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Improvement Test

Sub:	HVDC Transmission							Code:	10EE751
Date:	20/ 11/ 2017	Duration:	90 mins	Max Marks:	50	Sem:	7th	Branch:	EEE

Answer Any FIVE FULL Questions

		Marks	OBE CO	OBE RBT
1	Briefly explain why constant minimum ignition angles (CIA) control, constant current control (CC) are desired in a HVDC link.	[10]	CO5	L4
2	Explain and draw the schematic circuit of analog computer for CEA control with voltage waveform.	[10]	CO5	L4
3	Describe the combined characteristics of rectifier and inverter. What is current margin?	[10]	CO5	L2
4	Explain with neat diagram, how individual phase control (IPC) scheme of firing angle control is implemented using constant α control and inverse cosine control for a HVDC converter.	[10]	CO5	L4

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6	Determine the value of the inductance of the dc reactor required to prevent consequent commutation Failure in the inverter described below: Failure in the inverter described below: No of bridges per pole – 2 Rated voltage per bridge – 200kV Rated current – 1.8kA IS_2 -10 kA Frequency – 60Hz Normal Extinction angle γ_n = 16 deg γ_{min} = 8 deg.	[10]	CO4	L2
7	Explain current oscillations and applications of anode dampers with neat sketches. Why damper is less effective if it is connected to cathode side? Explain.	[10]	CO4	L4

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ANSWER KEY

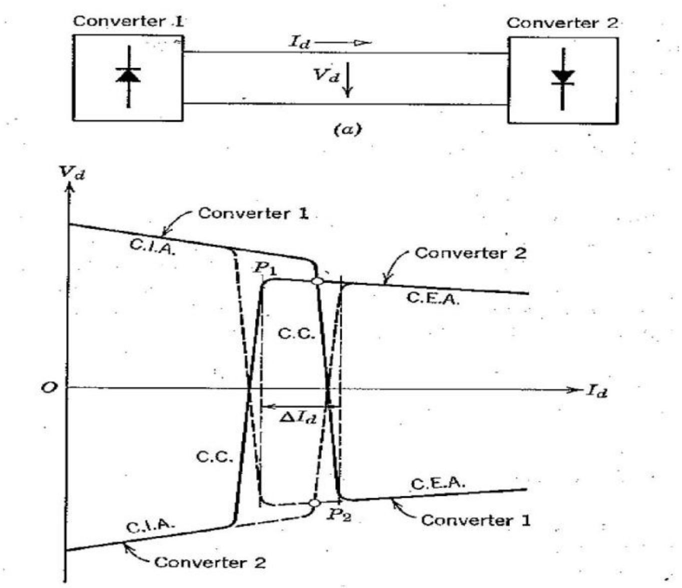
1ANS:

COMBINED CHARACTERISTICS OF RECTIFIER & INVERTER

- In a DC transmission link **each converter** must function as a rectifier & inverter.
- At times of **deenergising the line** both converters are called on to work as **inverter.**
- So **each converter** is given a **combined characteristics**.
- Consist of **3 linear portions**:

  C.I.A, C.C, C.E.A
- If chara is shown by **solid lines,**
- **Converter 1** POWER TRANSMITTED → **converter 2**
- If chara is shown by **broken lines**,
- **Converter 2** POWER TRANSMITTED → **converter 1**

so V is reversed(polarity is changed) with no change in direct current



- During the reversal of power & voltage, the shunt capacitance of the line must be first discharged & then recharged with opposite polarity.
- This implies a greater I will be present at the end of inverter line than a rectifier line.
- The difference of terminal voltage cannot exceed current margin.
- So shortest time of voltage reversal is

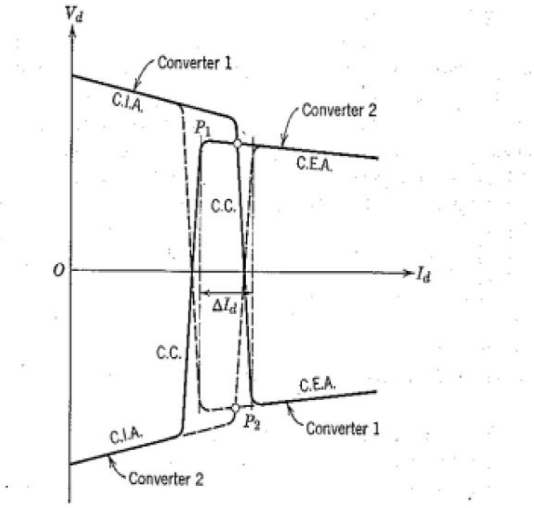
  $T = C\ \Delta V_d / \Delta i_d$ sec

  Where c = line capacitance

  ΔV_d = algebraic change in direct voltage

  ΔI_d = current margin

- Current margin corresponds to horizontal separation of C.C charac of two converters along the horizontal axis or between corner P1 & P2.



