GUJARAT TECHNOLOGICAL UNIVERSITY

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

Subject Name & Code:

POWER ELECTRONICS (3140915)

UNIT 6: MISCELLANEOUS (CYCLOCONVERTERS, MATRIX CONVERTERS, PROTECTION, EMI, DATASHEETS)

🔁 REPEATED QUESTIONS

R1. Explain working of 1-φ to 1-φ cycloconverter with input 50 Hz, output 10 Hz. (7 marks)

Appeared in: S25(7) OR, S24(7), S23(7), W25(7), W23(7) OR

Ans:

A single-phase to single-phase cycloconverter converts a fixed AC frequency (50 Hz) to a lower variable frequency (10 Hz) without an intermediate DC link. It uses two back-to-back full-wave controlled rectifiers (positive and negative converters) connected to the load.

Circuit diagram:

- Input: 50 Hz AC supply.
- Two thyristor bridges: **Positive converter (P)** – provides positive output voltage; **Negative converter (N)** – provides negative output voltage.
- Load is single-phase (R or RL).

Working principle (output 10 Hz, i.e., 1/5 of input frequency):

- Desired output frequency f_o = 10 Hz. Period = 100 ms. Input frequency 50 Hz, period = 20 ms.
- One cycle of output (10 Hz) contains 5 half-cycles of input.
- **Positive half of output cycle (0 to 50 ms):** Positive converter (P) is triggered at controlled firing angles to produce a low-frequency sinusoidal envelope.
- **Negative half of output cycle (50 to 100 ms):** Negative converter (N) is triggered to produce negative voltage.
- **Firing angle modulation:** The firing angle α is varied sinusoidally (e.g., $\alpha = \alpha\_max \sin \omega_o t$) to synthesize a low-frequency sine wave.
- At any instant, only one converter conducts; the other is disabled.

Waveforms:

- Input voltage (50 Hz sine).
- Output voltage: a chopped waveform whose envelope is a 10 Hz sine wave.
- For resistive load, current follows voltage. For inductive load, current may be continuous.

Applications: Low-frequency AC drives (e.g., 0–20 Hz for large synchronous motors), induction heating, aircraft power supplies.

[DG PROMPT]

Title: 1-φ to 1-φ Cycloconverter (50 Hz → 10 Hz)

Description:

- **Circuit:** Draw AC source (50 Hz). Connect to two full-wave SCR bridges (positive

converter P and negative converter N) in antiparallel. Load R between output terminals.
- **Waveforms** (stacked, time axis 0 to 100 ms):
    1. Desired output voltage envelope (10 Hz sine).
    2. Actual output voltage: groups of 5 half-cycles (positive from P, negative from N) with varying pulse widths.
    3. Gate pulses pattern for P and N.

R2. What is a cycloconverter? List industrial applications. (4 marks)
Appeared in: S24(4), W23(3)
Ans:
Cycloconverter – a single-stage AC-to-AC converter that directly changes the frequency and voltage of an AC supply to a lower frequency without a DC link. It uses naturally commutated thyristors and produces a stepped approximation of a sine wave at the output.
Key features:
- Output frequency f_o < input frequency f_i (typically $f_o \leq f_i/3$).
- Bidirectional power flow.
- Line commutated (no forced commutation).

Industrial applications:
1. **Low-speed large AC motor drives** – cement mills, ball mills, ore crushers (0–20 Hz).
2. **Ship propulsion** – synchronous motors.
3. **Induction heating** – low-frequency heating.
4. **Wind turbine generators** – variable frequency to grid.
5. **Aerospace ground power** – 400 Hz to 50/60 Hz.
6. **Electric traction** (limited use).

R3. Write short note on / Explain matrix converter. (4 marks)
Appeared in: S25(4) OR, S24(3) OR, W25(4), W24(4) OR, W22(4)
Ans:
Matrix converter – a direct AC-AC converter using an array of bidirectional switches (usually 9 for 3-φ to 3-φ) to connect any input phase to any output phase directly. No DC link or large energy storage components.
Circuit:
3 input lines (R,Y,B) and 3 output lines (U,V,W). Each output line connects to all three input lines via bidirectional switches (e.g., two IGBTs in antiparallel with series diodes? Actually, common configuration uses IGBTs with reverse blocking capability or back-to-back IGBTs).
Working principle:
- Switch matrix is controlled using PWM (e.g., Venturini modulation) to synthesize sinusoidal output voltages with desired frequency and amplitude.
- Output frequency can be above or below input frequency.
- Input power factor can be controlled (unity or leading).

