

## Fundamentals of Power Electronics (313335)

MSBTE K-Scheme · EE Sem III · Model Question Paper — Set B · Model Answers

Answers are written point-wise as expected in MSBTE model answers. Marks scheme lines in blue italics are indicative. All waveforms are plotted from the circuit equations and all numerical values were calculated by program.

### Q.1

#### a) Need of power electronic systems

2 M

- To **convert** electric power from one form to another efficiently — AC to DC (rectifier), DC to AC (inverter), DC to DC (chopper), AC to AC (AC voltage controller / cycloconverter).
- To **control** voltage, current, power, speed and frequency smoothly with very small loss (e.g. motor speed control, fan regulator).
- To interface renewable sources (solar, wind) and batteries with loads and grid; for UPS, SMPS and EV chargers.

(Any two, 1 M each)

#### b) Symbols of power MOSFET and IGBT

2 M

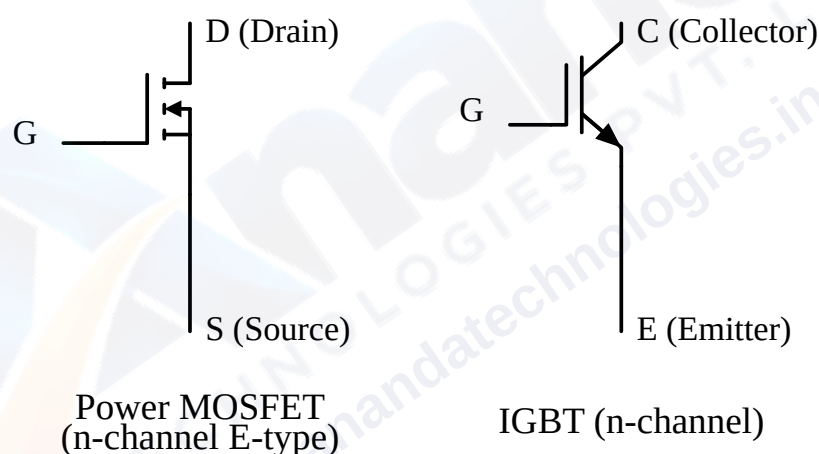


Fig.: Symbols of n-channel power MOSFET and IGBT

(1 M each)

#### c) Commutation and its types

2 M

**Commutation:** The process of turning OFF a conducting SCR is called commutation. It is done by reducing the anode current below the holding current and applying reverse voltage for a time greater than the turn-off time.

**Types:** (i) **Natural commutation** (class F — by AC supply reversal), (ii) **Forced commutation** (classes A to E — using external L-C commutating circuits in DC circuits).

(Definition 1 M, types 1 M)

#### d) Applications of SCR

2 M

- Controlled rectifiers (DC motor speed control, battery chargers)
- AC voltage controllers — light dimmers, fan regulators, heater control
- Inverters, choppers and UPS
- HVDC transmission, static switches, welding control

(Any two, 1 M each)

#### e) $T_{ON}$ , $T_{OFF}$ , chopping period

2 M

- **Turn-ON period ( $T_{ON}$ ):** the time interval for which the chopper switch is ON and the load is connected to the supply ( $v_o = V_s$ ).
- **Turn-OFF period ( $T_{OFF}$ ):** the time interval for which the chopper switch is OFF and the load is disconnected from the supply ( $v_o = 0$ ).
- **Chopping period ( $T$ ):** the total time of one ON–OFF cycle,  $T = T_{ON} + T_{OFF}$ . Chopping frequency  $f = 1/T$ .

