ACVR Numericals from PS Bimbhra

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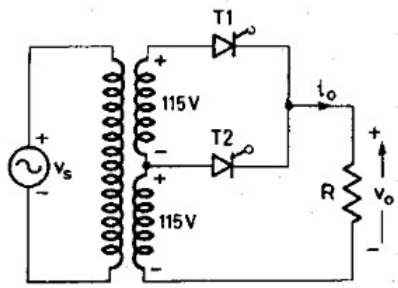
Questions

1. 1ϕ vltg controller has ip vltg of 230V, 50Hz, Load of R=15Ω. On & off for 6, 4 cycles. Det rms op vltg, ip pf, avg & rms thy currents. [Ex 9.1]
2. 1ϕ vltg controller feed power to R-load of 3Ω from 230V, 50 Hz src. Det:
   a. max value of avg & rms thy currents for any α.
   b. min cto time for any α
   c. ratio of 3rd harmonic vltg to fundamental vltg for α=60d.
   d. max di/dt in thy
   e. α at which greatest fwd or rev vltg is applied to either thy and mgnt of these vltg.
3. 1ph vltg controller is employed for controlling power flow from 230V, 50 Hz src into load ckt with R=3Ω and wL=4Ω, det:
   a. control range of firing angle
   b. max value of rms load current
   c. max power & pf
   d. max value of avg & rms thy currents
   e. max di/dt in thy
   f. conduction angle for α=0d, 120d assuming gate pulse duration of π rads.
4. 

   For ckt given, sketch wf of o/p vltg and crnt for given firing angles.
   - T2 only is triggered at $wt = 0, 2\pi, 4\pi, \ldots$
   - T1 only is triggered at $wt = 0, 2\pi, 4\pi, \ldots$
   - T2 is triggered at $wt = 0, 2\pi, 4\pi, \ldots$, T1 is trigerred at $wt = \alpha, 2\pi + \alpha, 4\pi + \alpha, \ldots$
   - Take $\alpha = 40°$

Solution

1. $n = 6, m = 4 \Rightarrow k = \dfrac{n}{n+m} = 0.6$

   $V_{or} = V_s\sqrt{k} = 230\sqrt{0.6} = 178.157\ \text{V}$

   $\text{IPF} = \sqrt{k} = 0.775\ \text{lag [how lag]}$

   $\text{Power delievered to Load} = \dfrac{V_{or}^2}{R} = 2116\ \text{W}$

   $\text{Input VA} = V_s I_s = V_s I_{or} = V_s \cdot \dfrac{V_{or}}{R} = 230 \times \dfrac{230\sqrt{0.6}}{15} = 2731.74\ \text{VA}$

   $\text{Input PF} = \dfrac{\text{Power to Load}}{\text{Input VA}} = 0.775\ \text{lag [how lag?]}$

   $\text{Peak thy current} = I_{T(mx)} = \dfrac{230\sqrt{2}}{15} = 21.681\ \text{A}$

   avg

$$I_{T(avg)} = \frac{kI_m}{\pi} = 4.1407\ A$$

$$I_{T(rms)} = \frac{I_m\sqrt{k}}{2} = 8.397\ A$$

2. $V_s = 230V, f = 50Hz, R = 3\Omega$
   - Current in one thy flow from α to π in full cycle.

     $$I_{T(avg)} = \frac{\int_\alpha^\pi \frac{V_m \sin wt}{R} dwt}{2\pi} = \frac{V_m}{2\pi R}(1 + \cos\alpha)$$

     Max Value is at $\alpha = 0° \Rightarrow \frac{V_m}{\pi R} = 34.512\ A$

     $$I_{T(rms)} = \sqrt{\frac{\int_\alpha^\pi \frac{V_m^2 \sin^2 wt}{R^2} dwt}{2\pi}} = \frac{V_m}{\sqrt{2\pi}R}\sqrt{\frac{\pi - \alpha}{2} + \frac{\sin 2\alpha}{2}}$$

