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*Firing angle control:

- The operation of CC & CEA controller is closely related to gate pulse of valves

- Two types of firing controls
  (1) Individual phase control (IPC) [used in past]
  (2) Equidistant pulse control (EPC)

• Individual phase control (IPC).
- firing instance is determined individually for each valve ie phase position of each control pulses is determined seperately for each valve and related to commutation voltage (zero crossing)
- Six parallel delay circuit is required.

- for eg; valves 1, 2, 3 ... will be fired at different angles $\alpha_1, \alpha_2, \alpha_3$.....

Note: In equidistant pulse control (EPC), one valve will be fired at an instant say 'α' & subsequent valves will be fired after 60°.

eg;
valve 1 ⟶ 5°
2 ⟶ 65°
3 ⟶ 125°
⋮

- Hence, there is a symmetricity in pattern of o/p voltage which is not the case with IPC.

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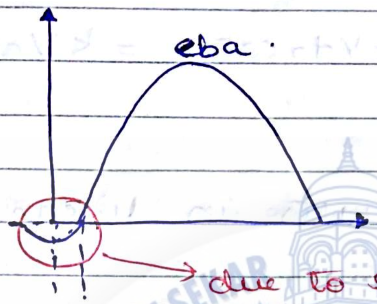
- Because the O/P voltage of IPC control is not symmetrical, it involves alot of harmonics.

- Since IPC is related to firing at commutation voltage zero crossing the following can happen.



due to some fault, zero crossing changes, hence changing 'α' & causing error

- For IPC since we are calculating from α_1 to α_6 we require the individual phase delay ckts. However in EPC, we need one 'α' control & can have a ring counter which gives 60° delay counter is a voltage control oscillator ckt. once pulse is given, '6' displaced ckts will be available which can be given to the phases individually.

- Two types of control measures are there for IPC.
  - Cosine control
  - Linear Control.

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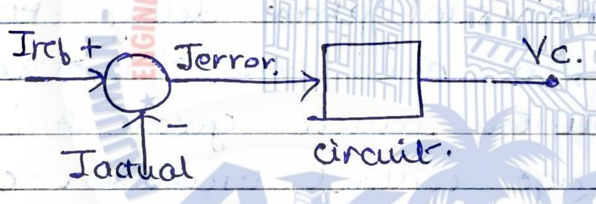
- Cosine control.

- There are several versions of this method.
- Pulse are generated at the crossing of control voltage(V_c) & ac line voltage.

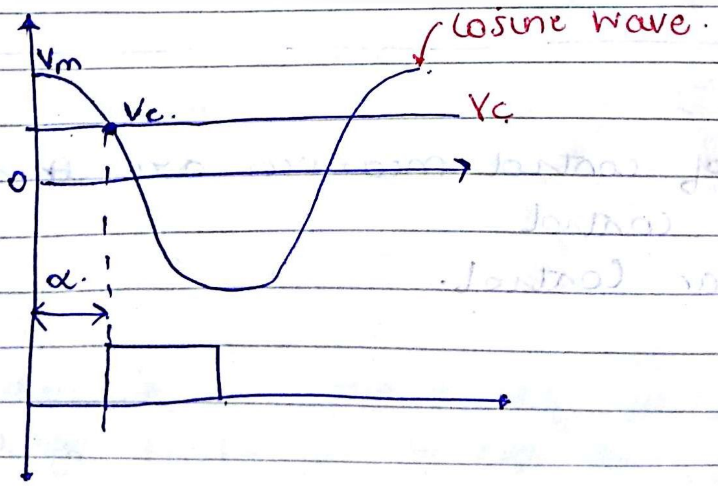
$$\alpha = \cos^{-1}\left(\frac{V_c}{V_m}\right) \quad ; \quad V_d = V_{do}\cos\alpha = kV_c.$$

- The control system results in linear transfer characteristic.

- To understand this method we need to understand what is control voltage. (V_c).



From the above its clear that the control voltage is derived from the error signal through some block(circuit).



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- from above it is clear that the 'Vc' is compared with cosine wave to get a point which indicates the firing instant of valves. (when the two are equal a pulse is generated.)