(Each  $\frac{2}{3}$  M)

#### f) Types of solar charge controllers

2 M

1. ON-OFF type (series / shunt) charge controller
2. PWM (pulse width modulation) charge controller
3. MPPT (maximum power point tracking) charge controller

(Types 2 M)

#### g) Methods of triggering SCR

2 M

1. **Gate triggering** — positive gate current applied (most common and reliable method)
2.  **$dv/dt$  triggering** — fast rising anode voltage; charging current of junction capacitance turns it ON
3. **Thermal (temperature) triggering** — high junction temperature increases leakage current
4. **Light triggering** — light falling on the junction (LASCR)
5. **Forward voltage triggering** —  $V_{AK}$  increased above breakover voltage  $V_{BO}$

(Any four,  $\frac{1}{2}$  M each)



## b) R firing circuit of SCR

4 M

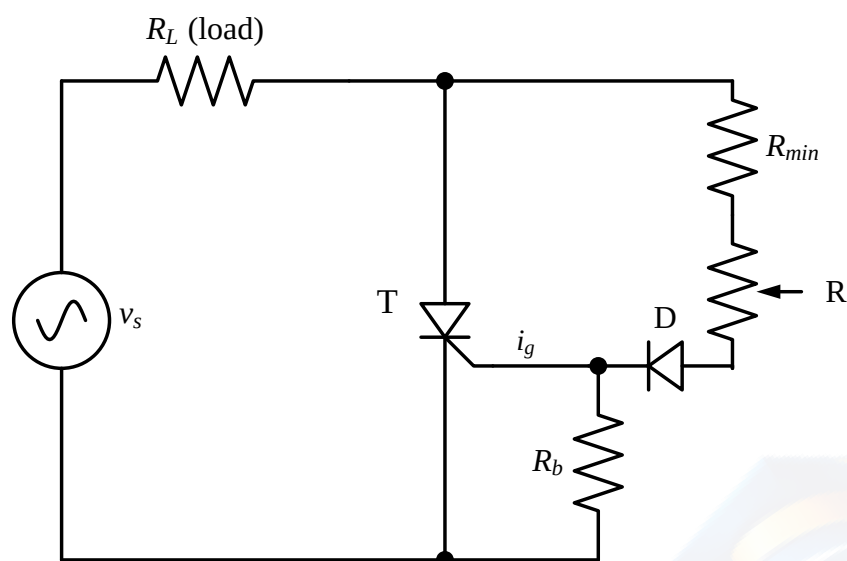


Fig.: Resistance (R) firing circuit of SCR

- **$R_{min}$**  limits the peak gate current to a safe value when R is zero; **R** (variable) controls the gate current and hence the firing angle.
- **Diode D** allows gate current only in the positive half cycle and blocks reverse gate voltage in the negative half cycle.
- **$R_b$**  limits the gate voltage (stabilising resistor) so that the gate voltage does not exceed its rating.
- In the positive half cycle the gate current rises with the supply voltage. The SCR fires when the gate voltage/current reaches the gate trigger value ( $V_{gt}$ ,  $I_{gt}$ ). Once ON, the voltage across the SCR falls to  $\approx 1$  V and the gate circuit current becomes almost zero.
- If R is increased, the gate current reaches  $I_{gt}$  later, so firing angle  $\alpha$  increases and average load voltage decreases.
- **Limitation:** the gate current is maximum at  $\omega t = 90^\circ$ ; hence  $\alpha$  can be varied only from about  $0^\circ$  to  $90^\circ$ . If R is too large, the SCR does not fire at all.

