# GUJARAT TECHNOLOGICAL UNIVERSITY

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

**Subject Name & Code:**

**POWER ELECTRONICS (3140915)**



## UNIT 4: AC-DC CONVERTERS (RECTIFIERS)

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### 🔁 REPEATED QUESTIONS

**R1. Explain single-phase full-wave controlled rectifier with R/RL load. (7 marks)**

*Appeared in: S25(7), S23(7) OR, W22(7) OR*

**Ans:**

A single-phase full-wave controlled rectifier uses four thyristors in a bridge configuration (fully controlled) or two thyristors + two diodes (semi-controlled). Here we explain **fully controlled bridge** with R and RL loads.

**Circuit diagram:**

AC supply ($V_s = V_m \sin \omega t$) connected to four SCRs: S1, S2 (forward group) and S3, S4 (reverse group). Load R (or R-L) connected across bridge output.

**For resistive load (R):**

- **Positive half-cycle (0 to π):** SCRs S1 and S4 are forward biased. At firing angle α, they are triggered. Load current flows from supply through S1 → load → S4. Output voltage follows supply voltage until π, then becomes zero when supply crosses zero (SCRs turn off naturally at ωt=π).
- **Negative half-cycle (π to 2π):** SCRs S2 and S3 triggered at π+α. Current reverses through load. Output voltage is negative (but for rectifier we take absolute value? Actually load voltage is positive if we define polarity consistently – the bridge inverts negative half-cycle to positive).
- **Output voltage waveform:** Positive pulses from α to π and from π+α to 2π. Average $V_o = (2V_m/\pi) \cos \alpha$.
- **Discontinuous current** for α > 0.

**For RL load (inductive):**

- When SCRs turn off at π, load inductance tries to maintain current. This keeps S1, S4 conducting beyond π until energy decays. However, without freewheeling diode, negative supply voltage appears across load until current zero. This causes negative voltage spike, reducing average voltage.
- With freewheeling diode across load, current freewheels during off periods, output voltage clamped to zero, giving same average voltage formula as R load but with continuous current for α < 90°.

**Waveforms (RL load with freewheeling diode):**

- Gate pulses at α, 2π+α, etc.
- Load voltage: positive from α to π, then zero from π to π+α, etc.
- Load current: exponential rise and fall, continuous for α < 90°.

**Average output voltage (continuous conduction):**

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

where $V_s$ is RMS supply voltage.
**Applications:** DC motor drives, battery chargers, electroplating.
[DG PROMPT]
**Title:** Single-Phase Full-Wave Controlled Rectifier with RL Load
**Description:**

- **Circuit:** Draw AC source (sine symbol) in series with a bridge of four SCRs (S1 top left, S2 top right? Actually standard: S1 and S2 on left leg? Better: Four SCRs: S1 (top left), S4 (bottom left), S2 (top right), S3 (bottom right). Load (R and L in series) connected between the two bridge midpoints. Freewheeling diode in parallel with load (cathode to positive). Label α.
- **Waveforms** (stacked, same time axis 0 to 2π):
  1. Supply voltage $V_s$ (sine wave)
  2. Gate pulses for S1,S4 (from α to π) and S2,S3 (from π+α to 2π)
  3. Load voltage $V_o$: positive pulses from α to π, zero from π to π+α, positive again from π+α to 2π
  4. Load current $i_o$: continuous (rippled DC) for RL with freewheeling diode.

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**R2a. Explain three-phase full converter with RL load and waveforms. (7 marks)**
*Appeared in: S25(7), S24(7), W25(7) OR, W23(7)*
**Ans:**
Three-phase full converter (fully controlled bridge) uses six thyristors – two per phase (one for positive group, one for negative group). It provides higher DC voltage and lower ripple than single-phase.
**Circuit:**
Three-phase supply (R, Y, B phases). Positive group: SCRs 1, 3, 5 (connected to R, Y, B respectively). Negative group: SCRs 4, 6, 2 (connected to R, Y, B respectively). Load (RL) between common cathodes of positive group and common anodes of negative group.
**Operation (continuous conduction mode, α < 60°):**
Each SCR conducts for 120° per cycle. Firing sequence: 1,2,3,4,5,6 at intervals of 60°. At any instant, two SCRs conduct (one from positive group, one from negative group). Line-to-line voltage appears across load.
**Waveforms:**

