

Advance Power Electronics (315340)

Model Question Paper — Set B · Model Answers

Q.1**a) Advantages and disadvantages of MCT.**

2 M

Advantages:

- Low forward voltage drop ($\approx 1\text{--}1.5\text{ V}$) like a thyristor, so conduction loss is low.
- Turned ON and turned OFF by a voltage pulse at a single MOS gate — low gate drive power.

Disadvantages:

- Limited reverse blocking capability.
- Complex fabrication and higher cost; limited availability of high ratings.

*(½ M each)***b) Snubber circuit: purpose and components.**

2 M

Purpose: A snubber circuit is connected across the SCR to limit the rate of rise of forward voltage (dv/dt) and prevent false turn-ON; it also suppresses voltage transients.

Components: resistor R_s and capacitor C_s in series (sometimes a diode across R_s).

*(Purpose 1 M, components 1 M)***c) Control strategies of chopper.**

2 M

- **Time ratio control (TRC):** (a) constant frequency (PWM) and (b) variable frequency (FM) system.
- **Current limit control (CLC).**

*(1 M each)***d) Role of freewheeling diode.**

2 M

- When the chopper switch turns OFF, the freewheeling diode provides a path for the inductive load current, so the current continues to flow and decays smoothly.
- It prevents high induced voltage ($L di/dt$) across the switch and protects it; it also makes the load voltage zero during T_{off} ($V_o = D \cdot V_s$).

*(Any two points, 1 M each)***e) Classification of inverters.**

2 M

- **(i) Input source:** voltage source inverter (VSI), current source inverter (CSI).
- **(ii) Output phases:** single-phase inverter (half bridge, full bridge), three-phase inverter.

*(1 M each)***f) Response time and load power factor of UPS.**

2 M

- **Response time:** Time taken by the UPS to respond to a mains failure and restore output from the inverter/battery. On-line UPS: zero (load always on inverter); off-line UPS: 2–10 ms (relay

change-over).

- **Load power factor:** The power factor of the load for which the UPS is rated (usually 0.8 lagging). $\text{kW rating} = \text{kVA rating} \times \text{load power factor}$; e.g., a 1 kVA UPS at 0.8 pf supplies 800 W.

(1 M each)

g) Advantages of PHEV over IC engine vehicle.

2 M

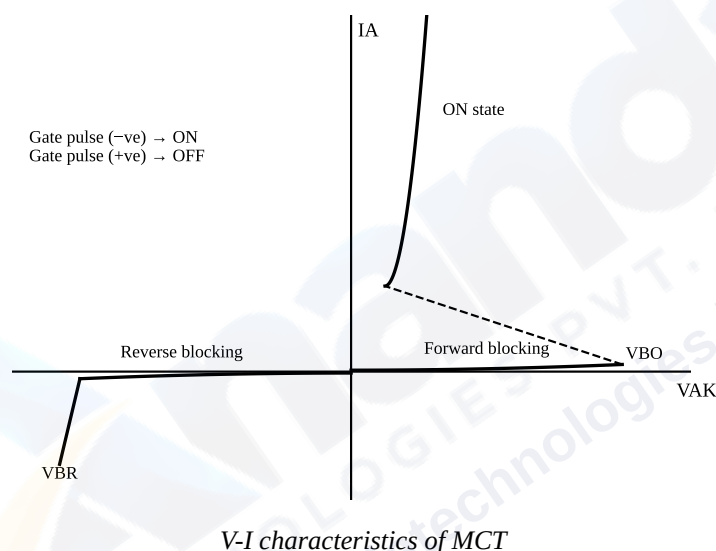
- Lower fuel consumption and running cost (short trips on battery).
- Low or zero tailpipe emission — less pollution.
- Regenerative braking recovers energy.
- Quiet operation and high torque at low speed.

(Any two, 1 M each)

Q.2

a) V-I characteristics of MCT; turn-ON and turn-OFF.

4 M



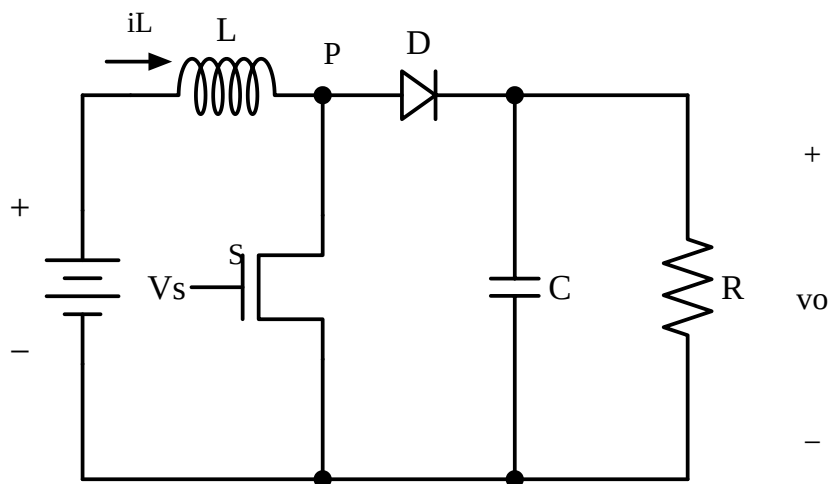
- **Forward blocking:** with no ON pulse, MCT blocks the forward voltage; only a small leakage current flows up to the forward breakover voltage V_{BO} .
- **ON state:** a gate pulse turns it ON at a voltage much below V_{BO} ; the operating point jumps to the ON-state region with a low drop ($\approx 1-1.5$ V), like a thyristor.
- **Turn OFF by gate:** an opposite gate pulse turns it OFF even when anode current is flowing (unlike an SCR).
- **Reverse region:** only small reverse blocking capability; leakage current flows up to the reverse breakdown voltage.

Turn ON / OFF (P-MCT): negative gate pulse w.r.t. anode turns ON the ON-FET → MCT turns ON; positive gate pulse turns ON the OFF-FET → shorts the emitter-base of the pnp section → MCT turns OFF.

