Title : AC Voltage Regulator: AC Voltage Controller with R and RL Load (Module-5)

Date: 23/03/2020

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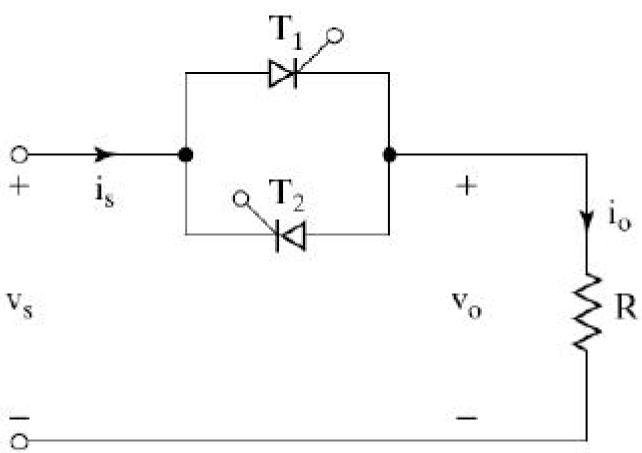
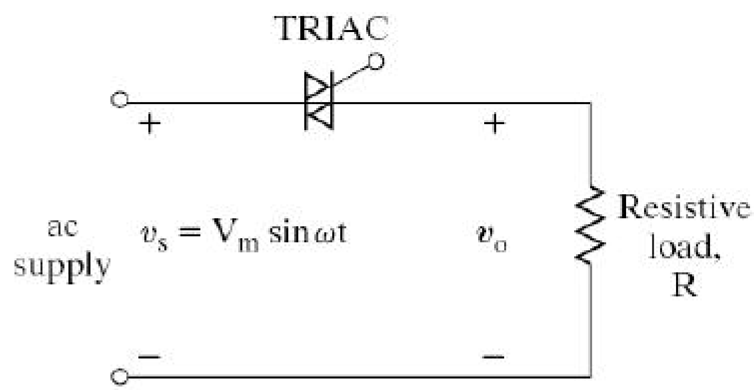
Lecture No: 5th (02:00 pm to 03:00 pm)

Source of information: Power Electronics: Converter, Applications and Design, N. Mohan, T. M. Undeland, W. M. Robbins, Wiley India Edition

SINGLE PHASE FULL WAVE AC VOLTAGE CONTROLLER (R-Load)

Single phase full wave ac voltage controller circuit using two SCRs or a single triac is generally used in most of the ac control applications. The ac power flow to the load can be controlled in both the half cycles by varying the trigger angle 'α'. Hence the full wave ac voltage controller is also referred to as to a bi-directional controller.

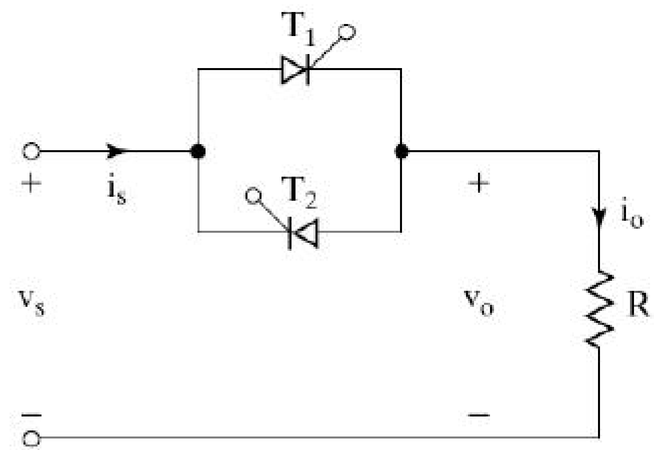




Instead of using two SCR’s in parallel, a Triac can be used for full wave ac voltage control.

SINGLE PHASE FULL WAVE AC VOLTAGE CONTROLLER (R-Load)

The thyristor T_1 is forward biased during the positive half cycle of the input supply voltage. The thyristor T_1 is triggered at a delay angle of 'α' ($0 \le \alpha \le \pi$).



