UNIT - V
AC VOLTAGE CONTROLLER AND CYCLOCONVERTER
(RMS VOLTAGE CONTROLLERS)

AC voltage controllers (ac line voltage controllers) are employed to vary the RMS value of the alternating voltage applied to a load circuit by introducing Thyristors between the load and a constant voltage ac source. The RMS value of alternating voltage applied to a load circuit is controlled by controlling the triggering angle of the Thyristors in the ac voltage controller circuits.

In brief, an ac voltage controller is a type of thyristor power converter which is used to convert a fixed voltage, fixed frequency ac input supply to obtain a variable voltage ac output. The RMS value of the ac output voltage and the ac power flow to the load is controlled by varying (adjusting) the trigger angle ‘\( \alpha \)’

There are two different types of thyristor control used in practice to control the ac power flow

1. On-Off control
2. Phase control

These are the two ac output voltage control techniques.

In On-Off control technique Thyristors are used as switches to connect the load circuit to the ac supply (source) for a few cycles of the input ac supply and then to disconnect it for few input cycles. The Thyristors thus act as a high speed contactor (or high speed ac switch).

PHASE CONTROL

In phase control the Thyristors are used as switches to connect the load circuit to the input ac supply, for a part of every input cycle. That is the ac supply voltage is chopped using Thyristors during a part of each input cycle.

The thyristor switch is turned on for a part of every half cycle, so that input supply voltage appears across the load and then turned off during the remaining part of input half cycle to disconnect the ac supply from the load.

By controlling the phase angle or the trigger angle ‘\( \alpha \)’ (delay angle), the output RMS voltage across the load can be controlled.

The trigger delay angle ‘\( \alpha \)’ is defined as the phase angle (the value of \( \omega t \)) at which the thyristor turns on and the load current begins to flow.

Thyristor ac voltage controllers use ac line commutation or ac phase commutation. Thyristors in ac voltage controllers are line commutated (phase commutated) since the input supply is ac. When the input ac voltage reverses and becomes negative during the negative half
cycle the current flowing through the conducting thyristor decreases and falls to zero. Thus the ON thyristor naturally turns off, when the device current falls to zero.

Phase control Thyristors which are relatively inexpensive, converter grade Thyristors which are slower than fast switching inverter grade Thyristors are normally used.

For applications upto 400Hz, if Triacs are available to meet the voltage and current ratings of a particular application, Triacs are more commonly used.

Due to ac line commutation or natural commutation, there is no need of extra commutation circuitry or components and the circuits for ac voltage controllers are very simple.

Due to the nature of the output waveforms, the analysis, derivations of expressions for performance parameters are not simple, especially for the phase controlled ac voltage controllers with RL load. But however most of the practical loads are of the RL type and hence RL load should be considered in the analysis and design of ac voltage controller circuits.

**TYPE OF AC VOLTAGE CONTROLLERS**

The ac voltage controllers are classified into two types based on the type of input ac supply applied to the circuit.

- Single Phase AC Controllers.
- Three Phase AC Controllers.

Single phase ac controllers operate with single phase ac supply voltage of 230V RMS at 50Hz in our country. Three phase ac controllers operate with 3 phase ac supply of 400V RMS at 50Hz supply frequency.

Each type of controller may be sub divided into

- Uni-directional or half wave ac controller.
- Bi-directional or full wave ac controller.

In brief different types of ac voltage controllers are

- Single phase half wave ac voltage controller (uni-directional controller).
- Single phase full wave ac voltage controller (bi-directional controller).
- Three phase half wave ac voltage controller (uni-directional controller).
- Three phase full wave ac voltage controller (bi-directional controller).

**APPLICATIONS OF AC VOLTAGE CONTROLLERS**

- Lighting / Illumination control in ac power circuits.
- Induction heating.
- Industrial heating & Domestic heating.
- Transformer tap changing (on load transformer tap changing).
- Speed control of induction motors (single phase and poly phase ac induction motor control).
- AC magnet controls.

**PRINCIPLE OF ON-OFF CONTROL TECHNIQUE (INTEGRAL CYCLE CONTROL)**

The basic principle of on-off control technique is explained with reference to a single phase full wave ac voltage controller circuit shown below. The thyristor switches $T_1$ and $T_2$ are turned on by applying appropriate gate trigger pulses to connect the input ac supply to the load for ‘n’ number of input cycles during the time interval $t_{\text{on}}$. The thyristor switches $T_1$ and $T_2$ are turned off by blocking the gate trigger pulses for ‘m’ number of input cycles during the
time interval $t_{off}$. The ac controller ON time $t_{on}$ usually consists of an integral number of input cycles.

$R = R_L = \text{Load Resistance}$

**Fig.: Single phase full wave AC voltage controller circuit**

**Example**
Referring to the waveforms of ON-OFF control technique in the above diagram,

- $n =$ Two input cycles. Thyristors are turned ON during $t_{on}$ for two input cycles.
- $m =$ One input cycle. Thyristors are turned OFF during $t_{off}$ for one input cycle.
Thyristors are turned ON precisely at the zero voltage crossings of the input supply. The thyristor $T_1$ is turned on at the beginning of each positive half cycle by applying the gate trigger pulses to $T_1$ as shown, during the ON time $t_{ON}$. The load current flows in the positive direction, which is the downward direction as shown in the circuit diagram when $T_1$ conducts. The thyristor $T_2$ is turned on at the beginning of each negative half cycle, by applying gating signal to the gate of $T_2$, during $t_{ON}$. The load current flows in the reverse direction, which is the upward direction when $T_2$ conducts. Thus we obtain a bi-directional load current flow (alternating load current flow) in a ac voltage controller circuit, by triggering the thyristors alternately.

This type of control is used in applications which have high mechanical inertia and high thermal time constant (Industrial heating and speed control of ac motors). Due to zero voltage and zero current switching of Thyristors, the harmonics generated by switching actions are reduced.

For a sine wave input supply voltage,

$$v_i = V_m \sin \omega t = \sqrt{2}V_s \sin \omega t$$

$V_s$ = RMS value of input ac supply = $\frac{V_m}{\sqrt{2}}$ = RMS phase supply voltage.

If the input ac supply is connected to load for ‘n’ number of input cycles and disconnected for ‘m’ number of input cycles, then

$$t_{ON} = n \times T, \quad t_{OFF} = m \times T$$

Where $T = \frac{1}{f} = \text{input cycle time (time period)}$ and

- $f$ = input supply frequency.
- $t_{ON}$ = controller on time = $n \times T$.
- $t_{OFF}$ = controller off time = $m \times T$.
- $T_o = \text{Output time period} = (t_{ON} + t_{OFF}) = (nT + mT)$.

We can show that,
Output RMS voltage \( V_{O(RMS)} = V_{i(RMS)} \sqrt{\frac{t_{ON}}{T_o}} = V_s \sqrt{\frac{t_{ON}}{T_o}} \)

Where \( V_{i(RMS)} \) is the RMS input supply voltage = \( V_s \).

**TO DERIVE AN EXPRESSION FOR THE RMS VALUE OF OUTPUT VOLTAGE, FOR ON-OFF CONTROL METHOD.**

Output RMS voltage \( V_{O(RMS)} = \sqrt{\frac{1}{\omega T_o} \int_{0}^{\omega t_{ON}} V_m^2 \sin^2 \omega t \, d(\omega t)} \)

Substituting for \( \sin^2 \theta = \frac{1 - \cos 2\theta}{2} \)

\( V_{O(RMS)} = \sqrt{\frac{V_m^2}{\omega T_o} \int_{0}^{\omega t_{ON}} \left[ \frac{1 - \cos 2\omega t}{2} \right] \, d(\omega t)} \)

\( V_{O(RMS)} = \sqrt{\frac{V_m^2}{2 \omega T_o} \left[ \int_{0}^{\omega t_{ON}} d(\omega t) - \int_{0}^{\omega t_{ON}} \cos 2\omega t \, d(\omega t) \right]} \)

\( V_{O(RMS)} = \sqrt{\frac{V_m^2}{2 \omega T_o} \left[ (\omega t_{ON})_0 - \frac{\sin 2\omega t_{ON} - \sin 0}{2} \right]} \)

Now \( t_{ON} = \) An integral number of input cycles; Hence

\( t_{ON} = T, 2T, 3T, 4T, 5T, \ldots \) & \( \omega t_{ON} = 2\pi, 4\pi, 6\pi, 8\pi, 10\pi, \ldots \)

Where \( T \) is the input supply time period \( (T = \) input cycle time period). Thus we note that \( \sin 2\omega t_{ON} = 0 \)

\( V_{O(RMS)} = \sqrt{\frac{V_m^2 \omega t_{ON}}{2 \omega T_o}} = \frac{V_m}{\sqrt{2}} \sqrt{\frac{t_{ON}}{T_o}} \)
\[ V_{O(RMS)} = V_{i(RMS)} \sqrt{\frac{t_{ON}}{T_o}} = V_s \sqrt{\frac{t_{ON}}{T_o}} \]

Where \( V_{i(RMS)} = \frac{V_m}{\sqrt{2}} = V_s \) = RMS value of input supply voltage;

\[ \frac{t_{ON}}{T_o} = \frac{t_{ON}}{t_{ON} + t_{OFF}} = \frac{nT}{nT + mT} = \frac{n}{(n + m)} = k = \text{duty cycle (d)}. \]

\[ V_{O(RMS)} = V_s \sqrt{\frac{n}{(m + n)}} = V_s \sqrt{k} \]

**PERFORMANCE PARAMETERS OF AC VOLTAGE CONTROLLERS**

1. **RMS Output (Load) Voltage**

\[ V_{O(RMS)} = \left[ \frac{n}{2 \pi (n + m)} \int_0^{2\pi} V_m^2 \sin^2 \omega t \, d(\omega t) \right]^{\frac{1}{2}} \]

\[ V_{O(RMS)} = V_m \sqrt{2} \sqrt{\frac{n}{(m + n)}} = V_{i(RMS)} \sqrt{k} = V_s \sqrt{k} \]

\[ V_{O(RMS)} = V_{i(RMS)} \sqrt{k} = V_s \sqrt{k} \]

Where \( V_s = V_{i(RMS)} \) = RMS value of input supply voltage.