Advantages:
- No bulky DC link capacitor/inductor.
- Bidirectional power flow.
- Sinusoidal input/output currents.

Disadvantages:
- Complex control.
- Voltage transfer ratio limited to ~0.866.
- Requires many bidirectional switches (9 for 3-φ).

Applications: Aerospace, variable frequency drives, wind energy systems.
[DG PROMPT]
Title: Matrix Converter (3-φ to 3-φ)
Description: Draw three input lines (R,Y,B) and three output lines (U,V,W). At each intersection, place a bidirectional switch symbol (two arrows opposite). Label 9 switches S_{11}, S_{12} … S_{33}.

R4. Describe adverse effects of EMI and remedial steps. (7 marks)
Appeared in: S25(7), W25(4) OR, W24(3)
Ans:
Electromagnetic Interference (EMI) in power electronics arises from high dv/dt and di/dt during switching.
Adverse effects of EMI:

1. **Malfunction of nearby electronic devices** – microcontrollers, PLCs, communication systems.
2. **Data corruption** – in digital circuits.
3. **Radio frequency interference** – disrupts AM/FM, TV, wireless communications.
4. **False triggering of SCRs / IGBTs** – leading to shoot-through or circuit failure.
5. **Heating in adjacent conductors** – eddy currents.
6. **Compliance issues** – violates EMC standards (CISPR, FCC).

Remedial steps (EMI mitigation):

1. **Snubber circuits** (RC across switches) – reduce dv/dt and di/dt.
2. **Soft switching** (resonant converters) – reduces switching transients.
3. **Shielding** – metal enclosures, shielded cables.
4. **Filtering** – EMI filters (common-mode and differential-mode chokes, X/Y capacitors) at input/output.
5. **Grounding** – proper low-impedance grounding.
6. **PCB layout** – short traces, separate power and signal grounds, ferrite beads.
7. **Spread spectrum clocking** – spreads energy over wider band.
8. **Use of opto-isolators / pulse transformers** – for gate isolation.

Real-world application: Designing SMPS, motor drives, and inverters to pass EMC tests.

R5. Explain snubber circuit and its design. (4 marks)
Appeared in: W24(4) OR, W23(4) OR
Ans:
A snubber circuit is an RC (or RCD) network connected across a power semiconductor to protect it from high dv/dt, voltage spikes, and ringing.
Basic snubber across SCR (or IGBT):

- Resistor R (10–100 Ω) in series with capacitor C (0.1–1 μF) connected from anode to cathode.
- Optional diode for unidirectional clamping.

Purpose:

1. Limits dv/dt – prevents false turn-on.
2. Absorbs energy from inductive load during turn-off.
3. Damps parasitic oscillations (LC ringing).

Design steps (for SCR turn-off snubber):

- Measure or estimate circuit inductance (L_s) and peak current (I_p).
- Choose capacitor C to limit dv/dt to a safe value:

$$C \geq \frac{I_p}{dv/dt_{\text{max}}}$$

Typically dv/dt_max = 50–100 V/μs for SCRs.

- Choose resistor R to damp oscillations and limit discharge current:

$$R = 2\sqrt{\frac{L_s}{C}}\text{(critical damping)}$$

Or empirical: R = 10–100 Ω.

- Power rating of R: $P_R = \frac{1}{2}CV^2 f_s$ (for each switching cycle).

RCD snubber (diode in parallel with R) – provides unidirectional clamping and lower losses.

Real-world application: Every power converter (rectifiers, inverters, choppers) with inductive loads.

[DG PROMPT]

Title: Snubber Circuit for SCR

Description: Draw SCR symbol (anode top, cathode bottom). Across it, connect a series RC branch (R and C). Optional: add a diode in parallel with R (cathode to anode of SCR). Label R_snub, C_snub.

📌 **OTHER IMPORTANT QUESTIONS**

O1. Explain midpoint cycloconverter briefly. (4 marks)

Appeared in: W25(4) OR

Ans:

Midpoint cycloconverter (or center-tapped cycloconverter) uses a transformer with a center-tapped secondary per phase. It is a single-phase to single-phase or three-phase to single-phase configuration.

Circuit:

- Input transformer secondary has a center tap.
- Two thyristor bridges (positive and negative groups) are connected from each end to the center tap.
- Load connected between the junction of the two converters and the center tap.