The load current flows through the ON thyristor T_1 and through the load resistor RL in the downward direction during the conduction time of T_1 from $\omega t = \alpha$ to π radians.

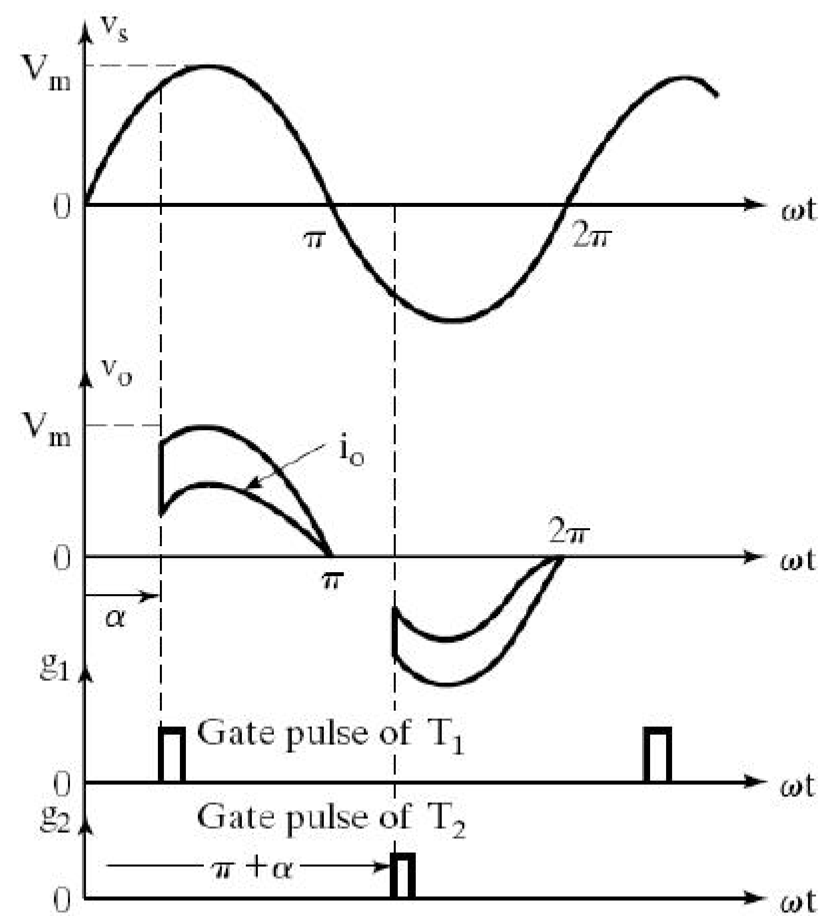
At $\omega t = \pi$, when the input voltage falls to zero the thyristor current (which is flowing through the load resistor RL) falls to zero and hence T_1 naturally turns off. No current flows in the circuit during $\omega t = \pi$ to $(\pi+\alpha)$.

The thyristor T_2 is forward biased during the negative cycle of input supply and when thyristor T_2 is triggered at a delay angle $(\pi+\alpha)$, the output voltage follows the negative half cycle of input from $\omega t = (\pi+\alpha)$ to 2π.

SINGLE PHASE FULL WAVE AC VOLTAGE CONTROLLER (R-Load)

The time interval (spacing) between the gate trigger pulses of T_1 and T_2 is kept at π radians or 180^0.

At ωt = 2π, the input supply voltage falls to zero and hence the load current also falls to zero and thyristor T_2 turn off naturally.



Input supply voltage

$$v_S = V_m \sin \omega t = \sqrt{2} V_S \sin \omega t \;;$$

Output voltage across the load resistor R_L;

$$v_O = v_L = V_m \sin \omega t \;;$$

$$\text{for } \omega t = \alpha \text{ to } \pi \text{ and } \omega t = (\pi + \alpha) \text{ to } 2\pi$$

Output load current

$$i_O = \frac{v_O}{R_L} = \frac{V_m \sin \omega t}{R_L} = I_m \sin \omega t \;;$$

$$\text{for } \omega t = \alpha \text{ to } \pi \text{ and } \omega t = (\pi + \alpha) \text{ to } 2\pi$$