2. **Duty Cycle**

\[ k = \frac{t_{ON}}{T_o} = \frac{t_{ON}}{t_{ON} + t_{OFF}} = \frac{nT}{(n + m)T} \]

Where, \( k = \frac{n}{(m + n)} = \text{duty cycle (d)}. \)

3. **RMS Load Current**

\[ I_{O(RMS)} = \frac{V_{O(RMS)}}{Z} = \frac{V_{O(RMS)}}{R_L}; \text{ for a resistive load } Z = R_L. \]

4. **Output AC (Load) Power**

\[ P_o = I_{O(RMS)}^2 \times R_L \]
5. **Input Power Factor**

\[
P_F = \frac{P_O}{V_A} = \frac{\text{output load power}}{\text{input supply volt amperes}} = \frac{P_O}{V_S I_S}
\]

\[
P_F = \frac{I_{O(\text{RMS})}^2 \times R_L}{V_{I(\text{RMS})} \times I_{I(\text{RMS})}}; \quad I_S = I_{\text{in(\text{RMS})}} = \text{RMS input supply current.}
\]

The input supply current is same as the load current \( I_{\text{in}} = I_O = I_L \).

Hence, RMS supply current = RMS load current; \( I_{\text{in(\text{RMS})}} = I_{O(\text{RMS})} \).

\[
P_F = \sqrt{k} = \sqrt{\frac{n}{m+n}}
\]

6. **The Average Current of Thyristor** \( I_{T(\text{Avg})} \)

**Waveform of Thyristor Current**

\[
I_{T(\text{Avg})} = \frac{n}{2\pi (m+n)} \int_0^\pi I_m \sin \omega t \, d(\omega t)
\]

\[
I_{T(\text{Avg})} = \frac{nI_m}{2\pi (m+n)} \left[ \sin \omega t \right]_0^\pi
\]

\[
I_{T(\text{Avg})} = \frac{nI_m}{2\pi (m+n)} \left[ -\cos \omega t \right]_0^\pi
\]

\[
I_{T(\text{Avg})} = \frac{nI_m}{2\pi (m+n)} \left[ -\cos \pi + \cos 0 \right]
\]
\[ I_{T(Avg)} = \frac{nI_m}{2\pi(m+n)}[-(1)+1] \]

\[ I_{T(Avg)} = \frac{n}{2\pi(m+n)}[2I_m] \]

\[ I_{T(Avg)} = \frac{I_m n}{\pi (m+n)} = \frac{k I_m}{\pi} \]

\[ k = \text{duty cycle} = \frac{t_{ON}}{(t_{ON} + t_{OFF})} = \frac{n}{(n+m)} \]

\[ I_{T(Avg)} = \frac{I_m n}{\pi (m+n)} = \frac{k I_m}{\pi} , \]

Where \( I_m = \frac{V_m}{R_L} \) = maximum or peak thyristor current.

7. RMS Current of Thyristor \( I_{T(RMS)} \)

\[ I_{T(RMS)} = \left( \frac{n}{2\pi(n+m)} \int_0^\pi I_m^2 \sin^2(\omega t) d(\omega t) \right)^\frac{1}{2} \]

\[ I_{T(RMS)} = \left( \frac{n}{2\pi(n+m)} \int_0^\pi \sin^2(\omega t) d(\omega t) \right)^\frac{1}{2} \]

\[ I_{T(RMS)} = \left( \frac{n}{2\pi(n+m)} \int_0^\pi \left(1 - \cos 2\omega t\right) \frac{d(\omega t)}{2} \right)^\frac{1}{2} \]

\[ I_{T(RMS)} = \left( \frac{n}{2\pi(n+m)} \left\{ \int_0^\pi d(\omega t) - \int_0^\pi \cos 2\omega t \frac{d(\omega t)}{2} \right\} \right)^\frac{1}{2} \]

\[ I_{T(RMS)} = \left( \frac{n}{2\pi(n+m)} \left\{ \int_0^\pi \left(\omega t\right)/2 \right\} \right)^\frac{1}{2} \]

\[ I_{T(RMS)} = \left( \frac{n}{2\pi(n+m)} \left(\pi - 0\right) - \left(\frac{\sin 2\omega t}{2}\right)_0^\pi \right)^\frac{1}{2} \]

\[ I_{T(RMS)} = \left( \frac{n}{2\pi(n+m)} \left(\pi - 0\right) - \left(\frac{2\pi - \sin 0}{2}\right) \right)^\frac{1}{2} \]
A single phase full wave ac voltage controller working on ON-OFF control technique has supply voltage of 230V, RMS 50Hz, load = 50Ω. The controller is ON for 30 cycles and off for 40 cycles. Calculate

1. **ON & OFF time intervals.**
2. **RMS output voltage.**
3. **Input P.F.**
4. **Average and RMS thyristor currents.**

**PROBLEM**

- A single phase full wave ac voltage controller working on ON-OFF control technique has supply voltage of 230V, RMS 50Hz, load = 50Ω. The controller is ON for 30 cycles and off for 40 cycles. Calculate
  1. **ON & OFF time intervals.**
  2. **RMS output voltage.**
  3. **Input P.F.**
  4. **Average and RMS thyristor currents.**

\[
V_{\text{in(RMS)}} = 230V, \quad V_m = \sqrt{2} \times 230V = 325.269V, \quad V_m = 325.269V,
\]

\[
T = \frac{1}{f} = \frac{1}{50Hz} = 0.02\text{sec}, \quad T = 20\text{ms}.
\]

\(n = \text{number of input cycles during which controller is ON; } n = 30.\)

\(m = \text{number of input cycles during which controller is OFF; } m = 40.\)

\[
t_{\text{ON}} = n \times T = 30 \times 20\text{ms} = 600\text{ms} = 0.6\text{sec}
\]

\[
t_{\text{ON}} = n \times T = 0.6\text{sec} = \text{controller ON time}.
\]

\[
t_{\text{OFF}} = m \times T = 40 \times 20\text{ms} = 800\text{ms} = 0.8\text{sec}
\]

\[
t_{\text{OFF}} = m \times T = 0.8\text{sec} = \text{controller OFF time}.
\]

Duty cycle \(k = \frac{n}{(m+n)} = \frac{30}{(40+30)} = 0.4285\)

**RMS output voltage**
\[
V_{O(RMS)} = V_{i(RMS)} \times \sqrt{\frac{n}{m+n}}
\]
\[
V_{O(RMS)} = 230V \times \sqrt{\frac{30}{30+40}} = 230 \sqrt{\frac{3}{7}}
\]
\[
V_{O(RMS)} = 230V \sqrt{0.42857} = 230 \times 0.65465
\]
\[
V_{O(RMS)} = 150.570V
\]
\[
I_{O(RMS)} = \frac{V_{O(RMS)}}{Z} = \frac{V_{O(RMS)}}{R_L} = \frac{150.570V}{50\Omega} = 3.0114A
\]
\[
P_O = I_{O(RMS)}^2 \times R_L = 3.0114^2 \times 50 = 453.426498W
\]

**Input Power Factor**

\[
PF = \sqrt{k}
\]
\[
PF = \sqrt{\frac{n}{m+n}} = \sqrt{\frac{30}{70}} = \sqrt{0.4285}
\]
\[
PF = 0.654653
\]

**Average Thyristor Current Rating**

\[
I_{T(Avg)} = \frac{I_m}{\pi} \times \left( \frac{n}{m+n} \right) = \frac{k \times I_m}{\pi}
\]

where

\[
I_m = \frac{V_m}{R_L} = \frac{\sqrt{2} \times 230}{50} = \frac{325.269}{50}
\]

\[
I_m = 6.505382A = \text{Peak (maximum) thyristor current.}
\]

\[
I_{T(Avg)} = \frac{6.505382}{\pi} \times \left( \frac{3}{7} \right)
\]

\[
I_{T(Avg)} = 0.88745A
\]

**RMS Current Rating of Thyristor**

\[
I_{T(RMS)} = \frac{I_m}{2} \sqrt{\frac{n}{m+n}} = \frac{I_m \sqrt{3}}{2} = \frac{6.505382}{2} \times \sqrt{\frac{3}{7}}
\]

\[
I_{T(RMS)} = 2.129386A
\]
PRINCIPLE OF AC PHASE CONTROL

The basic principle of ac phase control technique is explained with reference to a single phase half wave ac voltage controller (unidirectional controller) circuit shown in the below figure.

