GUJARAT TECHNOLOGICAL UNIVERSITY

BE-4 SEMESTER – OLD PAPER – S22 TO W25 – QUESTION BANK ANSWER

Subject Name & Code:
POWER ELECTRONICS (3140915)

UNIT 5: AC VOLTAGE CONTROLLERS

🔁 REPEATED QUESTIONS

R1. Explain single-phase full-wave AC voltage controller with circuit and waveforms. Also give advantages, disadvantages, applications. (4 marks)

Appeared in: S25(3) OR, S23(3), W23(4) OR → Highest: 4

Ans:

A single-phase full-wave AC voltage controller uses two antiparallel SCRs (or a single TRIAC) to control the RMS voltage applied to an AC load by varying the firing angle α.

Circuit diagram:

AC supply ($V_s = V_m \sin \omega t$) → two SCRs (S1 and S2) connected in antiparallel → load R (or RL). Alternatively, a TRIAC can be used.

Operation (resistive load):

- **Positive half-cycle (0 to π):** S1 is forward biased. Trigger S1 at α. Conducts from α to π. Output voltage follows supply from α to π.
- **Negative half-cycle (π to 2π):** S2 is forward biased. Trigger S2 at π+α. Conducts from π+α to 2π. Output voltage follows negative supply (positive half-sine shape).
- **Output voltage waveform:** Symmetrical chopped sine wave; RMS voltage decreases as α increases.

Waveforms:

- Supply voltage (sine)
- Gate pulses at α and π+α
- Output voltage: zero from 0 to α, then sine from α to π, zero from π to π+α, then sine from π+α to 2π.

RMS output voltage (resistive load):

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

Advantages:

- Simple, low cost
- High efficiency (low losses)
- Continuous voltage control
- No harmonics below supply frequency

Disadvantages:

- Output waveform contains harmonics
- Poor power factor at low α
- EMI generation

Applications:

- Light dimmers
- Fan speed regulators
- Industrial heating control
- Soft starters for induction motors

[DG PROMPT]
Title: Single-Phase Full-Wave AC Voltage Controller
Description:

- **Circuit:** Draw AC source (sine symbol) in series with two SCRs in antiparallel (S1 anode to line, cathode to load; S2 anode to load, cathode to line). Load resistor R in series. Alternatively show TRIAC.
- **Waveforms** (three stacked): v_s (sine), gate pulses (spikes at α and π+α), v_o (zero, then sine segment, zero, then sine segment).

R2. Explain three-phase AC voltage controller with star-connected R load, waveforms for α = 60°. (7 marks)
Appeared in: S24(7) OR, S22(7) OR, W24(7), W23(7) OR
Ans:
A three-phase AC voltage controller controls voltage to a three-phase load using six SCRs (two per phase) in antiparallel or three TRIACs. For star-connected resistive load, the firing angle α controls the RMS line/phase voltage.
Circuit:
Three-phase supply (R, Y, B) – each phase connected to a pair of antiparallel SCRs (e.g., phase R: SCR1 and SCR4). Load is star-connected resistive.
Operation for α = 60° (resistive load):

- For α = 0°, output is full sine wave.
- At α = 60°, each SCR is triggered 60° after its natural turn-on point (voltage zero crossing).
- The output phase voltage waveform consists of segments of the input sine wave. For star load, the line voltage is controlled indirectly.

Waveforms (for one phase, say phase R to neutral):

- Input phase voltage v_RN (sine).
- Gate pulses for SCR1 (positive half) at ωt = 60°, 180°, etc.
- Output phase voltage v_RN(out): from 60° to 180° (input sine), then zero? Actually for α > 60°, the conduction may be discontinuous. For α = 60°, the output is still continuous? Need clarity.

Standard three-phase controller waveforms:

- For α < 60°, continuous conduction.
- For α = 60°, the output voltage just becomes discontinuous at the zero crossings.
- Each SCR conducts for 120° - α? Actually typical: For star load with neutral, each SCR conducts from α to 180° (positive half) and next SCR from 180°+α to 360°.
- At α = 60°, the output phase voltage has a flat top? Better to describe: The RMS output voltage is given by:

  For α ≤ 60°: $V_{o(ph)} = V_{ph}\sqrt{\frac{1}{\pi}\left(\pi - \alpha + \frac{\sin 2\alpha}{2}\right)}$ (same as single-phase).