Operation:

- Positive group produces positive voltage pulses; negative group produces negative voltage pulses.
- By controlling firing angles, a low-frequency AC output is synthesized.
- Similar to bridge cycloconverter but requires fewer thyristors for low voltage, high current applications.

Advantages:

- Fewer thyristors for single-phase output.
- Good for low voltage, high current.

Disadvantages:

- Requires center-tapped transformer (heavy, costly).

Applications: Large low-speed AC drives (e.g., mine winders).

[DG PROMPT]

Title: Midpoint Cycloconverter (1-φ to 1-φ)

Description: Draw AC source feeding a transformer with center-tapped secondary. Two SCR bridges: one connected from top to center, other from bottom to center. Load between bridge output and center tap.

O2. Explain operation of three-phase to single-phase cycloconverter. (7 marks)
Appeared in: W23(7)
Ans:
A three-phase to single-phase cycloconverter converts a fixed three-phase AC supply into a single-phase variable frequency, variable voltage output. It uses two three-phase fully controlled converters (positive and negative) connected in antiparallel.
Circuit:
- Three-phase supply feeds a three-phase fully controlled bridge (positive group P) and another identical bridge (negative group N).
- The DC outputs of both bridges are connected in antiparallel across a single-phase load.

Working principle:
- Desired output frequency f_o (typically < $f_i/3$).
- Positive converter (P) is fired with variable firing angle $\alpha = \alpha\_max \sin \omega_o t$ to produce positive voltage envelope.
- Negative converter (N) is fired with $\alpha = \pi - \alpha\_max \sin \omega_o t$ to produce negative voltage envelope.
- Only one converter conducts at a time. For inductive load, a circulating current mode (with intergroup reactor) may be used to maintain continuity.

Waveforms:
- Input three-phase voltages.
- Output voltage: stepped waveform whose envelope is a low-frequency sine wave.
- Output current: nearly sinusoidal for RL load.

Why three-phase to single-phase?
- Provides higher power rating, lower output ripple, and better input power factor than single-phase cycloconverter.

Applications:
- Single-phase large induction heating (e.g., 50 Hz to 5–10 Hz).
- Railway traction (single-phase AC motor drives from three-phase grid).

[DG PROMPT]
Title: 3-φ to 1-φ Cycloconverter
Description: Draw three-phase source (R,Y,B). Two three-phase full-bridge SCR converters (P and N) with their DC outputs connected antiparallel across a single-phase load. Label P (positive group) and N (negative group).

O3. Draw basic circuit diagram of 3-phase to 3-phase cycloconverter. (3 marks)
Appeared in: W23(3) OR
Ans:
A three-phase to three-phase cycloconverter consists of three single-phase cycloconverters (each fed from the same three-phase supply) connected to the three output phases (U, V, W). Each output phase uses two three-phase converters (positive and negative groups).
Basic diagram:
- Input: three-phase lines R, Y, B.
- For output phase U: Positive converter group (P_U) and negative converter group (N_U) fed from R,Y,B. Output U is the common point.
- Similarly for V and W.
- Total 18 SCRs (6 per output phase? Actually each output phase requires 12 SCRs for three-phase to single-phase? Wait, a three-phase to single-phase cycloconverter uses 12 SCRs (two 3-phase bridges). For 3-φ to 3-φ, three such units are needed → 36 SCRs.)

Simplified drawing: Show three blocks labeled "Cycloconverter for phase U", "for V", "for W" each connected to input R,Y,B. Output terminals U,V,W to load.
[DG PROMPT]
Title: 3-φ to 3-φ Cycloconverter (Block Diagram)
Description: Draw three input lines (R,Y,B). Three identical cycloconverter units (U, V, W) each connected to all three input lines. Outputs U, V, W go to a three-phase load.

O4. Show that fundamental RMS output voltage per phase for m-pulse cycloconverter is: $V_{or} = V_{ph} \cdot \frac{m}{\pi} \sin\left(\frac{\pi}{m}\right)$. (7 marks)
Appeared in: W25(7) OR, W22(7) OR
Ans:
For a cycloconverter operating with output frequency much lower than input frequency, the output voltage is synthesized by firing thyristors at varying angles. The maximum possible fundamental RMS output voltage occurs when the firing angle α varies from 0 to π (or 0 to 180°) in a sinusoidal manner.
Consider an m-pulse cycloconverter (m = 6 for three-phase bridge). The output voltage waveform is a sequence of m pulses per half-cycle of output. The envelope of the output voltage is a sine wave.
Derivation:
Each pulse is a segment of the input AC voltage. The peak of the fundamental component of the output voltage can be obtained from the Fourier series of the pulse train.
Alternatively, known result: For a cycloconverter operating with ideal filtering, the maximum RMS fundamental output voltage is:

$$V_{or} = V_{ph} \cdot \frac{m}{\pi} \sin\left(\frac{\pi}{m}\right)$$

where V_{ph} is the RMS phase voltage of the input supply.
Proof (simplified):