CONSTANT CURRENT CONTROL:

- Second segment is constant current control.
- It involves the following
  1. **Measurement of direct current I_d**
  2. comparison of I_d with **set value I_{ds}**
  3. **Amplification of difference I_{ds} - I_d (error)**
  4. Application of output signal of amplifier to a **phase shift circuit** that **alters ignition angle α** of the **valve** in proper direction for **reducing error.**
- If the measured current I_d is < set current I_{ds}, α must be decreased in **order to increase cos α**
- Thus voltage of **rectifier Vd0 cos α will increase**
- The difference between internal voltage of rectifier & inverter is increased
- So direct current is increased proportionally.

- If the measured current I_d > set current I_{ds}, **α must be increased**
- So all are changed in opposite sense.

CONSTANT MINIMUM IGNITION ANGLE CONTROL:

- Next step is **to examine in detail how three line segments** of combined characteristics can be obtained.
  1. **Constant minimum ignition angle α_o / α_{min}**
  2. **Constant current**
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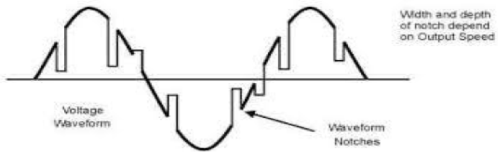
- Incase we are **using multi anode diodes** then valves require a minimum delay

  e.g. α_o = 5deg then control is required
  - **Voltage across each valve** is **measured**
  - Check **voltage across each valve < specified value**
  - So **constant current control** is prevented from **igniting the valve.**
  - In practice voltage across valve is not used instead secondary voltage of control transformer is taken.
  - These **voltages must be free of notches** caused by communication.



2ans:

CONSTANT EXTINCTION ANGLE CONTROL (C.E.A)

- It is the **third** segment of combined characteristics.
- Each valve is ignited at such a time that extinction occurs at a later time.
- But it must be earlier with a margin **before commutation voltage reverses**.
- When **conduction ceases** , voltage across outgoing valve must be **negative.**
- It should **remain negative** until **deionization of the arc path**.
- When **commutation voltage** first **turns positive**, time **t** & time angle **ωt** is measured.
- Instantaneous value of commutation voltage is

  $e_{ba} = \sqrt{3}\, E_m \sin \omega t$
- Commutation must **begin** after **ωt =0** & must be completed before **ωt = π**
- Under **normal conditions** commutation is **completed** at **$\omega t = \pi - \Upsilon_n$**

  Where **Ϫn is normal extinction advance angle.**
- For this to happen **commutation** must begin at **ignition angle $\omega t = \alpha = \pi - \beta$**
- It depends on **commutation voltage (**crest value **$\sqrt{3}\, E_m$**)

  Direct current I_d to be commutated, commutation inductance L_c **& desired Υ_n.**
- All four of these are assumed to **remain constant** during a particular commutation but **V & I vary** from one commutation to another.

- Time integral of **commutation voltage** is equal to change of **magnetic flux linkage ($-2L_cI_d$)**

$$\int_{t_1}^{t_2} e_{ba}\, dt = \sqrt{3}\, E_m \int_{t_1}^{t_2} \sin \omega t\, dt = \sqrt{3}\, E_m \left[\frac{-\cos \omega t}{\omega}\right]_{t_1}^{t_2}$$

$$= \frac{\sqrt{3}\, E_m}{\omega}(\cos \omega t_2 - \cos \omega t_1)$$

where $\omega t_1 = \alpha =$ ignition angle

$\omega t_2 = \pi - \gamma_n =$ normal extinction angle

Then the integral becomes

$$\frac{\sqrt{3}\, E_m}{\omega}[\cos(\pi - \gamma_n) - \cos \omega t_1]$$

$$= \frac{\sqrt{3}\, E_m}{\omega}(-\cos \gamma_n - \cos \omega t_1) \quad \text{volt-seconds}$$