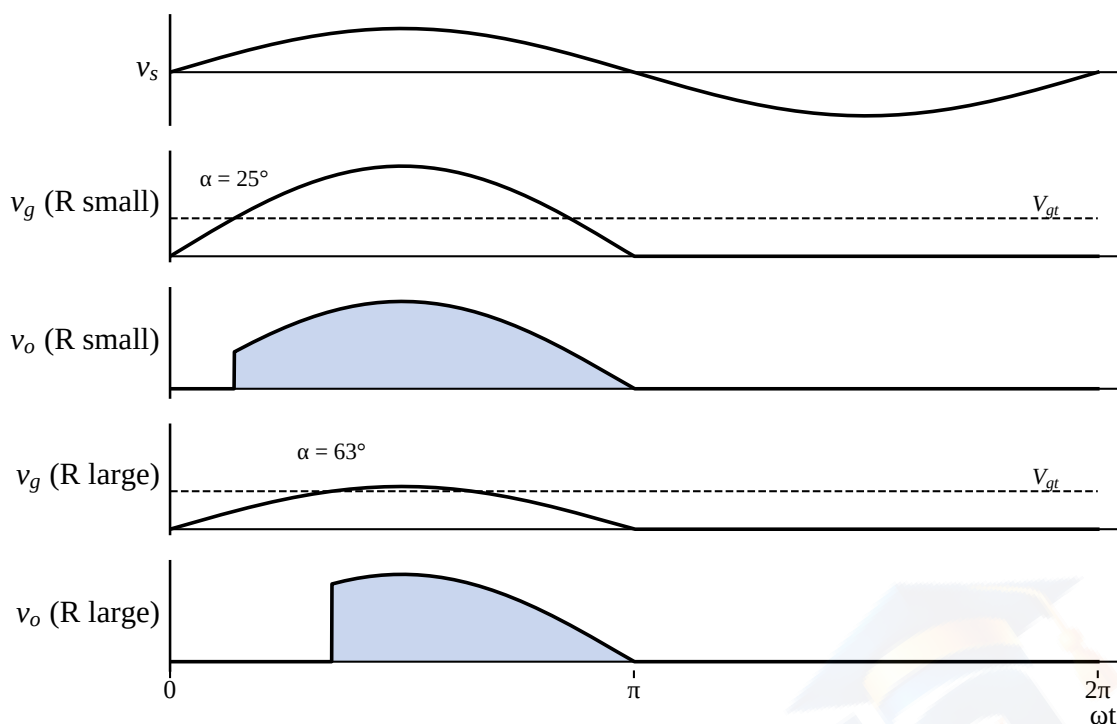


Fig.: Waveforms of R firing circuit — larger  $R$  gives larger  $\alpha$  (maximum  $90^\circ$ )

Plotted example ( $V_{gt} = 0.4$  of peak gate voltage): small  $R \rightarrow \alpha \approx 25^\circ$ , large  $R \rightarrow \alpha \approx 63^\circ$ .

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

### c) Compare R and RC triggering

4 M

| Point                              | R triggering                                                 | RC triggering                               |
|------------------------------------|--------------------------------------------------------------|---------------------------------------------|
| Components                         | Resistors $R_{min}$ , $R$ , $R_b$ and diode                  | Resistor $R$ , capacitor $C$ and two diodes |
| Range of firing angle $\alpha$     | $0^\circ$ to $90^\circ$ only                                 | $0^\circ$ to nearly $180^\circ$             |
| Average output voltage (half wave) | Can be reduced only to $V_m/2\pi$ (at $\alpha = 90^\circ$ )  | Can be reduced to nearly zero               |
| Gate voltage                       | In phase with supply                                         | Lags the supply (RC phase shift)            |
| Dependence on SCR                  | $\alpha$ depends strongly on gate parameters and temperature | Less dependent; better control              |
| Cost / use                         | Simplest, cheapest; low-cost uses                            | Simple and cheap; wider control range       |

(Any four points, 1 M each)

d) 1- $\phi$  half wave controlled rectifier, R load: 230 V,  $R = 50 \Omega$ ,  $\alpha = 45^\circ$

