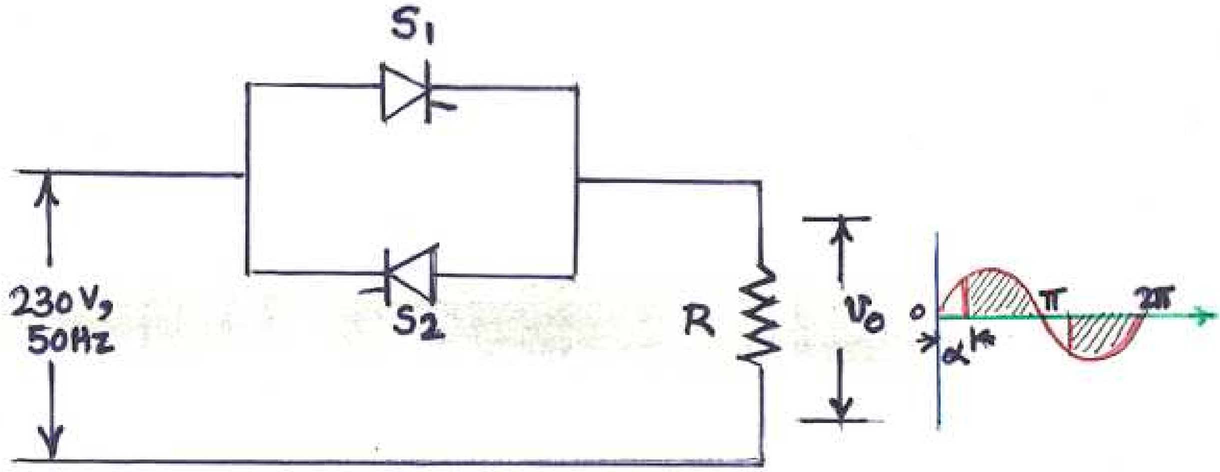
Single-phase voltage controller



Expression for $V_{o\,(rms)}$:

$$V_{o(rms)}^2 = \frac{1}{\pi}\int_{\alpha}^{\pi} V_m^2 \sin^2\theta \, d\theta$$

$$= \frac{V_m^2}{\pi}\int_{\alpha}^{\pi}\left[\frac{1-\cos 2\theta}{2}\right] d\theta$$

$$= \frac{V_m^2}{\pi}\left[\frac{1}{2}\theta - \frac{\sin 2\theta}{2\times 2}\right]_{\alpha}^{\pi}$$

$$= \frac{V_m^2}{\pi}\left[\frac{1}{2}(\pi-\alpha) - \cancel{\frac{\sin 2\pi}{4}}^{\,0} + \frac{\sin 2\alpha}{4}\right]$$

$$= \frac{V_m^2}{2\pi}\left[(\pi-\alpha) + \frac{\sin 2\alpha}{2}\right]$$

$$V_o = V\left[\frac{1}{\pi}\left(\pi - \alpha + \frac{\sin 2\alpha}{2}\right)\right]^{1/2}$$

$$= \frac{V_m^2}{2}\left[1 - \frac{\alpha}{\pi} + \frac{\sin 2\alpha}{2\pi}\right]$$

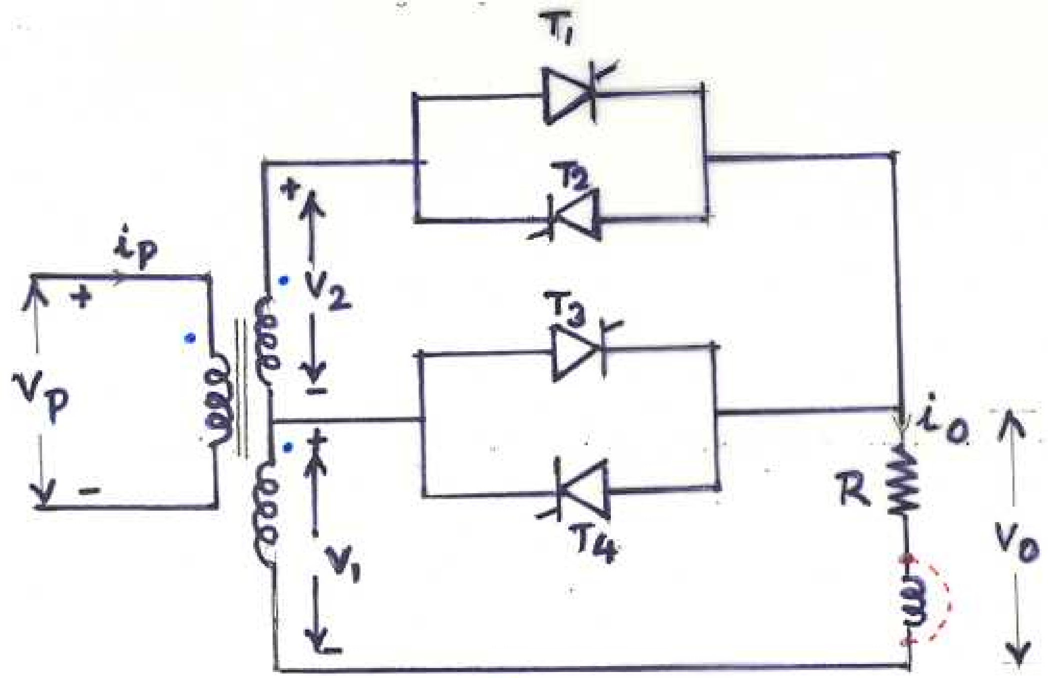
$$\therefore \; V_{o(rms)} = \sqrt{\frac{V_m^2}{2}\left[1 - \frac{\alpha}{\pi} + \frac{\sin 2\alpha}{2\pi}\right]}$$

