

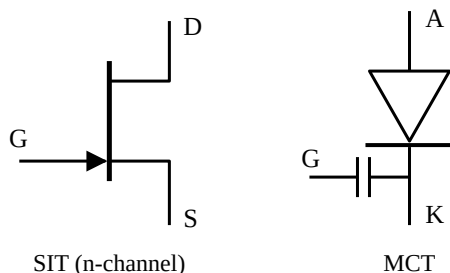
Advance Power Electronics (315340)

Model Question Paper — Set A · Model Answers

Q.1

a) Symbols of SIT and MCT.

2 M



Circuit symbols: SIT, MCT (A: anode, K: cathode, G: gate, D: drain, S: source)

(Each symbol with terminals 1 M)

b) Thermal resistance of SCR.

2 M

Thermal resistance (θ): It is the resistance offered to the flow of heat from one point to another (e.g., junction to case). It is the ratio of temperature difference to the heat (power) flow: $\theta = (T_1 - T_2)/P$.

Unit: °C/W (or K/W).

(Definition 1 M, unit 1 M)

c) Functions of DC chopper.

2 M

A **chopper** is a static DC-to-DC converter which converts a fixed DC input voltage into a variable DC output voltage. It is a high-speed ON/OFF semiconductor switch (MOSFET, IGBT, GTO or thyristor) connected between source and load.

- To obtain a **variable DC voltage** from a fixed DC source ($V_o = D \cdot V_s$).
- To **step-down** or **step-up** the DC voltage.
- Smooth speed control of DC motors (battery vehicles, traction) with fast response.

(Any two, 1 M each)

d) Output voltage of step-down and step-up chopper.

2 M

- **Step-down chopper:** $V_o = D \cdot V_s = (T_{on}/T) \cdot V_s$
- **Step-up chopper:** $V_o = V_s/(1 - D)$
- where $D = T_{on}/T =$ duty cycle, $V_s =$ input DC voltage.

(1 M each)

e) Inverter: definition and applications.

2 M

Inverter: A static power converter that converts DC power into AC power of desired output voltage and frequency.

- UPS and emergency power supplies
- Variable frequency (VFD) AC motor drives
- Solar PV / grid-tie inverters
- Induction heating

(Definition 1 M, any two applications 1 M)

f) Voltage stabilizer: definition and applications.

2 M

A **voltage stabilizer** is an electrical device that maintains a nearly constant AC output voltage (e.g., 230 V $\pm$ 1–5 %) at its output terminals in spite of variations in the input supply voltage and in the load.

- Refrigerators, air conditioners, TV, washing machines
- Medical equipment, labs, CNC machines
- Industries, offices, elevators, broadcasting

(Definition 1 M, two applications 1 M)

g) Applications of VFD.

2 M

- Pumps, fans and blowers (energy saving)
- Conveyors, lifts, cranes, hoists
- Compressors and HVAC systems
- Machine tools, textile and paper mills

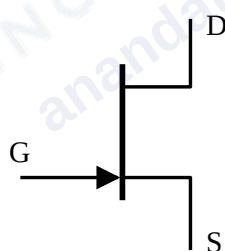
(Any two, 1 M each)

Q.2

a) Construction and working of SIT with V-I characteristics.

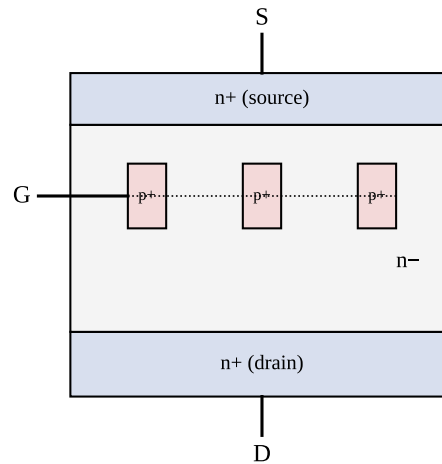
4 M

SIT (Static Induction Transistor) is a high-power, high-frequency, **normally-ON** majority-carrier device. Its operation is similar to a JFET / vacuum triode.



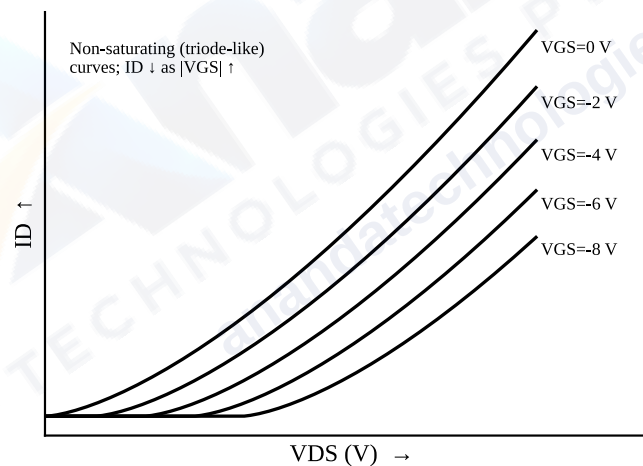
SIT (n-channel)

Circuit symbols: SIT (A: anode, K: cathode, G: gate, D: drain, S: source)



Basic vertical structure of Static induction transistor (SIT): buried p+ gate grids control the n-channel

- **Construction:** vertical structure with n^+ source (top) and n^+ drain (bottom) separated by a lightly doped n^- region. Heavily doped p^+ gate regions are buried in the n^- region as a grid; the n-channels lie between them.
- **Working:** with $V_{GS} = 0$ the channels are open and the SIT conducts (normally ON). When a **negative gate voltage** is applied, the depletion layers of the p^+n^- junctions spread into the channels and form a potential barrier; drain current reduces and the device is turned OFF (pinch-off).
- Drain current depends on both V_{DS} and V_{GS} , so the curves do not saturate (triode-like characteristics).



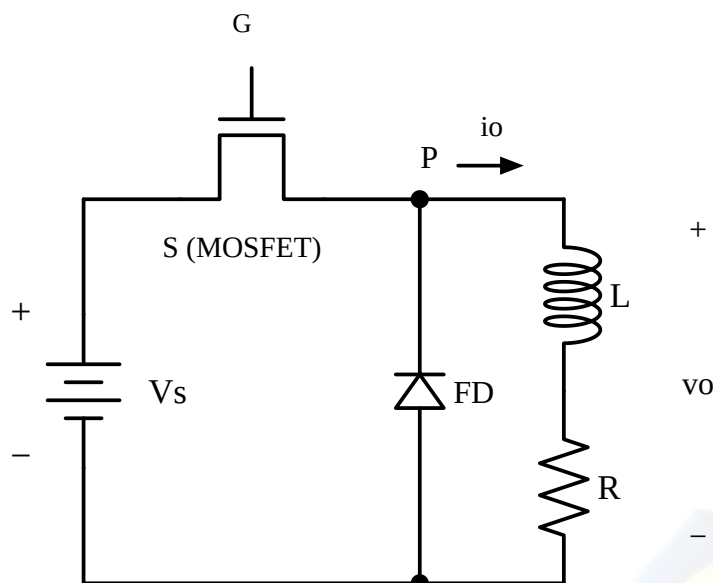
V-I (output) characteristics of n-channel SIT (normally ON device, computed shape)

- Characteristics are plotted as I_D versus V_{DS} for different gate voltages $V_{GS} = 0, -2, -4 \dots V$.
- At $V_{GS} = 0$ the current is maximum (normally ON device).
- As V_{GS} is made more negative, a larger V_{DS} is needed to start conduction and I_D reduces.
- Curves are **non-saturating** (triode-like) because the potential barrier is lowered by V_{DS} also.

