

GUJARAT TECHNOLOGICAL UNIVERSITY

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

Subject Name & Code:

POWER ELECTRONICS (3140915)

(Disclaimer: The purpose of these AI-generated responses is just education and reference. Utilise them to grasp topics and structure, but always rewrite in your own words and double-check)

UNIT 2: DC-DC CONVERTERS (SWITCHING VOLTAGE REGULATORS)

REPEATED QUESTIONS

R1. Explain Buck converter with circuit diagram and waveforms. (7 marks)

Appeared in: S25(7) OR, S24(3), S24(4), S23(3), W22(4) → Highest: 7

Ans:

Buck converter (step-down chopper) – produces average output voltage lower than input DC voltage.

Circuit diagram:

- DC input V_{in} (with filter capacitor)
- Switch (MOSFET/IGBT) in series with load
- Freewheeling diode across load (cathode to switch output)
- Inductor L and capacitor C filter at output
- Load resistance R

Modes of operation (CCM):

1. **Switch ON ($0 \leq t \leq DT$)** – Diode reverse biased. Inductor current rises linearly. $V_L = V_{in} - V_o$. Inductor stores energy.
2. **Switch OFF ($DT \leq t \leq T$)** – Diode forward biased (freewheeling). Inductor current decays through diode. $V_L = -V_o$.

Waveforms:

- Gate pulse (0 to T)
- Inductor current i_L (linear rise, linear decay)
- Inductor voltage V_L (positive then negative)
- Diode current i_D (zero during ON, equals i_L during OFF)
- Output voltage V_o (ripple small)

Output voltage derivation (CCM):

Volt-second balance: $V_o = D \times V_{in}$, where $D = \text{duty cycle} = t_{on}/T$.

Applications: Battery chargers, CPU VRMs, LED drivers.

[DG PROMPT]

Title: Buck Converter Circuit and Waveforms

Description:

- **Circuit:** Draw V_{in} (DC source) positive to switch (S). Switch output to one end of inductor L . Other end of L to capacitor C (parallel with load R). Cathode of freewheeling diode D connected to switch output, anode to ground. Ground line. Label V_{in} , S , L , C , R , D , V_o .
- **Waveforms** (three graphs stacked, same time axis):
 (1) Gate voltage V_{G_s} – high (DT), low ($T-DT$).
 (2) Inductor current i_L – rising ramp (0 to DT), falling ramp (DT to T).

(3) Inductor voltage V_L – positive $V_{in} - V_o$ during ON, negative $-V_o$ during OFF.

(4) Diode current i_D – zero during ON, same as i_L during OFF.

R2. Describe the principle of step-up chopper / Boost converter. Derive output voltage equation. (7 marks)

Appeared in: S24(7), S22(7) OR, W22(7)

Ans:

Boost converter (step-up chopper) – output voltage > input voltage.

Principle: Inductor stores energy when switch is ON and releases it in series with input when switch is OFF.

Circuit diagram:

- V_{in} in series with inductor L
- Switch (S) from inductor output to ground
- Diode from inductor output to capacitor C and load R

Modes:

1. **Switch ON ($0 \rightarrow DT$)** – Diode reverse biased. Inductor charges: $V_L = V_{in}$, i_L rises.
2. **Switch OFF ($DT \rightarrow T$)** – Diode forward biased. Inductor voltage reverses: $V_L = V_{in} - V_o$ (negative, because $V_o > V_{in}$). Inductor releases energy to load + capacitor.

Derivation of V_o :

Volt-second balance across inductor:

$$V_{in} \times DT + (V_{in} - V_o) \times (1-D)T = 0$$

$$V_{in} D + V_{in}(1-D) - V_o(1-D) = 0$$

$$V_{in} - V_o(1-D) = 0$$

$$V_o = V_{in} / (1 - D)$$

Important: $D > 0$; as $D \rightarrow 1$, $V_o \rightarrow \infty$ (theoretically). Practical limit.

Waveforms: Inductor current triangular, diode current pulsed.

Applications: Power factor correction (PFC), battery boost in EVs, regenerative braking.

[DG PROMPT]

Title: Boost Converter Circuit Diagram

Description: Draw V_{in} (DC) positive to one end of inductor L. Other end of L connected to switch S (to ground) and also to anode of diode D. Cathode of D to parallel combination of capacitor C and load R (other end to ground). Label V_{in} , L, S, D, C, R, V_o .

R3. Discuss operation of Flyback converter. (7 marks)

Appeared in: S25(3), S23(4) OR, W24(7) OR $\rightarrow$ Highest: 7

Ans:

Flyback converter – isolated DC-DC converter derived from buck-boost topology. Uses coupled inductor (transformer) for isolation and energy storage.