SINGLE PHASE FULL WAVE AC VOLTAGE CONTROLLER (R-Load)

Expression for The RMS Value of Output Voltage

The RMS value of output voltage (load voltage) can be found using the expression

$$V_{O(RMS)}^2 = V^2_{L(RMS)} = \frac{1}{2\pi}\int_0^{2\pi} v_L{}^2 d(\omega t)$$

$$V^2_{L(RMS)} = \frac{1}{\pi}\int_0^{\pi} V_m{}^2 \sin^2 \omega t . d\omega t$$

$$V^2_{L(RMS)} = \frac{1}{2\pi}\int_0^{2\pi} v_L{}^2 . d(\omega t) \ ;$$

$v_L = v_O = V_m \sin\omega t$; For $\omega t = \alpha$ to π and $\omega t = (\pi + \alpha)$ to 2π

Hence,

$$V_{L(RMS)}^2 = \frac{1}{2\pi}\left[\int_\alpha^\pi (V_m \sin\omega t)^2 d(\omega t) + \int_{\pi+\alpha}^{2\pi} (V_m \sin\omega t)^2 d(\omega t)\right]$$

$$= \frac{1}{2\pi}\left[V_m{}^2 \int_\alpha^\pi \sin^2 \omega t . d(\omega t) + V_m{}^2 \int_{\pi+\alpha}^{2\pi} \sin^2 \omega t . d(\omega t)\right]$$

SINGLE PHASE FULL WAVE AC VOLTAGE CONTROLLER (R-Load)

$$=\frac{V_m^2}{2\pi}\left[\int_{\alpha}^{\pi}\frac{1-\cos 2\omega t}{2}d(\omega t)+\int_{\pi+\alpha}^{2\pi}\frac{1-\cos 2\omega t}{2}d(\omega t)\right]$$

$$=\frac{V_m^2}{2\pi\times 2}\left[\int_{\alpha}^{\pi}d(\omega t)-\int_{\alpha}^{\pi}\cos 2\omega t.d(\omega t)+\int_{\pi+\alpha}^{2\pi}d(\omega t)-\int_{\pi+\alpha}^{2\pi}\cos 2\omega t.d(\omega t)\right]$$

$$=\frac{V_m^2}{4\pi}\left[(\omega t)\Big/_{\alpha}^{\pi}+(\omega t)\Big/_{\pi+\alpha}^{2\pi}-\left[\frac{\sin 2\omega t}{2}\right]_{\alpha}^{\pi}-\left[\frac{\sin 2\omega t}{2}\right]_{\pi+\alpha}^{2\pi}\right]$$

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

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

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

$$=\frac{V_m^2}{4\pi}\left[2(\pi-\alpha)+\frac{\sin 2\alpha}{2}+\frac{\sin(2\pi+2\alpha)}{2}\right] \quad =\frac{V_m^2}{4\pi}\left[2(\pi-\alpha)+\frac{\sin 2\alpha}{2}+\frac{1}{2}(\sin 2\pi.\cos 2\alpha+\cos 2\pi.\sin 2\alpha)\right]$$

SINGLE PHASE FULL WAVE AC VOLTAGE CONTROLLER (R-Load)

$$\sin 2\pi = 0 \quad \& \quad \cos 2\pi = 1$$

Therefore,

$$V_{L(RMS)}^2 = \frac{V_m^{\ 2}}{4\pi}\left[2(\pi-\alpha)+\frac{\sin 2\alpha}{2}+\frac{\sin 2\alpha}{2}\right]$$

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

$$V^2{}_{L(RMS)} = \frac{V_m^{\ 2}}{4\pi}\left[(2\pi-2\alpha)+\sin 2\alpha\right]$$