(Construction 1 M, working 1 M, characteristics 2 M)

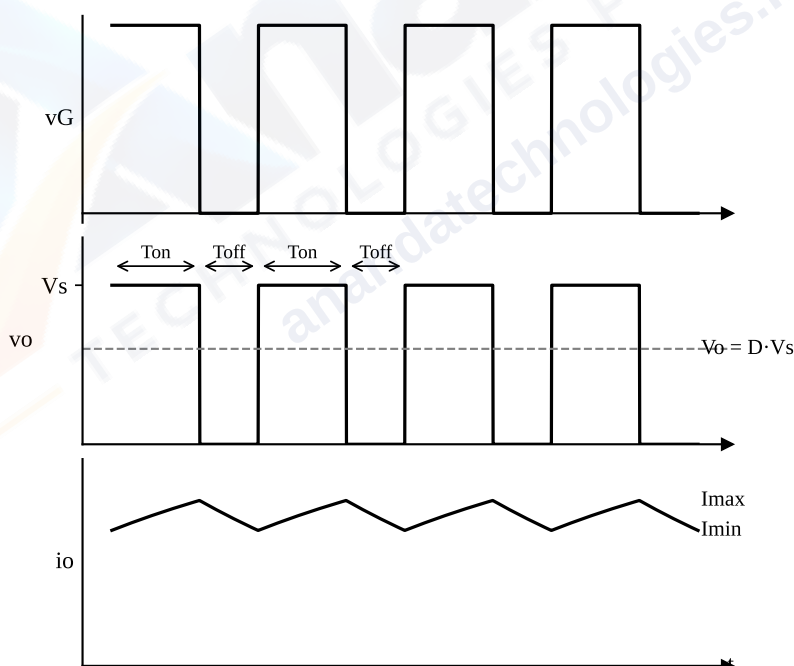
b) Type A chopper using MOSFET.

4 M



Step-down (Type A) chopper using MOSFET with R-L load

- **Mode 1 ($0 < t < T_{on}$):** MOSFET S is ON. Supply V_s is connected to load; $v_o = V_s$ and load current i_o rises exponentially from I_{min} to I_{max} . Freewheeling diode FD is reverse biased.
- **Mode 2 ($T_{on} < t < T$):** S is OFF. The load inductance keeps the current flowing through FD; $v_o = 0$ and i_o decays from I_{max} to I_{min} .
- **Average output voltage:** $V_o = (T_{on}/T) \cdot V_s = D \cdot V_s$. Since $D \leq 1$, $V_o \leq V_s$ (step-down). Both V_o and I_o are positive $\rightarrow$ first-quadrant (Type A) chopper.

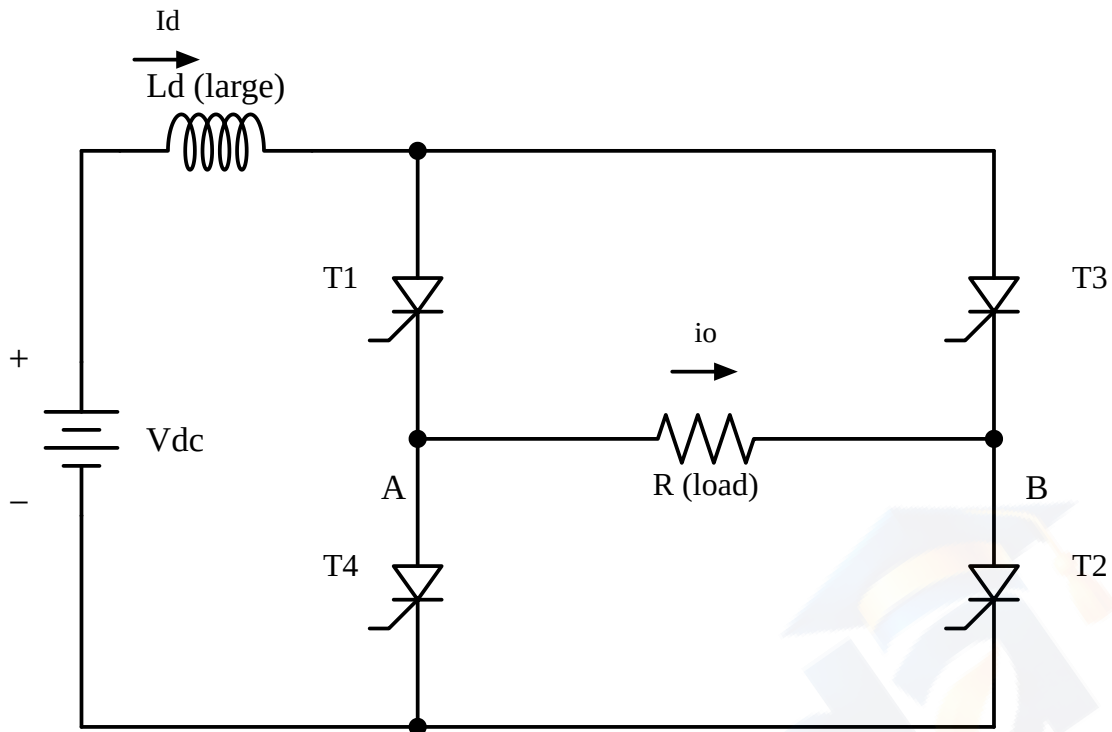


Waveforms of step-down chopper (computed, $D = 0.6$): gate pulse, load voltage and load current

(Circuit 1 M, working 2 M, waveforms 1 M)

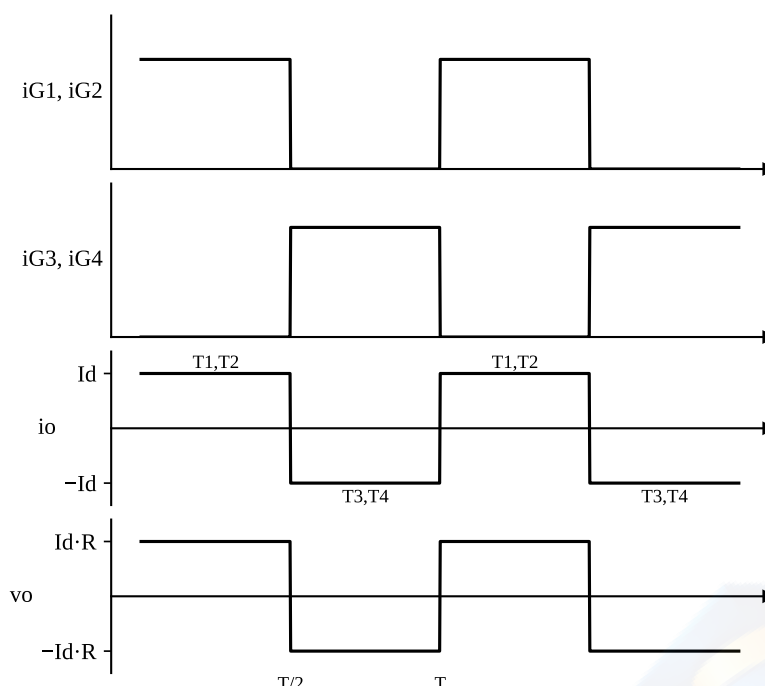
c) Single-phase CSI with resistive load.