- so we have;

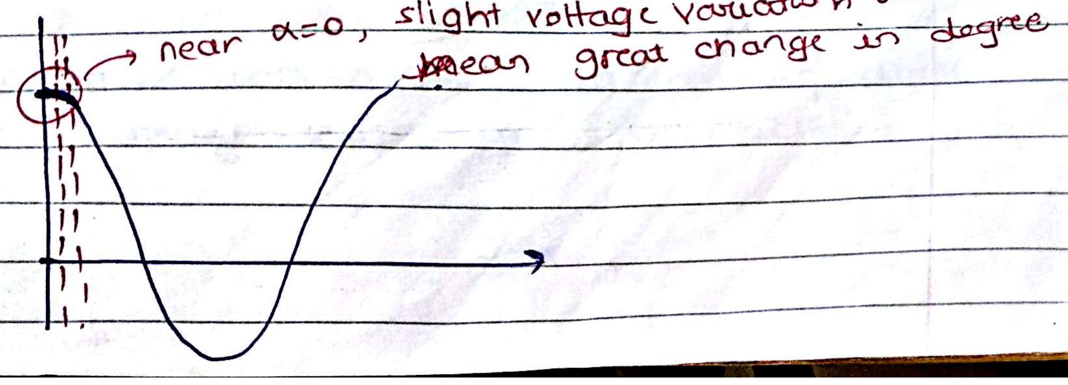
$$V_c = V_m \cos\alpha.$$

or
$$\alpha = \cos^{-1}\left(\frac{V_c}{V_m}\right).$$

- this cosine control is very advantageous because we know.

$$V_d = V_{do}\cos\alpha$$
$$= V_{do}\left(\frac{V_c}{V_m}\right)$$
$$= \frac{V_{do}}{V_m}\cdot V_c$$
$$V_d = k V_c.$$
→ o/p voltage is proportional to control voltage.

- the o/p voltage is independent on change in input ac voltage.
- However near alpha zero, it is very sensitive to Vc & leads to high inaccuracy.



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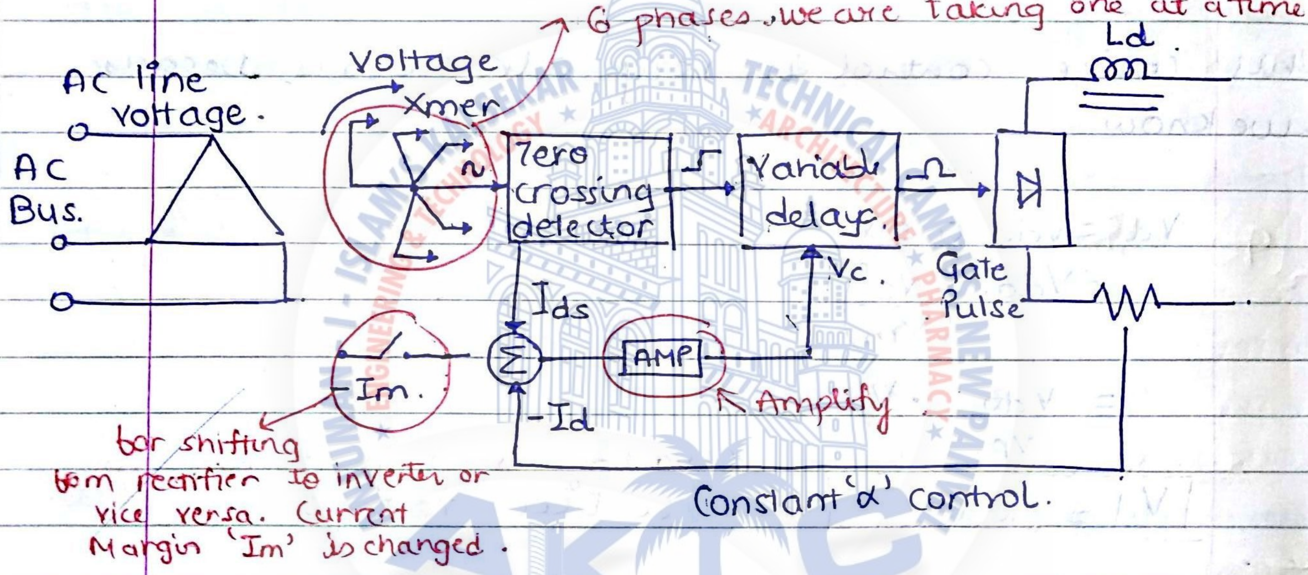
• Linear Control:

• Pulses are generated at the crossing of control voltage (Vc) & ac line voltage.