Equating the two quantities, we get

$$-\sqrt{3}\, E_m(\cos \gamma_n + \cos \omega t_1) = -2\omega L_c I_d = -2X_c I_d \quad \text{volts}$$

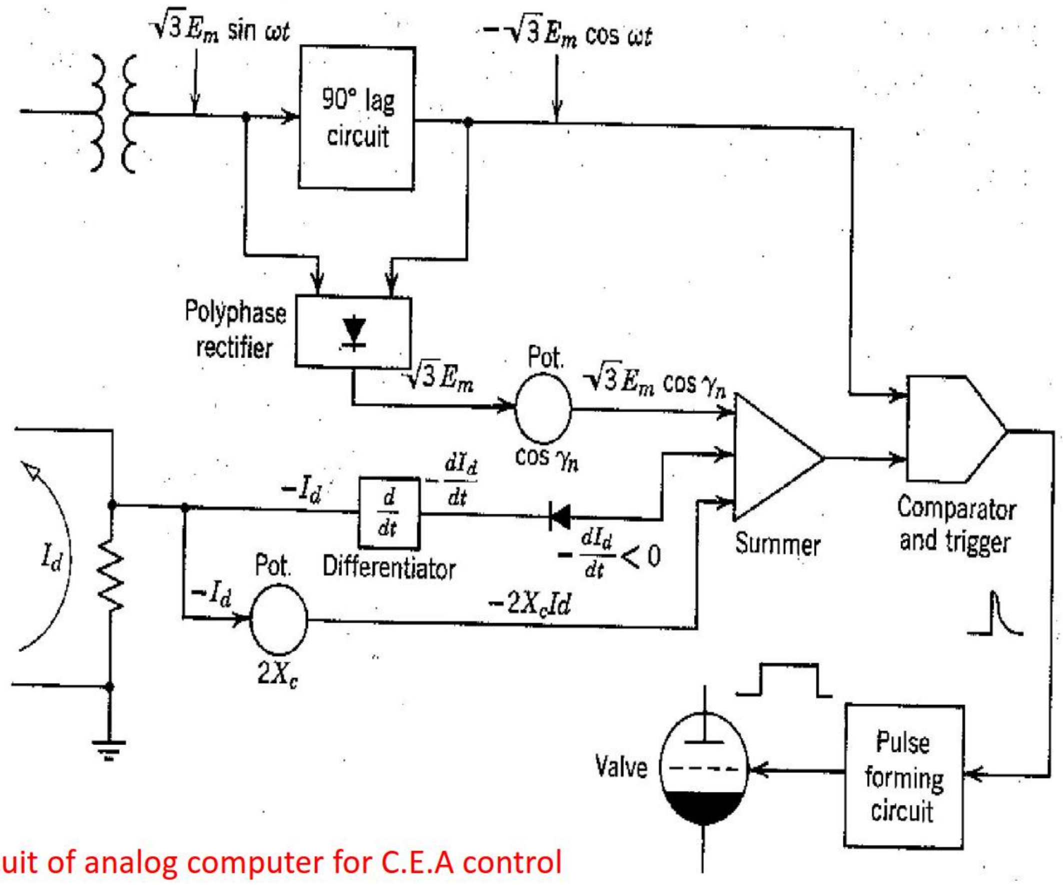


Fig: circuit of analog computer for C.E.A control

and the required firing angle β is given by

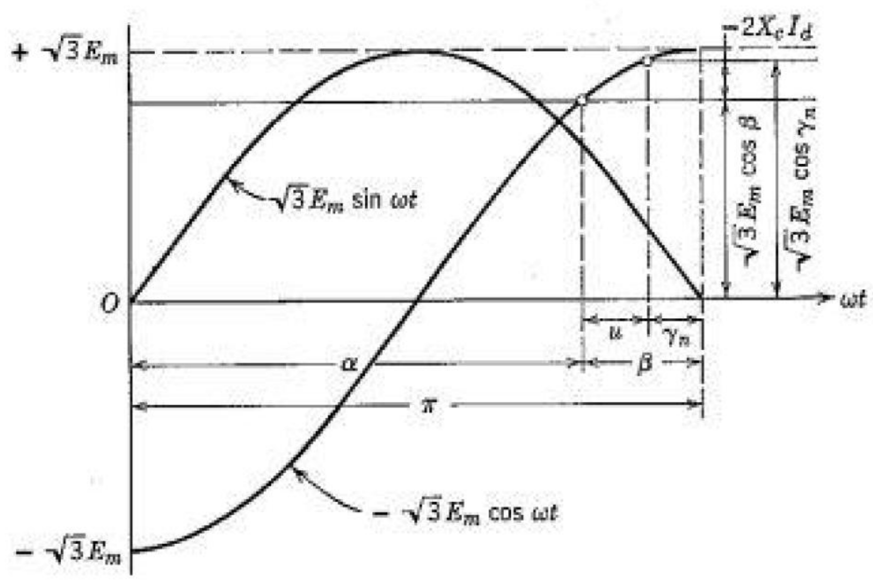
$$-\sqrt{3}\, E_m \cos \omega t_1 = \sqrt{3}\, E_m \cos \gamma_n - 2X_c I_d \quad \text{volts}$$