(Characteristics 2 M, explanation 1 M, turn-ON/OFF 1 M)

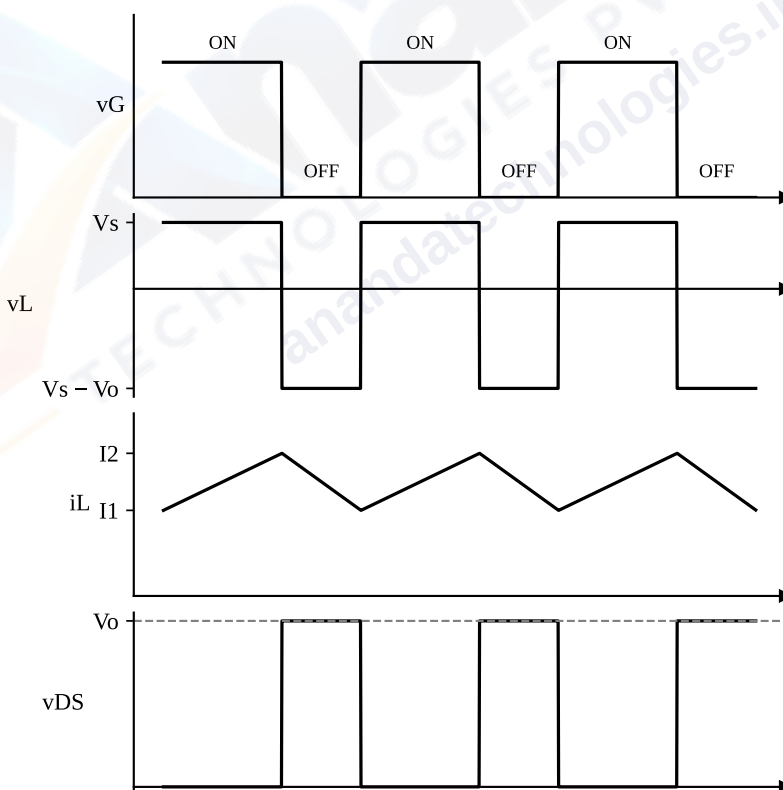
b) Step-up chopper using MOSFET.

4 M



Step-up chopper (boost converter) using MOSFET

- **Switch ON ($0 < t < T_{on}$):** MOSFET S conducts; inductor L is connected across V_s and stores energy; i_L rises from I_1 to I_2 . Diode D is reverse biased and capacitor C supplies the load.
- **Switch OFF ($T_{on} < t < T$):** the inductor voltage reverses and adds to V_s ; current flows through D into C and the load; i_L falls from I_2 to I_1 .
- **Output voltage:** volt-second balance on L gives $V_s \cdot T_{on} = (V_o - V_s) \cdot T_{off}$, so **$V_o = V_s / (1 - D)$** . As $D \rightarrow 1$, V_o increases; $V_o > V_s$ (step-up).
- MOSFET is used because it switches fast (tens of kHz), so L and C are small; it needs only gate voltage drive and turns OFF by itself (no commutation circuit).



Waveforms of step-up chopper ($D = 0.6$): gate, inductor voltage, inductor current, switch voltage ($V_o = V_s / (1 - D)$)

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

c) 180° vs 120° conduction modes.

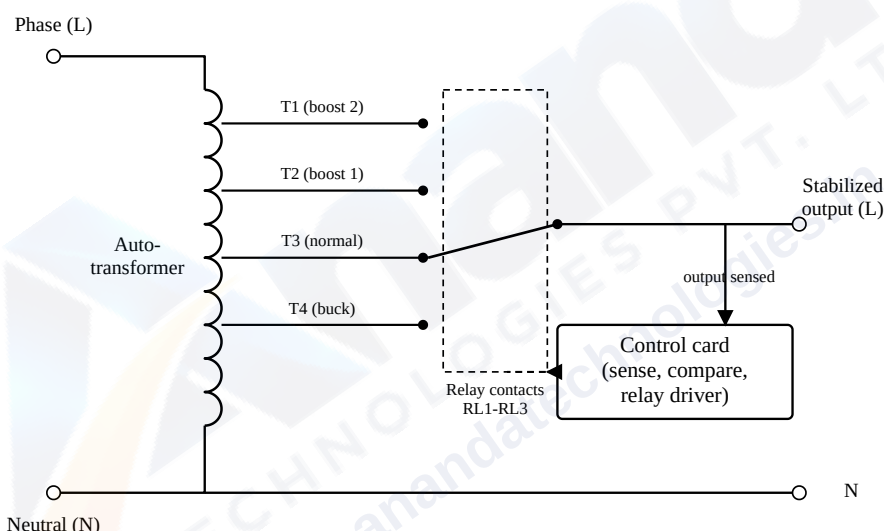
4 M

Point	180° mode	120° mode
Conduction period of each switch	180°	120°
Switches ON at a time	Three	Two
Phase voltage waveform	Six-step: $V_{dc}/3$, $2V_{dc}/3$	Quasi-square: $\pm V_{dc}/2$ with 60° zero gaps
Line voltage waveform	Quasi-square, 120° pulses of V_{dc}	Six-step: V_{dc} , $V_{dc}/2$
RMS phase voltage	0.471 V_{dc} (higher output)	0.408 V_{dc} (lower output)
Short-circuit (shoot-through) risk	Upper and lower switch of a leg switch at the same instant — risk of short circuit, dead time needed	60° gap between turning OFF one switch and ON the other in a leg — safer

(Any four points, 1 M each)

d) Relay type voltage stabilizer.

4 M



Relay type voltage stabilizer: relays select a suitable auto-transformer tap (one tap selected at a time)

- It consists of an **auto-transformer with several tapings**, relays, and an electronic control card (rectifier, comparators/op-amps with zener reference, transistor relay drivers).
- The output voltage is sensed, rectified and compared with preset reference levels.
- If input voltage falls, the control card energises the relay that connects the output to a **higher (boost) tap**; if input rises, a **lower (buck) tap** is selected. Thus output stays within a band (e.g., $230\text{ V} \pm 5\text{--}10\%$).
- **Advantages:** low cost, light and compact. **Disadvantages:** step-wise (not smooth) correction, relay contact wear, momentary break/clicks, lower accuracy.
- **Applications:** refrigerators, TV, small air conditioners, domestic use.

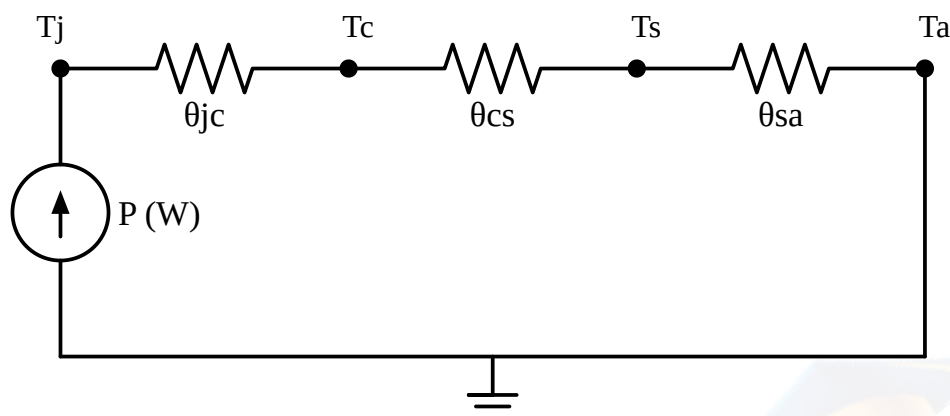
(Diagram 2 M, working 2 M)

Q.3

a) Heat sink thermal resistance numerical.