- Phase voltages (three sine waves 120° apart).
- Trigger pulses for SCRs – each shifted by α from natural commutation point.
- Output voltage $V_o$ consists of segments of line-to-line voltages.
- For α=0, $V_o = (3\sqrt{2}\ V_{ll}/\pi) \approx 1.35\ V_{ll}$ (RMS line-to-line).
- For general α (0 to 60°), average $V_o = (3\sqrt{2}\ V_{ll}/\pi) \cos\alpha$.
- For α > 60°, discontinuous conduction may occur unless load is highly inductive.

**RL load effect:**
Current is continuous for α < 60° with large L. Inductor smoothes current. Output voltage becomes negative when α > 90° (inverter mode).
**Applications:** High-power DC motor drives (up to MW), HVDC transmission.
[DG PROMPT]
**Title:** Three-Phase Full Converter Circuit and Waveforms
**Description:**

- **Circuit:** Three-phase source (star) with lines R,Y,B. Six SCRs: top group (S1,R; S3,Y; S5,B) cathodes connected together to load positive. Bottom group (S4,R; S6,Y;

S2,B) anodes connected together to load negative. RL load between.

- **Waveforms:** Draw three phase voltages. Below, draw output voltage $V_o$ – six pulses per cycle, segments of line-line voltages. For α=30°, show delay from natural commutation points.

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**R2b. Explain three-phase semi-converter with RL load and waveforms. (7 marks)**
*Appeared in: W25(7), W23(7) OR*
**Ans:**
Three-phase semi-converter uses three SCRs (positive group) and three diodes (negative group). It provides lower cost and improved power factor at lower firing angles.
**Circuit:**
Positive group: SCRs 1,3,5 (anodes to R,Y,B; cathodes common to load positive). Negative group: diodes 4,6,2 (cathodes to R,Y,B; anodes common to load negative). Load (RL) connected between common points.
**Operation:**

- During positive half-cycle of a phase, its SCR triggers at α and conducts until the next phase voltage becomes more positive (natural commutation).
- Diodes conduct without delay, providing a freewheeling path.
- Output voltage waveform consists of positive segments only (no negative portions) because diodes prevent negative voltage.
- For α=0, $V_o = (3\sqrt{2}\ V_{ll}/\pi)\ (1+\cos\alpha)/2$? Actually average output: $V_o = (3\sqrt{2}\ V_{ll}/2\pi)\ (1+\cos\alpha)$.
- Maximum voltage at α=0, reduces to zero at α=180°.

**Advantages over full converter:**

- Only three SCRs (less cost).
- No negative voltage across load – better for DC motor with freewheeling.
- Higher power factor at low α.

**Disadvantages:**

- Cannot operate in inverter mode (no negative voltage).
- Lower output voltage than full converter for same α.

**Waveforms:** Similar to full converter but output voltage never goes negative; freewheeling through diodes during off periods.
**Real-world application:** Low-cost DC drives, battery chargers.
[DG PROMPT]
**Title:** Three-Phase Semi-Converter Circuit
**Description:** Similar to full converter but replace bottom three SCRs with diodes (D4, D6, D2). Label SCRs S1,S3,S5 and diodes D4,D6,D2. RL load. Waveforms: output voltage positive pulses only.

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**R3. Discuss need of freewheeling diode in phase-controlled rectifier. (4 marks)**
*Appeared in: S25(3), S24(4), S23(3), W25(3), W23(3) → Highest: 4*
**Ans:**
A freewheeling diode (also called commutating diode) is connected in parallel with the load (reverse biased during normal conduction).
**Need:**

1. **Prevents negative output voltage** – In RL load, when SCRs turn off at the end of a half-cycle, the inductor tries to maintain current. Without freewheeling diode, the load voltage would become negative (supply reverse voltage), reducing average DC output. The diode provides a short circuit path for inductor current, clamping load voltage to nearly zero (diode drop).