     Max value $= \frac{V_m}{2R} = 54.211\ A$

     $$\left[I_{T(rms)(mx)} = \frac{\pi}{2} \times I_{T(avg)(mx)}\right]$$
   - From wf V_{T1}, V_{T2}, CTO is always π for any α

     $$\Rightarrow t_c = \frac{\pi}{w} = \frac{\pi}{2\pi f} = 10ms$$
   - For harmonic 3,

     $$A_3 = \frac{V_m}{\pi}\left[\frac{\sin(n+1)\alpha}{n+1} - \frac{\sin(n-1)\alpha}{n-1}\right] = \frac{230\sqrt{2}}{\pi}\left[\frac{\sin 240°}{4} - \frac{\sin 120°}{2}\right] = \frac{0.65V_m}{\pi}$$

     $$B_3 = \frac{V_m}{\pi}\left[\frac{\cos(n+1)\alpha - 1}{n+1} - \frac{\cos(n-1)\alpha - 1}{n-1}\right]$$

     $$= \frac{V_m}{\pi}\left[\frac{\cos 240° - 1}{4} - \frac{\cos 120° - 1}{2}\right] = \frac{0.38V_m}{\pi}$$

     $$\text{Ampt of H3} = \sqrt{A_3^2 + B_3^2} = \frac{0.75V_m}{\pi}$$

     $$V_{1m} = \frac{V_m}{\pi}\sqrt{\left[\frac{\sin 120°}{2} + \pi - \frac{\pi}{3}\right]^2 + \left[\frac{\cos 120° - 1}{2}\right]^2} = \frac{2.63V_m}{\pi}$$

     $$\Rightarrow \frac{V_{3m}}{V_{1m}} = 0.284$$
   - As there is sudden rise of current from 0 to $\frac{V_m}{R}\sin\alpha$ for \alpha firing angle, di/dt=inf

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(e) **The waveforms of v_{T1}, v_{T2} in Fig. 9.5 (b) reveal that the greatest forward or reverse voltage would appear across either of the thyristors when $\alpha = \frac{\pi}{2}$ or $\alpha > \frac{\pi}{2}$. The magnitude of these voltages is $V_m = \sqrt{2}\,V_s$.**

3. $V_s = 230V, f = 50\ Hz, R = 3\Omega, wL = 4\Omega$
   - For RL − load, minm α = load phase angle $= \tan^{-1}\frac{wL}{R} = 53.33°$

     Max $\alpha = 180°$.
   - $I_{or(mx)}$ occur at min $\alpha = 53.33°$. At this angle, full op vltg appear

     $$I_{or(mx)} = \frac{230}{\sqrt{R^2 + wL^2}} = 46\ A$$
   - $Max\ power = I_o^2 R = 46^2 \times 3 = 6348\ W$

     $$pf = \frac{I_o^2 R}{V_s I_o} = \frac{46 \times 3}{230} = 0.6$$

(*d*) Average thvristor current is maximum when $\alpha = \phi$ and conduction angle $\gamma = \pi$. From Fig. 9.6 (*c*),

$$I_{TAVM} = \frac{1}{2\pi}\int_{\alpha}^{\alpha+\pi} \frac{V_m}{Z} \sin(\omega t - \phi)\, d(\omega t)$$

$$= \frac{V_m}{\pi Z} = \frac{\sqrt{2} \times 230}{\pi \times \sqrt{3^2 + 4^2}} = 20.707 \text{ A.}$$

Similarly, maximum value of rms thyristor current is

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

$$= \frac{V_m}{2Z} = \frac{\sqrt{2} \times 230}{2 \times 5} = 32.527 \text{ A.}$$