or

$$\cos \beta = \cos \gamma_n - I_d'$$

- **Ignition time** t1 can be found by real time analog computer.
- Each term of the equation is represented in the following figure.

Fig: Waveforms of voltage in C.E.A analog computer



- The negative cosine wave can be derived from the sine wave of commutation voltage in either of two ways:

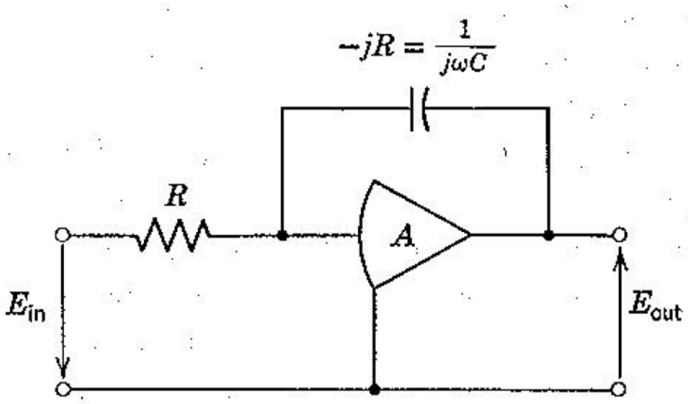
1. Use of an **RC or RL PHASE SHIFT CIRCUIT:**

❖ In this **output of circuit** will **lag input** by **90deg.**

2. Use of **analog integrator:**

❖ We have to **integrate commutation voltage**

❖ Output will be negative of the **time integral of input voltage**



Use of supplementary input signal: dI_d/d_t

- Some **commutation failure** can be **prevented.**
- The **control** is arranged such that **increasing the current advances firing angle** & **decreasing current does not retard it.**
- Usual value of Υ_n **is 16 deg.**
- Only **1 to 8 deg** is required for **deionization.**
- Larger angles are required for higher-power valves.

- **In both C.C & CEA CONTROL BECAUSE OF UNBALANCES & HARMONIC DISTORTION, THE 6 VALVES ARE NOT IGNITED AT EXACTLY THE SAME TIME**

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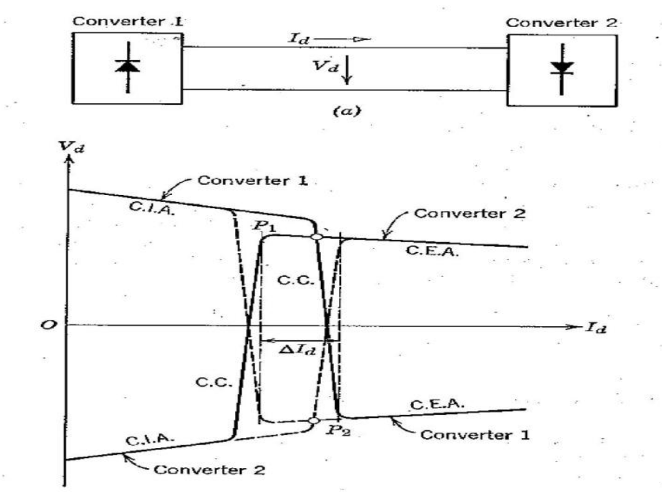