Taking the square root, we get

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

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

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

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

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

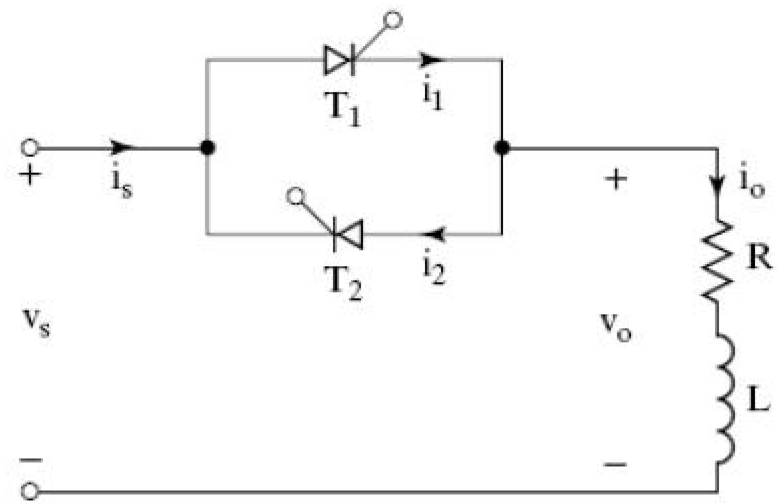
$$V_{L(RMS)} = V_{i(RMS)}\sqrt{\frac{1}{\pi}\left[(\pi-\alpha)+\frac{\sin 2\alpha}{2}\right]}$$

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

SINGLE PHASE FULL WAVE AC VOLTAGE CONTROLLER (BIDIRECTIONAL CONTROLLER) WITH RL LOAD

A single phase full wave ac voltage controller circuit (bidirectional controller) with an RL load using two thyristors T_1 and T_2 connected in parallel is shown in the figure below.

The thyristor T_1 is forward biased during the positive half cycle of input supply. Let us assume that T_1 is triggered at $\omega t = \alpha$, by applying a suitable gate trigger pulse to T_1 during the positive half cycle of input supply. The output voltage across the load follows the input supply voltage when T_1 is ON.



The load current i_0 flows through the thyristor T_1 and through the load in the downward direction.

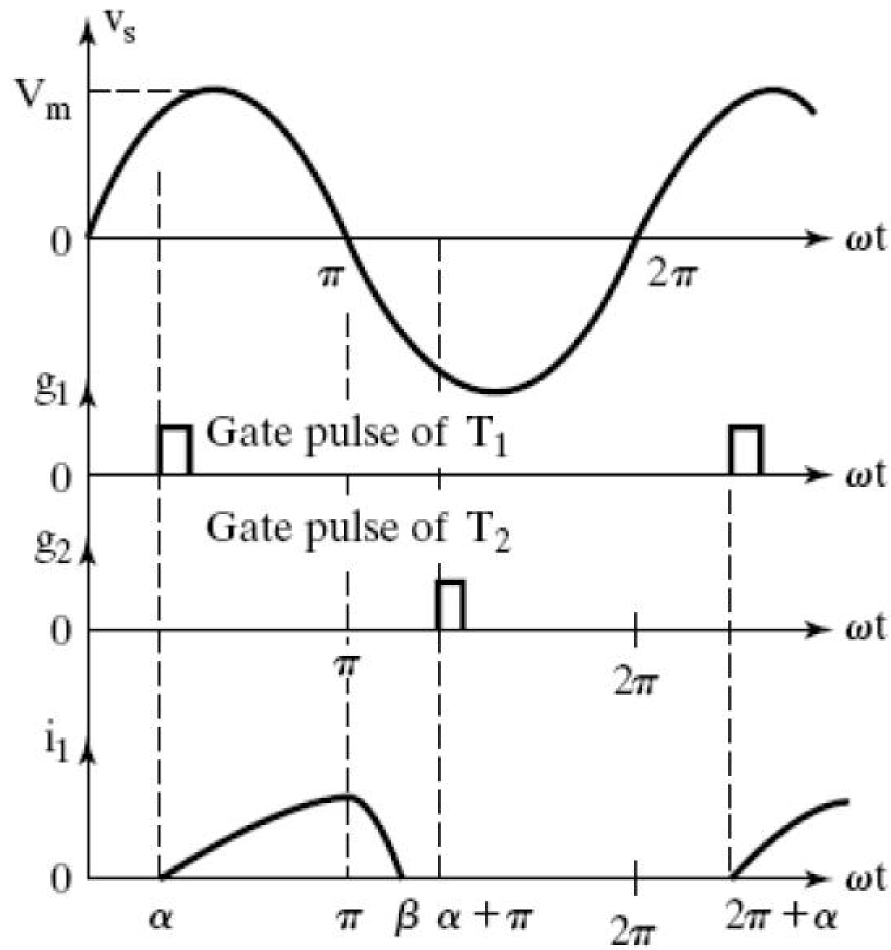
Due to the inductance in the load, the load current i_0 flowing through T_1 would not fall to zero at $\omega t = \pi$, when the input supply voltage starts to become negative.