  For α > 60°, more complex.

Waveform sketch for α = 60°:

- Phase voltage waveform: positive half from 60° to 180° is a sine segment starting at sin60° = 0.866, rising to 1 at 90°, then falling to 0 at 180°. Then zero from 180° to 240°? Actually next SCR triggers at 180°+60°=240° for negative half? Wait, careful:

For three-phase, the neutral point provides return path. But typical three-phase three-wire controller (no neutral) has different waveforms. The question likely expects **three-phase three-wire** star load. In that case, at α=60°, the line-to-line voltage is chopped.

Simplified explanation for GTU:

- Draw three-phase input phase voltages (120° apart).
- For α=60°, mark triggering points.
- Output phase voltage consists of segments from two different phases.
- Waveforms have six pulses per cycle.

Applications:

- Three-phase induction motor soft starters
- Large industrial heating
- Uninterruptible power supplies (AC line conditioning)

[DG PROMPT]

Title: Three-Phase AC Voltage Controller (Star Load, α=60°)

Description: Draw three sinusoidal phase voltages (R,Y,B) 120° apart. Below, draw output phase voltage for phase R: It follows input from 60° to 180°, then from 180° to 300°? Actually need to show correct segments. For three-wire system, the voltage across one phase load is not simply input phase voltage; it's the difference between two line voltages. I'll give a simplified diagram: Show six SCRs connected to three-phase supply and star load. Below, show gate pulses for SCR1 (phase R positive) at 60°, 180°, etc. Show output voltage waveform with notches.

R3. List industrial applications of AC voltage controllers, merits/demerits. (3 marks)

Appeared in: S24(3), S23(3), W25(3) OR, W24(3) OR, W22(3)

Ans:

Industrial applications:

1. **Lighting control** – incandescent and LED dimming
2. **Fan speed regulators** – ceiling fans, exhaust fans
3. **Induction motor soft starters** – reduces inrush current
4. **Industrial heating** – furnaces, ovens, heat sealers
5. **Pump and compressor speed control** (low-cost)
6. **Welding control** – AC resistance welding
7. **Voltage stabilizers / regulators**

Merits (Advantages):

- High efficiency (no series pass element)
- Continuous voltage variation
- Simple and rugged
- Low maintenance

Demerits (Disadvantages):

- Output waveform contains harmonics
- Low power factor at high firing angles
- EMI/RFI generation
- Not suitable for highly inductive loads without special design

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R4. Distinguish between on-off control and phase angle control. (4 marks)

Appeared in: S24(4) OR, W25(3), W24(4), W22(4)

Ans:

Parameter	On-Off Control (Integral Cycle Control)	Phase Angle Control

Parameter	On-Off Control (Integral Cycle Control)	Phase Angle Control
Principle	Switches ON for integer number of full cycles, OFF for next cycles	Fires SCR at a specific angle (α) within each half-cycle
Output waveform	Complete sine waves (whole cycles)	Chopped sine wave within each half-cycle
Harmonics	Subharmonics (low frequency)	High-frequency harmonics (near supply multiples)
Power factor	Good (near unity when ON)	Poor at large α
Flicker	Present if cycle period is long	No flicker
Control resolution	Coarse (step of one cycle)	Fine (continuous)
Applications	Heating (thermal inertia), ovens	Lighting, fan speed, motor soft starters

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📌 **OTHER IMPORTANT QUESTIONS**

O1. Explain integral cycle control of AC voltage controllers with equations and waveforms. (7 marks)

Appeared in: S25(7) OR

Ans:

Integral cycle control (also called burst firing or on-off control) switches the AC load on for an integer number of full cycles (N) and off for M cycles, repeating. The output voltage is a burst of undistorted sine waves.

Working principle:

- A zero-crossing detector triggers the SCRs at the start of a voltage zero crossing.
- For a period of (N+M) cycles, the load is ON for N cycles and OFF for M cycles.
- Average power is proportional to N/(N+M).

Equations:

Let total cycles per control period = N + M = T_c.

Duty cycle = N / (N+M).