4 M

Given: $P = 25 \text{ W}$, $\theta_{jc} = 0.6 \text{ }^{\circ}\text{C/W}$, $\theta_{cs} = 0.3 \text{ }^{\circ}\text{C/W}$, $T_j = 125 \text{ }^{\circ}\text{C}$, $T_a = 40 \text{ }^{\circ}\text{C}$



Ambient reference

Thermal equivalent circuit: $T_j - T_a = P (\theta_{jc} + \theta_{cs} + \theta_{sa})$

Step	Formula	Calculation	Result
Total θ_{ja}	$(T_j - T_a)/P$	$(125 - 40)/25$	$3.4 \text{ }^{\circ}\text{C/W}$
Heat sink θ_{sa}	$\theta_{ja} - \theta_{jc} - \theta_{cs}$	$3.4 - 0.6 - 0.3$	$2.5 \text{ }^{\circ}\text{C/W}$
Case temperature T_c	$T_j - P \cdot \theta_{jc}$	$125 - 25 \times 0.6$	$110.0 \text{ }^{\circ}\text{C}$
Sink temperature T_s	$T_c - P \cdot \theta_{cs}$	$110 - 25 \times 0.3$	$102.5 \text{ }^{\circ}\text{C}$

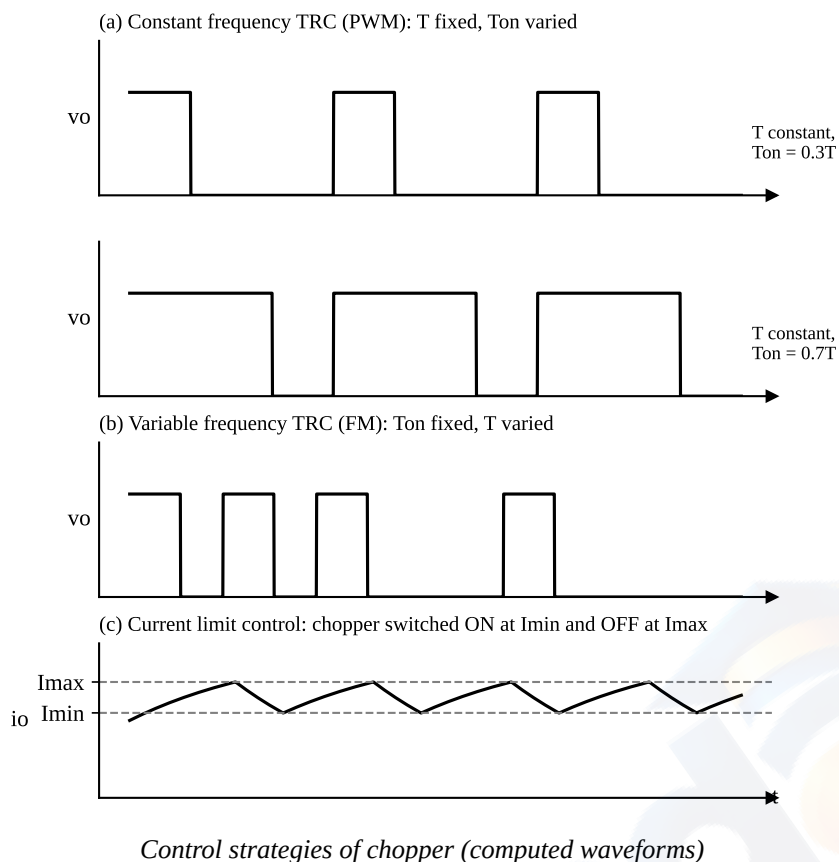
A heat sink with $\theta_{sa} \leq 2.5 \text{ }^{\circ}\text{C/W}$ must be selected.

(θ_{ja} 1 M, θ_{sa} 1 M, T_c 1 M, T_s 1 M)

b) TRC and CLC control strategies.

4 M

- **Time Ratio Control (TRC)** — the ratio T_{on}/T (duty cycle) is varied: (a) **Constant frequency system (PWM)**: T kept constant, T_{on} varied; (b) **Variable frequency system (FM)**: T_{on} (or T_{off}) kept constant, T varied.
- **Current Limit Control (CLC)** — the chopper is switched ON when load current falls to I_{min} and OFF when it rises to I_{max} ; the load current is kept between these limits.

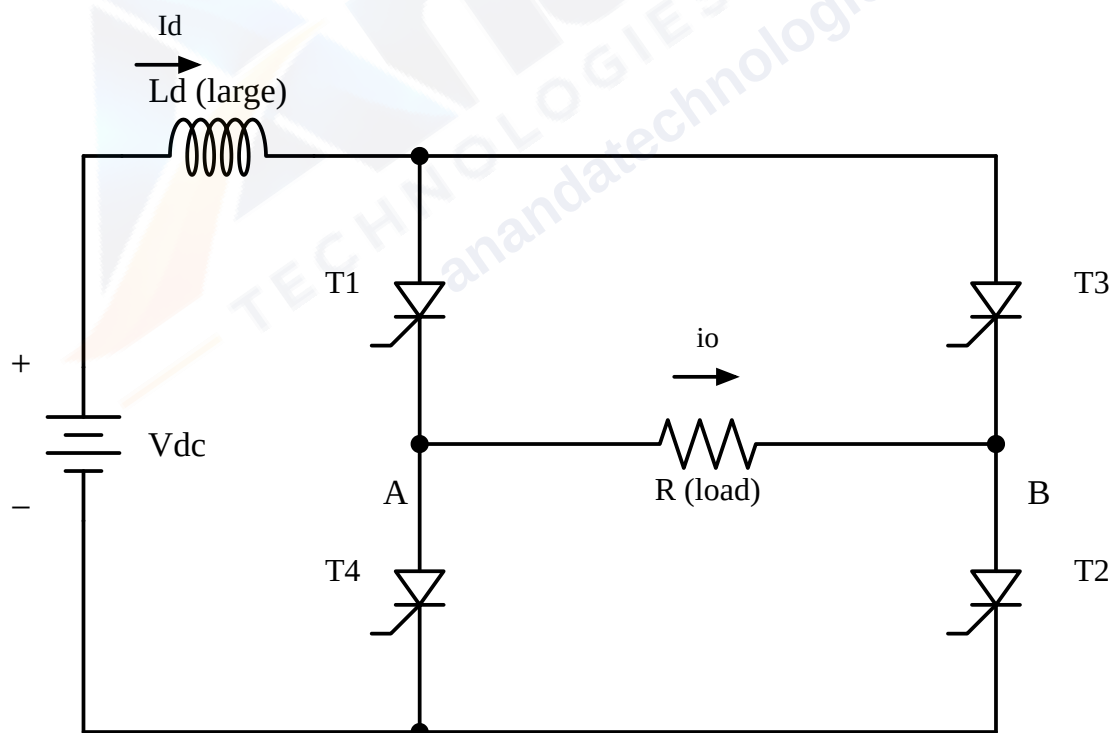


Average output voltage in TRC: $V_o = (T_{on}/T) \cdot V_s$. In CLC the switching frequency depends on load and the limits I_{max} , I_{min} .