4 M



Single-phase current source inverter (CSI) with resistive load

- A DC voltage source with a **large inductor L_d** in series acts as a constant current source I_d (current cannot change quickly in a large inductor).
- $0 < t < T/2$: thyristors T1 and T2 are triggered; current flows $A \rightarrow B$ through the load, $i_o = +I_d$.
- $T/2 < t < T$: T3 and T4 are triggered; T1, T2 turn OFF (with ideal switches) and current flows $B \rightarrow A$, $i_o = -I_d$.
- The **load current is a square wave** of amplitude I_d , independent of the load. The output voltage depends on the load: with resistive load $v_o = i_o \cdot R$, also a square wave of amplitude $I_d R$.
- Output frequency $f = 1/T$ is controlled by the triggering rate. In a practical thyristor CSI, a capacitor across the load provides commutation.

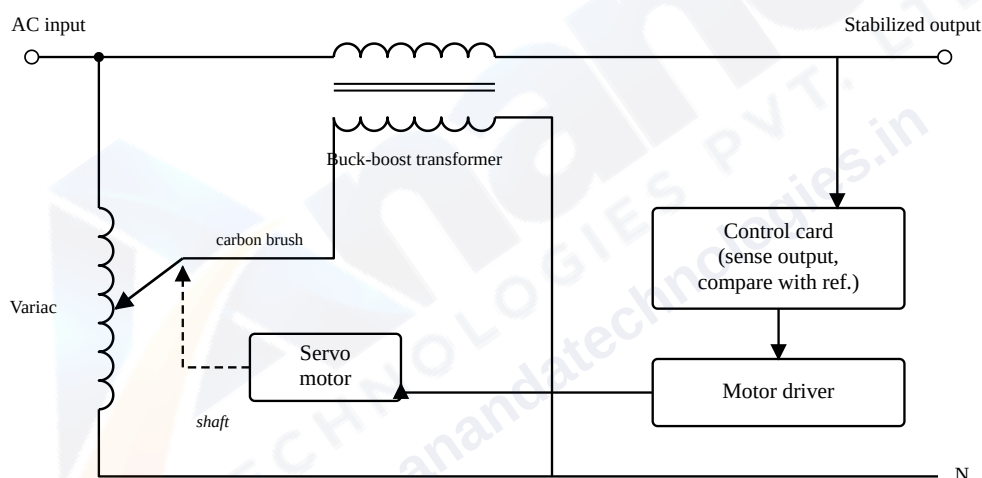


Single-phase CSI with R load: square-wave load current ($\pm I_d$); load voltage $v_o = i_o \cdot R$ has the same shape

(Circuit 1 M, working 2 M, waveforms 1 M)

d) Servo controlled voltage stabilizer.

4 M



Servo controlled voltage stabilizer: motor-driven variac feeds the buck-boost transformer in series with the line

- Main parts: **buck-boost transformer** (secondary in series with the line), **variac** (variable auto-transformer) feeding the buck-boost primary, **servo motor** that moves the variac carbon brush, and a **control card**.
- The control card continuously compares the output voltage with the set reference. If output is low, the error drives the servo motor in one direction; the variac applies an in-phase voltage to the buck-boost primary, and the secondary **adds** (boost) voltage.
- If output is high, the motor rotates in the opposite direction; the injected voltage is in anti-phase and is **subtracted** (buck). The motor stops when the error becomes zero.
- **Advantages:** high accuracy ($\pm 1\%$), smooth stepless correction, high capacity (single/three-phase, up to hundreds of kVA), no waveform distortion. **Disadvantages:** slower response

(moving parts), carbon brush wear needs maintenance, bulky and costly.

- **Applications:** industries, hospitals, CNC machines, laboratories, commercial buildings.

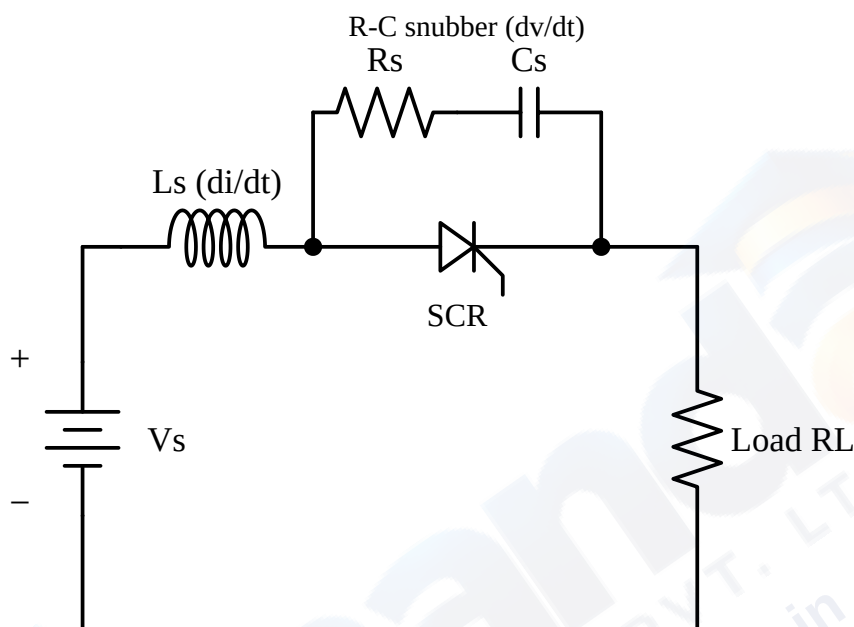
(Diagram 2 M, working 2 M)

Q.3

a) di/dt and dv/dt protection; R-C snubber.

4 M

Need: high di/dt at turn-ON causes local hot spots and damages the SCR; high dv/dt in the OFF state causes false turn-ON. Hence both must be limited below rated values.



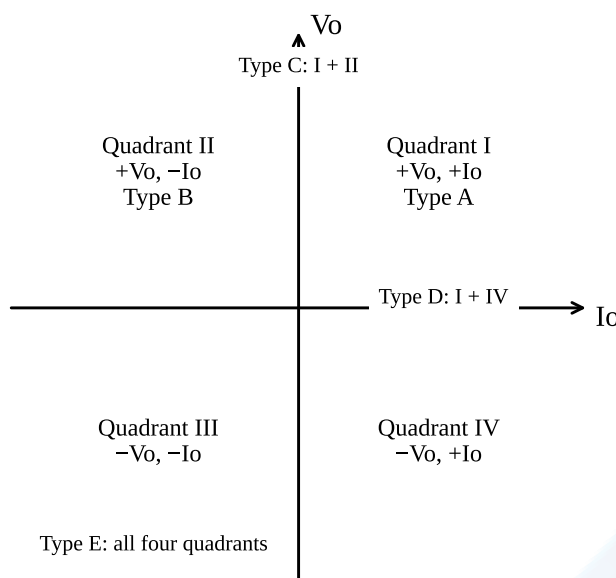
Protection of SCR: series inductor L_s (di/dt) and R-C snubber across SCR (dv/dt)

- When an SCR is in the OFF state, its junction J2 is reverse biased and acts as a capacitor C_j . If the forward voltage rises suddenly, charging current $i = C_j \cdot dv/dt$ flows through it. If dv/dt is large, this current acts like gate current and the SCR turns ON **falsely** (dv/dt triggering).
- A **snubber circuit** (series R_s and C_s) is connected **across the SCR**. At the instant the voltage is applied, C_s behaves as a short circuit, so the voltage across the SCR rises slowly as C_s charges. Hence dv/dt is limited below the rated value.
- R_s limits the discharge current of C_s through the SCR when the SCR is turned ON (otherwise a high di/dt would damage it) and damps oscillations.
- Sometimes a diode is connected across R_s (polarised snubber) so that C_s charges quickly through the diode and discharges through R_s .