Operation (CCM/DCM):

- **Switch ON:** Primary winding of transformer acts as inductor. Primary current rises linearly, energy stored in magnetizing inductance. Secondary diode reverse biased – no load current.
- **Switch OFF:** Magnetic field collapses. Secondary diode forward biased, stored energy transferred to load via secondary winding. Output capacitor supplies load during ON time.

Output voltage (DCM ideal):

$$V_o = V_{in} \times (N_2/N_1) \times D / (1 - D)$$

where D = duty cycle, N_2/N_1 = turns ratio.

Advantages: Simple, multiple outputs possible (by adding secondary windings), inherently isolated.

Disadvantages: High ripple, transformer core saturation risk, poor cross-regulation.

Applications: Low-power SMPS (phone chargers, standby supplies), auxiliary power supplies.

[DG PROMPT]

Title: Flyback Converter Circuit

Description: Draw V_{in} positive to primary of transformer (N_1). Other end of primary to switch S to ground. Secondary winding (N_2) in opposite polarity dot convention. Secondary anode to diode D, cathode to capacitor C in parallel with load R. Ground reference for secondary side separate from primary. Label all components.

R4. Explain multi-quadrant operation of DC-DC converter. (7 marks)

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

Ans:

Multi-quadrant operation refers to ability of DC-DC converter to handle positive/negative voltage and current – i.e., power flow in both directions or regenerative braking.

Four quadrants (V-I plane):

- **Quadrant I:** $V > 0, I > 0$ (forward motoring) – power flows from source to load.
- **Quadrant II:** $V > 0, I < 0$ (forward braking) – load returns power to source (regeneration).
- **Quadrant III:** $V < 0, I < 0$ (reverse motoring).
- **Quadrant IV:** $V < 0, I > 0$ (reverse braking).

Type-A chopper – single quadrant (I only).

Type-B chopper – Quadrant II only (regenerative).

Two-quadrant (Type C) – I and II (forward motoring + braking).

Four-quadrant (Type D/E) – all four quadrants (using H-bridge or dual converters).

Example – Four-quadrant chopper (H-bridge):

- Switches S1, S4 ON $\rightarrow V_o$ positive, I positive (Q1).
- S1, S4 ON with reverse current $\rightarrow Q2$.
- S2, S3 ON $\rightarrow V$ negative, I negative (Q3).
- S2, S3 ON with reverse current $\rightarrow Q4$.

Applications: Electric vehicle drives (regenerative braking), servo motor control, crane hoists.

[DG PROMPT]

Title: Four-Quadrant Operation of DC-DC Converter

Description: Draw X-axis Voltage (V), Y-axis Current (I). Divide into four quadrants. Label Quadrant I (+,+), II (-,+), III (-,-), IV (+,-). Below, draw H-bridge circuit: V_{in} rail, four switches S1 (top left), S2 (top right), S3 (bottom left), S4 (bottom right). Load between midpoints. Show conduction paths for each quadrant.

♦ OTHER IMPORTANT QUESTIONS

O1. What is buck regulator? Draw circuit and waveforms for voltage across freewheeling diode, current through inductor. (3 marks)

Appeared in: S24(3), S22(3)

Ans:

Buck regulator = Buck converter (step-down).

Circuit: Same as R1.

Waveforms:

- **Inductor current i_L** – triangular rising during switch ON, falling during OFF.
- **Freewheeling diode voltage V_D** – during switch ON: $V_D = -V_o$ (reverse biased). During OFF: $V_D \approx 0$ (forward drop). Negative spike at turn-off.

[DG PROMPT – short]

Same as R1 diagram but highlight diode voltage waveform.

O2. Give classification and types of DC-DC converter topologies. (3 marks)

Appeared in: S23(3)

Ans:

Classification by isolation:

1. **Non-isolated** – Buck, Boost, Buck-Boost, Cuk, SEPIC, Zeta.
2. **Isolated** – Flyback, Forward, Push-Pull, Half-bridge, Full-bridge.

By quadrants:

- Single quadrant (Type A)
- Two quadrant (Type B, C)
- Four quadrant (Type D, E)

By control: Voltage mode, Current mode, Hysteretic.

O3. Compare linear voltage regulator and switching voltage regulator. (3 marks)

Appeared in: W25(3)

Ans:

Parameter	Linear Regulator	Switching Regulator
Efficiency	Low (30–50%)	High (80–95%)
Size	Large heatsink needed	Small heatsink
Ripple	Very low	Higher (needs filtering)
EMI	Negligible	Significant
Cost	Low	Moderate to high
Application	Low power, noise sensitive	High power, battery powered

O4. Explain working of 2-quadrant chopper. (4 marks)

Appeared in: S22(4), W25(4)

Ans:

Two-quadrant chopper (Type C) – operates in QI (forward motoring) and QII (forward braking).