(TRC 2 M, CLC 1 M, waveforms 1 M)

c) Single-phase CSI: circuit and function of components.

4 M



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

- **DC source (V_{dc}):** supplies DC power.

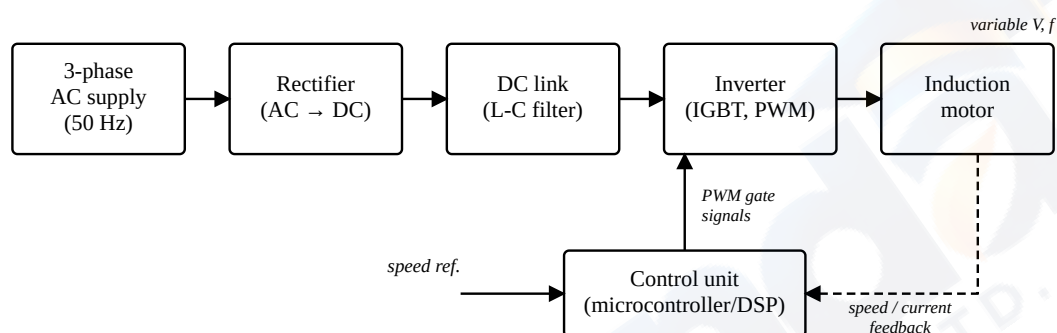
- **Large inductor L_d :** keeps the input current constant (I_d), so the DC source behaves as a current source; also limits fault current.
- **Thyristors T1-T4 (bridge):** T1, T2 conduct in one half cycle and T3, T4 in the next, reversing the current through the load (square-wave current).
- **Load (R):** receives alternating square-wave current; voltage $v_o = i_o R$. (In practical CSI a capacitor across the load helps commutation.)

(Circuit 2 M, functions 2 M)

d) VFD and its block diagram.

4 M

A **Variable Frequency Drive (VFD)** is a power-electronic controller that controls the speed of an AC (induction) motor by varying the **frequency** and **voltage** of its supply ($N_s = 120 f / P$), keeping V/f constant.



Block diagram of variable frequency drive (VFD): V/f is kept constant while frequency is varied

- **Rectifier:** diode bridge converts fixed-frequency 3-phase AC into DC.
- **DC link:** L-C filter smooths the DC and stores energy.
- **Inverter:** IGBT bridge converts DC into AC of variable voltage and variable frequency using PWM.
- **Control unit:** microcontroller/DSP takes speed reference and feedback, keeps V/f constant, generates PWM gate signals and provides protections (over-current, over-voltage, overload).
- Applications: pumps, fans, blowers, compressors, conveyors, lifts, cranes, machine tools, HVAC.

(Definition 1 M, block diagram 2 M, explanation 1 M)

Q.4

a) Compare SIT, MCT and FCT.

4 M

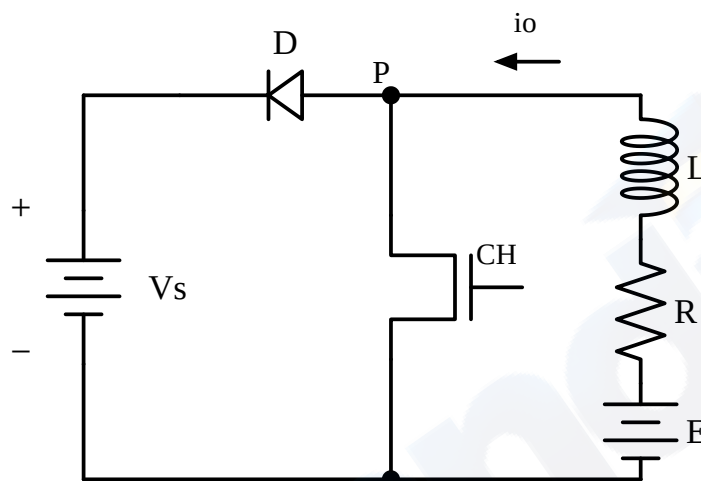
Point	SIT	MCT	FCT
Type of device	Transistor (majority carrier, normally ON)	Thyristor with MOS gate (ON-FET, OFF-FET)	Thyristor-like, normally ON (static induction thyristor)
Control	Turned OFF by negative gate voltage	Turned ON and OFF by gate voltage pulses	Turned OFF by negative gate voltage

ON-state drop	High (no conductivity modulation)	Low ($\approx 1-1.5$ V)	Low (conductivity modulation by p^+ anode)
Switching speed	Very high (MHz range)	High	High
Applications	RF / audio amplifiers, induction heating, high-frequency supplies	Motor drives, UPS, circuit breakers, high-power converters	Induction heating, high-frequency inverters, choppers

(Any four points, 1 M each)

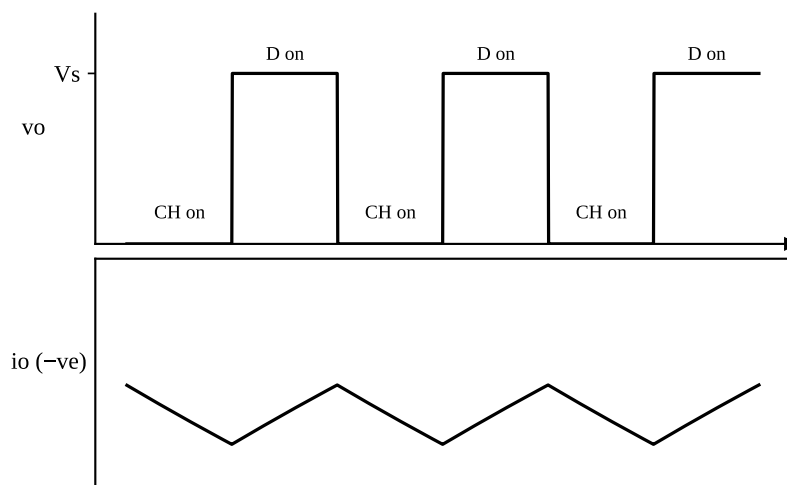
b) Type B chopper.