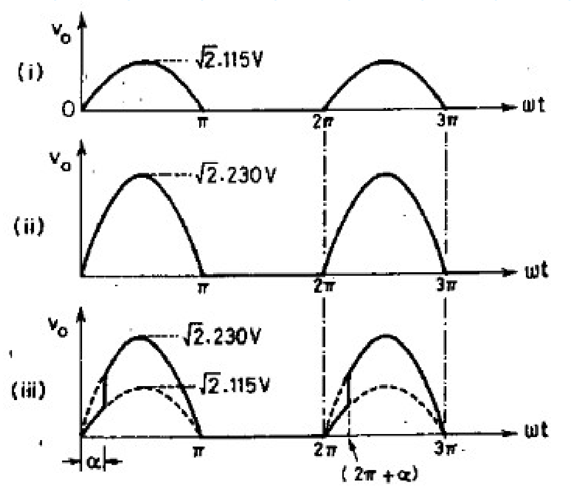
(*e*) Maximum value of $\frac{di_0}{di}$ occurs when $\alpha = \phi$. From Eq. (9.23),

$$\frac{di_0}{dt} = \frac{\omega \cdot V_m}{Z} \cos(\omega t - \phi) - 0.$$

Its value is maximum when $\cos(\omega t - \phi) = 1$

$$\therefore \quad \left(\frac{di_0}{dt}\right)_{max} = \frac{\sqrt{2}.230 \cdot 2\pi \times 50}{5} = 2.0437 \times 10^4 \text{ A/sec.}$$

(*f*) For $\alpha = 0°$, Fig. 9.7 shows that conduction angle γ is 180°. For $\alpha = 120°$ and $\phi = 53.13°$, Fig. 9.7 gives a conduction angle of about 95°.

4. 

Problems

1. <u>Ind appns of ACVR, merits and demerits of ACVR.</u>
2. <u>Two types of ACVR and which is more preferred?</u>
3. <u>Psb configs of 1ph ACVR and compare them.</u>

4. A single-phase voltage controller using two SCRs in antiparallel must have its trigger sources isolated from each other. Why ? Explain with a suitable diagram.

isolated from each other. Why ? Explain with a suitable diagram.

5. **9.2.** (*a*) Describe the principle of burst firing control for a single-phase ac voltage controller.

(*b*) A single-phase ac voltage controller uses burst firing control for heating a load of $R = 5\ \Omega$ with an input voltage of 230 V, 50 Hz. For a load power of 5 kW, determine (*i*) the duty cycle (*ii*) input power factor (*iii*) average and rms thyristor currents. Derive the expressions used.

[**Ans.** (*b*) 0.4726, 0.6875 lag, 9.785 A, 22.3575 A]

6. **9.3.** (*a*) For a single-phase voltage controller feeding a resistive load, draw the waveforms of source voltage, gating signals, output voltage, source and output currents and voltage across one SCR. Describe its working with reference to the waveforms drawn.

(*b*) Analyse the output voltage waveform into various harmonics with Fourier series and find expressions for the amplitude of *n*th harmonic V_{nm} and its phase ϕ_n.

9.4. (*a*) For single-phase voltage controller connected to a resistive load, analyse the output voltage

7. **9.4. (a)** For single-phase voltage controller, connected to a resistive load, analyse the output voltage waveform into various harmonics using Fourier series and find expressions for the amplitude of fundamental voltage component V_{1m} and its phase ϕ_1.

Question 9.4b

A 230V, 1kW heater is fed by triac from 230V, 50Hz src. Find load power for firing delay of 70d. Derive exp used for vltg.

Solution

$$\text{Heater} \Rightarrow \text{R} - \text{Load}, V_m = 230\sqrt{2}, f = 50\text{Hz}, \alpha = 70d$$

$$R = \frac{V^2}{P} = \frac{230^2}{1000} = 52.9\Omega$$

$$V_{o(avg)} = \frac{\int_{\alpha}^{\pi} V_m \sin wt\, dwt + \int_{\pi+\alpha}^{2\pi} V_m \sin wt\, dwt}{2\pi} = 0$$