2. **Improves average voltage** – By eliminating negative voltage spikes, $V_o$ increases for a given firing angle.
3. **Reduces ripple** – Current becomes smoother and continuous even at low α.
4. **Protects SCRs** – Prevents high reverse voltage across SCRs during inductive kickback.
5. **Enables discontinuous-to-continuous transition** – Allows the rectifier to operate in continuous conduction mode at lower load currents.

**Without freewheeling diode:** The output voltage formula becomes $V_o = (2V_m/\pi)\cos\alpha$ only for continuous current; with discontinuous current, the average drops significantly.
**Application:** All phase-controlled rectifiers feeding inductive loads (DC motor armature, large filter inductors).

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**R4a. Derive output voltage equation for single-phase half-wave rectifier. (4 marks)**
*Appeared in: S24(4), W23(4) OR, W22(4) OR*
**Ans:**
Single-phase half-wave controlled rectifier with resistive load. Supply voltage $v_s = V_m \sin\omega t$. Thyristor triggered at α.
**Waveform:** Output voltage $v_o = 0$ for 0 to α, then $V_m \sin\omega t$ from α to π, then 0 from π to 2π.
**Average output voltage:**

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

**For resistive load only.** If load includes inductance, current may be continuous or discontinuous, and expression changes.
**RMS output voltage:**

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

**Real-world application:** Low-power battery charging, simple lamp dimmers.

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**R4b. Derive output voltage equation for single-phase full-wave rectifier. (7 marks)**
*Appeared in: S25(7), W25(3) OR*
**Ans:**
Single-phase full-wave controlled rectifier (bridge) with resistive load. Supply $v_s = V_m \sin\omega t$. Thyristors triggered in pairs: (S1,S4) from α to π, (S2,S3) from π+α to 2π.
**Output voltage waveform:**

- Positive pulse from α to π: $v_o = V_m \sin\omega t$
- Positive pulse from π+α to 2π: $v_o = -V_m \sin\omega t$ (since bridge inverts negative half-cycle)
- Zero elsewhere.

**Average output voltage:**

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

Because each half-cycle contributes same positive area over π (not 2π) due to symmetry.

$$= \frac{V_m}{\pi}[-\cos\ \omega t]_{\alpha}^{\pi} = \frac{V_m}{\pi}(-\cos\ \pi + \cos\ \alpha) = \frac{V_m}{\pi}(1 + \cos\ \alpha)$$

**In terms of RMS supply voltage V_s = V_m/√2:**

$$V_{o(av)} = \frac{2\sqrt{2}V_s}{\pi}\cos^2(\alpha/2) \text{(since 1+cosα = 2cos²(α/2))}$$

More commonly written as:

$$V_{o(av)} = \frac{2V_m}{\pi}\cos\ \alpha\text{? No – careful: } \frac{V_m}{\pi}(1 + \cos\ \alpha) = \frac{2V_m}{\pi}\cos^2(\alpha/2)$$

Wait, confusion. Standard formula for full-wave controlled rectifier (with continuous current) is $V_{o(av)} = \frac{2V_m}{\pi}\cos\ \alpha$ for RL load with freewheeling? Actually for pure resistive load, the integral from α to π gives $\frac{V_m}{\pi}(1 + \cos\ \alpha)$. For RL load with freewheeling diode (continuous conduction), the same formula holds because each half-cycle contributes same area. Many textbooks use $V_{o(av)} = \frac{2V_m}{\pi}\cos\ \alpha$ for full-wave with inductive load and α < 90° (continuous). But note: $\frac{2V_m}{\pi}\cos\ \alpha$ is NOT equal to $\frac{V_m}{\pi}(1 + \cos\ \alpha)$ unless α=0. So there are two different cases.

**Clarification for GTU:** They often ask derivation for **resistive load** giving $V_{o(av)} = \frac{V_m}{\pi}(1 + \cos\ \alpha)$. For RL load with continuous conduction, the formula is $V_{o(av)} = \frac{2V_m}{\pi}\cos\ \alpha$ (since negative voltage portion appears if no freewheeling diode). But with freewheeling diode, it reverts to resistive load formula. I'll provide the general expression.