4 M

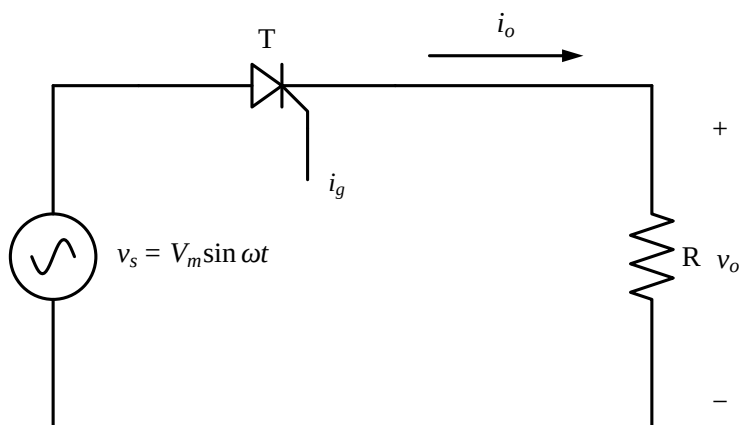


Fig.: Single phase half wave controlled rectifier with R load

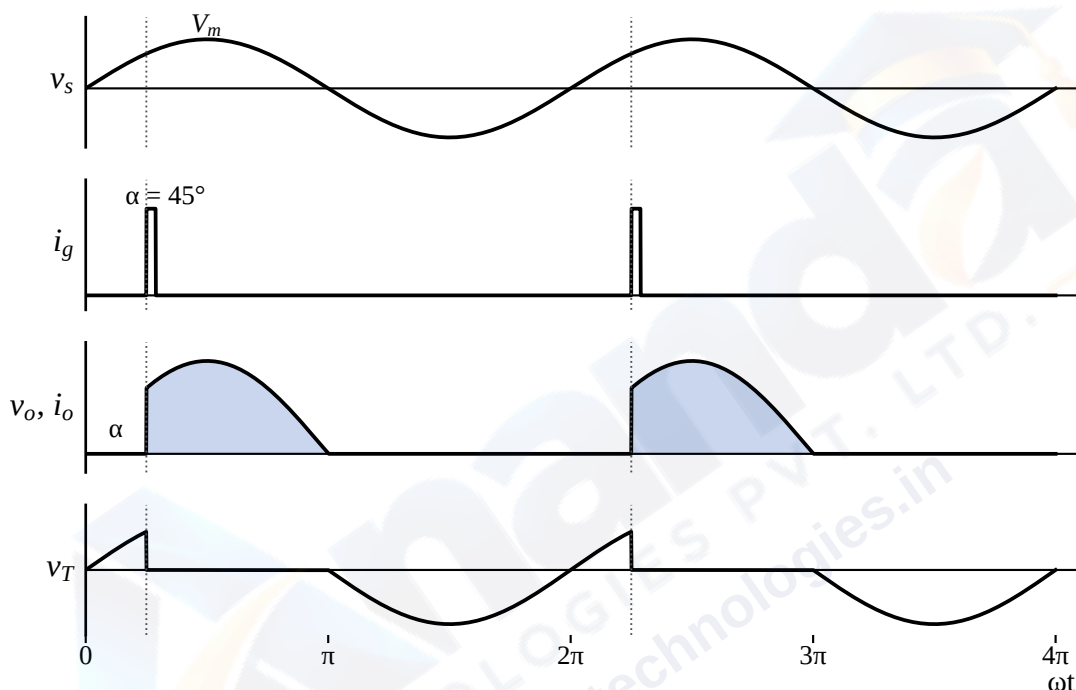


Fig.: Waveforms of 1- $\phi$  half wave controlled rectifier with R load ( $\alpha = 45^\circ$ )

During the positive half cycle the SCR is forward biased and fires at  $\omega t = \alpha$ ;  $v_o = v_s$  from  $\alpha$  to  $\pi$ . At  $\pi$  the current becomes zero and the SCR turns off; in the negative half cycle it is reverse biased and  $v_o = 0$ .

$$V_{dc} = (V_m/2\pi)(1 + \cos \alpha)$$

$$V_m = \sqrt{2} \times 230 = 325.27 \text{ V}$$

$$V_{dc} = (325.27 / 2\pi)(1 + \cos 45^\circ) = 51.77 \times 1.7071 = \mathbf{88.37 \text{ V}}$$

$$I_{dc} = V_{dc}/R = 88.37/50 = \mathbf{1.767 \text{ A}}$$

(numerical average of computed waveform = 88.37 V)

(Circuit & waveform 2 M,  $V_{dc}$  1 M,  $I_{dc}$  1 M)