The half wave ac controller uses one thyristor and one diode connected in parallel across each other in opposite direction that is anode of thyristor $T_1$ is connected to the cathode of diode $D_1$ and the cathode of $T_1$ is connected to the anode of $D_1$. The output voltage across the load resistor ‘R’ and hence the ac power flow to the load is controlled by varying the trigger angle ‘$\alpha$’.

The trigger angle or the delay angle ‘$\alpha$’ refers to the value of $\omega t$ or the instant at which the thyristor $T_1$ is triggered to turn it ON, by applying a suitable gate trigger pulse between the gate and cathode lead.

The thyristor $T_1$ is forward biased during the positive half cycle of input ac supply. It can be triggered and made to conduct by applying a suitable gate trigger pulse only during the positive half cycle of input supply. When $T_1$ is triggered it conducts and the load current flows through the thyristor $T_1$, the load and through the transformer secondary winding.

By assuming $T_1$ as an ideal thyristor switch it can be considered as a closed switch when it is ON during the period $\omega t = \alpha$ to $\pi$ radians. The output voltage across the load follows the input supply voltage when the thyristor $T_1$ is turned-on and when it conducts from $\omega t = \alpha$ to $\pi$ radians. When the input supply voltage decreases to zero at $\omega t = \pi$, for a resistive load the load current also falls to zero at $\omega t = \pi$ and hence the thyristor $T_1$ turns off at $\omega t = \pi$. Between the time period $\omega t = \pi$ to $2\pi$, when the supply voltage reverses and becomes negative the diode $D_1$ becomes forward biased and hence turns ON and conducts. The load current flows in the opposite direction during $\omega t = \pi$ to $2\pi$ radians when $D_1$ is ON and the output voltage follows the negative half cycle of input supply.

![Figure: Halfwave AC phase controller (Unidirectional Controller)]
Equations

Input AC Supply Voltage across the Transformer Secondary Winding.

\[ v_s = V_m \sin \omega t \]
\[ V_S = V_{m(RMS)} = \frac{V_m}{\sqrt{2}} \text{ RMS value of secondary supply voltage.} \]

Output Load Voltage

\[ v_o = v_L = 0 \; \text{for } \omega t = 0 \text{ to } \alpha \]
\[ v_o = v_L = V_m \sin \omega t \; \text{for } \omega t = \alpha \text{ to } 2\pi \text{.} \]

Output Load Current

\[ i_o = i_L = \frac{v_o}{R_L} = \frac{V_m \sin \omega t}{R_L} \; \text{for } \omega t = \alpha \text{ to } 2\pi \text{.} \]
\[ i_o = i_L = 0 \; \text{for } \omega t = 0 \text{ to } \alpha \text{.} \]

**TO DERIVE AN EXPRESSION FOR RMS OUTPUT VOLTAGE** \( V_{o(RMS)} \)

\[ V_{o(RMS)} = \sqrt{\frac{1}{2\pi} \int_0^{2\pi} V_m^2 \sin^2 \omega t \cdot d(\omega t)} \]

\[ V_{o(RMS)} = \sqrt{\frac{V_m^2}{2\pi} \int_0^{2\pi} \left( 1 - \cos 2\omega t \right) \cdot d(\omega t)} \]
\[ V_{O(RMS)} = \sqrt{\frac{V_m^2}{4\pi} \left[ \int_{-\alpha}^{\alpha} (1 - \cos 2\omega t) d(\omega t) \right]^2} \]

\[ V_{O(RMS)} = \frac{V_m}{2\sqrt{\pi}} \sqrt{\left[ \int_{-\alpha}^{\alpha} d(\omega t) - \int_{-\alpha}^{\alpha} \cos 2\omega t d\omega t \right]^2} \]

\[ V_{O(RMS)} = \frac{V_m}{2\sqrt{\pi}} \sqrt{\left( \int_{-\alpha}^{\alpha} (\omega t)^2 d\omega t - \left( \frac{\sin 2\omega t}{2} \right)^2 \right)^2} \]

\[ V_{O(RMS)} = \frac{V_m}{2\sqrt{\pi}} \sqrt{(2\pi - \alpha) - \left( \frac{\sin 4\pi}{2} - \frac{\sin 2\alpha}{2} \right)} \quad ; \sin 4\pi = 0 \]

\[ V_{O(RMS)} = \frac{V_m}{2\sqrt{\pi}} \sqrt{(2\pi - \alpha) + \frac{\sin 2\alpha}{2}} \]

\[ V_{O(RMS)} = \frac{V_m}{\sqrt{2}\sqrt{2\pi}} \sqrt{(2\pi - \alpha) + \frac{\sin 2\alpha}{2}} \]

\[ V_{O(RMS)} = \frac{V_m}{\sqrt{2}} \sqrt{\left( \frac{2\pi - \alpha}{2} + \frac{\sin 2\alpha}{2} \right)} \]

\[ V_{O(RMS)} = \sqrt{V_{i(RMS)}^2 \left( \frac{2\pi - \alpha}{2} + \frac{\sin 2\alpha}{2} \right)} \]

\[ V_{O(RMS)} = V_s \sqrt{\frac{1}{2\pi} \left( \frac{2\pi - \alpha}{2} + \frac{\sin 2\alpha}{2} \right)} \]

Where, \( V_{i(RMS)} = V_s = \frac{V_m}{\sqrt{2}} \) = RMS value of input supply voltage (across the transformer secondary winding).

**Note:** Output RMS voltage across the load is controlled by changing \( '\alpha' \) as indicated by the expression for \( V_{O(RMS)} \).
PLOT OF $V_{O(RMS)}$ VERSUS TRIGGER ANGLE $\alpha$ FOR A SINGLE PHASE HALF-WAVE AC VOLTAGE CONTROLLER (UNIDIRECTIONAL CONTROLLER)

$$V_{O(RMS)} = \frac{V_m}{\sqrt{2}} \sqrt{\frac{1}{2\pi} \left( \frac{2\pi - \alpha}{2} \right)}$$

$$V_{O(RMS)} = V_s \sqrt{\frac{1}{2\pi} \left( \frac{2\pi - \alpha}{2} \right)}$$

By using the expression for $V_{O(RMS)}$ we can obtain the control characteristics, which is the plot of RMS output voltage $V_{O(RMS)}$ versus the trigger angle $\alpha$. A typical control characteristic of single phase half-wave phase controlled ac voltage controller is as shown below

<table>
<thead>
<tr>
<th>Trigger angle $\alpha$ in degrees</th>
<th>Trigger angle $\alpha$ in radians</th>
<th>$V_{O(RMS)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>$V_s = \frac{V_m}{\sqrt{2}}$</td>
</tr>
<tr>
<td>30°</td>
<td>$\frac{\pi}{6}$ : $\left(\frac{\pi}{6}\right)$</td>
<td>0.992765 $V_s$</td>
</tr>
<tr>
<td>60°</td>
<td>$\frac{\pi}{3}$ : $\left(\frac{2\pi}{6}\right)$</td>
<td>0.949868 $V_s$</td>
</tr>
<tr>
<td>90°</td>
<td>$\frac{\pi}{2}$ : $\left(\frac{3\pi}{6}\right)$</td>
<td>0.866025 $V_s$</td>
</tr>
<tr>
<td>120°</td>
<td>$\frac{2\pi}{3}$ : $\left(\frac{4\pi}{6}\right)$</td>
<td>0.77314 $V_s$</td>
</tr>
<tr>
<td>150°</td>
<td>$\frac{5\pi}{6}$ : $\left(\frac{5\pi}{6}\right)$</td>
<td>0.717228 $V_s$</td>
</tr>
<tr>
<td>180°</td>
<td>$\pi$ : $\left(\frac{6\pi}{6}\right)$</td>
<td>0.707106 $V_s$</td>
</tr>
</tbody>
</table>
Fig.: Control characteristics of single phase half-wave phase controlled ac voltage controller

Note: We can observe from the control characteristics and the table given above that the range of RMS output voltage control is from 100% of $V_s$ to 70.7% of $V_s$ when we vary the trigger angle $\alpha$ from zero to 180 degrees. Thus the half wave ac controller has the drawback of limited range RMS output voltage control.