(Need 1 M, circuit 1 M, explanation 2 M)

b) Classification of choppers by quadrant.

4 M



Classification of choppers according to quadrant of operation (Vo-Io plane)

- **Type A** — first quadrant (+Vo, +Io): step-down, motoring.
- **Type B** — second quadrant (+Vo, -Io): regenerative braking.
- **Type C** — first and second quadrant (Vo positive, Io reversible).
- **Type D** — first and fourth quadrant (Io positive, Vo reversible).
- **Type E** — all four quadrants (both Vo and Io reversible).

(Diagram 2 M, classification 2 M)

c) Compare VSI and CSI.

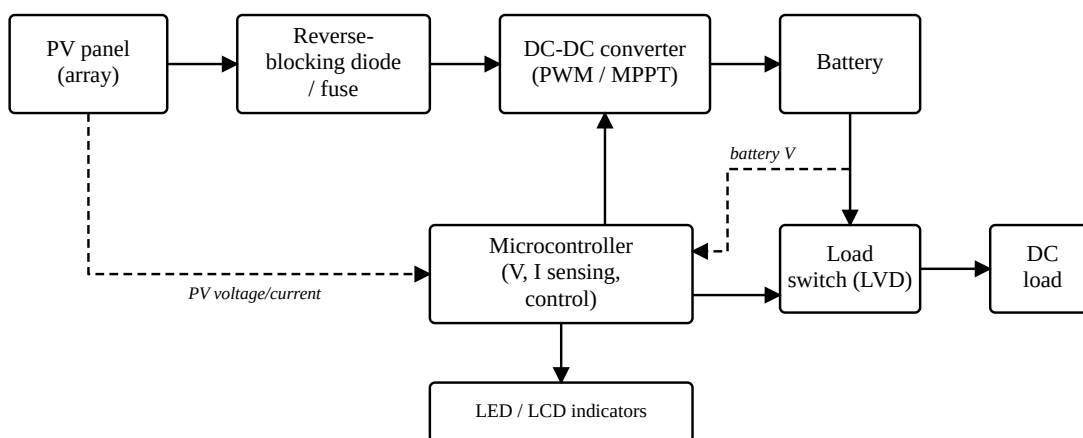
4 M

Point	VSI	CSI
Input source	Stiff DC voltage source (low impedance, large capacitor across DC input)	DC current source (DC supply with large series inductor L_d)
Output controlled	Output voltage waveform is fixed by inverter; current depends on load	Output current waveform is fixed; voltage depends on load
Commutation circuit	Complex forced-commutation circuit needed for thyristor VSI (or self-commutated devices)	Simple commutation using capacitors; no feedback diodes needed
Protection	Short circuit at output is dangerous — fast fuses/current limiting needed	Inherent short-circuit protection (L_d limits current); over-voltage protection needed
Feedback diodes	Required across each switch for reactive load	Not required

(Any four points, 1 M each)

d) Charge controller in PV system.

4 M



Block diagram of PV charge controller

- **PV panel** converts sunlight to DC; output varies with irradiance and temperature.
- **Blocking diode / fuse** prevents reverse flow and protects against faults.
- **DC-DC converter (PWM / MPPT stage):** regulates charging voltage and current; MPPT type operates the panel at its maximum power point.
- **Microcontroller:** senses PV and battery voltage/current, decides charging stage (bulk, absorption, float) and controls the converter and load switch.
- **Load switch (LVD):** disconnects load at low battery voltage. **Indicators** show charging status and battery level.

(Block diagram 2 M, explanation 2 M)

Q.4

a) Step-down chopper numerical ($V_s = 200 \text{ V}$, $R = 10 \Omega$, $f = 1 \text{ kHz}$, $D = 0.4$).

4 M

Given: $V_s = 200 \text{ V}$, $R = 10 \Omega$, $f = 1 \text{ kHz}$, $D = 0.4$

Quantity	Formula	Calculation	Result
Period T	$T = 1/f$	$1/1000$	1 ms
Ton	$T_{on} = D \cdot T$	$0.4 \times 1 \text{ ms}$	0.4 ms
Toff	$T_{off} = T - T_{on}$	$1 - 0.4$	0.6 ms
Average output voltage	$V_o = D \cdot V_s$	0.4×200	80 V
Average output current	$I_o = V_o/R$	$80/10$	8 A
RMS output voltage	$V_{o(rms)} = \sqrt{D} \cdot V_s$	$\sqrt{0.4} \times 200$	126.49 V
Output power	$P_o = V_{o(rms)}^2/R$	$126.49^2 / 10$	1600 W

(Ton, Toff 1 M; Vo, Io 1 M; Vrms 1 M; power 1 M)

b) Types of PWM and advantages.

4 M

Types of PWM:

- **Single-pulse PWM:** one pulse in each half cycle; width controls output voltage.

- **Multiple-pulse (uniform) PWM (MPWM):** several equal-width pulses per half cycle.
- **Sinusoidal PWM (SPWM):** several pulses whose widths vary sinusoidally.
- Others: modified SPWM, selective harmonic elimination, space-vector PWM.

Advantages of PWM:

- Output voltage is controlled inside the inverter — no external voltage regulator needed.
- Lower-order harmonics are reduced / eliminated, so the filter is small and cheap.
- Fast response; voltage and frequency can be varied together (constant V/f for motor drives).
- Output waveform is close to sine wave — less heating and torque pulsation in motors.

(Types 2 M, advantages 2 M)

c) Compare on-line and off-line UPS.

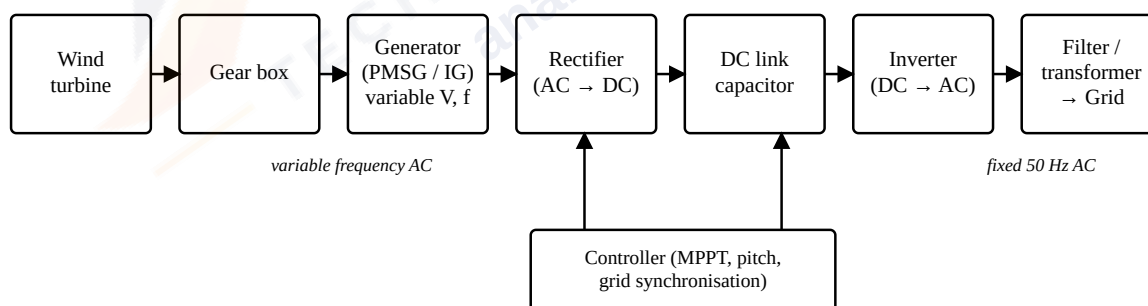
4 M

Specification	On-line UPS	Off-line UPS
Input voltage range	Wide ($\approx 110\text{--}300\text{ V}$); rectifier accepts large variation	Narrow ($\approx 180\text{--}260\text{ V}$); outside this it switches to battery
Output frequency	Fixed $50\text{ Hz} \pm 0.1\%$ (crystal-controlled inverter), independent of mains	Follows mains frequency in normal mode; fixed only in battery mode
Total harmonic distortion (THD)	Low, $< 3\%$ (pure sine-wave inverter)	High in battery mode (quasi-square output); mains waveform passed as it is
Transfer / response time	Zero (no break)	2–10 ms break during change-over
Nature of output waveform	Pure sine wave at all times	Mains (normal), square / modified sine (battery mode)

(Any four points, 1 M each)

d) AC-to-AC converter with DC link in wind power generation.