$\alpha = k_1 V_c$ $\quad\therefore V_d = V_{do} \cos(k_1 V_c)$

• This makes linear transfer characteristics non-linear. But error is of $\pm 1°$.



• Advantages of IPC:

• DC O/P voltage is higher.

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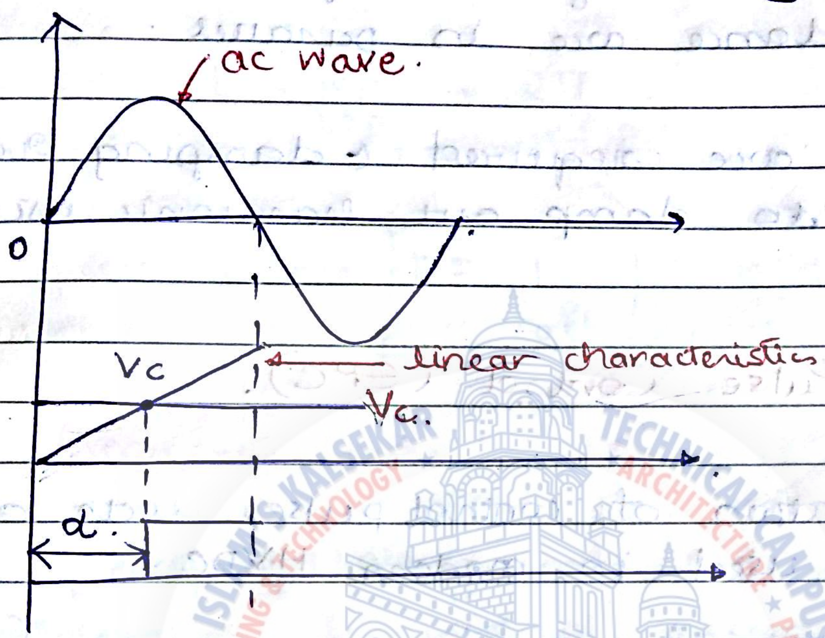
Note: Linear control has the following waveshape.



- Once zero crossing of ac wave is detected, a linear generator is used to obtain linear relationship & wherever 'Vc' intersects linear characteristic, the firing pulse is generated.

$\therefore \quad V_c = (K)\,\alpha.$ → slope [some constant value]

- **Disadvantages of IPC:**

(1) Due to fault, distortion etc, zero crossing will shift & this may result in uncharacteristic harmonics

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(2) May cause harmonic instability (weak ac system) at frequencies where filter impedance & system impedance are in parallel.

(3) More filters are required & damping resistance is required to damp out harmonic oscillations.

- Equidistant Pulse Control (EPC).

- No syncronisation of control pulses with applied ac voltage & used in modern HVDC.

- It produces pulses at intervals of $\left[\frac{1}{f_p}\right]$.

- There are 2 methods of EPC.

    - Pulse frequency control (PFC)
    - Pulse Phase control (PPC)

- The method gives low D.C O/P voltage but is succesful in weak ac systems

- EPC scheme also results in high negative damping contribution to torsional oscillations

$P_d = (V_d)(I_d)$ | $P_d = (V_d)(-I_d)$ | $P_d = V_d I_d$ —
$P_d = (-V_d)(I_d)$ | $P_d = (V_d)(-I_d)$ | $P_d = -V_d I_d$ —

duration of each pulse

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→ we know that $\omega t = \frac{2\pi}{P}$ → 360° divided by no of pulses gives us ωt.