**For RL load without freewheeling diode (continuous current):**

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

Derivation: Integrate from α to π+α, voltage is $V_m$ sinωt for α to π, and $-V_m$ sinωt for π to π+α (since bridge inverts). Area = $\int_{\alpha}^{\pi} V_m \sin\ \theta d\theta + \int_{\pi}^{\pi+\alpha} - V_m \sin\ \theta d\theta = V_m(1 + \cos\ \alpha) + V_m(1 - \cos\ \alpha) = 2V_m \cos\ \alpha$. Then divide by π (period π for average). Yes.

So I'll present both: Resistive load: $\frac{V_m}{\pi}(1 + \cos\ \alpha)$; RL continuous: $\frac{2V_m}{\pi}\cos\ \alpha$.

**Conclusion for 7 marks:** Show step-by-step integration, waveforms, and mention the two cases.

[DG PROMPT]

**Title:** Single-Phase Full-Wave Controlled Rectifier Output Voltage Derivation

**Description:** Draw one cycle of supply sine wave. Mark firing angle α. Shade the conduction intervals. For resistive load, show positive pulses from α to π and π+α to 2π. For RL without freewheeling, show also negative pulse from π to π+α.

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## 📌 OTHER IMPORTANT QUESTIONS

**O1. Draw circuit of 1-φ half-wave controlled rectifier with R load and waveforms (α=30°). (4 marks)**

*Appeared in: S24(3), S22(3), W25(4)*

**Ans:**

**Circuit:** AC supply → SCR (anode to supply, cathode to load R) → load R → return to supply. Gate triggering circuit not shown.

**For α=30°:**

- Supply voltage $v_s = V_m \sin \omega t$.
- SCR triggered at $\omega t=30°$ ($\pi/6$). Conducts from 30° to 180°.
- Output voltage $v_o$ follows $v_s$ from 30° to 180°, then zero from 180° to 360°.
- Load current $i_o = v_o/R$, same shape as $v_o$.

**Waveforms (draw):**

1. $v_s$ (sine) with $\alpha$ marked at 30°.
2. Gate pulse at 30° (short spike).
3. $v_o$ (positive half-sine from 30° to 180°, zero elsewhere).
4. $i_o$ (same shape).

[DG PROMPT]
**Title:** Half-Wave Controlled Rectifier with R Load ($\alpha$=30°)
**Description:** Draw circuit: AC source, SCR symbol, resistor R. Waveforms: three stacked graphs: $v_s$ (sine), gate pulse (vertical line at 30°), $v_o$ (partial sine from 30° to 180°).

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**O2. Explain working of single-phase semi-converter with voltage/current waveforms under resistive load. (7 marks)**
*Appeared in: W25(7), W23(7) OR*
**Ans:**
Single-phase semi-converter (half-controlled bridge) has two SCRs and two diodes.
**Circuit:** AC supply, SCR1 (top left), SCR2 (top right? Wait: Standard semi-converter: one leg with two SCRs? Actually: Bridge: S1 (top left), D1 (bottom left), S2 (top right), D2 (bottom right). Load between midpoints.
Better description: For positive half-cycle, SCR1 and D2 conduct; for negative half-cycle, SCR2 and D1 conduct.
**Operation (resistive load):**

- **Positive half-cycle (0 to $\pi$):**
  - From 0 to $\alpha$: SCR1 off, no conduction (D2 reverse biased). $v_o$=0.
  - At $\alpha$, trigger SCR1. Current flows: supply → SCR1 → load → D2 → supply. $v_o = v_s$ (positive).
  - At $\pi$, $v_s$ crosses zero; SCR1 turns off.
- **Negative half-cycle ($\pi$ to $2\pi$):**
  - From $\pi$ to $\pi+\alpha$: SCR2 off, D1 reverse biased, $v_o$=0.
  - At $\pi+\alpha$, trigger SCR2. Current: supply → D1 → load → SCR2 → supply. $v_o = -v_s$ (positive because load polarity same as before).
  - At $2\pi$, SCR2 turns off.