4 M



AC-to-AC conversion with DC link in a variable-speed wind energy system

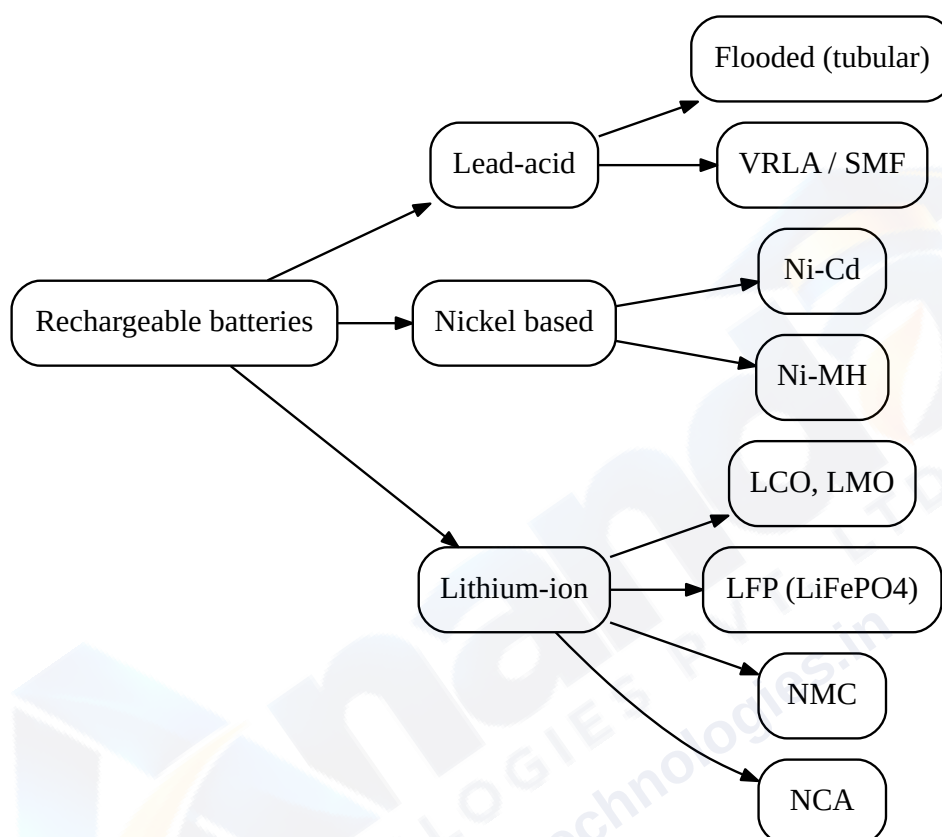
- Wind speed keeps changing, so the turbine/generator speed and the generated **voltage and frequency vary**. The grid needs constant 50 Hz and voltage, so direct connection is not possible.
- **Rectifier (AC → DC):** converts the variable-frequency generator output to DC.
- **DC link capacitor:** smooths the DC and **decouples** generator frequency from grid frequency.

- **Inverter (DC → AC):** PWM inverter produces AC at fixed 50 Hz synchronised with the grid; filter and step-up transformer connect it to the grid.
- **Controller:** MPPT (optimum rotor speed for each wind speed), pitch control and grid synchronisation; also controls reactive power.
- **Advantages:** variable-speed operation captures more energy, less mechanical stress, good power quality and fault ride-through.

(Block diagram 2 M, explanation 2 M)

e) Classification of rechargeable batteries; NMC vs NCA.

4 M



Classification of rechargeable batteries

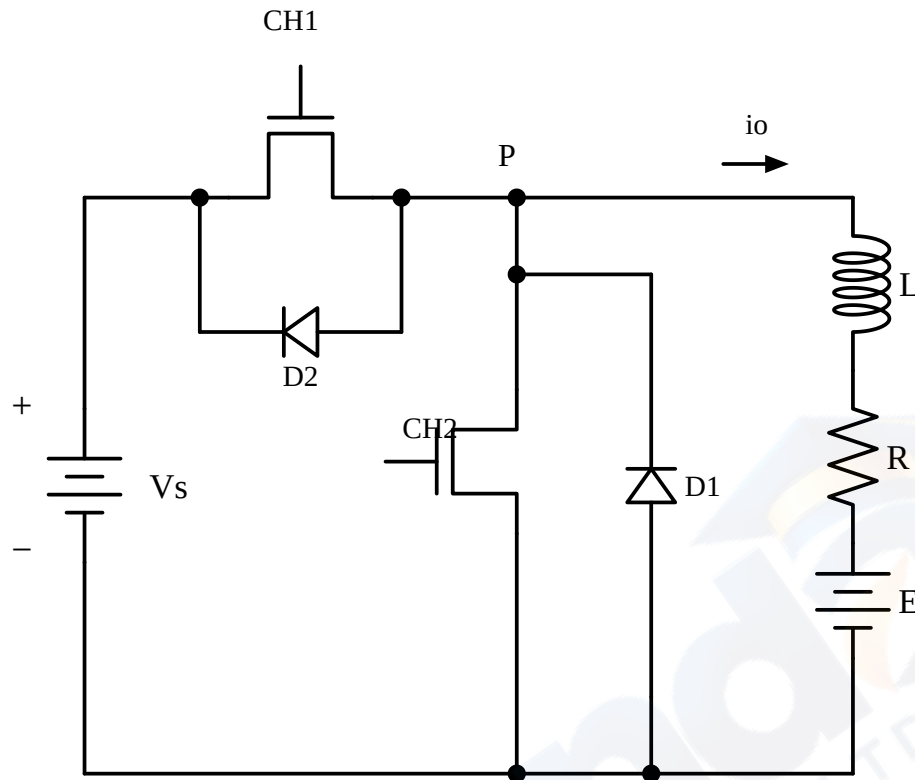
Point	NMC	NCA
Full name	Lithium Nickel Manganese Cobalt oxide (LiNiMnCoO ₂)	Lithium Nickel Cobalt Aluminium oxide (LiNiCoAlO ₂)
Nominal cell voltage	3.6–3.7 V	3.6 V
Energy density	High, ≈ 150–220 Wh/kg	Very high, ≈ 200–260 Wh/kg
Cycle life	≈ 1000–2000	≈ 500–1000
Safety / thermal stability	Good	Lower; needs careful BMS and cooling
Applications	EVs, e-bikes, power tools, energy storage	High-range EVs, high-energy packs