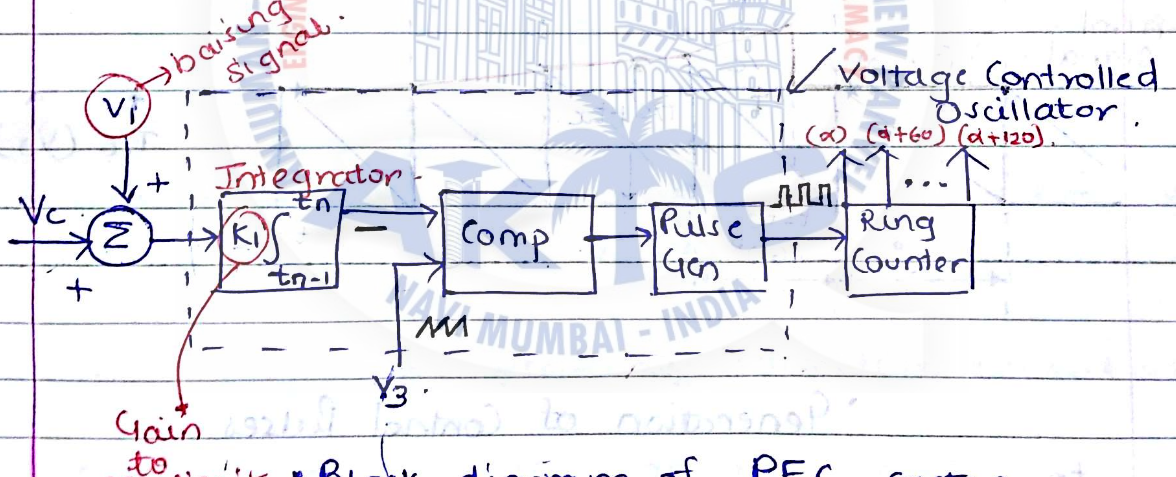
$\therefore \; t = \frac{2\pi}{\omega P} = \frac{2\pi}{2\pi f_0 P}$

f_0 → nominal frequency (50Hz)

$$t = \frac{1}{f_0 P}$$

• Pulse Frequency Control (PFC).

- The frequency of voltage control oscillator (VCO) is determined by control voltage (Vc) related to the error in current, gamma, or voltage.



• Block diagram of PFC system

- Baising signal should be greater than zero to make entire system stable.

- Control voltage (generated due to error in curren/γ/voltage) is added to this baising signal & integrated.

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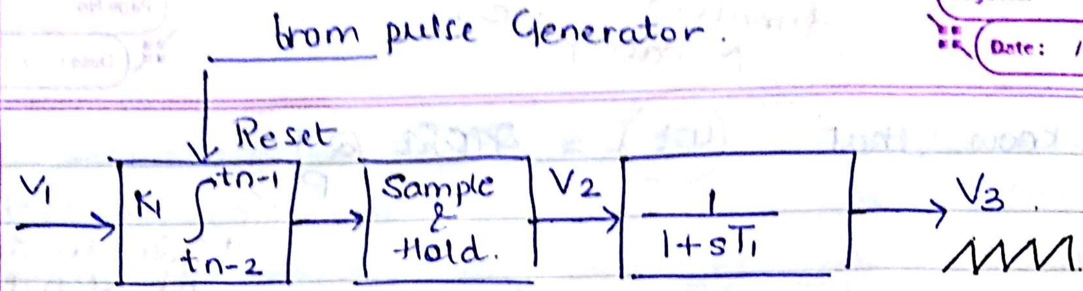
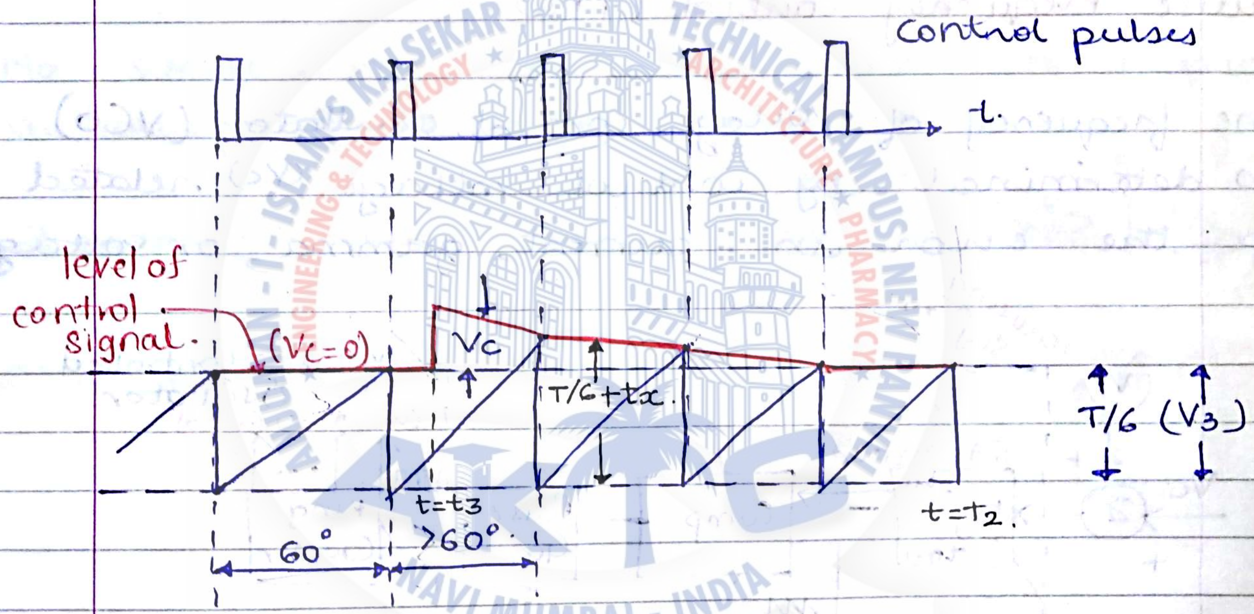