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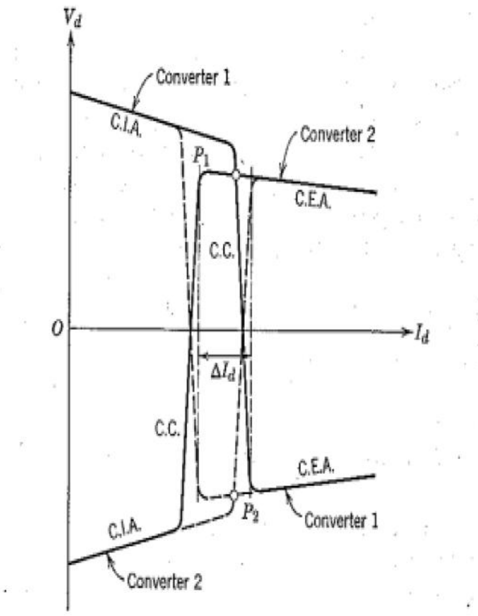

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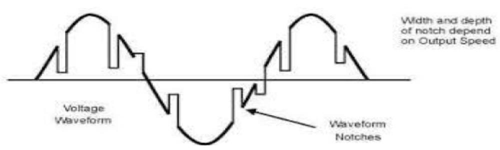

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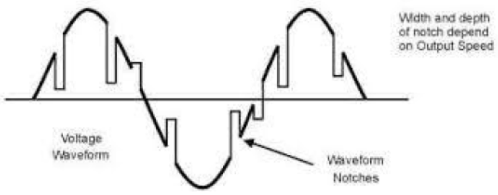
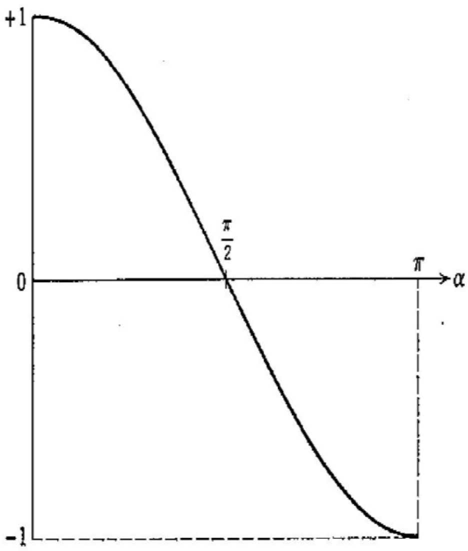


Curve of cos α versus α



- Anywhere in this range a **decrease of α increases** algebraic **internal voltage** $V_{d0} \cos \alpha$
- So same **C.C controller** can be used during **rectification & inversion**.

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- **Error** signal of inverter current regulator is

  $\varepsilon = I_{ds} - \Delta I_d - I_d$

- Current regulator is a simple feedback amplifier with a **gain** & **time constant**
- Differential equation is

  $v + T\,dv/dt = K\,\varepsilon$

  Where v = **instantaneous value of V_{do} cosα**

  T = R_2C = time constant

  K = **gain** of amplifier & **phase shift circuit**

  ε = error signal

- **Transfer function** is

  $v / \varepsilon = K/Ts + 1$

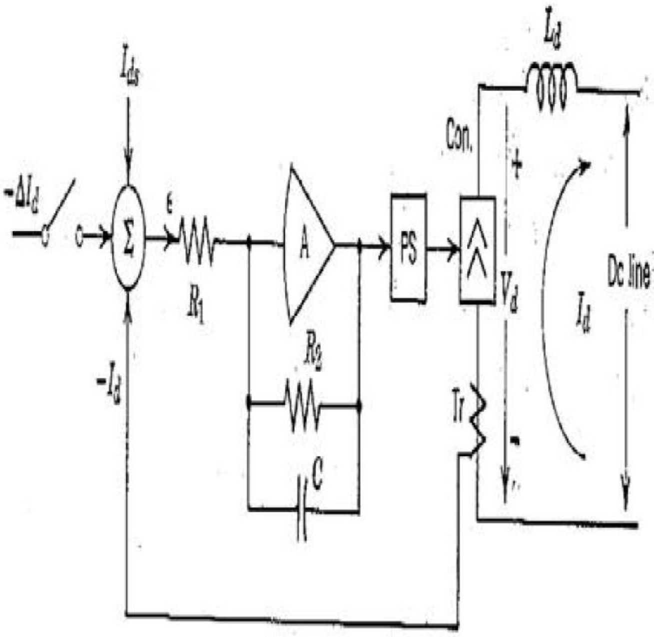


Fig: Constant current regulator

5ans:

Clearing line faults and Regeneration

⇒ short Circuits on a two terminal DC line are cleared by grid control of the valves.