TO CALCULATE THE AVERAGE VALUE (DC VALUE) OF OUTPUT VOLTAGE

$$V_{o_{(dc)}} = \frac{1}{2\pi} \int_{\alpha}^{2\pi} V_m \sin \omega t \, d(\omega t)$$

$$V_{o_{(dc)}} = \frac{V_m}{2\pi} \int_{\alpha}^{2\pi} \sin \omega t \, d(\omega t)$$

$$V_{o_{(dc)}} = \frac{V_m}{2\pi} \left[-\cos \omega t \right]_{\alpha}^{2\pi}$$

$$V_{o_{(dc)}} = \frac{V_m}{2\pi} \left[-\cos 2\pi \cos \alpha \right] \quad ; \quad \cos 2\pi = 1$$

$$V_{dc} = \frac{V_m}{2\pi} \cos \alpha - 1 \quad ; \quad V_m = \sqrt{2}V_s$$

Hence $V_{dc} = \frac{\sqrt{2}V_s}{2\pi} (\cos \alpha - 1)$

When $\alpha$ is varied from 0 to $\pi$, $V_{dc}$ varies from 0 to $\frac{-V_m}{\pi}$

DISADVANTAGES OF SINGLE PHASE HALF WAVE AC VOLTAGE CONTROLLER.

- The output load voltage has a DC component because the two halves of the output voltage waveform are not symmetrical with respect to ‘0’ level. The input supply current waveform also has a DC component (average value) which can result in the problem of core saturation of the input supply transformer.

- The half wave ac voltage controller using a single thyristor and a single diode provides control on the thyristor only in one half cycle of the input supply. Hence ac power flow to the load can be controlled only in one half cycle.

- Half wave ac voltage controller gives limited range of RMS output voltage control. Because the RMS value of ac output voltage can be varied from a maximum of 100% of $V_s$ at a trigger angle $\alpha = 0$ to a low of 70.7% of $V_s$ at $\alpha = \pi$ Radians.

These drawbacks of single phase half wave ac voltage controller can be overcome by using a single phase full wave ac voltage controller.
APPLICATIONS OF RMS VOLTAGE CONTROLLER

- Speed control of induction motor (polyphase ac induction motor).
- Heater control circuits (industrial heating).
- Welding power control.
- Induction heating.
- On load transformer tap changing.
- Lighting control in ac circuits.
- Ac magnet controls.

Problem

A single phase half-wave ac voltage controller has a load resistance \( R = 50 \Omega \), input ac supply voltage is 230V RMS at 50Hz. The input supply transformer has a turns ratio of 1:1. If the thyristor \( T_1 \) is triggered at \( \alpha = 60^\circ \). Calculate

- RMS output voltage.
- Output power.
- RMS load current and average load current.
- Input power factor.
- Average and RMS thyristor current.

Given,

\[ V_p = 230V, \text{RMS primary supply voltage.} \]
\[ f = \text{Input supply frequency} = 50Hz. \]
\[ R_L = 50\Omega \]
\[ \alpha = 60^\circ = \frac{\pi}{3} \text{ radians.} \]
\[ V_s = \text{RMS secondary voltage.} \]

\[ \frac{V_p}{V_s} = \frac{N_p}{N_s} = 1 \]

Therefore \( V_p = V_s = 230V \)

Where, \( N_p = \text{Number of turns in the primary winding.} \)
\[ N_s = \text{Number of turns in the secondary winding.} \]
• RMS Value of Output (Load) Voltage $V_{o(RMS)}$

$$V_{o(RMS)} = \sqrt{\frac{1}{2\pi} \int_{\alpha}^{\beta} V_m^2 \sin^2 \omega t \, d(\omega t)}$$

We have obtained the expression for $V_{o(RMS)}$ as

$$V_{o(RMS)} = V_s \sqrt{\frac{1}{2\pi} \left( (2\pi \alpha - \alpha) + \sin \frac{2\alpha}{2} \right)}$$

$$V_{o(RMS)} = 230 \sqrt{\frac{1}{2\pi} \left( \frac{2\pi}{3} - \frac{\pi}{3} \right) + \sin \frac{120^0}{2}}$$

$$V_{o(RMS)} = 230 \sqrt{\frac{1}{2\pi} [5.669]} = 230 \times 0.94986$$

$$V_{o(RMS)} = 218.4696 \text{ V} \approx 218.47 \text{ V}$$

• RMS Load Current $I_{o(RMS)}$

$$I_{o(RMS)} = \frac{V_{o(RMS)}}{R_L} = \frac{218.46966}{50} = 4.36939 \text{ Amps}$$

• Output Load Power $P_o$

$$P_o = I_{o(RMS)}^2 \times R_L = (4.36939)^2 \times 50 = 954.5799 \text{ Watts}$$

$$P_o = 0.9545799 \text{ KW}$$

• Input Power Factor

$$PF = \frac{P_o}{V_s \times I_s}$$

$V_s = \text{RMS secondary supply voltage} = 230\text{V}$.
$I_s = \text{RMS secondary supply current} = \text{RMS load current}.

$$\therefore I_s = I_{o(RMS)} = 4.36939 \text{ Amps}$$

$$\therefore PF = \frac{954.5799 \text{ W}}{230 \times 4.36939 \text{ W}} = 0.9498$$
• **Average Output (Load) Voltage**

\[ V_{o_{(dc)}} = \frac{1}{2\pi} \left[ \int_{\alpha}^{2\pi} V_m \sin \omega t \, d\omega t \right] \]

We have obtained the expression for the average / DC output voltage as,

\[ V_{o_{(dc)}} = \frac{V_m}{2\pi} \left[ \cos \alpha - 1 \right] \]

\[ V_{o_{(dc)}} = \frac{\sqrt{2} \times 230}{2\pi} \left[ \cos \left( 60^\circ \right) - 1 \right] = \frac{325.2691193}{2\pi} \left[ 0.5 - 1 \right] \]

\[ V_{o_{(dc)}} = \frac{325.2691193}{2\pi} \left[ -0.5 \right] = -25.88409 \text{ Volts} \]

• **Average DC Load Current**

\[ I_{o_{(dc)}} = \frac{V_{o_{(dc)}}}{R_L} = \frac{-25.884094}{50} = -0.51768 \text{ Amps} \]

• **Average & RMS Thyristor Currents**

![Thyristor Current Waveform](image)

**Fig.: Thyristor Current Waveform**

Referring to the thyristor current waveform of a single phase half-wave ac voltage controller circuit, we can calculate the average thyristor current \( I_{T(Avg)} \) as

\[ I_{T(Avg)} = \frac{1}{2\pi} \left[ \int_{\alpha}^{\pi} I_m \sin \omega t \, d\omega t \right] \]

\[ I_{T(Avg)} = \frac{I_m}{2\pi} \left[ \int_{\alpha}^{\pi} \sin \omega t \, d\omega t \right] \]
Where, \( I_m = \frac{V_m}{R_L} \) = Peak thyristor current = Peak load current.

\[
I_{T(Avg)} = \frac{I_m}{2\pi} \left[ -\cos(\omega t) \right] \left( \frac{\pi}{\alpha} \right)
\]

\[
I_{T(Avg)} = \frac{I_m}{2\pi} \left[ -\cos(\pi) + \cos \alpha \right]
\]

\[
I_{T(Avg)} = \frac{I_m}{2\pi} \left[ 1 + \cos \alpha \right]
\]

\[
I_{T(Avg)} = I_m \left[ 1 + \cos \alpha \right]
\]

\[
I_m = \frac{\sqrt{2} \times 230}{50}
\]

\[
I_m = 6.505382 \text{ Amps}
\]

\[
I_{T(Avg)} = \frac{V_m}{2\pi R_L} \left[ 1 + \cos \alpha \right]
\]

\[
I_{T(Avg)} = \frac{\sqrt{2} \times 230}{2\pi \times 50} \left[ 1 + \cos \left( 60^\circ \right) \right]
\]

\[
I_{T(Avg)} = \frac{\sqrt{2} \times 230}{100\pi} \left[ 1 + 0.5 \right]
\]

\[
I_{T(Avg)} = 1.5530 \text{ Amps}
\]

- RMS thyristor current \( I_{T(RMS)} \) can be calculated by using the expression

\[
I_{T(RMS)} = \sqrt{\frac{1}{2\pi} \int_{\alpha}^{\pi} I_m^2 \sin^2 \omega t \cdot d(\omega t)}
\]

\[
I_{T(RMS)} = \sqrt{\frac{I_m^2}{2\pi} \int_{\alpha}^{\pi} (1 - \cos 2\omega t) \cdot d(\omega t)}
\]

\[
I_{T(RMS)} = \sqrt{\frac{I_m^2}{4\pi} \int_{\alpha}^{\pi} d(\omega t) - \int_{\alpha}^{\pi} \cos 2\omega t \cdot d(\omega t)}
\]

\[
I_{T(RMS)} = I_m \sqrt{\frac{1}{4\pi} \left[ \int_{\alpha}^{\pi} (\omega t) \cdot \left( \frac{\sin 2\omega t}{2} \right) \cdot d(\omega t) \right]}
\]
\[ I_{T(RMS)} = I_m \sqrt{\frac{1}{4\pi} \left[ (\pi - \alpha) - \frac{\sin 2\pi - \sin 2\alpha}{2} \right]} \]

\[ I_{T(RMS)} = I_m \sqrt{\frac{1}{4\pi} \left[ (\pi - \alpha) + \frac{\sin 2\alpha}{2} \right]} \]

\[ I_{T(RMS)} = \frac{I_m}{\sqrt{2}} \sqrt{\frac{1}{2\pi} \left[ (\pi - \alpha) + \frac{\sin 2\alpha}{2} \right]} \]

\[ I_{T(RMS)} = \frac{6.50538}{\sqrt{2}} \sqrt{\frac{1}{2\pi} \left[ \left( \frac{\pi - \pi}{3} \right) + \frac{\sin 120^\circ}{2} \right]} \]

\[ I_{T(RMS)} = 4.6 \sqrt{\frac{1}{2\pi} \left[ \left( \frac{2\pi}{3} \right) + \frac{0.8660254}{2} \right]} \]

\[ I_{T(RMS)} = 4.6 \times 0.6342 = 2.91746A \]

\[ I_{T(RMS)} = 2.91746 \text{ Amps} \]
UNIT – 1

1. **What is power electronics?**
   Power electronics is a subject that concerns the applications electronics principles into situations that are rated at power level rather than signal level. It may be defined as a subject deals with the apparatus and equipment working on the principle of electronics but at rated power level.