$$V_{or} = \sqrt{\frac{\int_{\alpha}^{\pi} V_m^2 \sin^2 wt\, dwt + \int_{\pi+\alpha}^{2\pi} V_m^2 \sin^2 wt\, dwt}{2\pi}} = \sqrt{\frac{2\int_{\alpha}^{\pi} V_m^2 \sin^2 wt\, dwt}{2\pi}}$$

$$= \frac{V_m}{\sqrt{\pi}}\sqrt{\frac{\pi-\alpha}{2} - \frac{\sin 2\pi - \sin 2\alpha}{4}} = \frac{V_m}{\sqrt{2\pi}}\sqrt{\pi - \alpha + \frac{\sin 2\alpha}{2}} = \frac{230\sqrt{2}}{\sqrt{2\pi}}\sqrt{\pi - \frac{70\pi}{180} + \frac{\sin 140°}{2}} = 194.26$$

$$\Rightarrow P_{load} = \frac{V_{or}^2}{R} = \frac{194.26^2}{52.9} = 713.414\text{ W}$$

Question 9.5a

For 1ϕ AC vltg controller feeding R − load, PT pf is given by: $\sqrt{\frac{1}{\pi}\left\{[\pi - \alpha] + \frac{\sin 2\alpha}{2}\right\}}$

Solution

$$PF = \frac{P_{load}}{P_{in}} = \frac{V_{or} I_{or}}{V_s I_s} = \frac{V_{or}}{V_s} = \frac{\frac{V_m}{\sqrt{2\pi}}\sqrt{\pi - \alpha + \frac{\sin 2\alpha}{2}}}{\frac{V_m}{\sqrt{2}}} = \sqrt{\frac{\pi - \alpha + \frac{\sin 2\alpha}{2}}{\pi}}$$

Question 9.5b

For 1ϕ half wave AC vltg controller, using one SCR in anti − parallel with a diode, feed 1kW, 230V heater.
Find load power for firing angle delay of 0°, 180°, 70°.

Solution

$$R = \frac{230^2}{1000} = 52.9\Omega$$

$$V_{or} = \sqrt{\frac{\int_{\alpha}^{\pi} V_m^2 \sin^2 wt\, dwt + \int_{\pi}^{2\pi} V_m^2 \sin^2 wt\, dwt}{2\pi}}$$

$$= \frac{V_m^2}{\sqrt{2\pi}}\sqrt{\frac{\pi-\alpha}{2} - \frac{\sin(2\pi) - \sin(2\alpha)}{4} + \frac{2\pi - \pi}{2} - \frac{\sin(2\pi) - \sin(\pi)}{4}}$$

$$= \frac{V_m}{2\sqrt{\pi}}\sqrt{2\pi - \alpha + \frac{\sin(2\alpha)}{2}} = \frac{230\sqrt{2}}{2\sqrt{\pi}}\sqrt{2\pi - \alpha + \frac{\sin(2\alpha)}{2}}$$

$$\alpha = 0 \Rightarrow V_{or} = 230 \Rightarrow P_{load} = \frac{V_{or}^2}{R} = \frac{230^2}{52.9} = 1000\text{W}$$

$$\alpha = \pi \Rightarrow V_{or} = 162.63 \Rightarrow P_{load} = \frac{V_{or}^2}{R} = 500\text{W}$$

$$\alpha = \frac{70\pi}{180} \Rightarrow V_{or} = 212.884 \Rightarrow P_{load} = \frac{V_{or}^2}{R} = 856.707\text{W}$$

Question 9.6a

a. Merits of heater power control by triac using integral cycle control over phase-angle control.