4 M



Type B (second quadrant) chopper

- Load must contain a DC source E (e.g., back emf of a DC motor during braking). V_o is positive but current flows from load to source, so I_o is negative — **second quadrant**.
- **CH ON:** load terminals are shorted through CH; E drives current through L and R; energy is stored in L; $v_o = 0$.
- **CH OFF:** the induced voltage of L adds to E, so $(E + L \frac{di}{dt}) > V_s$; diode D conducts and the current is fed back to the source; $v_o = V_s$.
- Average voltage $V_o = (1 - D) \cdot V_s$. It works as a step-up chopper and is used for **regenerative braking** of DC motors.



Type B chopper waveforms (computed): load voltage and load current (current flows from load to source, so i_o is negative)
(Circuit 1 M, operation 2 M, application 1 M)

c) 180° mode VSI numerical ($V_{dc} = 400$ V, $R = 10$ Ω).

4 M

Given: $V_{dc} = 400$ V, star-connected $R = 10$ Ω /phase, 180° conduction mode

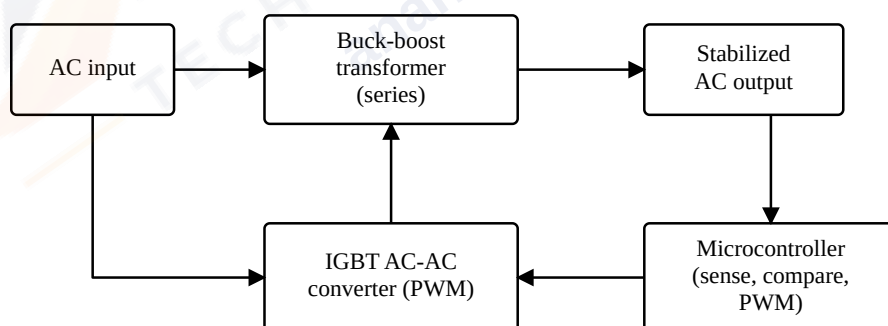
Quantity	Formula	Result
RMS line voltage	$V_L = \sqrt{(2/3)} \cdot V_{dc} = 0.8165 \times 400$	326.60 V
RMS phase voltage	$V_{ph} = (\sqrt{2/3}) \cdot V_{dc} = 0.4714 \times 400$	188.56 V
RMS phase current	$I_{ph} = V_{ph}/R$	18.86 A
Load power	$P = 3 \cdot I_{ph}^2 \cdot R$	10667 W $\approx$ 10.67 kW

Check: the RMS values computed numerically from the six-step waveform give $V_L = 326.60$ V and $V_{ph} = 188.56$ V (same). RMS of fundamental line voltage = $0.7797 V_{dc} = 311.9$ V.

(V_L 1 M, V_{ph} 1 M, I_{ph} 1 M, power 1 M)

d) Static voltage stabilizer.

4 M



Static voltage stabilizer (no moving parts): PWM converter injects $\pm$ voltage through buck-boost transformer

- Has **no moving parts**. A microcontroller samples the output voltage many times per cycle and compares it with the reference.
- An IGBT-based PWM AC-AC converter generates a correction voltage of required magnitude and phase (in-phase to boost, anti-phase to buck) and injects it through a buck-boost transformer

in series with the line.

- **Advantages:** very fast correction (within a few milliseconds), accuracy $\pm 1\%$, compact, silent, maintenance free. **Disadvantages:** costly, IGBT switching produces harmonics (needs filter), electronics sensitive to surges.
- **Applications:** sensitive electronic loads, data centres, medical equipment, CNC, telecom.

(Block diagram 2 M, working 1 M, advantages 1 M)

e) Functions of charge controller; PWM vs MPPT.

4 M

Functions:

- Prevents **overcharging** of the battery by reducing/stopping charging current at full charge.
- Prevents **deep discharge** by disconnecting the load at low battery voltage (LVD).
- Prevents **reverse current** from battery to PV panel at night (blocking diode/MOSFET).
- Extracts maximum power from the panel (MPPT type) and gives status indication.

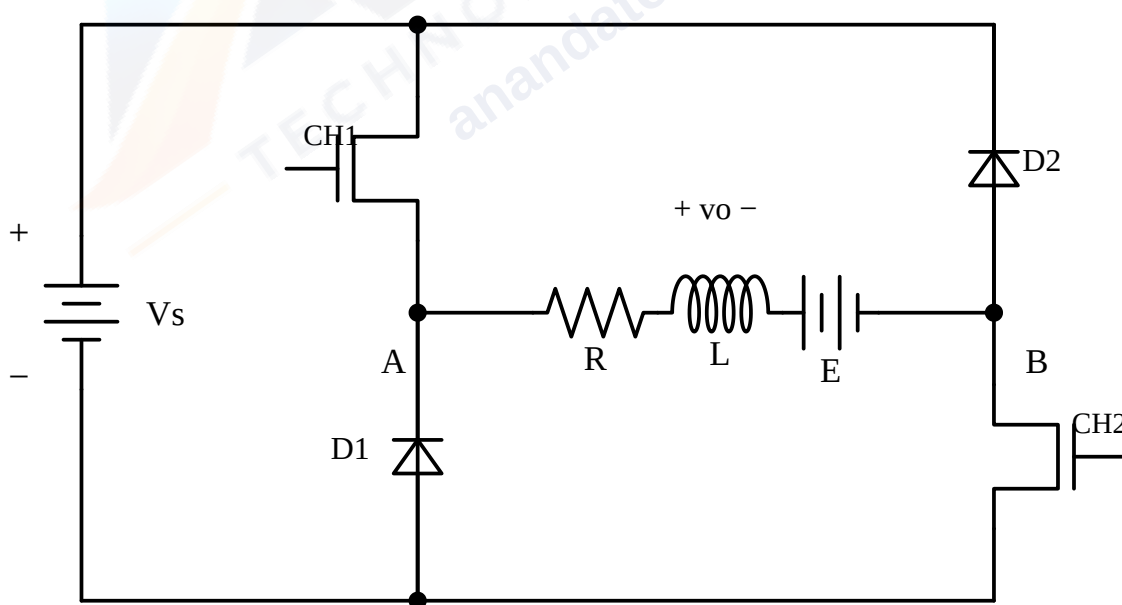
Point	PWM controller	MPPT controller
Working	Switches PV to battery with PWM pulses; panel voltage pulled down to battery voltage	DC-DC converter operates panel at its maximum power point (V_{mp}) and converts to battery voltage
Efficiency / energy	Lower	15–30 % more energy harvested
Panel voltage	Must match battery voltage	Panel voltage can be higher than battery
Cost	Cheap	Costly