2. **Give the applications of power electronics.**
   - Aerospace
   - Commercial
   - Industrial
   - Telecommunications

3. **Classify power semiconductor devices give examples.**
   - Diodes: power diodes
   - Thyristors: SCR
   - Control switches: BJT, MOSFET and IGBT

4. **What are the types of power transistors?**
   - Bipolar Junction Transistor (BJT)
   - Metal Oxide Semiconductor Field Effect Transistor (MOSFET)
   - Insulated Gate Bipolar Transistor (IGBT)

5. **Why IGBT is very popular nowadays?**
   a. Lower hate requirements
   b. Lower switching losses
   c. Smaller snubber circuit requirements

6. **What are the different methods to turn on the thyristor?**
   a. Forward voltage triggering
   b. Gate triggering
   c. \( \frac{dv}{dt} \) triggering
   d. Temperature triggering
   e. Light triggering

7. **What is the difference between power diode and signal diode?**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Power diode</th>
<th>Signal diode</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Constructed with n-layer, called drift region between p+ layer and n+ layer.</td>
<td>Drift region is not present.</td>
</tr>
<tr>
<td>2.</td>
<td>The voltage,</td>
<td>Lower</td>
</tr>
</tbody>
</table>

21
8. **IGBT is a voltage-controlled device. Why?**  
   Because the controlling parameter is gate-emitter voltage.

9. **Power MOSFET is a voltage-controlled device. Why?**  
   Because the output (drain) current can be controlled by gate-source voltage.

10. **Power BJT is a current controlled device. Why?**  
    Because the output (collector) current can be controlled by base current.

11. **What is the relation between $\alpha$ and $\beta$?**  
    $$\beta = \alpha$$  
    $$1 - \alpha$$  
    $$\alpha = \frac{\beta}{1 - \beta}$$  

12. **What are the different types of power MOSFET?**  
    a. N-channel MOSFET  
    b. P-channel MOSFET

13. **How can a thyristor turned off?**  
    A thyristor can be turned off by making the current flowing through it to a level below the holding current.

14. **Define latching current.**  
    The latching current is defined as the minimum value of anode current which it must attain during turn on process to maintain conduction when gate signal is removed.

15. **Define holding current.**  
    The holding current is defined as the minimum value of anode current below which it must fall to for turning off the thyristor.

16. **What is a snubber circuit?**  
    It consists of a series combination of a resistor and a capacitor in parallel with the thyristors. It is mainly used for $dv / dt$ protection.

17. **What losses occur in a thyristor during working conditions?**  
    a. Forward conduction losses  
    b. Loss due to leakage current during forward and reverse blocking  
    c. Switching losses at turn-on and turn-off.  
    d. Gate triggering loss.
18. Define hard-driving or over-driving.
When gate current is several times higher than the minimum gate current required, a thyristor is said to be hard-fired or over-driven. Hard-firing of a thyristor reduces its turn-on time and enhances its di/dt capability.

19. Define circuit turn off time.
It is defined as the time during which a reverse voltage is applied across the thyristor during its commutation process.

20. Why circuit turn off time should be greater than the thyristor turn-off time?
Circuit turn off time should be greater than the thyristor turn-off time for reliable turn-off, otherwise the device may turn-on at an undesired instant, a process called commutation failure.

21. What is meant by commutation?
It is the process of changing the direction of current flow in a particular path of the circuit. This process is used in thyristors for turning it off.

22. What are the types of commutation?
   a. Natural commutation
   b. Forced commutation

23. What is the turn-off time for converter grade SCRs and inverter grade SCRs?
Turn-off time for converter grade SCRs is 50 – 100 ms turn-off time for converter grade SCRs and inverter grade SCRs and for inverter grade SCRs is 3 – 50 ms.

24. What are the advantages of GTO over SCR?
   o Elimination commutating components in forced commutation, resulting in reduction in cost, weight and volume.
   o Reduction in acoustic noise and electromagnetic noise due to elimination of commutation chokes.
   o Faster turn-off, permitting high switching frequencies.
   o Improved efficiency of the converters.

25. Write down the applications of IGBT?
They are widely used for medium power applications.
   AC and DC motor drives
   UPS systems
   Power supplies
   Relays and Contactors

26. Compare Power MOSFET with BJT.

<table>
<thead>
<tr>
<th></th>
<th>Power MOSFET</th>
<th>BJT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Lower Switching loss</td>
<td></td>
<td>Higher switching loss</td>
</tr>
</tbody>
</table>
2. High on state resistance so more lower conduction losses
3. Voltage controlled device Current controlled device
4. It has positive temperature coefficient. It has negative temperature coefficient

27. Why IGBT is very popular now a days?

• Lower gate drive requirement
• Lower switching losses
• Smaller snubber circuit requirements

28. What are the different methods to turn on the thyristor?
   Forward voltage triggering, Gate triggering, dv/dt triggering, temperature triggering & light triggering

29. Define forward breakovervoltage .
   When anode is positive w.r.to cathode with gate current open, the junction J1 & J3 are forward biased but J2 is reverse biased. When the forward voltage is increased junction J2 will have an avalanche breakdown at a voltage. This voltage is called forward breakover voltage.

30. Define reverse breakovervoltage .
   When cathode is positive w.r.to anode with gate current open, the junction J1 & J3 are reverse biased but J2 is forward biased. When the reverse voltage is increased junctions J1 & J3 will have an avalanche breakdown at a voltage. This voltage is called as critical breakdown voltage Vbr.

31. IGBT is a voltage controlled device. Why?
   IGBT is a voltage controlled device because the controlling parameter is gate emitter voltage VGE

32. Power MOSFET is a voltage controlled device. Why?
   Power MOSFET is a voltage controlled device because the output current can Controlled by gate source voltage VGS.

33. What is meant by over drive factor?
   It is defined as the ratio of IB & IBS
   ODF = IB / IBS
UNIT – II
PHASE CONTROLLED CONVERTERS

1. **What is meant by phase controlled rectifier?**
   It converts fixed ac voltage into variable dc voltage.

2. **Mention some of the applications of controlled rectifier**
   Steel rolling mills, printing press, textile mills and paper mills employing dc motor drives, DC traction, Electro chemical and electro-metallurgical process, Portable hand tool drives, Magnet power supplies, HVDC

3. **What is the function of freewheeling diodes in controlled rectifier?**

4. **What are the advantages of freewheeling diodes in a controlled in a controlled rectifier?**
   - Input power factor is improved.
   - Load current waveform is improved and thus the load performance is better.

5. **What is meant by delay angle?**
   The delay angle is defined as the angle between the zero crossing of the input voltage and the instant the thyristor is fired.

6. **What are the advantages of single phase bridge converter over single phase mid-point converter?**
   - SCRs are subjected to a peak-inverse voltage of 2Vm in a fully controlled bridge rectifier. Hence for same voltage and current ratings of SCRs, power handled by mid-point configuration is about
• In mid-point converter, each secondary winding should be able to supply the load power. As such, the transformer rating in mid-point converter is double the load rating.

8. **What is commutation angle or overlap angle?**
   The commutation period when outgoing and incoming thyristors are conducting is known as overlap period. The angular period, when both devices share conduction is known as the commutation angle or overlap angle.

9. **What are the different methods of firing circuits for line commutated converter?**
   • UJT firing circuit.
   • The cosine wave crossing pulse timing control
   • Digital firing schemes.

10. **Give an expression for average voltage of single-phase semiconverters.**
    Average output voltage \( V_{dc} = \left( \frac{V_m}{\pi} \right) (1 + \cos \alpha) \).

11. **What is meant by input power factor in controlled rectifier?**
    The input power factor is defined as the ratio of the total mean input power to the total RMS input volt-amperes.
    \[ PF = \frac{(V1 I1 \cos \phi1)}{(V_{rms}I_{rms})} \]

12. **What are the advantages of six-pulse converter?**
    • Commutation is made simple.
    • Distortion on the ac side is reduced due to the reduction in lower order harmonics.
    • Inductance reduced in series is considerably reduced.

13. **What are the disadvantages of continuous gating signal?**
    • More heating of the SCR gate.
    • Increases the size of pulse transformer.

14. **What is meant by high frequency carrier gating?**
    Thyristor is turned on by using a train of pulses from to. This type of signal is called as high frequency carrier gating.