• Frequency correction for PFC-

– If o/p of integrator & V3 match. pulse is generated



• Generation of Control Pulses.

$$- \; K_1 \int_{t_{n-1}}^{t_n} (V_c + V_1)\, dt = V_3 \quad \text{—} (1) \qquad \text{or} \qquad K_1 (V_c + V_1) = \frac{V_3}{t_n - t_{n-1}} = V_3\, p f_0.$$

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- In Voltage controlled Oscillator, a ramp circuit is generated.
- When $V_c = 0$, the difference between the control pulses is $60°$.
- So corresponding to every ramp, we have a control pulse
- If there is error in the system, V_c will have some value & hence increases beyond $V_c = 0$ [ie
- So in order to delay the control pulse, the value of 'V_c' should be greater.

- At steady state, $V_c = 0$ and thus,

$$K_1 = \frac{V_3\, p f_0}{V_1}$$

if $V_1 = 0$, K_1 (gain) has to be very high & that causes instability

- V_1 is required?

- Frequency change is not taken care of, Hence with V_3 reset, f_0 is also be reset.

- Ainsworth suggested frequency correction control as

$$K_1 = \int_{t_{n-1}}^{t_n} V_1\, dt = V_3 + V_c \quad \text{or} \quad K_1 = \frac{V_3\, p f_0}{V_1}$$

— from (1)

- PFC has better stability but problem of harmonics as control (Vc) shift is not integrated

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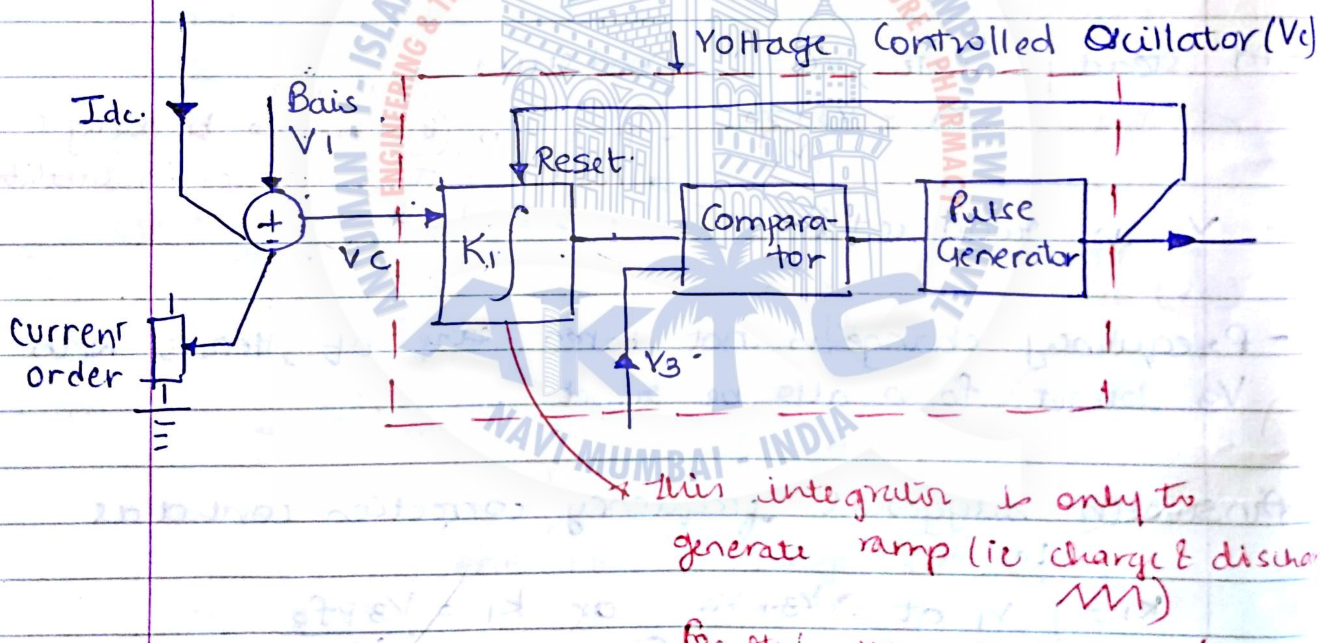
- **Pulse Phase Control (PPC)**