(Functions 2 M, comparison 2 M)

Q.5

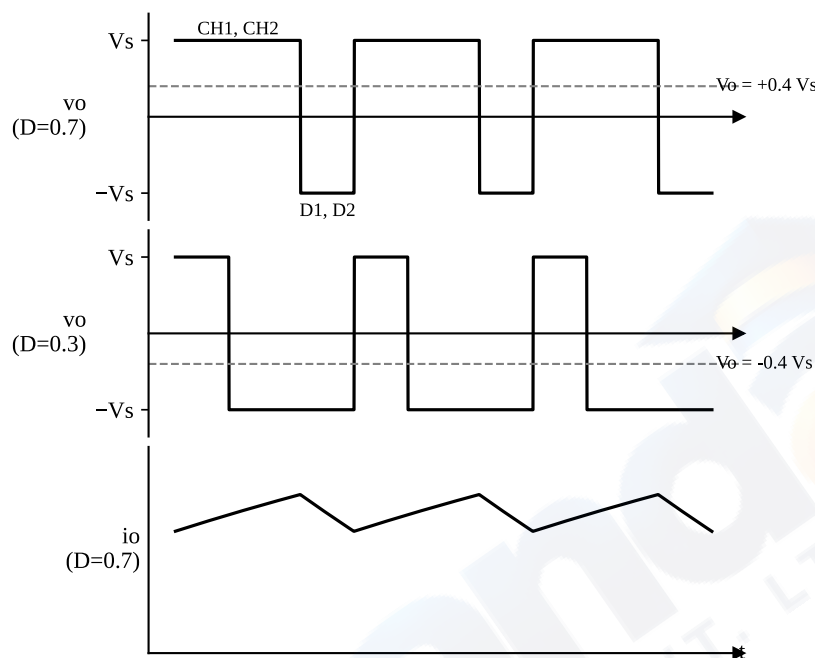
a) Type D chopper; $V_o = (2D - 1)V_s$; numerical.

6 M



Type D (two-quadrant, voltage reversible) chopper

- Consists of two switches CH1, CH2 and two diodes D1, D2. Load current I_o is always positive; V_o can be positive or negative — **first and fourth quadrant**.
- **CH1 and CH2 ON ($0 < t < T_{on}$):** $v_o = +V_s$; current flows $V_s \rightarrow CH1 \rightarrow \text{load} \rightarrow CH2$.
- **CH1 and CH2 OFF:** load inductance forces current through D1 and D2 back to the source; $v_o = -V_s$ (energy returned).
- Average voltage: $V_o = [T_{on} \cdot V_s - (T - T_{on}) \cdot V_s] / T = (2D - 1) \cdot V_s$. $D > 0.5 \rightarrow V_o$ positive (Quadrant I); $D < 0.5 \rightarrow V_o$ negative (Quadrant IV); $D = 0.5 \rightarrow V_o = 0$.



Type D chopper (computed): v_o is $+V_s$ or $-V_s$, average $V_o = (2D - 1)V_s$; load current always positive

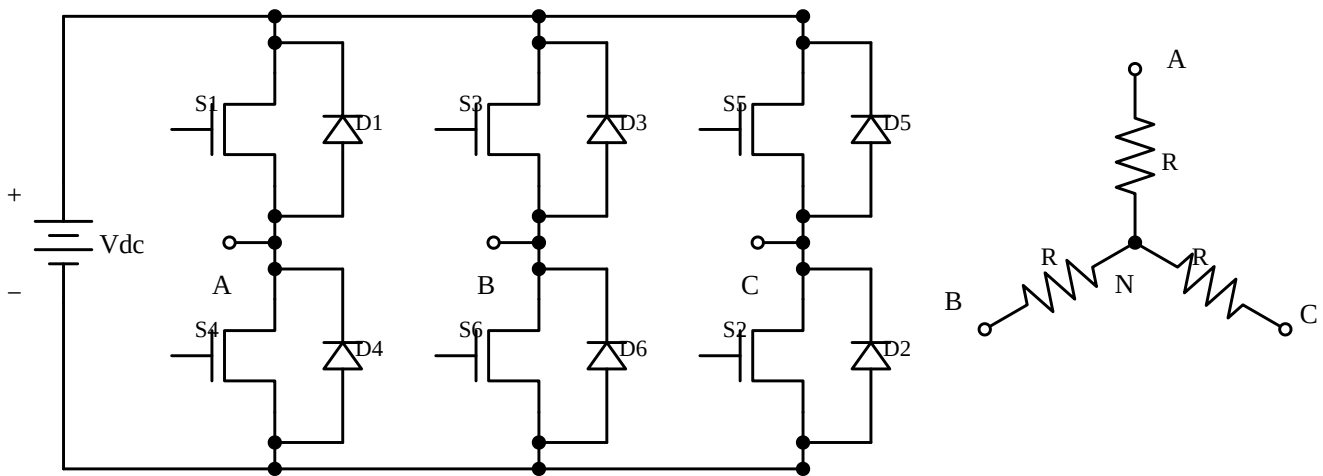
Derivation: during T_{on} , $v_o = +V_s$; during $T_{off} = T - T_{on}$, $v_o = -V_s$. Average $V_o = [V_s \cdot T_{on} - V_s(T - T_{on})] / T = V_s(2T_{on} - T) / T = (2D - 1)V_s$.

Duty cycle D	$V_o = (2D - 1) \cdot V_s$	Result	Quadrant
0.7	$(2 \times 0.7 - 1) \times 220$	+88 V	I (power to load)
0.3	$(2 \times 0.3 - 1) \times 220$	-88 V	IV (power returned to source)

(Circuit 1 M, operation 2 M, waveforms 1 M, derivation 1 M, numerical 1 M)

b) Three-phase VSI in 120° conduction mode.