**Waveforms:** Output voltage consists of positive pulses from $\alpha$ to $\pi$ and $\pi+\alpha$ to $2\pi$. No negative voltage.
**Average voltage:** Same as full-wave controlled rectifier with resistive load: $V_{o(av)} = \frac{V_m}{\pi}(1 + \cos\alpha)$.
**Advantages:** Only two SCRs, freewheeling action inherent via diodes, improved power factor at low $\alpha$.
**Real-world application:** Low-cost DC drives (small motors).
[DG PROMPT]
**Title:** Single-Phase Semi-Converter Circuit and Waveforms
**Description:** Circuit: AC source, SCR1 (top left), D2 (bottom left? Actually typical: two SCRs on top, two diodes on bottom – but semi-converter often uses one SCR and one diode per leg. I'll draw standard: top: SCR1 (left), SCR2 (right); bottom: D1 (left), D2 (right). Load between midpoints. Waveforms: $v_s$, gate pulses at $\alpha$ and $\pi+\alpha$, $v_o$ (positive pulses only).

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**O3. Explain dual converter operation with circulating current mode (single-phase**

**supply). (7 marks)**
*Appeared in: S25(7)*
**Ans:**
Dual converter consists of two fully controlled rectifiers (Converter 1 and Converter 2) connected in antiparallel across the load. It allows four-quadrant operation (motoring/braking in both directions).
**Circulating current mode:**

- Both converters are fired simultaneously.
- Converter 1 provides positive voltage ($\alpha_1 < 90°$), Converter 2 provides negative voltage ($\alpha_2 = 180° - \alpha_1$) so that average voltages are equal in magnitude but opposite polarity.
- A circulating current flows between the two converters (through the load and intergroup reactor) because instantaneous voltages differ.
- A **circulating current reactor (inductor)** is placed between the two converters to limit this current.
- Advantages: Fast response (no dead time), continuous current at all loads.
- Disadvantages: Requires large reactor, higher losses.

**Working principle (single-phase):**

- For positive load current (motoring forward): Converter 1 works as rectifier ($\alpha_1 < 90°$), Converter 2 works as inverter ($\alpha_2 > 90°$).
- For negative load current (reverse motoring): Converter 2 rectifies, Converter 1 inverts.
- Circulating current mode ensures both converters are always conducting, eliminating discontinuous current region.

**Control:** $\alpha_1 + \alpha_2 = 180°$ (constant).
**Applications:** Four-quadrant DC motor drives, rolling mills, elevators.
[DG PROMPT]
**Title:** Dual Converter with Circulating Current Mode
**Description:** Draw two single-phase full bridges connected antiparallel across load. Between them, a reactor (inductor) labeled "Circulating current reactor". Label Converter 1 ($\alpha_1$) and Converter 2 ($\alpha_2$). Show load (RLE).

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**O4. Discuss power factor improvement techniques for AC-DC converter. (7 marks)**
*Appeared in: S22(3), W24(7) OR*
**Ans:**
Power factor (PF) in controlled rectifiers is low because current waveform lags voltage (due to firing angle delay) and contains harmonics. Techniques to improve PF:

1. **Use of freewheeling diode** – Reduces negative voltage portion, improves displacement factor ($\cos \varphi$).
2. **Semi-converters** – Have better PF than full converters at the same $\alpha$ because output voltage never goes negative.
3. **Extinction angle control (EAC)** – Instead of firing angle control, use symmetrical angle control to keep current in phase.
4. **Input filters (LC)** – Reduce harmonic content, improving distortion factor.
5. **Power factor correction (PFC) boost converter** – Active PFC stage before rectifier forces input current to be sinusoidal and in phase with voltage.
6. **Multi-pulse converters** – 12-pulse, 18-pulse, 24-pulse rectifiers reduce harmonic distortion, improving true power factor.
7. **Passive filters (tuned LC traps)** – Eliminate low-order harmonics (5th, 7th, 11th, etc.).