⇒ On a bipolar DC line, each pole has seperate and independent fault clearing devices.

SOME METHOD OF CLEARING SHORT CKT's are described below:-

i) EFFECT OF CURRENT CONTROL

* Even if NO protective device are used in DC line, the current Regurators will limit the short CKT current by decreasing the line Voltage.

* The Short Circuit causes rectifier current to increase (overshoot) and inverter current to decrease.

* In attempting to decrease the current to the set value, the current regulator of the rectifier decreases the direct voltage.

* To increase the current to the set value - the Current margin, the current regulator of the inverter also decreases the direct voltage.

* If no other control action is present, the reduction of direct voltage will continue untill each converter develops a voltage just sufficient enough to supply RI drop in the line, from the converter to the fault.

* Thus voltage profile will shift from curve 1 to curve 2 as shown in fig. below.

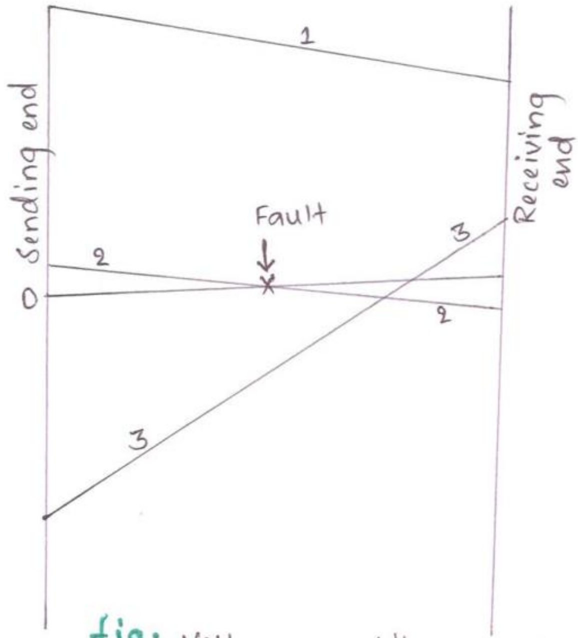


fig: Voltage profile on DC line
1 → Normal condition
2 → short circuit at centre, currents are maintained.
3 → Fault clearing, $\alpha = 135°$ at rectifier and $\alpha = 100°$ at inverter.

* The Inverter will have to reverse its voltage and become a rectifier in order to maintain its current.

* With both converters current maintained, the final steady current in the fault would be the current margin which is having a value of 0.10 to 0.15 times rated current.

ii) CONTROL FOR FAULT CLEARING

* Eventhough current control limit the fault current to a small value it is not adiquate for extinguishing the fault arc.

* For sure extinguish, both fault current and recovery voltage across the fault, power should be brought to zero.

* Additional control is required for this.

* The best way to bring the line current and voltage to zero is to establish terminal voltages of both converters invert.

* Then both converters drain energy from DC circuit where it is stored in electric and magnetic fields associated with the shunt capacitance and series Inductance of line and of the DC reactors and deliver energy to ac reactors.

* The difference of terminal voltage required for both converters to invert is opposite to that for maintaing the direct current.

* This inturn produce a gradient in the voltage profile as indicated by curve S.

* Valve action prevents reversal, therefore line current becomes and remain zero.

* The fault current a/c becomes zero. As faulted conductor was grounded through the fault untill or near untill the line current becomes zero until the conductor is left at near to ground potential so that arc donot restrike.

* In order to establish terminal voltage of correct polarity for fault clearing two steps are taken:-

RE-ENERGISATION

After an over head line conductor has been deenergised for approximately 0.2 to 0.5 seconds. An arcing fault is generally deionised so that the arc path withstands normal voltage.

⇒ Automatic fault clearing is ~~designed~~ desired can follow by automatic or reenergisation.

⇒ In most cases line is restored to normal voltage and to the same power as before the fault.

⇒ If the fault is permanant or if the arc restrikes because of inadequate deionization of the fault is cleared again. If 2 or 3 attempts of reenergisation may be made automatically in succession with increasing dead time.

⇒ Re-energisation of a DC line is done by rising the direct voltage, not in one big step, as by closing a switch, but slowly and continuosly under control of starting control unit, so that there is no overshoot of voltage.