- The output voltage is generated by sequentially firing thyristors at intervals of 2π/m (where m is number of pulses per cycle of input).
- The average value of the output voltage over a small interval follows the reference sine wave.
- The fundamental component of the output voltage is proportional to the area under the envelope.
- For maximum output, the firing angle α varies as: $\alpha = \alpha_0 \cos \omega_o t$.
- The maximum RMS output voltage is $V_{or} = V_{ph} \cdot \sin(\pi/m)/(\pi/m)$ actually the formula given is m/π sin(π/m). This is a standard formula for the maximum output of a cycloconverter.

Example for m=6 (three-phase bridge):

$$V_{or} = V_{ph} \cdot \frac{6}{\pi} \sin\left(\frac{\pi}{6}\right) = V_{ph} \cdot \frac{6}{\pi} \cdot 0.5 = V_{ph} \cdot \frac{3}{\pi} \approx 0.955 V_{ph}$$

Thus, maximum output ≈ 95.5% of input phase voltage.
Application: Used to determine the voltage rating of cycloconverter-fed motors.

O5. Discuss why 3-phase to 1-phase cycloconverter requires positive/negative group converters, and when they work as inverters/rectifiers. (7 marks)
Appeared in: W22(7) OR
Ans:
A 3-phase to single-phase cycloconverter uses two three-phase fully controlled converters

(positive group P and negative group N) connected in antiparallel to produce a low-frequency AC output.

Why positive and negative groups?

- To generate both positive and negative half-cycles of the output AC voltage.
- Positive group (P) conducts during the positive half of the output cycle, producing positive voltage across the load.
- Negative group (N) conducts during the negative half of the output cycle, producing negative voltage.
- This arrangement allows bidirectional current flow and true AC output without DC offset.

When do they work as rectifiers or inverters?

- **Rectifier mode:** When the converter delivers power from the AC source to the load (motoring). The firing angle α is less than 90°.
    - Positive group acts as rectifier during positive output half-cycle ($\alpha < 90°$).
    - Negative group acts as rectifier during negative output half-cycle ($\alpha < 90°$ relative to its own supply polarity).
- **Inverter mode:** When power flows from the load back to the source (regenerative braking). The firing angle α is greater than 90°.
    - For positive group: $\alpha > 90° \Rightarrow$ average output voltage is negative while current is positive → power flows into source.
    - For negative group: $\alpha > 90°$ (in its reference) also gives regeneration.

Why both groups are needed even for simple resistive load?

- For inductive load, current may lag. When the output voltage changes polarity, the current may still be positive. The positive group cannot turn off until current falls to zero. The negative group is disabled until current reverses. This ensures proper commutation.

Practical operation:

- For output frequency f_o, the firing angles are modulated: $\alpha\_P = \alpha_0 \sin \omega_o t$ (positive group), $\alpha\_N = \pi - \alpha_0 \sin \omega_o t$ (negative group).
- At any instant, only one group conducts; the other is blocked.

Real-world application: Low-speed high-power AC drives (e.g., ball mills).

O6. List any six applications of power electronics. (3 marks)

Appeared in: W22(3) OR

Ans:

Six applications of power electronics:

1. **Uninterruptible Power Supply (UPS)** – for computers, hospitals.
2. **Electric vehicle (EV) drives** – motor controllers, battery chargers.
3. **Renewable energy systems** – solar inverters, wind turbine converters.
4. **Industrial motor drives** – variable frequency drives (VFDs).
5. **Power supplies** – SMPS for computers, chargers, LED drivers.
6. **HVDC transmission** – rectifiers and inverters for long-distance power transfer.

O7. Explain working of series inverter with diagram and waveforms. (7 marks)

Appeared in: W24(7) OR

Ans:

A series inverter (also called load-resonant inverter) uses an LC series resonant circuit as the load. It is used for high-frequency AC power (e.g., induction heating). It is a forced-commutated inverter using SCRs or IGBTs.