Circuit: Two switches (S1, S2) and two diodes (D1, D2) with center-tapped inductor or H-bridge half.

- **QI (Motoring):** S1 ON, D2 reverse biased. Current positive, voltage positive.
- **QII (Braking):** S2 ON, D1 conducts. Current negative (regeneration), voltage positive.

Application: Electric vehicle braking energy recovery.

O5. Explain working of buck-boost converter with circuit diagram of different modes of operation. (7 marks)

Appeared in: W22(7) OR

Ans:

Buck-boost converter – output voltage can be lower or higher than input, but polarity reversed (inverting).

Circuit: $V_{in} \rightarrow \text{switch } S \rightarrow \text{inductor } L \rightarrow \text{diode } D \rightarrow \text{capacitor } C // \text{load } R$. Inductor between switch and diode. Diode cathode to output positive, anode to ground.

Modes (CCM):

- **Mode 1 (S ON):** Diode reverse biased. $V_1 = V_{in}$. Inductor stores energy. Load supplied by capacitor.
- **Mode 2 (S OFF):** Diode forward biased. $V_1 = -V_o$. Inductor releases energy to load + capacitor.

Output voltage: $V_o = -V_{in} \times D/(1-D)$. Negative output.

Waveforms: Inductor current triangular, diode current pulsed.

Applications: Battery chargers, negative voltage generators.

O6. Discuss discontinuous mode of operation in buck-boost converter with waveforms. (7 marks)

Appeared in: W24(7) OR

Ans:

Discontinuous Conduction Mode (DCM) – inductor current falls to zero before end of switching period.

Conditions for DCM: Load current low, or inductance small, or switching frequency low.

Waveforms in DCM (buck-boost):

- **Interval 1 ($0 - D_1T$):** S ON, i_L rises from 0 to I_{peak} .
- **Interval 2 ($D_1T - (D_1+D_2)T$):** S OFF, i_L decays linearly to zero.
- **Interval 3 (remaining):** $i_L = 0$, diode off. Output capacitor supplies load.

Key differences from CCM:

- Output voltage becomes load-dependent: $V_o = V_{in} \times D / \sqrt{(2Lf/R)}$ approx.
- Higher peak currents.
- No reverse recovery loss in diode.

Advantage: Smaller inductor possible.

Disadvantage: Higher ripple, complex control.

[DG PROMPT]

Title: Buck-Boost DCM Waveforms

Description: Three plots: (1) Gate pulse (high D_1T , low rest), (2) Inductor current – triangle starting at zero, rising to peak, falling to zero before next cycle, (3) Diode current – zero during interval 1, equals i_L during interval 2, zero interval 3.

O7, O8, O9 – Additional Concepts (Concise notes)

O7. Closed loop control for voltage regulation – Uses feedback (voltage divider, error amplifier, PWM comparator) to adjust duty cycle for constant V_o despite input/load changes. Common ICs: TL494, UC3842.

O8. CCM vs DCM:

- **CCM:** i_L never zero, lower peak currents, larger L required.
- **DCM:** i_L zero each cycle, smaller L , higher ripple, load-dependent V_o .

O9. Applications of DC-DC converters:

- Buck: CPU VRM, battery chargers
- Boost: PFC, LED boost drivers
- Buck-boost: negative rail, battery backup
- Isolated: telecom, medical, SMPS

NUMERICAL QUESTIONS

N1. A step-up chopper has input voltage 220 V and output voltage 660 V. If turn-off time is 100 μ s, compute turn-on time. (7 marks)

Appeared in: S23(7)

Given:

$$V_{in} = 220 \text{ V}, V_o = 660 \text{ V}, t_{off} = 100 \mu\text{s}$$

$$\text{For step-up chopper (boost type): } V_o = V_{in} / (1 - D)$$

$$\text{Also } D = t_{on} / T, T = t_{on} + t_{off}$$

To find: t_{on}

Formula:

$$1 - D = V_{in} / V_o = 220/660 = 1/3$$

$$\Rightarrow D = 1 - 1/3 = 2/3$$

$$\Rightarrow t_{on} / (t_{on} + t_{off}) = 2/3$$

$$\Rightarrow 3 t_{on} = 2 t_{on} + 2 t_{off}$$

$$\Rightarrow t_{on} = 2 t_{off} = 2 \times 100 \mu\text{s} = \mathbf{200 \mu\text{s}}$$

Final Answer: $t_{on} = 200 \mu\text{s}$

N2. A boost converter has input voltage 6 V, average output voltage 15 V, switching frequency 20 kHz. Find duty cycle. (7 marks)

Appeared in: S23(7) OR

Given:

$$V_{in} = 6 \text{ V}, V_o = 15 \text{ V}, f = 20 \text{ kHz (not needed for D)}$$

$$\text{Formula: } V_o = V_{in} / (1 - D)$$

$$\Rightarrow 1 - D = V_{in} / V_o = 6/15 = 0.4$$

$$\Rightarrow D = 1 - 0.4 = \mathbf{0.6 \text{ (or 60\%)}}$$

Final Answer: $D = 0.6$

N3. For type A chopper, dc source voltage = 230 V, load resistance 10 Ω , voltage drop 2 V across chopper when on, duty cycle 0.4. Calculate average and RMS output voltage and chopper efficiency.