6 M

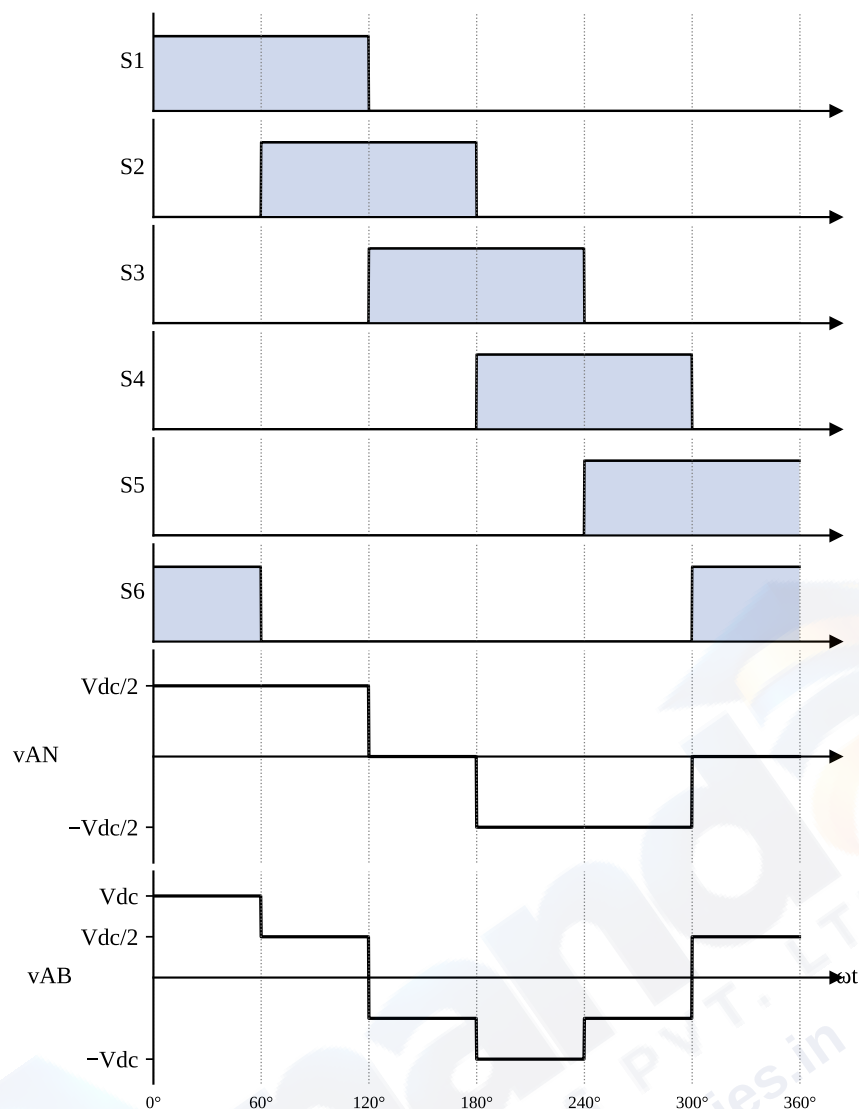


Star-connected R load

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

- In 120° mode each switch conducts for **120°**; switches are triggered in the order S1 ... S6 at 60° intervals. **Only two switches conduct at any instant** — one from the upper group and one from the lower group.
- Conducting pairs: (S6, S1), (S1, S2), (S2, S3), (S3, S4), (S4, S5), (S5, S6).
- In each interval one phase is connected to +, one to −, and the third phase is **floating** (open).

Interval	Switches ON	V_{AN}	V_{BN}	V_{CN}	V_{AB}
0–60°	S6, S1	$V_{dc}/2$	$-V_{dc}/2$	0	V_{dc}
60–120°	S1, S2	$V_{dc}/2$	0	$-V_{dc}/2$	$V_{dc}/2$
120–180°	S2, S3	0	$V_{dc}/2$	$-V_{dc}/2$	$-V_{dc}/2$



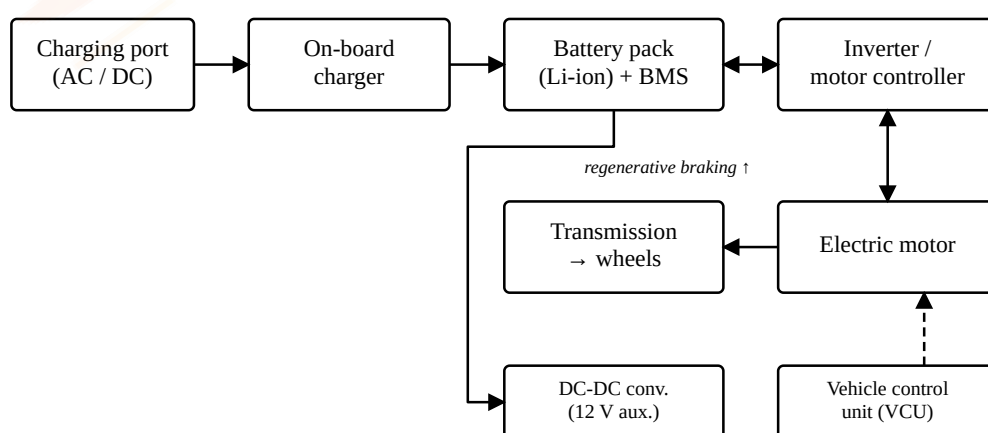
120° conduction mode (computed): each switch conducts 120°, only two switches ON at a time; quasi-square phase voltage

Phase voltage is a quasi-square wave of 120° pulses ($\pm V_{dc}/2$); line voltage is six-step (V_{dc} , $V_{dc}/2$). $V_{ph(rms)} = 0.408 V_{dc}$, $V_{L(rms)} = 0.707 V_{dc}$ (computed from the waveforms).

(Circuit 1 M, explanation 2 M, gating sequence 1 M, waveforms 2 M)

c) PEV block diagram; PEV vs PHEV.

6 M



Block diagram of plug-in electric vehicle (PEV / battery EV)

- A **PEV (plug-in electric / battery electric vehicle)** runs only on electric power stored in a battery that is charged by plugging into an external supply.
- **Charging port and on-board charger** convert grid AC into DC to charge the battery (DC fast chargers feed the battery directly).
- **Battery pack + BMS:** Li-ion pack stores energy; BMS monitors cell voltage, temperature and state of charge, and balances cells.
- **Inverter / motor controller:** converts battery DC to variable-frequency AC for the traction motor as per accelerator command from the VCU.
- **Electric motor and transmission** drive the wheels. During braking the motor works as a generator (regenerative braking) and charges the battery.
- **DC-DC converter** supplies the 12 V auxiliary system (lights, wipers).