⇒ Re-energisation of an ac line through the CKT breaker may cause transient over voltages of 2 or 3 times normal crest voltage, unless series resistors are used to limit the overshoot.

⇒ Direct current lines (cables) are not reenergised because cable faults are nearly always permanent.

7ans:

Problem:

Q) Find the inductance of the dc reactor required to prevent consequent commutation failure in the inverter described below -

i) No. of bridges per pole = 2
ii) Rated voltage per bridge = 200KV
iii) Rated current = 1.8 KA
IV) I_{s2} = 10KA
v) Frequency = 60Hz

Solution

$$L_d = \frac{\Delta V \Delta t}{\Delta I_d}$$

$I_{dn} = 1.8KA$
$I_{s2} = 10KA$
$f = 60Hz$

$$\Delta t = \frac{\beta_n - 1 - \gamma_m}{360 f}$$

$$\cos\beta_n = \cos\gamma_n - \frac{I_{dn}}{I_{s2}}$$

$\cos\beta_n = \cos 16 - 1.8/10$

$\cos\beta_n = 0.751$

$\beta_n = 38.62°$

$$\Delta t = \frac{38.62 - 1 - 8}{360 \times 60}$$

$\Delta t = 1.371 \times 10^{-2}$ seconds

$\beta = 37.6$ $[\beta_{n-1}]$

$\Delta I_d = 2 \times 10 [\cos 8 - \cos 37.6] - 2 \times 1.8$

$\Delta I_d = 0.359 \approx 0.36KA$

$$L_d = \frac{200 \times 1.371 \times 10^{-3}}{0.36}$$

$L_d = 0.761 H$

8ans:

CURRENT OSCILLATIONS AND ANODE DAMPERS

→ If ignition of a valve is delayed, a positive voltage builds up across it. It collapses when the valve is ignited.

→ Any stray capacitance across the valve is charged to this voltage and discharge through the valve as soon as the valve ignites.

⇒ Because of inductance (stray or lumped) in the discharge circuit, the discharge ~~circuit~~ is always oscillatory. Because of low resistance in the circuit, the oscillations are lightly damped.

→ Because of multiplicity of the stray capacitance and that of stray and lumped inductance, there are oscillations of multiple frequencies. The frequencies are grouped in to 2 different bands. (Medium frequency band, High frequency band)

Medium frequency → 20 to 60 kHz

High frequency → 0.5 to 10 MHz

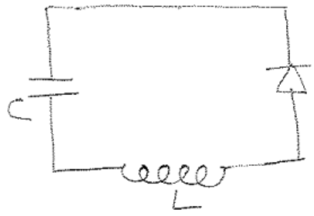
→ These current oscillation have several detrimental effects:

1) Extinction of the cathode spot in the incoming valve with cosequant misfire.
2) Increased chance of the outgoing valve if the overlap is short.
3) Radio Interference
4) All these effects depends on the magnitude of ignition voltage jump (V_{ji}) and are therefore greater during temporary operation at abnormally large converter angles than during Normal Operation

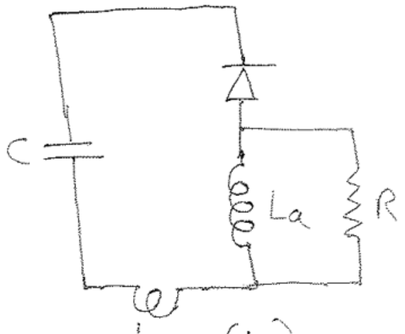
EXTINCTION OF CATHODE SPOT

- → Mercury arc valves used in high voltage DC converters are known as excitrons in which mercury vapours is kept ionized during Non-conduction period by means of arcs from one or more excitation anode to mercury pool cathode.
- → The arcs terminate in a cathode spot (which is a source of electrons).
- → The movement of electrons through the valve constitute the valve current.
- → If the net cathode current (sum of currents from main anodes and excitation anodes) becomes zero, the spot becomes unstable and those cathode spot extinguishes.
- → Then the valve cannot conduct again until the spot is re-established by ignition electrode.
- → Even during oscillation excitation would occur. So, the main current goes negative by the amount of excitation current.
- → The main anode current will reverse its direction of current only when arc backs occur. At this time a small negative current can flow because of deionization in the space between the main anode and control grid. This time is more than enough for a half cycle of high frequency oscillation

→ Current of the incoming valve at the begining of commutation can be calculated by using equivalent circuits.