SINGLE PHASE FULL WAVE AC VOLTAGE CONTROLLER (BIDIRECTIONAL CONTROLLER) WITH RL LOAD

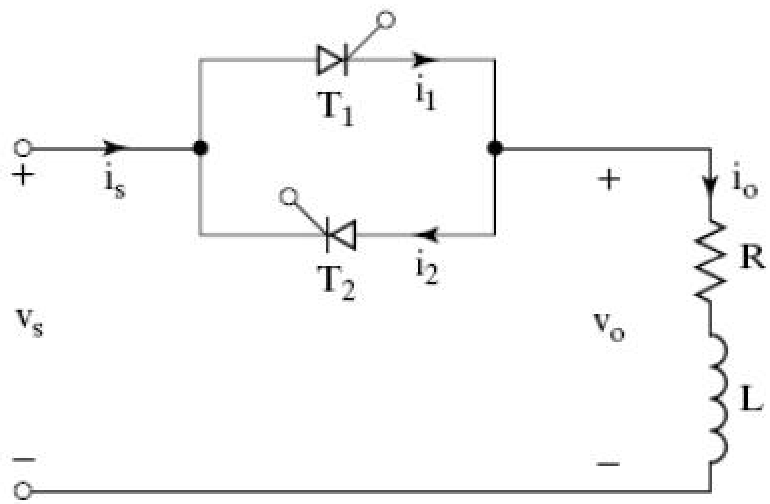
The thyristor T_1 will continue to conduct the load current until all the inductive energy stored in the load inductor L is completely utilized and the load current through T_1 falls to zero at ωt = β, where β is referred to as the Extinction angle, (the value of ωt) at which the load current falls to zero.

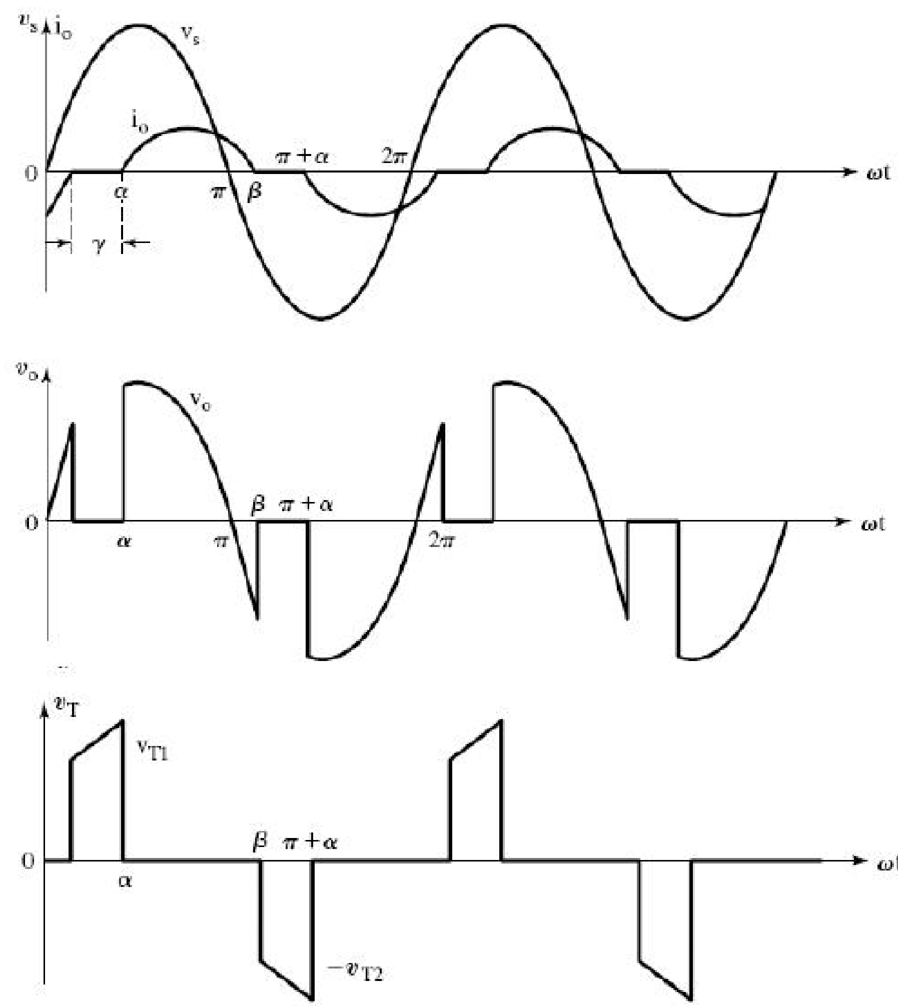
The extinction angle β is measured from the point of the beginning of the positive half cycle of input supply to the point where the load current falls to zero.