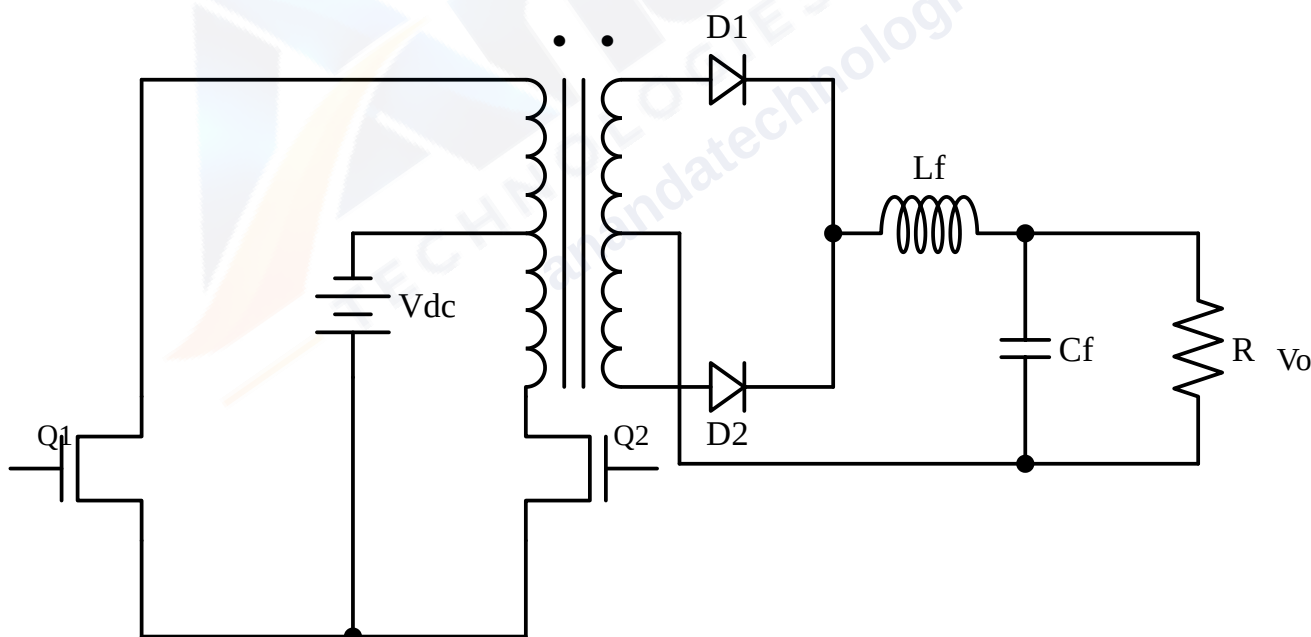
Point	PEV	PHEV
Energy source	Battery only (electricity)	Battery + fuel (petrol/diesel)
Prime mover	Electric motor only	Electric motor + IC engine
Tailpipe emission	Zero	Low (zero in EV mode)
Driving range	Limited by battery (charging needed)	Long — engine extends range
Battery size	Large	Medium

(Block diagram 2 M, explanation 2 M, comparison 2 M)

Q.6

a) Push-pull converter.

6 M



Push-pull converter: centre-tapped transformer, MOSFETs Q1 and Q2 switched alternately

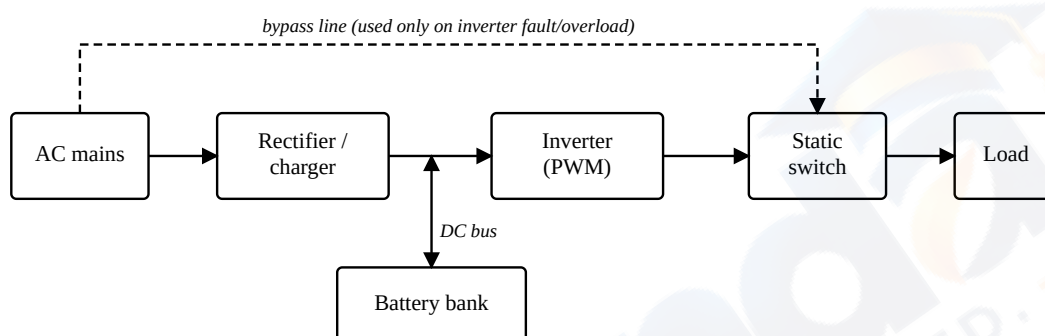
- Q1 and Q2 are switched ON **alternately**, each for $T_{on} < T/2$ (dead time prevents both being ON).

- **Q1 ON:** current flows through the upper half of the primary; secondary voltage forward biases D1; power flows to the load through Lf.
- **Q2 ON:** current flows through the lower half of the primary in the opposite direction; D2 conducts. Thus the core is magnetised in both directions.
- **Both OFF:** Lf current freewheels through D1 and D2.
- $V_o = 2 \cdot D \cdot V_s \cdot (N_s/N_p)$, where $D = T_{on}/T$ of each switch.
- **Advantages:** better transformer core utilisation, both MOSFET sources grounded (simple gate drive), suitable for medium power and low input voltage (battery inverters). **Limitation:** switch voltage stress $2V_s$ and possible core saturation due to flux imbalance.

(Circuit 2 M, working 3 M, advantages and limitation 1 M)

b) On-line UPS and its specifications.

6 M



On-line (double conversion) UPS: load is always fed from the inverter

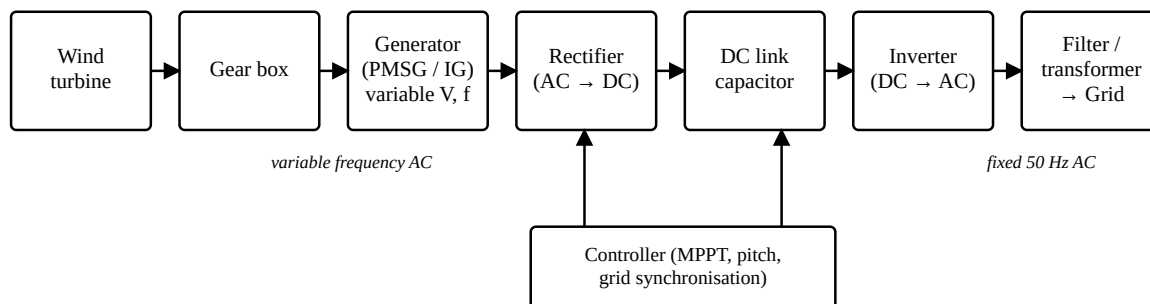
- **Rectifier/charger** converts AC mains to DC, feeds the inverter and charges the battery continuously.
- **Inverter (PWM)** converts DC to regulated 50 Hz sine-wave AC; the load is **always** supplied by the inverter (double conversion).
- On mains failure the battery, already connected to the DC bus, supplies the inverter — there is **no break** (transfer time zero).
- **Static switch** transfers the load to the bypass line only if the inverter fails or is overloaded.

Specification	On-line UPS
Input voltage range	Wide ($\approx 110\text{--}300\text{ V}$); rectifier accepts large variation
Output frequency	Fixed $50\text{ Hz} \pm 0.1\%$ (crystal-controlled inverter), independent of mains
Total harmonic distortion (THD)	Low, $< 3\%$ (pure sine-wave inverter)
Load power factor	Designed for $0.8\text{--}0.9$ lagging; handles non-linear loads well

(Block diagram 2 M, working 1 M, four specifications 3 M)

c) AC-DC-AC converter in wind power generation.

6 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.

(Need 1 M, block diagram 2 M, explanation 3 M)

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