8. **PWM rectifiers (active front end)** – Use IGBTs to shape input current sinusoidally, achieving near unity PF.

**Comparison:** Passive methods are cheaper but bulky; active PFC gives best PF but higher cost.

**Real-world application:** Power supplies (SMPS with PFC), industrial drives (12-pulse rectifiers).

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**O5. Explain effect of source inductance in converters. (3 marks)**

*(Implied question)*

**Ans:**

Source inductance ($L_s$) in AC supply causes **commutation overlap** in controlled rectifiers.

- When a thyristor turns on, the current cannot change instantly; there is an overlap period (μ) when two SCRs conduct simultaneously.
- This reduces average output voltage by an amount called **commutation drop**: $\Delta V = (L_s I_o) / (\pi/\omega)$ for single-phase.
- For three-phase: $\Delta V = (3\omega L_s I_o)/\pi$.
- Causes notches in AC line voltage, leading to EMI and distortion.
- Increases the effective firing angle delay.
- Can be mitigated by using larger snubbers or adding commutation inductors.

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**O6. Explain single-phase fully controlled center-tapped converter with R load, derive V_RMS. (7 marks)**

*Appeared in: W22(7)*

**Ans:**

Center-tapped converter uses two SCRs (S1 and S2) and a transformer with center-tapped secondary. Load R connected between center tap and common cathode point.

**Circuit:** AC supply primary; secondary with two windings (top: phase A, bottom: phase B, 180° apart). S1 anode to top winding, S2 anode to bottom winding. Cathodes of both SCRs connected together to one end of load R; other end of load to center tap.

**Operation (resistive load):**

- Positive half-cycle: top winding positive; trigger S1 at α. Current: top winding → S1 → load → center tap. $v_o = V_m \sin \omega t$ from α to π.
- Negative half-cycle: bottom winding positive; trigger S2 at π+α. Current: bottom winding → S2 → load → center tap. $v_o = V_m \sin \omega t$ (since bottom winding voltage is also positive relative to center tap). Waveform same as full-wave bridge.

**Average voltage:** Same as full-wave resistive: $V_{o(av)} = \frac{V_m}{\pi}(1 + \cos\ \alpha)$.

**RMS output voltage derivation:**

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

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

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

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

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

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

**Application:** Low-voltage high-current rectifiers (electrolysis, battery chargers).

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**O7. Draw circuit of single-phase fully controlled converter with R-L load, derive equations, sketch waveforms. (7 marks)**
*Appeared in: W24(7) OR*
**Ans:**
Circuit same as R1 (full-bridge) with RL load.
**Derivation for average output voltage (continuous conduction without freewheeling diode):**
From earlier (R4b): $V_{o(av)} = \frac{2V_m}{\pi} \cos\ \alpha$.
**Derivation steps:**

- Period = π (since output repeats every π).
- Output voltage $v_o = V_m \sin \omega t$ from α to π (S1,S4 on), and $v_o = -V_m \sin \omega t$ from π to π+α (S2,S3 on – but note that during π to π+α, S1,S4 are off but load current continues through diodes? Actually without freewheeling, SCRs turn off only when current falls to zero. For RL, current may continue beyond π, causing negative voltage until current zero. The derivation assumes continuous current and that S2,S3 are triggered at π+α, but before that, at π, the current naturally transfers? Standard derivation:
  Area = $\int_{\alpha}^{\pi+\alpha} v_o\, d\theta$ where $v_o = V_m \sin \theta$ for θ from α to π (S1,S4), and $v_o = -V_m \sin \theta$ for θ from π to π+α (but careful: for θ from π to π+α, sinθ is negative, so $-V_m$ sinθ becomes positive? Actually $v_o = -V_m$ sinθ. At θ=π, sinπ=0, $v_o$=0; at θ>π, sinθ negative => $-V_m$(negative)=positive. So indeed $v_o$ remains positive during the overlap? This is confusing. Standard textbook derivation: Average $V_o$ = (1/π) [∫*{α}^{π} $V_m$ sinθ dθ +* ∫{π}^{π+α} $V_m$ sinθ dθ? No – that would double count. Actually better to derive from Fourier or known result: $V_o = (2V_m/\pi)$ cosα. I'll present the final formula.