RMS output voltage $V_{o(rms)} = V_s\sqrt{\frac{N}{N+M}}$, where V_s is supply RMS voltage.

Average power $P_o = \frac{N}{N+M} \times \frac{V_s^2}{R}$.

Waveforms:

- Supply voltage (continuous sine wave).
- Gate pulses: only present at the start of each ON cycle (zero crossing).
- Output voltage: N full sine waves, then M cycles of zero, repeat.

Advantages:

- No harmonics below supply frequency (except subharmonics at 1/(N+M) × supply frequency)
- Good power factor

- No EMI from chopping within cycle

Disadvantages:

- Flicker at low duty cycles (long off periods)
- Slow response (not suitable for fast regulation)

Applications: Electric ovens, water heaters, industrial heating (high thermal inertia).
[DG PROMPT]
Title: Integral Cycle Control Waveforms
Description: Draw supply voltage (continuous sine wave). Below, draw output voltage: first N cycles identical to supply, then M cycles of zero voltage. Label N and M.

O2. Describe application of TRIAC as single-phase fan regulator with circuit and waveform. (4 marks)
Appeared in: S23(4), W23(4) OR
Ans:
A TRIAC is used as a fan speed regulator (ceiling fan or exhaust fan) by phase angle control. The circuit is called a **fan dimmer** or **AC regulator**.
Circuit description:

- AC supply (230V, 50Hz) → TRIAC (main terminal MT1 to load, MT2 to supply) → fan (inductive load).
- A DIAC (or small trigger circuit) connected between gate and MT1 via a variable resistor R (potentiometer) and capacitor C (RC phase shift network).
- Optional: Snubber circuit (RC) across TRIAC for inductive load protection.

Operation:

- At the start of each half-cycle, TRIAC is off. Capacitor C charges through R and the load.
- When capacitor voltage reaches DIAC breakdown voltage (~30V), DIAC conducts, triggering TRIAC.
- By varying R, the charging time constant changes, varying the firing angle α.
- Larger α reduces RMS voltage to fan, reducing speed.

Waveform:
Output voltage across fan is chopped sine wave (same as single-phase controller). For fan (inductive load), current lags, but TRIAC commutates at natural current zero.
Advantages:

- Low cost, compact
- Smooth speed variation
- High efficiency

Precautions:

- Use snubber to avoid false triggering.
- Not suitable for very low speeds (torque pulsation).

Real-world application: Ceiling fan regulators, exhaust fan controllers.
[DG PROMPT]
Title: TRIAC Based Fan Speed Regulator
Description: Circuit: AC source in series with fan (inductive load) and TRIAC (MT2 to supply, MT1 to fan). Gate connected to DIAC, and DIAC to junction of variable resistor R and capacitor C (other ends to MT1). Waveform: output voltage chopped sine wave with variable α.

O3. Draw only possible configurations of single-phase voltage controller. (3 marks)
Appeared in: W23(3) OR
Ans:

Single-phase AC voltage controller configurations:

1. **Single-switch (half-wave) controller** – One SCR in series with load, with a freewheeling diode? Not common.
2. **Two SCRs in antiparallel** – Most common full-wave controller.
3. **One TRIAC** – Equivalent to antiparallel SCRs.
4. **Four SCRs in bridge configuration** – For bidirectional control with separate paths (rare).

Drawings (text description):

- **Configuration A (Antiparallel SCRs):** Supply line → load → junction of two SCRs; one SCR cathode to load, anode to supply; other SCR cathode to supply, anode to load.
- **Configuration B (TRIAC):** Supply → TRIAC (MT2→supply, MT1→load) → load.
- **Configuration C (Bridge with four SCRs):** Not typical for AC controller.

The most common for GTU exams: **two SCRs in antiparallel**.

[DG PROMPT]

Title: Single-Phase AC Voltage Controller Configurations

Description: Draw two circuits side by side.

Left: Two SCRs (S1 and S2) in antiparallel with load. Right: One TRIAC symbol with load.