Question 9.6b,c

a. A heater load is controlled by triac from 1ph src. Det firing angle when power is 50%, 70% of max power. Derive expression used. [90,71.5d]
b. A heater load is controlled by 1ph acvr. Det firing angle when controlled power is 50%, 70% of max power. Derive expression used. [180,99d]

Solution

a. $V_{or} = \frac{V_m}{\sqrt{2\pi}}\sqrt{\pi - \alpha + \frac{\sin 2\alpha}{2}}$ [Derived many times bf]

$$P_{load} = \frac{V_{or}^2}{R} = \frac{V_m^2}{2\pi}\left[\pi - \alpha + \frac{\sin 2\alpha}{2}\right]$$

$$P_{load(max)}\Big|_{\alpha=0} = \frac{V_m^2}{2} \Rightarrow \frac{P_{load}}{P_{mx}} = \frac{1}{\pi}\left[\pi - \alpha + \frac{\sin 2\alpha}{2}\right]$$

$$\Rightarrow P(\alpha) = \frac{1}{\pi}\left[\pi - \alpha + \frac{\sin 2\alpha}{2}\right]P_{mx}$$

$$50\% \Rightarrow 0.5 = \frac{1}{\pi}\left[\pi - \alpha + \frac{\sin 2\alpha}{2}\right] \Rightarrow \alpha - \frac{\sin 2\alpha}{2} = \frac{\pi}{2} \Rightarrow \alpha = 90d$$

$$70\% \Rightarrow 0.7 = \frac{1}{\pi}\left[\pi - \alpha + \frac{\sin 2\alpha}{2}\right] = \Rightarrow \alpha - \frac{\sin 2\alpha}{2} = \frac{3\pi}{10} \Rightarrow \alpha = 71.5d$$

b. $V_{or} = \frac{V_m}{2\sqrt{\pi}}\sqrt{2\pi - \alpha + \frac{\sin(2\alpha)}{2}}$ [half wave ACVR]

$$P_{load} = \frac{V_{or}^2}{R} = \frac{V_m^2}{4\pi}\left[2\pi - \alpha + \frac{\sin 2\alpha}{2}\right]$$

$$P_{load(max)}\Big|_{\alpha=0} = \frac{V_m^2}{2} \Rightarrow \frac{P_{load}}{P_{mx}} = \frac{1}{2\pi}\left[2\pi - \alpha + \frac{\sin 2\alpha}{2}\right]$$

$$\Rightarrow P(\alpha) = \frac{1}{2\pi}\left[2\pi - \alpha + \frac{\sin 2\alpha}{2}\right]P_{mx}$$

$$50\% \Rightarrow 0.5 = \frac{1}{2\pi}\left[2\pi - \alpha + \frac{\sin 2\alpha}{2}\right] \Rightarrow \alpha - \frac{\sin 2\alpha}{2} = \frac{\pi}{2} \Rightarrow \alpha = 180d$$

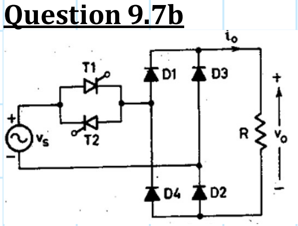
$$70\% \Rightarrow 0.7 = \frac{1}{2\pi}\left[2\pi - \alpha + \frac{\sin 2\alpha}{2}\right] \Rightarrow \alpha - \frac{\sin 2\alpha}{2} = \frac{6\pi}{10} \Rightarrow \alpha = 99d$$

Question 9.7a

Define pf. Derive exp for 1ph vltg controller feeding r-load ckt.

PT $\text{pf} = \sqrt{\text{PU power}}$

Question 9.7b



a. For given ckt, sketch wf for 2 cycle of supply vltg, supply current, load vltg, load current for firing angle of 45d for both thy.
b. For 230V, 50Hz supply vltg, find power consumed by load in case of $\alpha = 60°$, $R = 10\Omega$. Derive exp of power.
c. If D1 is open ckted, draw load crnt wf and det power delivered to load for same values.