**For RL load with continuous current (α < 90°):**

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

**Load current $i_o$** is continuous and determined by solving L di/dt + R $i_o$ = $v_o$. Waveform is nearly DC with ripple.
**Waveforms:**

- Supply voltage $v_s$ (sine)
- Gate pulses: S1,S4 from α to π+α? No, they are triggered at α and π+α? Actually S1,S4 triggered at α, conduct until current falls to zero at β > π. Then S2,S3 triggered at π+α.
- Output voltage $v_o$: positive from α to β, then negative from β to π+α? For continuous current, β = π+α (the next pair triggers exactly when current reaches zero). So $v_o$ is positive from α to π, negative from π to π+α? That gives average $(2V_m/\pi)$cosα.
- Load current $i_o$: sinusoidal-like with DC offset.

[DG PROMPT]

**Title:** Single-Phase Full Converter with RL Load (Continuous Current)
**Description:** Waveforms: $v_s$ (sine), gate pulses (vertical lines at α and π+α), $v_o$ (positive from α to π, negative from π to π+α), $i_o$ (continuous ripple).

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**O8. Describe working of single-phase full converter in rectifier mode with RLE load, derive average output voltage. (7 marks)**
*(Incomplete, assumed 7)*
**Ans:**
RLE load (DC motor back EMF + resistance + inductance). Single-phase full bridge converter operates in rectifier mode (α < 90°). The back EMF (E) opposes the current.
**Working:**

- SCRs triggered at α. Current builds up when $v_o > E$.
- The converter supplies power to load when $v_o > E$ (motoring).
- Due to inductance, current continues even when $v_o$ drops below E, but if $v_o < E$ for too long, current may become discontinuous.
- For continuous conduction, the average output voltage $V_{o(av)} = \frac{2V_m}{\pi}\cos\alpha$ must be greater than E for rectifier mode.

**Derivation of average current:**
From Kirchhoff's voltage law: $V_o = E + I_o R$.
Thus average current $I_{o(av)} = \frac{V_{o(av)} - E}{R}$, provided $V_o(av) > E$.
**Waveforms:**

- Supply voltage, gate pulses, output voltage (same as RL load).
- Load current: rises during conduction, falls during freewheeling, with average value set by E and R.

**Application:** DC motor speed control (armature voltage control).
[DG PROMPT]
**Title:** Single-Phase Full Converter with RLE Load
**Description:** Draw circuit (bridge + RLE series). Waveforms: $v_o$, $i_o$, and back EMF line (horizontal line E).

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**O9. Distinguish between fully controlled and half-controlled bridge converter. (3 marks)**
*Appeared in: W24(3) OR*
**Ans:**

| Parameter | Fully Controlled Bridge | Half-Controlled Bridge (Semi-converter) |
|---|---|---|
| Number of SCRs | 4 | 2 |
| Number of diodes | 0 | 2 |
| Output voltage | Can be positive or negative (inverter mode) | Only positive |
| Freewheeling action | External diode needed | Inherent via diodes |
| Power factor | Poor at low α | Better at low α |

| Parameter | Fully Controlled Bridge | Half-Controlled Bridge (Semi-converter) |
|---|---|---|
| Cost | Higher | Lower |
| Applications | Four-quadrant drives, HVDC | Single-quadrant drives, battery chargers |

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**O10. Define and explain need of snubber circuit for SCR. (4 marks)**
*Appeared in: S25(4), W24(4) OR*
**Ans:**
**Snubber circuit** – an RC network (sometimes including a diode) connected across an SCR to protect it from high dv/dt and voltage spikes.
**Need:**
1. **dv/dt protection** – High rate of rise of forward voltage can falsely turn on SCR even without gate pulse. Snubber capacitor limits dv/dt.
2. **Peak voltage clamping** – During turn-off, inductive load causes voltage spikes. The snubber absorbs this energy.
3. **Reduces switching losses** – Shapes voltage-current overlap.
4. **Prevents false triggering** – Suppresses transients from supply or other SCRs.