$$= \frac{V_m}{\sqrt{2}}\left[1 - \frac{\alpha}{\pi} + \frac{\sin 2\alpha}{2\pi}\right]^{1/2}$$

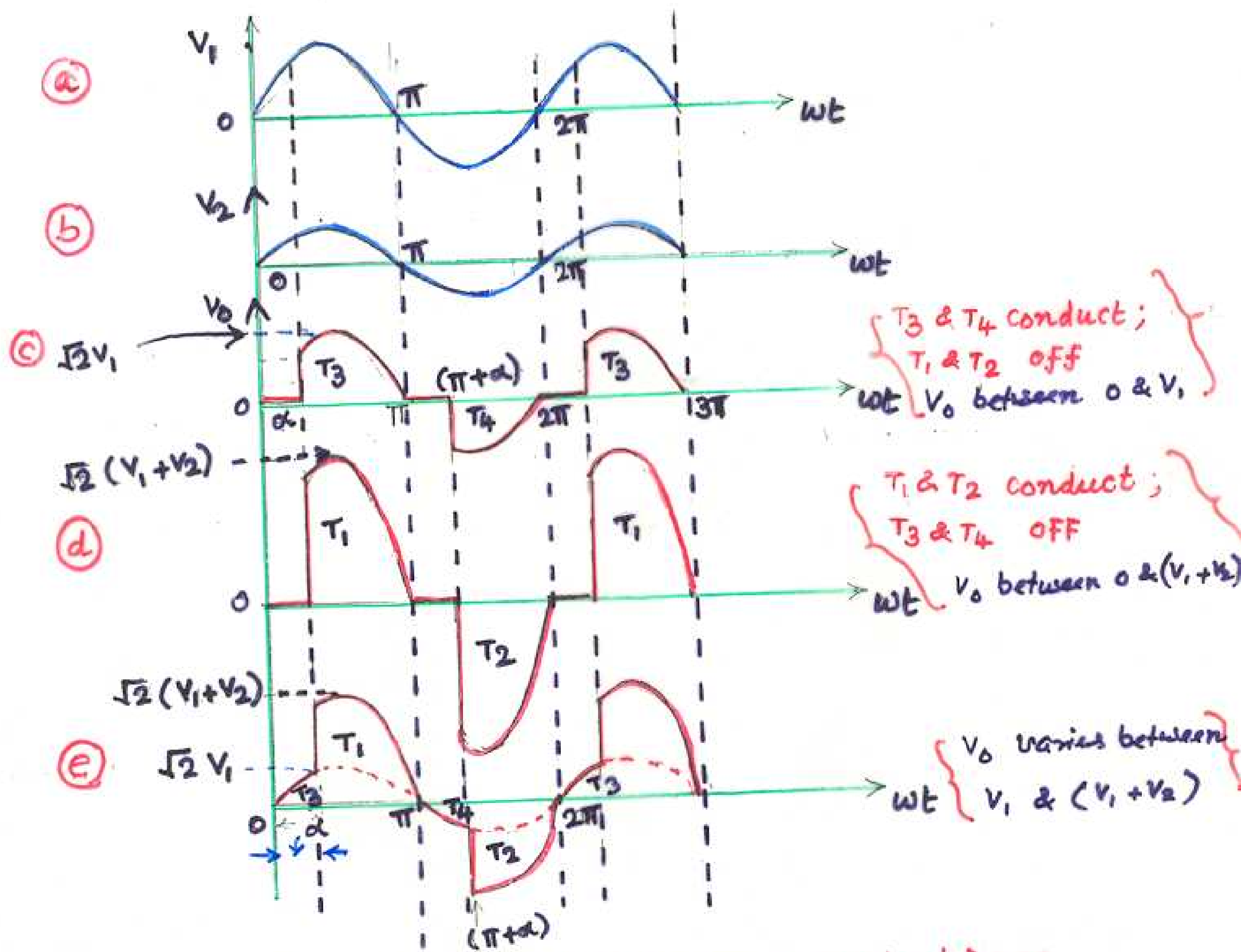
i.e., $\boxed{V_{o(rms)} = V\left[1 - \frac{\alpha}{\pi} + \frac{\sin 2\alpha}{2\pi}\right]^{1/2}}$ where

V is the rms line voltage

SStt1



Power circuit



Solid state Transformer Tap changing - single-phase (For resistive load)

The secondary instantaneous voltages are :

$v_1 = \sqrt{2}\, V_1 \sin \omega t$

and $v_2 = \sqrt{2}\, V_2 \sin \omega t$

V_1 and V_2 are the RMS secondary voltages

A tap changer is most commonly used for resistive heating loads.