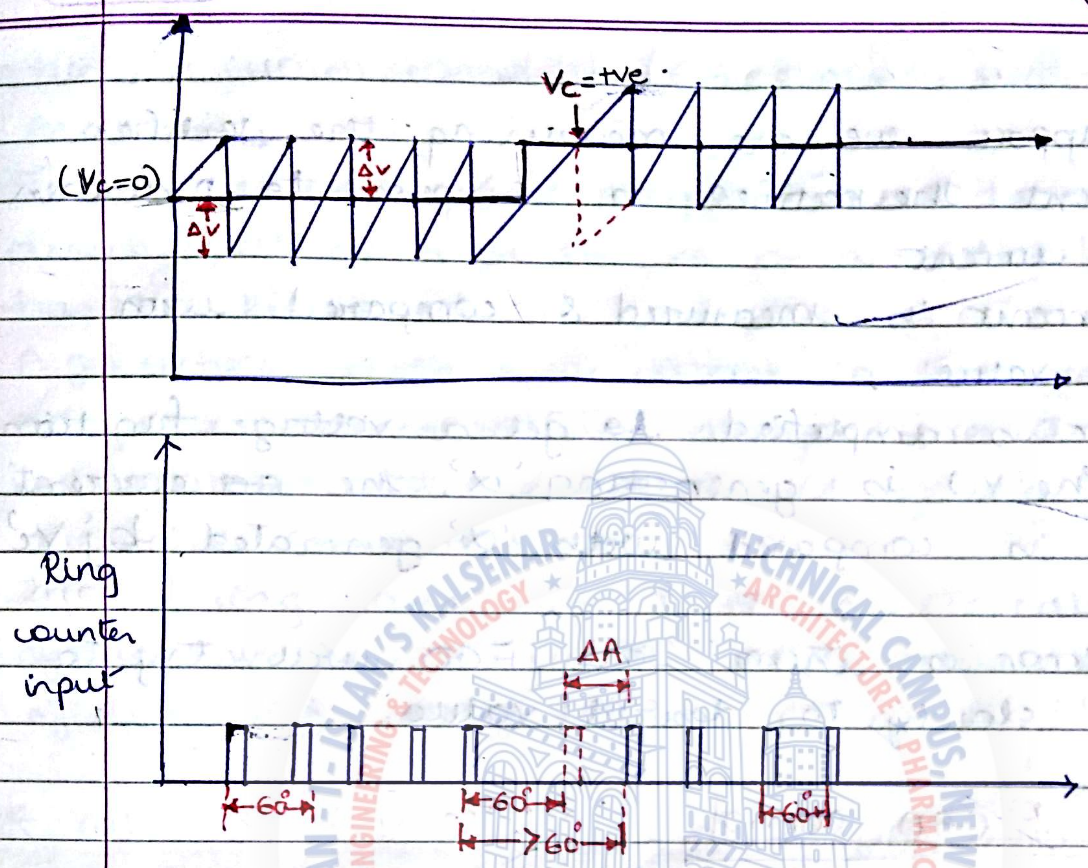
- A train of pulses are generated proportional to the control voltage (V_c).

- Response of this system is fast as it does not have integrator characteristics.

- The charging & discharging of capacitor is maintained between $\pm \Delta V$.



- In this method we are not integrating V_c, V_1
∴ It is faster.



- Constant Current Control (CCC) [Rectifier End]