15. **Define Displacement Factor.**
    The input displacement factor is defined as the cosine of the input displacement angle.

16. **Define voltage ripple factor.**
    It is defined as the ratio of the net harmonic content of the output voltage to the average output voltage.

17. **is mean by uncontrolled rectifier?**
    The uncontrolled rectifier uses only diodes and it converts fixed ac voltage into fixed dc voltage.
18. **How to classify rectifier circuits.** (i) Uncontrolled rectifier (ii) Controlled rectifier

19. **What is meant by full converter?**
   A fully controlled converter uses thyristors only and there is a wider control over the level of dc output voltage. It is also known as two quadrant converter.

20. **What are the performance factors of line commutated converters?**
   Input displacement angle, input power factor, DC voltage ratio, Input harmonic factor, Voltage & current ripple factor.

21. **What are the two configuration of single phase 2 pulse controlled rectifier?**
   • Mid-point converter
   • Bridge Converter

22. **What is meant by 2 pulse converter?**
   Two pulse converter is defined as two triggering pulses or two sets of triggering pulses are to be generated during every cycle of the supply to trigger the various SCRs.

23. **What is meant by rectification mode in single phase fully controlled converter?**
   In single phase full converter $< 90^0$ the voltage at the dc terminal is positive. Therefore, power flows from source to load & the converter operates as a rectifier. Source voltage is $V_s$ & Current is positive. This is known as rectification mode.

24. **What is meant by inversion mode?**
   In single phase full converter $> 90^0$ the voltage at the dc terminal is negative. Therefore, power flows from load to source & the converter operates as line commutated inverter. Source voltage $V_s$ is negative & Current is positive. This is known as inversion mode or synchronous mode.

25. **What are the different types of controlled rectifier?**
   • According to input supply – Single phase controlled rectifier & Three phase controlled rectifier
   • According to Quadrant operation – semiconverter, full converter, dual converter
   • According to no. pulses / cycle – one pulse, two pulse, three pulse, Six pulse & twelve pulse converter.

26. **What are the difference between half controlled & fully controlled bridge rectifier?**
   Half Controlled Bridge Rectifier
   1. Power circuit consists of mixture of diodes & SCRs
   2. It is one quadrant Converter
3. The Dc output voltage has limited control level.
4. Input power factor is more.

**Full Controlled Bridge Rectifier**
1. Power circuit consists of SCRs only
2. It is 2 quadrant Converter
3. The Dc output voltage has wider control level.
4. Input power factor is less.

27. **What is meant continuous current operation of thyristor converter?**
When a free wheeling diode is connected across the output, load current continuous flow through the load. Whenever the load voltage tends to go to negative, freewheeling diode starts conduct. As a result load current is transferred from SCR to freewheeling diode. This is called continuous current operation of thyristor converter.

28. **What is meant by sequence control of ac voltage regulators?**
It means that the stages of voltage controllers in parallel triggered in a proper sequence one after the other so as to obtain a variable output with low harmonic content.

29. **What are the advantages of sequence control of ac voltage regulators?**
   - System power factor is improved.
   - Harmonics are reduced in the source current and the load voltage.

---

**UNIT – III**

**DC – DC CHOPPERS**

1. **What is meant by commutation?**
   It is the process of changing the direction of current flow in a particular path of the circuit. This process is used in thyristors for turning it off.

2. **What are the types of commutation?**
   Natural commutation
3. **What is meant by natural commutation?**
   Here the current flowing through the thyristor goes through a natural zero and enable the thyristor to turn off.

4. **What is meant by forced commutation?**
   In this commutation, the current flowing through the thyristor is forced to become zero by external circuitry.

5. **What is meant by dc chopper?**
   A dc chopper is a high speed static switch used to obtain variable dc voltage from a constant dc voltage.

6. **What are the applications of dc chopper?**
   - Battery operated vehicles
   - Traction motor control in electric traction
   - Trolley cars
   - Marine hoists
   - Mine haulers
   - Electric braking.

7. **What are the advantages of dc chopper?**
   Chopper provides
   - High efficiency
   - Smooth acceleration
   - Fast dynamic response
   - Regeneration

8. **What is meant by step-up and step-down chopper?**
   In a step-down chopper or Buck converter, the average output voltage is less than the input voltage. In a step-up chopper or Boost converter, the average output voltage is more than the input voltage.

9. **Write down the expression for average output voltage for step down chopper.**
   Average output voltage for step down chopper \( V_0 = \alpha V_s \), \( \alpha \) is the duty cycle

10. **Write down the expression for average output voltage for step up chopper.**
    Average output voltage for step down chopper \( V_0 = V_s (1 - \alpha) \) \( \alpha \) is the duty cycle

11. **What is meant by duty-cycle?**
    Duty cycle is defined as the ratio of the on time of the chopper to the total time period of the chopper. It is denoted by \( \alpha \).

12. **What are the two types of control strategies?**
• Time Ratio Control (TRC)
• Current Limit Control method (CLC)

13. **What is meant by TRC?**
   In TRC, the value of $\text{Ton} / \text{T}$ is varied in order to change the average output voltage.

14. **What are the two types of TRC?**
   • Constant frequency control
   • Variable frequency control

15. **What is meant by FM control in a dc chopper?**
   In frequency modulation control, the chopping frequency $f$ (or the chopping period $T$) is varied. Here two controls are possible.
   - On-time $\text{Ton}$ is kept constant
   - Off period $\text{Toff}$ is kept constant.

16. **What is meant by PWM control in dc chopper?**
   In this control method, the on time $\text{Ton}$ is varied but chopping frequency is kept constant. The width of the pulse is varied and hence this type of control is known as Pulse Width Modulation (PWM).

17. **Write down the expression for the average output voltage for step down and step up chopper.**
   - Average output voltage for step down chopper is $\text{VO} = \text{VS}$.
   - Average output voltage for step up chopper is $\text{VO} = \text{VS} \times \left[ \frac{1}{1 - \text{X}} \right]$.

18. **What are the different types of chopper with respect to commutation process?**
   • Voltage commutated chopper.
   • Current commutated chopper.
   • Load commutated chopper.

19. **What is meant by voltage commutation?**
   In this process, a charged capacitor momentarily reverse biases the conducting thyristor and turn it off.

20. **What is meant by current commutation?**
   In this process, a current pulse is made to flow in the reverse direction through the conducting thyristor and when the net thyristor current becomes zero, it is turned off.

21. **What is meant by load commutation?**
   In this process, the load current flowing through the thyristor either becomes zero or is transferred to another device from the conducting thyristor.

22. **What are the advantages of current commutated chopper?**
• The capacitor always remains charged with the correct polarity. Commutation is reliable as load current is less than the peak commutation current ICP.
• The auxiliary thyristor TA is naturally commutated as its current passes through zero value.

23. What are the different types of chopper configuration?
   Depending upon the direction of current & voltages choppers can be classified into following types
   1. Type A or First Quadrant chopper
   2. Type B or Second Quadrant chopper
   3. Type C or Two Quadrant type B chopper
   4. Type D or Two Quadrant type C chopper
   5. Type E or Four Quadrant chopper

24. What are the disadvantages of FM control?
    The chopping frequency has to be varied over a wide range for the control of output Voltage. It generate harmonics at unpredictable frequencies

25. What are the disadvantages of voltage commutated chopper?
    • A starting circuit is required & the starting circuit should be switch that it triggers auxiliary SCR TA first
    • At the commutation occurs load voltage = 2Vs □ Turn off time is load dependent.
    • It does not work at no-load conditions

26. Write down the expression for average load current?

\[ Io = \frac{(Vo - E)}{R} \]

Vo = Avg. output voltage
E = Back emf & R = load resistance

27. Differentiate between constant frequency & variable frequency control strategies of varying the duty cycle of DC chopper.
   Constant frequency control – Frequency of the chopper remains constant, but ON period is changed to vary the output. variable frequency control - Either Ton or Toff is kept constant & frequency is varied to change the output.

28. What is meant by commutation?
   It is the process of changing the direction of current flow in a particular path of the circuit. This process is used in thyristors for turning it off.

29. What are the types of commutation?
   a. Natural commutation
   b. Forced commutation

30. What is meant by natural commutation?
Here the current flowing through the thyristor goes through a natural zero and enable the thyristor to turn off.

31. **What is meant by forced commutation?**
   In this commutation, the current flowing through the thyristor is forced to become zero by external circuitry.

32. **What is meant by PWM control in dc chopper?**
   In this control method, the on time Ton is varied but chopping frequency is kept constant. The width of the pulse is varied and hence this type of control is known as Pulse Width Modulation (PWM).

---

**UNIT – IV – INVERTERS**

1. **What is meant by inverter?**
   A device that converts dc power into ac power at desired output voltage and frequency is called an inverter.

2. **What are the applications of an inverter?**
   - Adjustable speed drives
   - Induction heating
- Stand-by aircraft power supplies
- UPS
- HVDC transmission

3. **What are the main classification of inverter?**
   - Voltage Source Inverter
   - Current Source Inverter

4. **Why thyristors are not preferred for inverters?**
   Thyristors require extra commutation circuits for turn off which results in decreased complexity of the circuit. For these reasons thyristors are not preferred for inverters.