(Classification 1 M, comparison 3 M)

Q.5

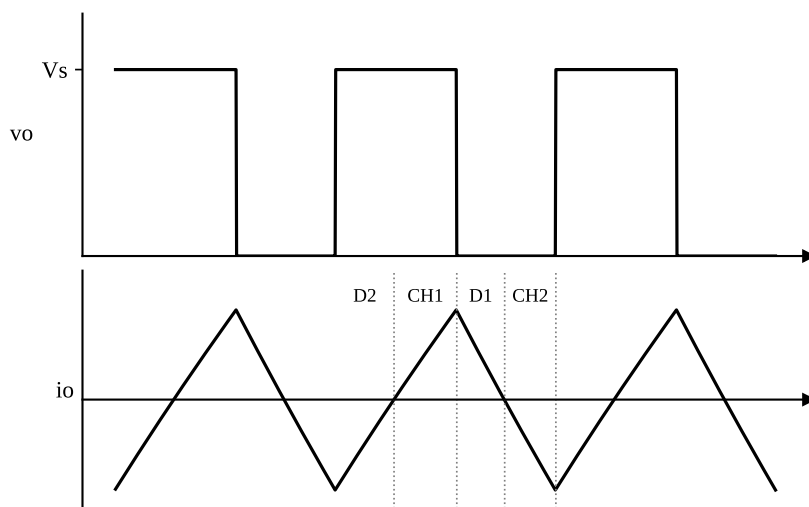
a) Type C (two-quadrant) chopper.

6 M



Type C (two-quadrant, current reversible) chopper

- Type C is a combination of Type A (CH1 + D1) and Type B (CH2 + D2) choppers. V_o is always positive while I_o can be positive or negative — **first and second quadrant** operation.
- **Quadrant I (motoring):** CH1 is chopped, CH2 OFF. CH1 ON $\rightarrow v_o = V_s$; CH1 OFF $\rightarrow$ current freewheels through D1, $v_o = 0$. Power flows from source to load.
- **Quadrant II (regenerative braking):** CH2 is chopped, CH1 OFF. CH2 ON $\rightarrow$ E drives current through CH2, energy stored in L; CH2 OFF $\rightarrow$ current flows through D2 into the source.
- CH1 and CH2 must **never be ON together**, otherwise the source is short-circuited.
- Used for DC motor drives needing both motoring and regenerative braking (electric traction).

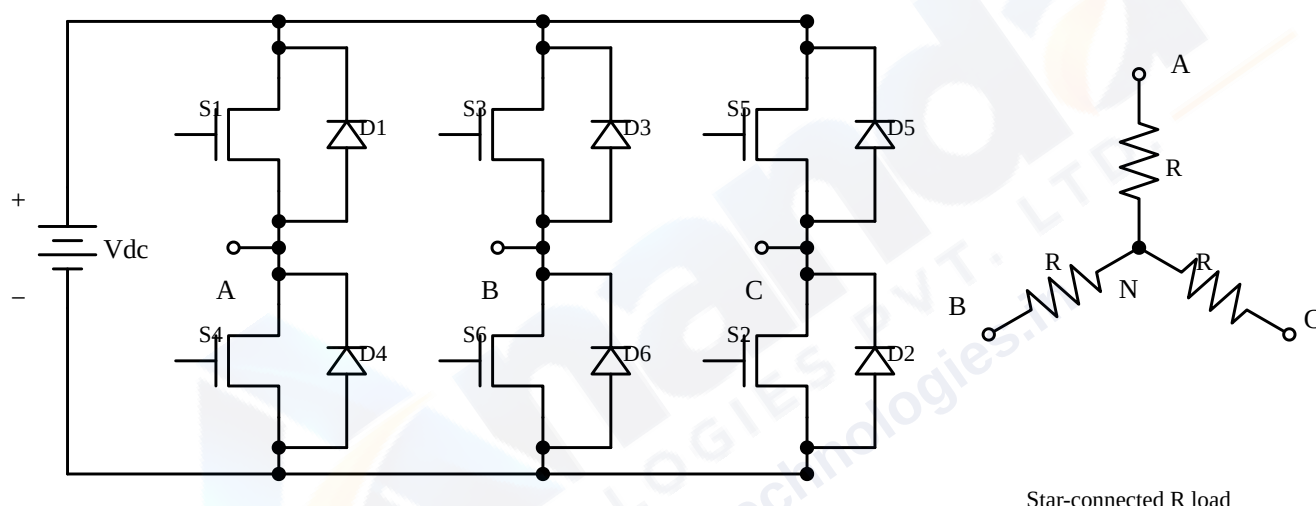


Type C chopper waveforms (computed): load current swings positive (CH1/D1, Quadrant I) and negative (CH2/D2, Quadrant II)

(Circuit 2 M, operation 2 M, waveforms 2 M)

b) Three-phase VSI in 180° conduction mode.

6 M



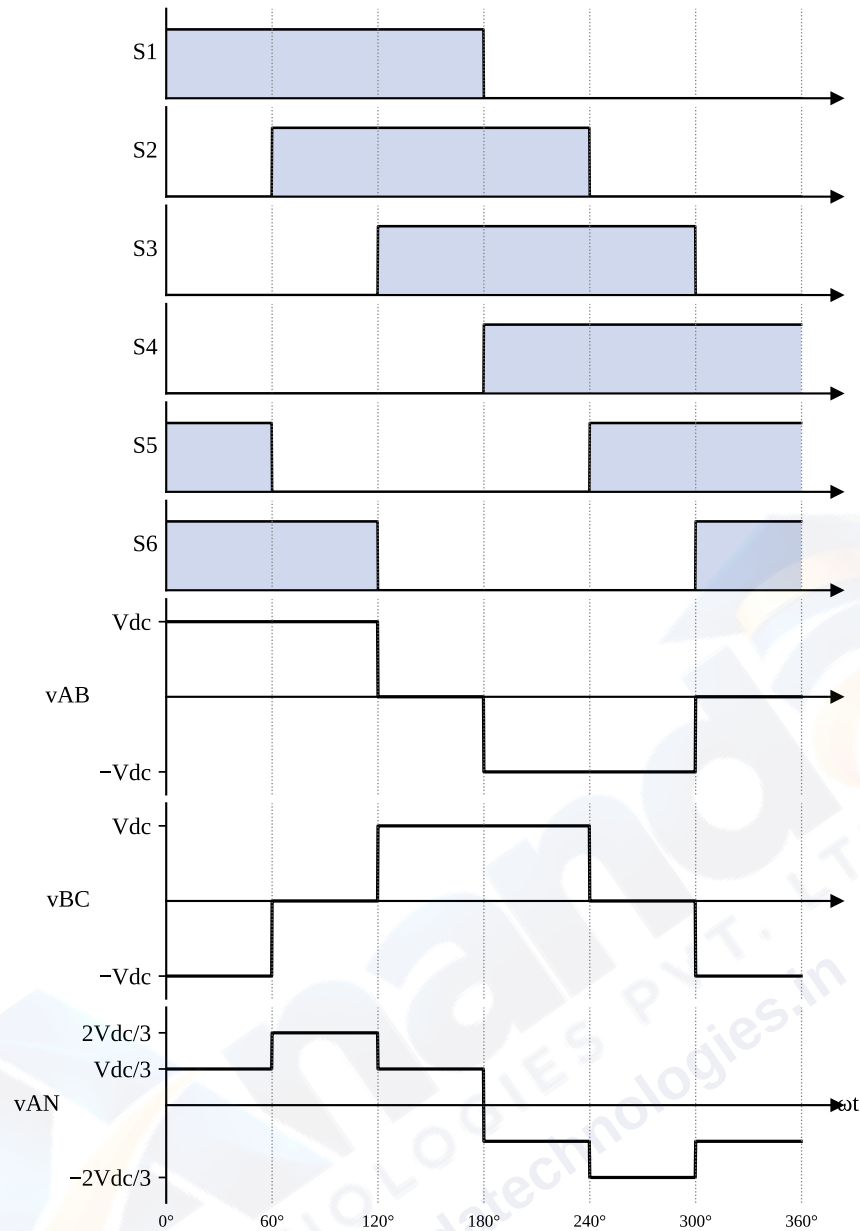
Three-phase bridge VSI (S1-S6 with feedback diodes D1-D6) feeding a balanced star-connected load