Solution

Ckt will behave as FWR triggered at α in each cycle.

a. Supply vltg is sin wave, load vltg is o/p as FWR triggered at 45d, load current and supply current will be same and similar to load voltage reduced by factor of R.

b. $$V_{or} = \sqrt{\frac{2\int_{\alpha}^{\pi} V_m^2 \sin^2 wt}{2\pi}} = \frac{V_m}{\sqrt{\pi}}\sqrt{\frac{\pi-\alpha}{2} - \frac{\sin(2\pi)-\sin(2\alpha)}{4}}$$

$$V_{or} = \frac{V_m}{\sqrt{2\pi}}\sqrt{\pi-\alpha+\frac{\sin(2\alpha)}{2}}$$

$$\Rightarrow P = \frac{V_{or}^2}{R} = \frac{V_m^2}{2\pi R}\left[\pi-\alpha+\frac{\sin(2\alpha)}{2}\right] \Rightarrow P(10\Omega, 60°) = 4255.8\text{W}$$

c. $$V_{or} = \sqrt{\frac{\int_{\alpha}^{\pi} V_m^2 \sin^2 wt}{2\pi}} = \frac{V_m}{\sqrt{2\pi}}\sqrt{\frac{\pi-\alpha}{2} - \frac{\sin(2\pi)-\sin(2\alpha)}{4}}$$

$$V_{or} = \frac{V_m}{2\sqrt{\pi}}\sqrt{\pi-\alpha+\frac{\sin(2\alpha)}{2}}$$

$$\Rightarrow P = \frac{V_m^2}{4\pi}\left[\pi-\alpha+\frac{\sin(2\alpha)}{2}\right] \Rightarrow P = 2127.9\text{W}$$

Question 9.8

1ph vltg controller with rst load has 230V, 50Hz mains supply, $R = 4\Omega$. Det:

- Firing angle α at which greatest fwd or rev vltg is applied to either thy and mgnt of these vltg.
- Greatest fwd or rev vltg that appears across either of thy for α=60d, 120d.
- Rms of fifth harmonic crnt and its phase for α=π/4.

value of fifth harmonic current and its phase for ...

- [Ans. (a) $\alpha = \frac{\pi}{2}$ or at $\alpha > \frac{\pi}{2}$, 325.27 V (b) 281.691 V, 325.27 V (c) 27.284 V, – 63.435°]

Solution

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Question 9.9a

a. 1ph vltg controller with 2 thy arranged in anti-parallel is connected to RL-load. Discuss working when firing angle is more than load pf angle. Illustrate answer with wf of src vltg, gate signals, load & src currents, o/p vltg, vltg across both thy.
   Derive exp for op current in terms of src vltg, load impd, firing angle.
b. 1ph vltg controller has data: src vltg 230V, 50Hz, load=4jΩ. Det:
   i. Control range of α
   ii. Max value of rms load crnt.
   iii. Max value of avg & rms thy currents.
   iv. Max di/dt in thy
   v. Value of cnd angle for α=90d assuming gate pulse width of pi rads.

Solution

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onduction angle for $\alpha = 90°$ assuming gate pulse width of π radians.

[Ans. (b) $90° \le \alpha \le 180°$; 57.5 A ; 25.88 A, 40.66 A ; 2.5546×10^4 A/sec ; 180°]

Question 9.10

a. For 1ph vltg, find relation bw cnd angle \gamma and α firing angle, plot their varn as fn of load phase angle phi. For what conds is \gamma =\pi.
   Derive exp for op current in terms of src vltg, load impd, firing angle.
b. Discuss op of 1ph vltg controller with RL-load when firing angle α ≤ load phase angle ϕ.
   ST for α < ϕ, op vltg of ac vltg controller can't be regulated.
c. For 1ph vltg controller, how pulse gating is suitable for R-load and not for RL-load. ST high freq carrier gating is essential for RL-loads.

9.11a

Desc working of 2 stage seq control of vltg controller for R & RL loads. What is ad of this controller over 1ph full-wave vltg controller?

9.11b

Dfrt bw 2-stage & multi-stage seq control of vltg controller. Write ad of multistage over 2-stage seq control. Describe multi-stage seq control.

9.12

Desc 1ph sinsd vltg controller with vernier winding. What are fns of controlled and by-pass thyristors? Discuss how op vltg waveform from 7-8V can be obtd from this vltg controller.