5. **How output frequency is varied in case of a thyristor?**
   The output frequency is varied by varying the turn off time of the thyristors in the inverter circuit, i.e. the delay angle of the thyristors is varied.

6. **Give two advantages of CSI.**
   - CSI does not require any feedback diodes.
   - Commutation circuit is simple as it involves only thyristors.

7. **What is the main drawback of a single phase half bridge inverter?** It require a 3-wire dc supply.

8. **Why diodes should be connected in antiparallel with the thyristors in inverter circuits?**
   For RL loads, load current will not be in phase with load voltage and the diodes connected in antiparallel will allow the current to flow when the main thyristors are turned off. These diodes are called feedback diodes.

9. **What types of inverters require feedback diodes?**
   VSI with RL load.

10. **What is meant a series inverter?**
    An inverter in which the commutating elements are connected in series with the load is called a series inverter.

11. **What is the condition to be satisfied in the selection of L and C in a series inverter?**
    \[
    R^2 < 4L \frac{1}{C}
    \]

12. **What is meant a parallel inverter?**
    An inverter in which the commutating elements are connected in parallel with the load is called a parallel inverter.

13. **What are the applications of a series inverter?**
The thyristorised series inverter produces an approximately sinusoidal waveform at a high output frequency, ranging from 200 Hz to 100kHz. It is commonly used for fixed output applications such as Ultrasonic generator, Induction heating, Sonar Transmitter, Fluorescent lighting.

14. **How is the inverter circuit classified based on commutation circuitry?**
   - Line commutated inverters.
   - Load commutated inverters. □ Self commutated inverters □ Forced commutated inverters.

15. **What is meant by McMurray inverter?**
    It is an impulse-commutated inverter, which relies on LC circuit and an auxiliary thyristor for commutation in the load circuit.

16. **What are the applications of a CSI?**
    - Induction heating
      - Lagging VAR compensation
      - Speed control of ac motors
      - Synchronous motor starting.

17. **What is meant by PWM control?**
    In this method, a fixed dc input voltage is given to the inverter and a controlled ac output voltage is obtained by adjusting the on and off periods of the inverter components. This is the most popular method of controlling the output voltage and this method is termed as PWM control.

18. **What are the advantages of PWM control?**
    - The output voltage can be obtained without any additional components.
    - Lower order harmonics can be eliminated or minimized along with its output voltage control.
    - As the higher order harmonics can be filtered easily, the filtering requirements are minimized.

19. **What are the disadvantages of the harmonics present in the inverter system?**
    - Harmonic currents will lead to excessive heating in the induction motors. This will reduce the load carrying capacity of the motor.
    - If the control and the regulating circuits are not properly shielded, harmonics from power ride can affect their operation and malfunctioning can result.
    - Harmonic currents cause losses in the ac system and can even some time produce resonance in the system. Under resonant conditions, the instrumentation and metering can be affected.
    - On critical loads, torque pulsation produced by the harmonic current can be useful.
20. What are the methods of reduction of harmonic content?
   - Transformer connections
   - Sinusoidal PWM
   - Multiple commutation in each cycle

21. Compare CSI and VSI.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>VSI</th>
<th>CSI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Input voltage is maintained constant</td>
<td>Input current is constant but adjustable</td>
</tr>
<tr>
<td>2.</td>
<td>The output voltage does not depend on the load</td>
<td>The output current does not depend on the load</td>
</tr>
<tr>
<td>3.</td>
<td>The magnitude of the output current and its waveform depends on the nature of the load impedance</td>
<td>The magnitude of the output voltage and its waveform depends on the nature of the load impedance</td>
</tr>
<tr>
<td>4.</td>
<td>It requires feedback diodes</td>
<td>It does not require feedback diodes</td>
</tr>
<tr>
<td>5.</td>
<td>Commutation circuit is complicated i.e. it contains capacitors and inductors.</td>
<td>Commutation circuit is simple i.e. it contains only capacitors.</td>
</tr>
</tbody>
</table>

22. What are the disadvantages of PWM control?
   SCRs are expensive as they must possess low turn-on and turn-off times.

30. What is mean by VSI?
   A VSI is one which the dc source has small or negligible impedance. In other words a VSI has stiff dc voltage source at its input terminals.

31. What is meant by VSI?
   A current fed inverter or CSI is fed with adjustable current from a dc source of high impedance is from a stiff dc current source.

32. What are the different methods of forced commutation employed in inverter circuits?
   i) Auxiliary commutation
   ii) Complementary commutation

33. What are the methods of voltage control inverters?
   - External control of ac output voltage
   - External control of dc input voltage
   - Internal control of inverter
34. **What is meant by feedback diodes or return current diodes?**
   For RL loads current io will not be in phase with voltage & diodes connected in antiparallel with SCR will allow the current to flow when the main SCRs are turned off. These diodes are called feedback diodes.

35. **What are the different types of PWM control?**
   - Single pulse width modulation
   - Multiple pulse width modulation
   - Sinusoidal pulse width modulation

36. **How the thyristor inverters are classified?**
   According to the method of communal
   - i. Line commutated inverter
   - ii. Forced commutated inverter
   According to the connection
   - iii. series inverter
   - iv. parallel inverter
   - v. Bridge inverter

37. **What are the disadvantages of the harmonics present in the inverter system?**
   - Harmonic currents will lead to excessive heating in the induction motors. This will reduce the load carrying capacity of the motor.
   - If the control and the regulating circuits are not properly shielded, harmonics from power ride can affect their operation and malfunctioning can result.
   - Harmonic currents cause losses in the ac system and can even some time produce resonance in the system. Under resonant conditions, the instrumentation and metering can be affected.
   - On critical loads, torque pulsation produced by the harmonic current can be useful.

**UNIT – V**

1. **What does ac voltage controller mean?**
   It is device, which converts fixed alternating voltage into a variable voltage without change in frequency.

2. **What are the applications of ac voltage controllers?**
   - Domestic and industrial heating
   - Lighting control
• Speed control of single phase and three phase ac motors
• Transformer tap changing

3. **What are the advantages of ac voltage controllers?**
   - High efficiency
   - Flexibility in control
   - Less maintenance

4. **What are the disadvantages of ac voltage controllers?**
   The main drawback is the introduction of harmonics in the supply current and the load voltage waveforms particularly at low output voltages.

5. **What are the two methods of control in ac voltage controllers?**
   - ON-OFF control
   - Phase control

6. **What is the advantage of ON-OFF control?**
   Due to zero-voltage and zero current switching of thyristors, the harmonics generated by the switching action are reduced.

7. **What is the difference between ON-OFF control and phase control?**
   ON-OFF control: In this method, the thyristors are employed as switches to connect the load circuit to the source for a few cycles of the load voltage and disconnect it for another few cycles. Phase control: In this method, thyristor switches connect the load to the ac source for a portion of each half cycle of input voltage.

8. **What is the disadvantage of ON-OFF control?**
   This type of control is applicable in systems that have high mechanical inertia and high thermal time constant.

9. **What is the duty cycle in ON-OFF control method?**
   Duty cycle \( K = n/ (n + m) \), where \( n = \) no. of ON cycles, \( m = \) no. of OFF cycles.

10. **What is meant by unidirectional or half-wave ac voltage controller?**
    Here the power flow is controlled only during the positive half-cycle of the input voltage.

11. **What are the disadvantages of unidirectional or half-wave ac voltage controller?**
    - Due to the presence of diode on the circuit, the control range is limited and the effective RMS output voltage can be varied between 70 gg. 7% and 100%.
    - The input current and output voltage are asymmetrical and contain a dc component.
    - If there is an input transformer, saturation problem will occur. It is only used for low power resistive load.
12. **What is meant by bidirectional or half-wave ac voltage controller?**
   Here the power flow is controlled during both cycles of the input voltage.

13. **What is the control range of firing angle in ac voltage controller with RL load?**
    The control range is $<180^\circ$, where $\alpha_\text{load}$ = load power factor angle.

14. **What type of gating signal is used in single phase ac voltage controller with RL load?**
    High frequency carrier gating signal is used for single phase ac voltage controller with RL load.

15. **What is meant by cyclo-converter?**
    It converts input power at one frequency to output power at another frequency with one-stage conversion. Cycloconverter is also known as frequency changer.

16. **What are the two types of cyclo-converters?**
    - Step-up cyclo-converters
    - Step-down cyclo-converters

17. **What is meant by step-up cyclo-converters?**
    In these converters, the output frequency is less than the supply frequency.

18. **What is meant by step-down cyclo-converters?**
    In these converters, the output frequency is more than the supply frequency.

19. **What are the applications of cyclo-converter?**
    - Induction heating
    - Speed control of high power ac drives
    - Static VAR generation
    - Power supply in aircraft or ship boards

20. **What is meant by positive converter group in a cycloconverter?**
    The part of the cycloconverter circuit that permits the flow of current during positive half cycle of output current is called positive converter group.

21. **What is meant by negative converter group in a cycloconverter?**
    The part of the cycloconverter circuit that permits the flow of current during negative half cycle of output current is called negative converter group.