Given:

- V_s (source voltage) = 230 V
- R (load resistance) = 10 Ω
- V_l (on-state voltage drop of chopper switch) = 2 V
- Duty cycle $\alpha = D = 0.4$
- Chopper type: Type A (single-quadrant, step-down)

To find:

1. Average output voltage ($V_{o(av)}$)
2. RMS output voltage ($V_{o(rms)}$)
3. Chopper efficiency (η)

Assumptions:

- Ideal freewheeling diode (zero drop)
- Continuous conduction mode (CCM)
- Switching frequency high enough that load current is continuous
- No other losses except chopper on-state drop

Step 1: Average output voltage

For a Type A chopper (buck converter) with voltage drop:

$$V_{o(av)} = D \times (V_s - V_{ch}) + (1 - D) \times 0$$

Because during off-time, freewheeling diode conducts and output voltage is nearly zero

(neglecting diode drop).

If diode drop is considered negligible, then:

$$V_{o(av)} = D \times (V_s - V_{ch})$$

Substitute values:

$$V_{o(av)} = 0.4 \times (230 - 2) = 0.4 \times 228 = 91.2 \text{ V}$$

Step 2: RMS output voltage

For a Type A chopper with voltage drop (assuming constant V_s and ideal diode, output voltage waveform is rectangular: $V_s - V_{ch}$ during $D \cdot T$, zero during $(1-D)T$):

$$V_{o(rms)} = \sqrt{D \times (V_s - V_{ch})^2 + (1 - D) \times 0^2}$$

$$V_{o(rms)} = \sqrt{D} \times (V_s - V_{ch})$$

$$V_{o(rms)} = \sqrt{0.4} \times 228 = 0.63246 \times 228 = 144.2 \text{ V}$$

Step 3: Chopper efficiency

Efficiency = (Output power) / (Input power)

Load current (average):

Assuming resistive load with average voltage:

$$I_{o(av)} = \frac{V_{o(av)}}{R} = \frac{91.2}{10} = 9.12 \text{ A}$$

Average output power:

$$P_o = V_{o(av)} \times I_{o(av)} = 91.2 \times 9.12 = 831.74 \text{ W}$$

Input power:

Source sees current only during ON time. Average source current:

$$I_{s(av)} = D \times I_{o(av)} = 0.4 \times 9.12 = 3.648 \text{ A}$$

$$P_{in} = V_s \times I_{s(av)} = 230 \times 3.648 = 839.04 \text{ W}$$

Efficiency:

$$\eta = \frac{P_o}{P_{in}} \times 100\% = \frac{831.74}{839.04} \times 100\% \approx 99.13\%$$

Alternatively, efficiency can be found from voltage ratio (ignoring switching losses):

$$\eta = \frac{V_{o(av)}}{D \times V_s} = \frac{91.2}{0.4 \times 230} = \frac{91.2}{92} = 0.9913 \rightarrow 99.13\%$$

Final Answers:

- Average output voltage = 91.2 V
- RMS output voltage = 144.2 V
- Chopper efficiency = 99.13 %

N4. For boost regulator, derive formula of rise time and fall time of inductor current and output voltage. (4 marks)

Appeared in: S22(4) OR

Ans:

For boost converter in CCM:

Rise time (t_r) of i_l (during switch ON):

$$di_l/dt = V_{in} / L$$

$$\Delta i_l = V_{in} \times t_{on} / L \Rightarrow t_{on} \text{ (i.e., rise time)} = \Delta i_l \times L / V_{in}$$

Fall time (t_f) of i_l (during switch OFF):

$$di_l/dt = -(V_o - V_{in})/L \text{ (since } V_l = V_{in} - V_o, \text{ negative)}$$

$$\Delta i_l \text{ (fall)} = (V_o - V_{in}) \times t_{off} / L$$

$$\Rightarrow t_{off} = \Delta i_l \times L / (V_o - V_{in})$$

Output voltage ripple (rise/fall):

$$\Delta V_o = (I_o \times D \times T) / C$$

where $I_o = V_o/R$. Rise and fall times of V_o are determined by capacitor charging/discharging during switch OFF/ON.
