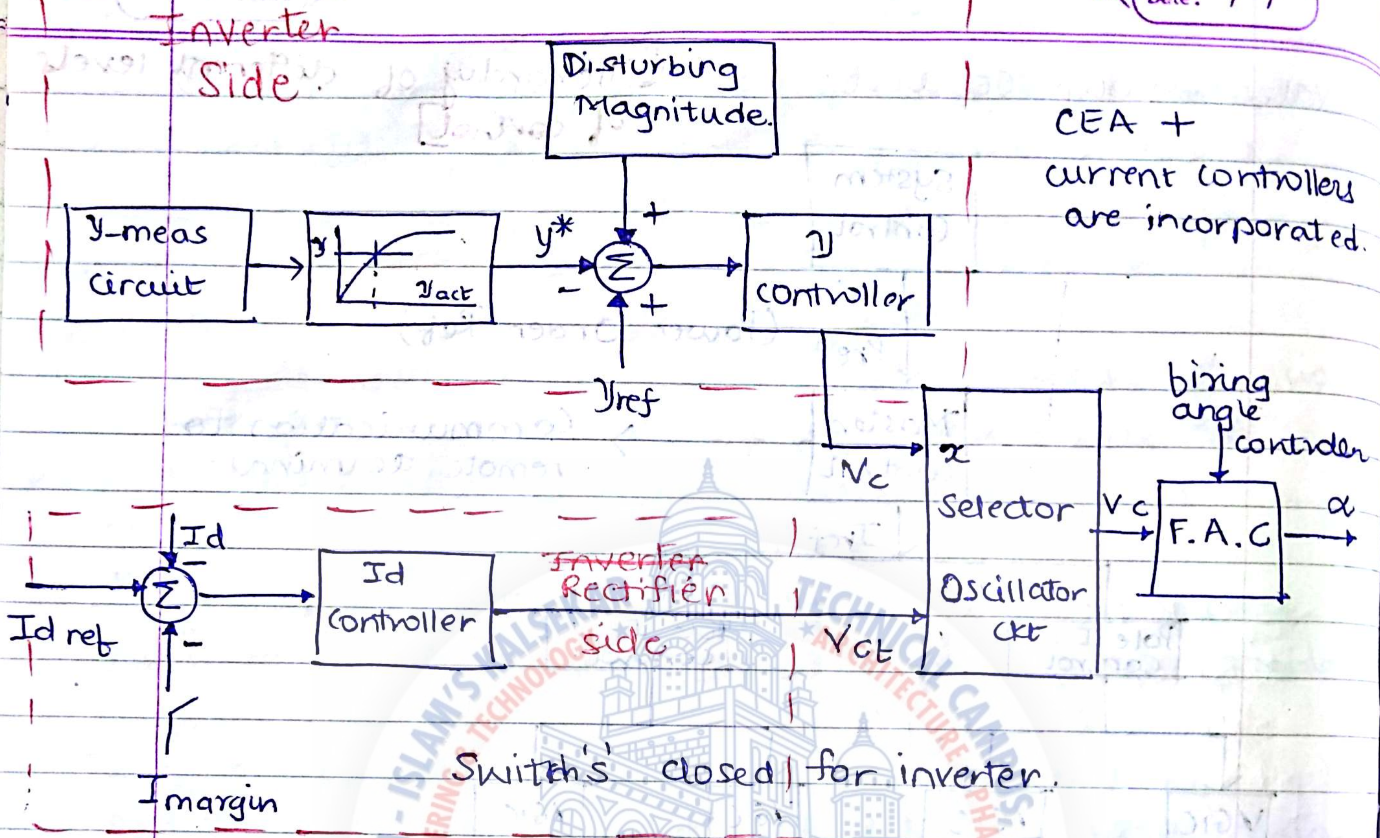


• Controller Hierarchy

- System control includes the control of everything including the rectification / inversion process & the entire AC/DC n/w. The O/P is the power reference depending on the level of power flow in link.

- The master control then generates the current ref which should be maintained constant in the dc link.

- Pole 'I' & Pole 'II' control ensures that the same current flows between them. (Bipolar operation) which is obtained by proper control of the valves.



*Block diagram of firing angle Control.

- For valve group control, 'α' will be varied
  α > 90 for inversion
  α < 90 for rectification

- The actual value in the link Id is compared with reference value Idref to generate error which is given to a controller which generates a voltage

- This voltage is applied to an oscillator ckt which generates 6 pulses. These 6 pulses at 60° delay is given to the firing angle controller 6 valves of the 6 pulse converter ckt.

- The Imargin switch is acted during power reversal to change the 'α' accordingly.

- In the inverter side the γ measuring ckt is present which measures the zero crossing of commutating voltage to generate γ value.