**Typical values:** R = 10–100 Ω, C = 0.1–1 μF, with diode for unidirectional clamping.
**Real-world application:** All SCR-based power circuits (motor drives, rectifiers, inverters).

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## 🔢 NUMERICAL QUESTIONS

**N1. A single-phase full-wave AC-DC converter supplied by 230 V, 50 Hz, load R = 10 Ω, α = 30°. Determine average output voltage and current. (4 marks)**
*Appeared in: S23(4) OR*
**Given:**
$V_s$(rms) = 230 V, R = 10 Ω, α = 30° = π/6 rad.
Assume resistive load (or RL with freewheeling diode – same formula).
**Formula for full-wave controlled rectifier (resistive load):**

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

**Solution:**
$V_m$ = 1.414 × 230 = 325.22 V
cos α = cos 30° = 0.866
$V_o$(av) = (325.22 / π) × (1 + 0.866) = (103.5) × 1.866 = 193.1 V
$I_o$(av) = $V_o$(av) / R = 193.1 / 10 = 19.31 A
**Final Answer:** $V_o$(av) = **193.1 V**, $I_o$(av) = **19.31 A**.

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**N2. Derive expression for average output voltage for 1-φ half-wave controlled rectifier with RL load. (4 marks)**
*Appeared in: S22(4) OR*
**Ans:**
For half-wave controlled rectifier with RL load (without freewheeling diode), the current becomes discontinuous for most α > 0. The SCR conducts from α to extinction angle β (where current returns to zero). The average output voltage is:

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

β is found by solving the load current equation:

$$i_o(\omega t) = \frac{V_m}{Z}\left[\sin\,(\omega t - \phi) - \sin\,(\alpha - \phi)e^{-(\omega t-\alpha)/\tan\,\phi}\right]$$

Set i_o(β)=0 to find β. Where $Z = \sqrt{R^2 + (\omega L)^2}$, $\phi = \tan^{-1}(\omega L/R)$.
For purely resistive load, β = π, and the expression reduces to $\frac{V_m}{2\pi}(1 + \cos\ \alpha)$.
**For inductive load,** β > π. The average output voltage is less than the resistive case.

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**N3. Derive expression for resistance used for static voltage equalization for series-connected SCR string. (4 marks)**
*Appeared in: W22(4) OR*
**Ans:**
When SCRs are connected in series to block higher voltage, the leakage currents differ.
A **static equalizing resistor** (R) is connected in parallel with each SCR to force equal voltage sharing.
**Derivation:**
Consider two SCRs in series across DC voltage V. Leakage currents $I_1$ and $I_2$ ($I_1 > I_2$).
Without resistors, the SCR with lower leakage current ($I_2$) would have higher voltage.
With equalizing resistor R across each SCR, the total current through each parallel branch is I_leakage + V_x/R. For equal voltage sharing V/2 across each, we need:

$$I_1 + \frac{V/2}{R} = I_2 + \frac{V/2}{R} \Rightarrow I_1 = I_2$$

But since $I_1 \neq I_2$, we choose R small enough that the resistor current dominates over leakage current mismatch. Typically, R is chosen such that the resistor current is at least 5 times the maximum leakage current difference.
**Expression:**
Let $\Delta I = I_1 - I_2$ (maximum difference). For equal sharing, the voltage imbalance without resistor is $\Delta V = \Delta I \times$ (off-state resistance of SCR). To limit imbalance to a small value (say 10% of rated voltage),

$$R \leq \frac{V_{rated}}{5 \times \Delta I_{\max}}\text{(approximate)}$$

More precisely, for n SCRs in series, the required resistor value is:

$$R = \frac{V_{SCR(rated)} - V_{actual}}{I_{\max\,(leakage)}}$$

where V_actual is the voltage across one SCR when sharing is acceptable.
**Practical value:** R = 10 kΩ to 100 kΩ, power rating = $V^2/R$.
**Real-world application:** High-voltage DC transmission, series stacks of thyristors.

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