- Six switches S1–S6 with feedback diodes form three legs; star-connected resistive load R per phase.
- In 180° mode each switch conducts for **180°**; the switches are triggered in sequence S1, S2, S3, S4, S5, S6 at 60° intervals. **Three switches conduct at any instant.**
- Conducting sets in the six 60° intervals: (S5, S6, S1), (S6, S1, S2), (S1, S2, S3), (S2, S3, S4), (S3, S4, S5), (S4, S5, S6).

Interval	Switches ON	Equivalent circuit	V_{AN}	V_{BN}	V_{CN}
0–60°	S5, S6, S1	A, C to +; B to –	$V_{dc}/3$	$-2V_{dc}/3$	$V_{dc}/3$
60–120°	S6, S1, S2	A to +; B, C to –	$2V_{dc}/3$	$-V_{dc}/3$	$-V_{dc}/3$
120–180°	S1, S2, S3	A, B to +; C to –	$V_{dc}/3$	$V_{dc}/3$	$-2V_{dc}/3$

In each interval two load resistors are in parallel ($R/2$) and in series with the third (R); total $3R/2$, so the phase in series gets $2V_{dc}/3$ and the parallel pair gets $V_{dc}/3$. The pattern repeats for 180–

360° with opposite signs.



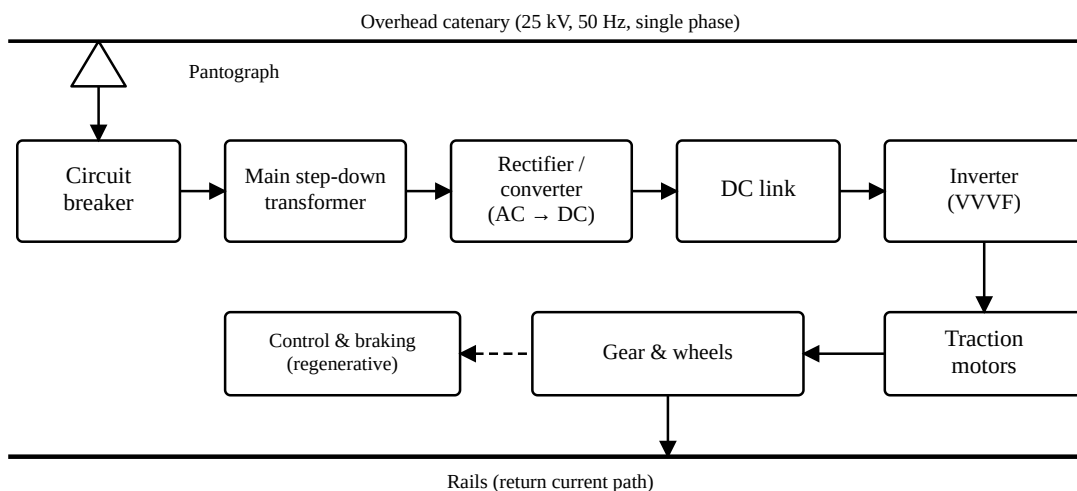
180° conduction mode (computed): gating of S1–S6 (each 180°, 60° apart), six-step line voltage and phase voltage

Result: phase voltage is a **six-step** wave ($\pm V_{dc}/3$, $\pm 2V_{dc}/3$); line voltage is a quasi-square wave of 120° width and amplitude V_{dc} . $V_{L(rms)} = \sqrt{(2/3)} \cdot V_{dc} = 0.816 V_{dc}$, $V_{ph(rms)} = (\sqrt{2/3}) \cdot V_{dc} = 0.471 V_{dc}$.

(Circuit 2 M, explanation 2 M, waveforms 2 M)

c) Electrical traction system.

6 M



Electric traction system (25 kV AC locomotive / EMU): power flow from overhead line to wheels

- **Electric traction** means driving vehicles (locomotives, EMUs, metro, trams) by electric motors.
- Power is taken from the **overhead catenary** (25 kV, 50 Hz in Indian Railways) through the **pantograph**, and returns through the rails.
- **Circuit breaker** protects the system; the **main transformer** steps down the voltage.
- **Rectifier/line converter** converts AC to DC; **DC link** filters it; the **VVVF inverter** supplies variable-voltage variable-frequency AC to 3-phase induction **traction motors** (older locos use DC series motors).
- Motors drive the wheels through gears. During **regenerative braking** the motors work as generators and return energy to the line.

Applications:

- Main-line electric locomotives (Indian Railways)
- Suburban EMU and metro rail
- Trams and trolley buses
- Mine and industrial haulage
- Electric vehicles (road traction)

(Diagram 2 M, working 3 M, applications 1 M)

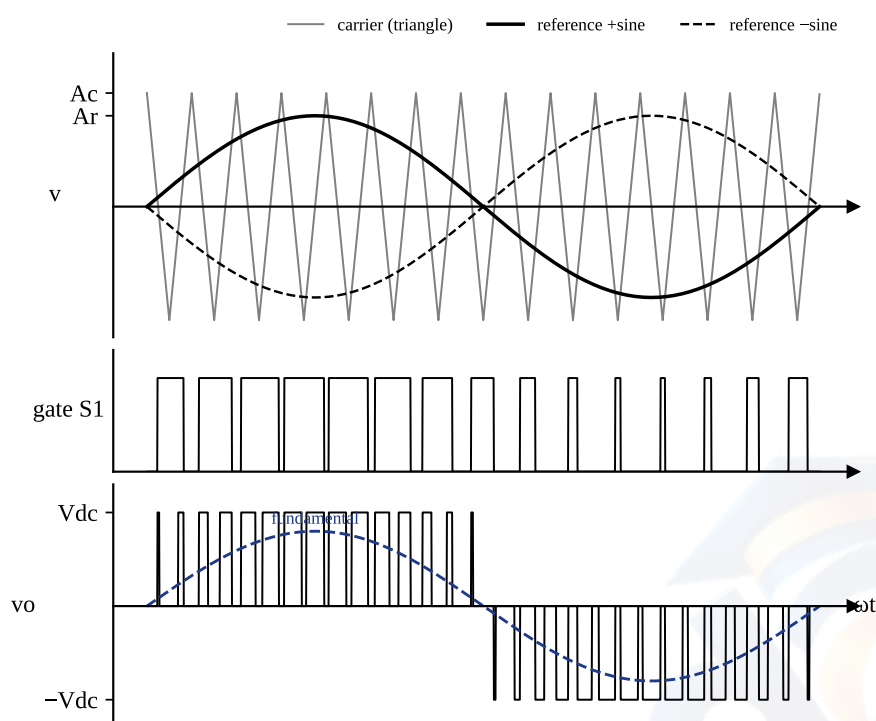
Q.6

a) Sinusoidal PWM.