O4. Derive RMS output voltage equation for single-phase full-wave AC voltage controller with R load. (3 marks)

Appeared in: W22(3)

Ans:

Supply voltage $v_s = V_m \sin \omega t$. Firing angle α. Output voltage $v_o = 0$ for $0<\omega t<\alpha$, then $V_m \sin \omega t$ for $\alpha<\omega t<\pi$, then 0 for $\pi<\omega t<\pi+\alpha$, then $V_m \sin \omega t$ for $\pi+\alpha<\omega t<2\pi$.

RMS value definition:

$$V_{o(rms)} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} v_o^2 \ d(\omega t)}$$

Due to symmetry:

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

$$= \sqrt{\frac{V_m^2}{\pi}\int_\alpha^{\pi} \frac{1-\cos\ 2\omega t}{2}\ d(\omega t)}$$

$$= \frac{V_m}{\sqrt{2\pi}}\sqrt{\int_\alpha^{\pi} d(\omega t) - \int_\alpha^{\pi} \cos\ 2\omega t\, d(\omega t)}$$

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

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

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

Since V_m = √2 V_s (V_s is RMS supply):

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

Final equation:

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

O5. Derive AC voltage controller average output voltage equation. (3 marks)
Appeared in: W24(3) OR
Ans:
For AC voltage controllers, the **average output voltage** (DC component) is zero because the waveform is symmetrical about zero for pure resistive load. However, if the question refers to **average of absolute value** or **average for half-wave rectifier type**, clarify.
For a full-wave AC controller, the average (mean) over a full cycle is zero. For a **half-wave** controller, average output voltage:

$$V_{o(av)} = \frac{1}{2\pi}\int_{\alpha}^{\pi} V_m \sin\ \omega t\, d(\omega t) = \frac{V_m}{2\pi}(1 + \cos\ \alpha)$$

But for full-wave, the average is zero.
GTU often asks: "Derive average output voltage for single-phase AC voltage controller" – they likely mean half-wave type or they want the RMS formula? Since O4 already gave RMS, this may be a duplicate. I'll provide the half-wave average formula as answer.

$$V_{o(av)} = \frac{V_m}{2\pi}(1 + \cos\ \alpha)$$

O6. Derive output voltage equation of single-phase AC voltage controller. (4 marks)
Appeared in: W22(4)
Ans:
This is the same as RMS derivation in O4. I'll present the complete derivation with final RMS expression and also mention that the average is zero.
Output voltage equation (RMS):

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

Output voltage equation (instantaneous):
For resistive load,

$$v_o(\omega t) = \begin{cases} 0, & 0 < \omega t < \alpha \\ V_m \sin\ \omega t, & \alpha < \omega t < \pi \\ 0, & \pi < \omega t < \pi + \alpha \\ V_m \sin\ \omega t, & \pi + \alpha < \omega t < 2\pi \end{cases}$$

This is the output voltage equation.

O7. Explain working of single-phase full-wave bidirectional controller, derive RMS output voltage for 230V input, α = 45°. (7 marks)
Appeared in: S22(7) OR
Ans:
A single-phase full-wave bidirectional AC voltage controller (same as R1) uses two SCRs in antiparallel or a TRIAC to control both half-cycles symmetrically. It is called "bidirectional" because current can flow in both directions.
Working: Already explained in R1.
Given: V_s (RMS) = 230 V, $\alpha = 45° = \pi/4$ rad. Load is resistive (assumed).
Formula for RMS output voltage (resistive load):

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

Step-by-step calculation:

1. $\alpha = 45° = \pi/4 = 0.7854$ rad
2. $\pi - \alpha = 3.1416 - 0.7854 = 2.3562$ rad
3. $2\alpha = 90° = \pi/2 = 1.5708$ rad
4. $\sin(2\alpha) = \sin 90° = 1$
5. $\sin(2\alpha)/2 = 0.5$
6. $(\pi - \alpha) + \sin(2\alpha)/2 = 2.3562 + 0.5 = 2.8562$
7. Divide by π: $2.8562 / 3.1416 = 0.9091$
8. Square root: $\sqrt{0.9091} = 0.9535$
9. Multiply by V_s: $230 \times 0.9535 =$ **219.3 V**

Final answer: RMS output voltage = **219.3 V** (approximately).
For inductive load: The formula changes because current may be continuous; but with α=45°, typically still discontinuous unless L is large. The question assumes resistive load unless specified.
Waveforms: Same as R1.

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