22. **What are the applications of power electronics?**
    - Variable speed electric drives
    - Temperature and illumination controllers
    - Power supplies
    - HVDC transmission
23. **What are parameters controlled using facts?**
   Series impedance, shunt impedance, current, voltage, phase angle and damping frequencies.

24. **What are the types of facts controllers?**
   Series controllers
   - Shunt controllers
   - Combined series-series controllers
   - Combined series-shunt controllers

25. **What are the types HVDC transmission lines?**
   - Monopolar line
   - Bipolar line
   - Homopolar line

26. **What are the types of ac power supplies in static var system?**
   - Switched –mode ac power supplies
   - Resonant ac power supplies
   - Bidirectional ac power supplies

27. **Define Voltage mode control.**
   The duty cycle is increased to cause a subsequent increase in output voltage in the mode control is called voltage mode control.

28. **Define current mode control.**
   The current mode control uses the current as the feedback signal to achieve output voltage control.

29. **What are the different modes of controlling in drives?**
   - Motoring mode
   - Reverse motoring mode (Braking mode)
   - Generating mode
   - Reverse generating mode

30. **What are the types of ac power supplies in static var system?**
    - Resonant ac power supplies
    - Bidirectional dc power supplies.

31. **What are the types of various faults?**
    - Phase failure (PF)
    - Gate Pulse Failure (GPF)
    - Turn-on Failure of Thyristor (TFT)
    - Short Circuit across Thyristor (SCT)
    - Short Circuit across DC Terminals (SCD)

32. **What is meant by SMPS?**
SMPS means Switch Mode Power Supply. SMPS is based on the chopper principle. Varying the duty cycle of chopper by PWM techniques controls the output dc voltage.

33. **What are the types of SMPS?**
   - Fly back SMPS
   - Push pull SMPS
   - Half bridge SMPS
   - Full bridge SMPS

34. **Advantages of SMPS.**
   For the same power rating, SMPS is of smaller size,
   Lighter in weight and processes,
   Higher efficiency,
   High frequency operation
   Less sensitive to input voltage variations.

35. **Disadvantages of SMPS.**
   - It has higher output ripple and regulation is worse.
   - It is a source of both electromagnetic and ratio interference due to high frequency switching
   - Control of ratio frequency noise requires the use of filters on both input and output.

36. **Define thyristor valve.**
   The term of thyristor valve, used on HVDC systems, denotes a number of thyristors connected in series and parallel to get the required voltage and current ratings.

37. **What are the advantages static switches over electromechanical switches?**
   - On time of a static switch (SS) is of the order of 3 microseconds, it has therefore very high switching speed.
   - No moving parts; its maintenance is therefore very low.
   - No bouncing at the time of turning on.
   - It has long operational life.

38. **Define static circuit breakers.**
   Static circuit breakers are semi conductor-based circuits capable of providing fast and reliable interruption to a continuous current.

39. **Define resonant converters.**
   The converter circuits, which employ zero-voltage and or zero current switching, are called resonant converters.

40. **What are the types of resonant converters?**
   - Zero Voltage Switching (ZVS)
   - Zero Current Switching (ZCS)
41. **What are the methods of reduction of harmonic content?**
   - Transformer connections
   - Sinusoidal PWM
   - Multiple commutation in each cycle
   - Stepped wave inverters

42. **What is meant by sequence control of ac voltage regulators?**
   It means that the stages of voltage controllers in parallel triggered in a proper sequence one after the other so as to obtain a variable output with low harmonic content.

43. **What are the types of UPS?**
   (i) On line UPS
   (ii) Off line UPS
   (iii) Line interactive UPS

44. **What are the advantages of on line UPS?**
   (i) It provides isolation between main supply and load
   (ii) Since inverter is always on, the quality of load voltage is free from distortion
   (iii) Voltage regulation is better
   (iv) Transfer time is practically zero since inverter is always on.

45. **What are the disadvantages of on line UPS?**
   - Over all efficiency of UPS is reduced
   - Cost is high
   - The wattage of the rectifier is increased

46. **What are the applications of online UPS?**
   (i) Induction motor drives
   (ii) Motor control applications
   (iii) Medical equipments

47. **What are the application of off line UPS?**
   (i) Computers
   (ii) Printers
   (iii) Scanners
   (iv) Emergency power supplies
5. Define circuit turn off time. Why circuit turn off time should be greater than the thyristor turn-off time?
6. What is the turn-off time for converter grade SCRs and inverter grade SCRs?
7. What are the advantages of GTO over SCR?
8. Compare Power MOSFET with BJT.
9. Define forward breakover voltage and reverse breakover voltage.
10. Write down the applications of IGBT?

PART-B

1. Explain the principle of operation of IGBT with its switching characteristics.
2. Explain the principle of operation of MOSFET with its switching characteristics.
3. Explain the principle of operation of SCR with its switching characteristics.
4. Explain the different turn-on and turn-off characteristics of a thyristor.
5. Explain the different type of over current & over voltage protection in SCR.
6. Explain in detail about Series and parallel operation of SCR.

UNIT-II

PART-A
1. What is meant by phase controlled rectifier? State applications of controlled rectifier.
2. What is the function of freewheeling diodes in controlled rectifier?
3. What is meant by delay angle?
4. What is commutation angle or overlap angle?
5. What are the differences between half controlled & fully controlled bridge rectifier?
6. What is meant continuous current operation of thyristor converter?
7. What is meant by sequence control of ac voltage regulators? Advantages of sequence control of ac voltage regulators
8. What is meant by 2 pulse converter?
9. What is meant by rectification mode & inversion mode in single phase fully controlled converter?
10. Give an expression for average voltage of single phase semi converters and Full Converter.

PART-B
1. Draw and explain the single phase fully controlled converter operation with R, RL, RE load and derive the average and rms valve of output voltage and power factor.
2. Draw and explain the single phase half controlled converter operation with R, RL, RE load and derive the average and rms valve of output voltage and power factor.
3. Draw and explain the Three phase fully controlled converter operation with R, RL, RE load and derive the average and rms valve of output voltage and power factor.
4. Draw and explain the Three phase half controlled converter operation with R, RL, RE load and derive the average and rms value of output voltage and power factor.

5. Explain the effect of source inductance in single and three phase converter.

6. Explain in detail about harmonic improvement method of controlled rectifier.

7. Explain the operation of dual converter for single and three phase converter.

UNIT-III
PART-A
1. What is meant by dc chopper? Applications of dc chopper
2. What is meant by step-up and step-down chopper?
3. What is meant by duty-cycle?
4. What is meant by TRC? What are types of TRC?
5. What is meant by FM control in a dc chopper?
6. What is meant by PWM control in dc chopper?
7. What is meant by voltage commutation?
8. What is meant by current commutation?
9. What is meant by load commutation?
10. What are the advantages of current commutated chopper?
11. What are the advantages of load commutated chopper?
12. What are the disadvantages of load commutated chopper

PART-B
1. Explain the operation of Voltage commutated chopper and current commutated chopper.
2. Explain four quadrant operation of chopper.
3. Explain the operation of step-down and Step-up chopper with duty cycle and hence derive its output equation.
4. Describe the working principle of boost, buck converter with relevant waveform.
5. Explain the working principle of multiphase chopper.

UNIT-IV
PART-A
1. What is meant by inverter? State applications of an inverter.
2. Compare CSI and VSI.
3. What is meant a series inverter?
4. What are the applications of a series inverter?
5. What is meant by McMurray inverter?
6. What are the applications of a CSI?
7. What is meant by PWM control? Advantages of PWM control
8. What are the disadvantages of the harmonics present in the inverter system?
9. How the thyristor inverters are classified?
10. What are the methods of reduction of harmonic content?

PART-B
1. Explain the operation of 120-degree mode three-phase voltage source inverter (VSI).
2. Explain the operation of 180-degree mode three-phase voltage source inverter (VSI).
3. Briefly explain about different voltage control techniques and harmonic reduction techniques.
4. Explain the operation of modified McMurray half bridge inverter.
5. Discuss the principle of operation of single phase commutated CSI with R load and single phase auto sequential commutator inverter.
6. Explain the operation of single phase VSI Half and Full bridge with R Load.

UNIT-V
PART-A
1. What does ac voltage controller mean? Applications of ac voltage controllers
2. What is the difference between ON-OFF control and phase control?
3. What is meant by cyclo-converter? Applications of cyclo-converter
4. What is meant by step-up cyclo-converters?
5. What is meant by step-down cyclo-converters?
6. What is meant by SMPS? what are different types of SMPS
7. Advantages of SMPS and disadvantages of SMPS.
8. What are the types of UPS?
9. What are the advantages and disadvantages of on line UPS
10. What are the applications of online UPS? application of off line UPS
11. Define Voltage mode control.
12. Define current mode control.
13. What are the different modes of controlling in drives?

PART-B
1. Describe the basic principle of working of single phase to single phase cyclo converter.
2. Describe the basic principle of working of three phase to Single phase cyclo converter.
3. Explain the operation of single phase AC voltage controller with R and RL load.
4. Explain the operation of UPS.
5. Explain the different types of HVDC links.
6. Briefly discuss about reactive power compensation.
7. Explain in detail about SMPS.