(a)



(b).

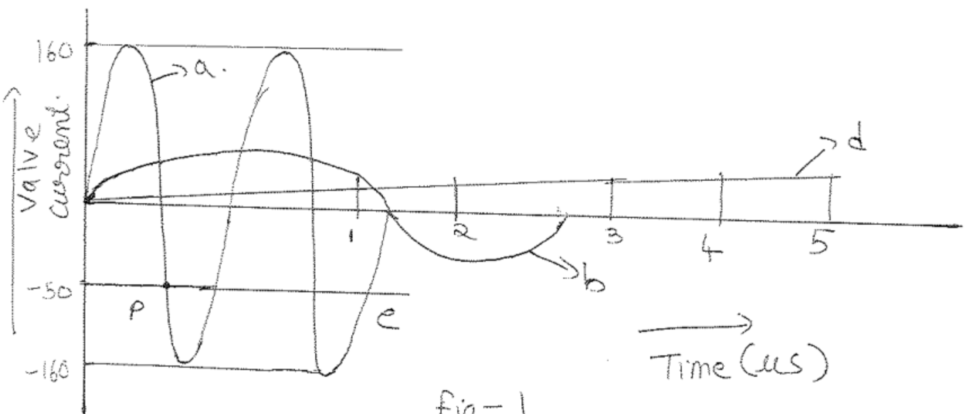


fig-1

a → without anode reactor
b → with anode reactor
d → power frequency component of valve current.
e → negative of excitation current.

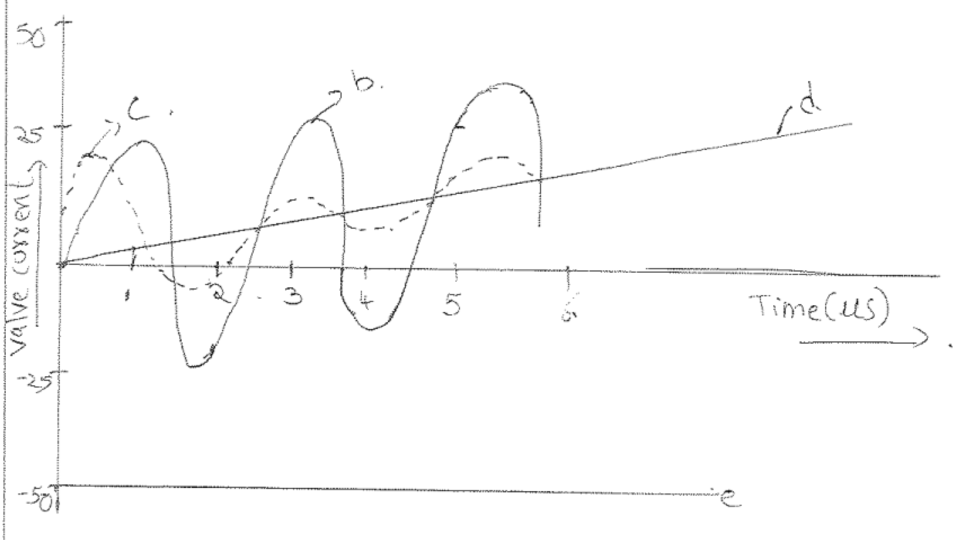
→ In fig a stray capacitance is initially charged to voltage V_i when valve is ignited.
→ The capacitance discharges through stray inductance L and valve.
→ A freq oscillation occur as shown in fig 1 when C discharges

→ At this time negative main exceeds the excitation current causing spot extinction at point P. Spot extinction is avoided and radio interference is decreased by addition of circuit components as shown in fig b.

→ A Reactor La having an inductance of 1 to 2.5mH is connected in series with the valve.

→ A resistor R with a value of 2 to 7 kΩ is connected in parallel with the reactor.

The Reactor lower both frequency and amplitude of current oscillations as shown in figure below.



b → with anode reactor
c → with anode reactor and resistor
d → power frequency component of valve current
e → negative of excitation current

→ The resistor increases the damping of oscillation and thus decreases the reverse main current as shown in c.

→ Such a reversal of moderate current having crest value less than excitation value is harmless.

→ The reactor is connected on anode side and therefore called anode reactor

→ The combination of reactor and resistor is called as anode damper

→ If the damper was connected on cathode side it is less effective because it will be bypassed by the greater capacitance value than on anode.

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