Circuit diagram (basic SCR version):

- DC supply (V_dc) with two SCRs (S1, S2) in a half-bridge configuration? Actually classic series inverter: two SCRs (S1, S2) and a center-tapped transformer or two capacitors? Standard series inverter:
  - DC source with a large inductor L_d (current source behavior) or voltage source with commutating capacitor. Better to describe: **Series resonant inverter** – DC supply, two SCRs (S1, S2) in antiparallel with diodes, resonant capacitor C and inductor L (load) in series across the SCRs.

Working principle (voltage source version):

- Initially, capacitor C is charged. Trigger S1. Capacitor discharges through L and S1, producing a sinusoidal current pulse (half cycle).
- When current falls to zero, S1 turns off (forced commutation by resonant current zero).
- Then trigger S2. Capacitor recharges in opposite polarity and discharges through S2, producing next half-cycle.
- Output frequency $f_r = 1/(2\pi\sqrt{LC})$.

Waveforms:

- Gate pulses for S1 and S2 (alternating).
- Load current: sinusoidal bursts (half-cycles).
- Load voltage: nearly sinusoidal due to resonance.
- Capacitor voltage: triangular or sinusoidal.

Advantages:

- Simple commutation (load commutation).
- High frequency possible (kHz range).

Disadvantages:

- Output frequency depends on load (LC tuning).
- Not suitable for wide range frequency variation.

Applications: Induction heating, high-frequency soldering, fluorescent lamp ballasts.
[DG PROMPT]
Title: Series Inverter (Resonant Inverter)
Description: Draw DC source V_dc. Two SCRs (S1, S2) in series with each other across DC? Actually draw half-bridge: DC source, S1 and S2 in series with center tap? I'll draw classic: DC source, resonant inductor L and capacitor C in series with the SCR pair. Show S1 and S2 in antiparallel with diodes D1, D2. Load is L and C. Waveforms: gate pulses, load current (sinusoidal half-cycles).

O8. Explain working of 1-φ current source inverter with waveforms. (7 marks)
Appeared in: S22(7) OR
Ans:
A single-phase current source inverter (CSI) uses a constant DC current source (large inductor in series with DC supply) and switches (thyristors) to convert DC current to AC current. Output current is a square wave, and voltage depends on load.
Circuit:

- DC source with large series inductor (current source).
- Four thyristors (S1, S2, S3, S4) in bridge configuration.
- AC load (R-L) connected at bridge output.
- Commutation capacitors across each thyristor (or a common capacitor) for forced commutation.

Working (square wave operation):

- **Mode 1 (0 to T/2):** Trigger S1 and S4. Load current flows from supply through S1 → load → S4. Output current = +I_dc (constant).

- **Commutation (at T/2):** Turn off S1, S4 and turn on S2, S3 using commutation capacitors (capacitor voltage forces reverse current through S1, S4 to turn them off).
- **Mode 2 (T/2 to T):** S2 and S3 conduct, load current reverses = –I_dc.
- Load current is a square wave of amplitude I_dc.

Waveforms:

- Output current i_o: square wave ±I_dc.
- Output voltage v_o: shaped by load (for R-L, voltage is sinusoidal-like with spikes due to commutation).
- Gate pulses for S1,S4 and S2,S3 (alternating).

Advantages:

- Short-circuit protection (current source limits current).
- Simple control.

Disadvantages:

- Requires large DC inductor.
- Forced commutation adds complexity.

Applications: Large induction heating, high-power motor drives (with forced commutation).
[DG PROMPT]
Title: Single-Phase Current Source Inverter
Description: Draw DC source with large inductor L_d in series (current source). Four SCRs in bridge (S1 top left, S2 top right, S3 bottom left, S4 bottom right). Load between midpoints. Commutation capacitors shown across each SCR (or one across output). Waveforms: square wave output current, output voltage with spikes.

O9. Compare CSI and VSI. (3 marks)
Appeared in: W24(3) OR
Ans:

Parameter	VSI (Voltage Source Inverter)	CSI (Current Source Inverter)
DC source	Voltage source (capacitor across DC)	Current source (large inductor in series)
Output waveform	Voltage is controlled (PWM); current depends on load	Current is controlled (square wave); voltage depends on load
Commutation	Usually self-commutated (MOSFET/IGBT)	Needs forced commutation (thyristors)
Protection	Requires overcurrent protection	Inherently short-circuit proof
Harmonics	Lower (with PWM)	Higher (square wave current)
Efficiency	High	Moderate
Applications	UPS, motor drives (low to medium power)	High-power induction heating, large motor drives

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