6 M

- A **sine reference wave** of the desired output frequency f_r and amplitude A_r is compared with a **triangular carrier** of high frequency f_c and amplitude A_c .
- When the sine is greater than the carrier the comparator turns ON the switch (S1); otherwise it is OFF. For the other leg, $-sine$ is compared (unipolar SPWM). The output therefore has many pulses whose **width is proportional to the instantaneous value of the sine wave**.
- **Modulation index** $m_a = A_r/A_c$ controls the output voltage (fundamental peak = $m_a \cdot V_{dc}$ for a full bridge, $m_a \leq 1$). Reference frequency controls the output frequency.

- **Frequency modulation ratio** $m_f = f_c/f_r$ decides the number of pulses; harmonics appear near m_f and its multiples and are easily filtered.



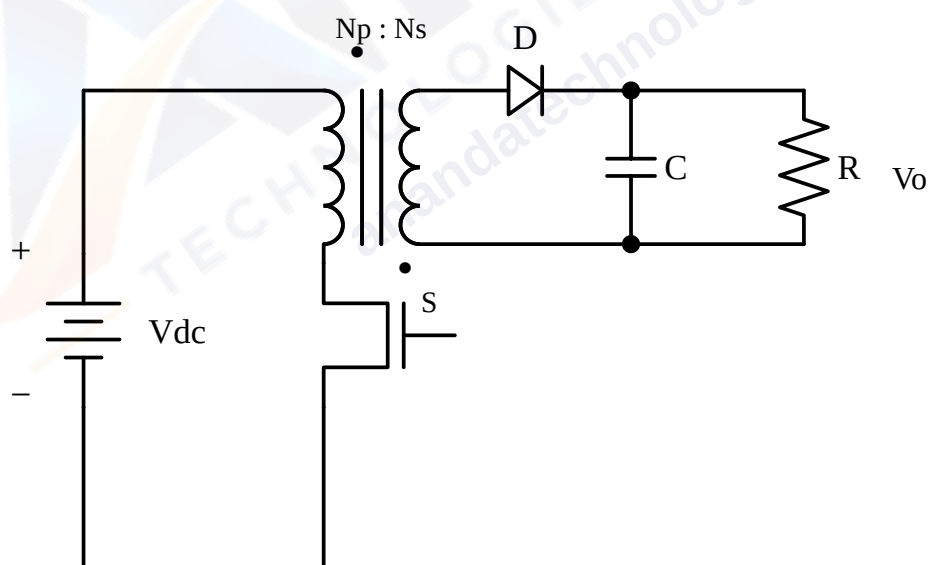
Sinusoidal PWM (computed, $ma = 0.8$, $mf = 15$): pulse width varies sinusoidally; output contains a strong fundamental

Advantages: low-order harmonics eliminated, near-sinusoidal current, small filter, smooth voltage control — used in VFDs, UPS and solar inverters.

(Principle 2 M, waveforms 3 M, modulation index 1 M)

b) Flyback converter and advantages of SMPS.

6 M



Flyback converter (isolated SMPS); dots show opposite winding polarity

- **S ON:** primary current rises and energy is stored in the magnetising inductance of the transformer (coupled inductor). Because of the dot polarity, the secondary voltage reverse biases D; C supplies the load.

- **S OFF:** winding voltages reverse; D becomes forward biased and the stored energy is transferred to C and load.
- Output: $V_o = V_s \cdot (N_s/N_p) \cdot D / (1 - D)$. Simple, needs only one switch and no output inductor; gives isolation and multiple outputs.
- Used for low power (up to ≈ 150 W): mobile chargers, TV/monitor supplies, auxiliary supplies.

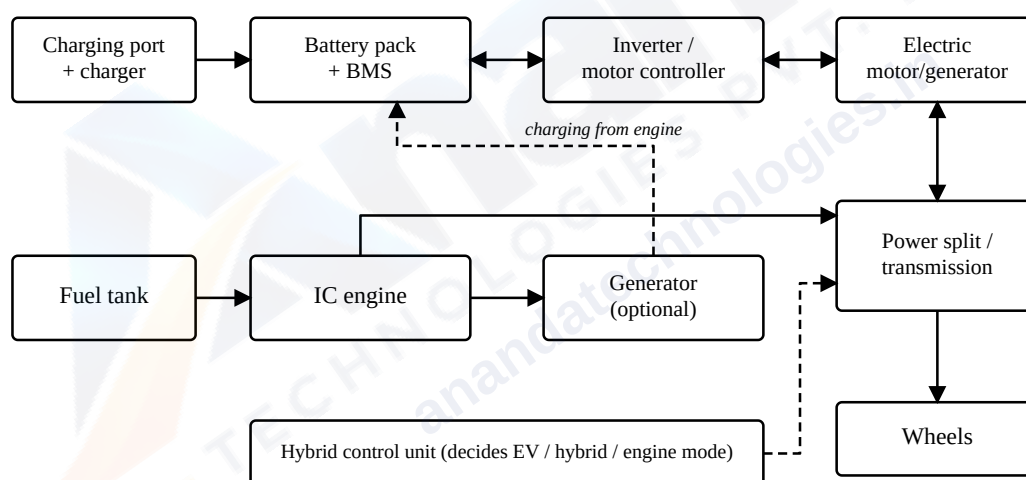
Advantages of SMPS over linear power supply:

Point	SMPS	Linear supply
Efficiency	High, 70–95 % (switch works ON/OFF)	Low, 30–60 % (series transistor in active region)
Size and weight	Small and light (HF transformer, small L, C)	Large and heavy (50 Hz transformer)
Heat / heat sink	Less heat, small heat sink	More heat, large heat sink
Input range	Wide input voltage range	Narrow input range
Output	Step-up, step-down, inverted and multiple outputs possible	Only step-down

(Circuit 2 M, working 2 M, advantages 2 M)

c) Plug-in Hybrid Electric Vehicle (PHEV).

6 M



Block diagram of plug-in hybrid electric vehicle (PHEV): battery + IC engine, battery charged from grid

- A **PHEV (plug-in hybrid electric vehicle)** has both a **battery-powered electric motor** and an **IC engine**; its battery (larger than in an ordinary hybrid) can be charged from the grid by plugging in.
- **EV mode:** for short trips (≈ 30 – 80 km) the vehicle runs only on the battery and motor — zero tailpipe emission.
- **Hybrid mode:** when battery charge falls or more power is needed, the IC engine starts; engine and motor drive the wheels together through the power-split transmission.
- **Charging:** from the grid (plug-in), by the engine-driven generator, and by regenerative braking.
- **Hybrid control unit** decides the operating mode for best efficiency.

Configurations: series, parallel and series-parallel (power-split) hybrids.

(Block diagram 3 M, construction and working 3 M)

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