The thyristor T_1 conducts from ωt = α to β. The conduction angle of T_1 is δ = (β-α), which depends on the delay angle α and the load impedance angle ϕ.



SINGLE PHASE FULL WAVE AC VOLTAGE CONTROLLER (BIDIRECTIONAL CONTROLLER) WITH RL LOAD





SINGLE PHASE FULL WAVE AC VOLTAGE CONTROLLER (BIDIRECTIONAL CONTROLLER) WITH RL LOAD

Expression for The RMS Value of Output Voltage

When α > ϕ , the load current and load voltage waveforms become discontinuous

$$V_{O(RMS)} = \left[\frac{1}{\pi}\int_{\alpha}^{\beta} V_m^{\,2}\sin^2 \omega t.d(\omega t)\right]^{\frac{1}{2}}$$

Output $v_o = V_m \sin \omega t$, for $\omega t = \alpha$ to β, when T_1 is ON.

$$V_{O(RMS)} = \left[\frac{V_m^{\,2}}{\pi}\int_{\alpha}^{\beta}\frac{(1-\cos 2\omega t)}{2}d(\omega t)\right]^{1/2}$$

$$V_{O(RMS)} = \left[\frac{V_m^{\,2}}{2\pi}\left\{\int_{\alpha}^{\beta} d(\omega t) - \int_{\alpha}^{\beta}\cos 2\omega t.d(\omega t)\right\}\right]^{1/2}$$

$$V_{O(RMS)} = \left[\frac{V_m^{\,2}}{2\pi}\left\{(\omega t)\Big/_{\alpha}^{\beta} - \left(\frac{\sin 2\omega t}{2}\right)\Big/_{\alpha}^{\beta}\right\}\right]^{1/2}$$

$$V_{O(RMS)} = \left[\frac{V_m^{\,2}}{2\pi}\left\{(\beta-\alpha) - \frac{\sin 2\beta}{2} + \frac{\sin 2\alpha}{2}\right\}\right]^{1/2}$$

$$V_{O(RMS)} = V_m\left[\frac{1}{2\pi}\left\{(\beta-\alpha) + \frac{\sin 2\alpha}{2} - \frac{\sin 2\beta}{2}\right\}\right]^{1/2}$$

$$V_{O(RMS)} = \frac{V_m}{\sqrt{2}}\left[\frac{1}{\pi}\left\{(\beta-\alpha) + \frac{\sin 2\alpha}{2} - \frac{\sin 2\beta}{2}\right\}\right]^{1/2}$$

The RMS output voltage across the load can be varied by changing the trigger angle α.

Assignment

1. Explain single phase full controller with RL load with detailed analysis.

Hard copy submission date (03/4/2020).

For any kind of Query, do contact on following contact any time.
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