When only T_3 & T_4 are alternately fired with $\alpha = 0°$;

$$v_0 = V_1$$

When only T_1 & T_2 are alternately fired with $\alpha = 0°$:

$$v_0 = (V_1 + V_2)$$

When α is varied, the ranges of output voltage :

(i) $0 \leq V_0 \leq V_1$:

To vary the load voltage within this range, T_1 & T_2 are turned off.

T_3 & T_4 can operate as a single-phase voltage controller. The instantaneous load voltage waveform is shown in Fig. c for a resistive load.

The rms load voltage which can be determined is $V_0 = V_1 \left[\frac{1}{\pi}\left(\pi - \alpha + \frac{\sin 2\alpha}{2}\right)\right]^{1/2}$ and ...(1)

the range of delay angle is $0 \leq \alpha \leq \pi$

The RMS current of T_3 & T_4 = $I_{R3} = \frac{V_1}{R}\left[\frac{1}{\pi}\left(\alpha - \frac{\sin 2\alpha}{2}\right)\right]^{1/2}$?

(ii) $0 \leq V_0 \leq (V_1+V_2)$:

T_3 & T_4 are turned off. T_1 & T_2 operate as a single-phase voltage controller.

Fig. d shows the load voltage v_o (which is same as i_o) for a resistive load.

The rms load voltage can be obtained as

$$V_0 = (V_1+V_2)\left[\frac{1}{\pi}\left(\pi - \alpha + \frac{\sin 2\alpha}{2}\right)\right]^{1/2} \quad \ldots (2)$$

$$\left.\begin{matrix}\text{Rms current of} \\ T_1 \,\&\, T_2\end{matrix}\right\} = I_{R_1} = \frac{V_1+V_2}{R}\left[\frac{1}{\pi}\left(\pi - \alpha + \frac{\sin 2\alpha}{2}\right)\right]^{1/2} \quad \ldots (3)$$

(iii) $V_1 \leq V_0 \leq (V_1+V_2)$:

T_3 is turned on at $\omega t = 0$ and the secondary voltage v_1 appears across the load.

If T_1 is turned on at $\omega t = \alpha$, it applies a reverse bias (v_2) across T_3 and hence T_3 is turned off.

The voltage appearing across the load is

$v_o = (v_1 + v_2)$.

At $\omega t = \pi$, T_1 is self commutated and T_4 is turned on.

The secondary voltage v_1 appears across the load until T_2 is fired at $\omega t = (\pi + \alpha)$.

When T_2 is turned on at $\omega t = (\pi+\alpha)$, T_4 is turned off due to reverse voltage v_2 and the load voltage is $v_o = (v_1+v_2)$.

At $\omega t = 2\pi$, T_2 is self commutated. T_3 is turned on again and the cycle is repeated.

The instantaneous load voltage v_0 (& hence i_0) is shown in Fig. e for a resistive load.

A tap changer with this type of control is also known as a synchronous tap changer, which uses two step control.

A part of secondary voltage v_2 is super-imposed on a sinusoidal voltage, v_1.

As a result, the harmonic contents are less than that would be obtained by a normal phase delay as discussed for control range 2.

The rms load voltage can be obtained from

$$V_0 = \left[\frac{1}{2\pi}\int_0^{2\pi} v_0^2 \, d(\omega t)\right]^{1/2}$$

$$= \left\{\frac{2}{2\pi}\left[\int_0^{\alpha} 2V_1^2 \sin^2\omega t \, d(\omega t) + \int_{\alpha}^{\pi} 2(V_1+V_2)^2 \sin^2\omega t \, d(\omega t)\right]\right\}^{1/2}$$

$$= \left[\frac{V_1^2}{\pi}\left(\alpha - \frac{\sin 2\alpha}{2}\right) + \frac{(V_1+V_2)^2}{\pi}\left(\pi - \alpha + \frac{\sin 2\alpha}{2}\right)\right]^{1/2}$$

$$= \left[\frac{V_1^2}{\pi}\left(\alpha - \frac{\sin 2\alpha}{2}\right) + \frac{(V_1+V_2)^2}{\pi}\left(\pi - \alpha + \frac{\sin 2\alpha}{2}\right)\right]^{1/2}$$

(OR)

$$\boxed{V_0 = \frac{1}{\pi}\left[\underbrace{\int_0^{\alpha} (\sqrt{2}\, V_1 \sin\omega t)^2 \, d\omega t}_{V_1^2\left(\alpha - \frac{\sin 2\alpha}{2}\right)} + \underbrace{\int_{\alpha}^{\pi} \{\sqrt{2}\,(V_1+V_2)\sin\omega t\}^2 \, d\omega t}_{(V_1+V_2)^2\left(\pi - \alpha + \frac{\sin 2\alpha}{2}\right)}\right]^{1/2}}$$