### Q.3

#### a) Resonant (class A) commutation

4 M

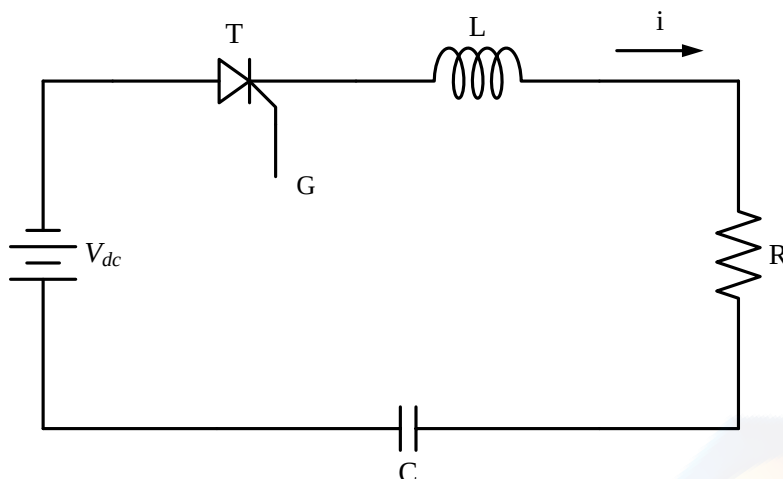


Fig.: Class A (resonant / load) commutation circuit

- Class A is also called **self commutation, load commutation or resonant commutation**.
- An inductor  $L$  and capacitor  $C$  are connected with the load so that the circuit is **under-damped** (for series R-L-C:  $R < 2\sqrt{L/C}$ ).
- When SCR  $T$  is triggered, current flows from  $V_{dc}$  through  $T$ ,  $L$  and the load and charges capacitor  $C$ . Because of resonance the current rises, reaches a peak and then **falls to zero naturally**.
- When the current falls below the holding current,  **$T$  turns OFF by itself**. The capacitor is now charged to nearly  $2V_{dc}$  ( $> V_{dc}$ ), so the SCR gets a reverse voltage for some time, which ensures turn-off.
- The capacitor then discharges through the load and the circuit is ready for the next triggering.
- Used for high frequency (above 1 kHz) applications such as **series inverters**.

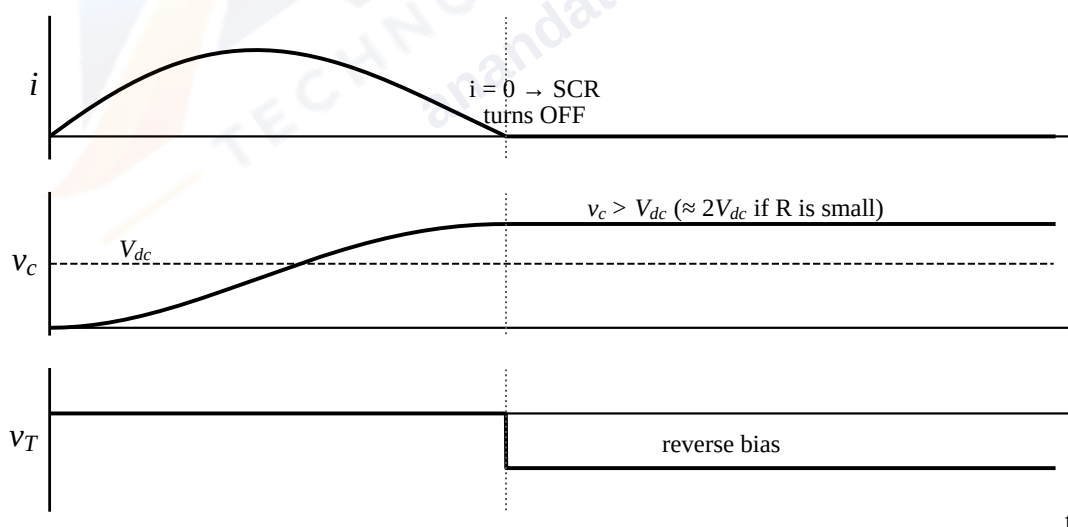


Fig.: Class A commutation — load current is oscillatory (computed for  $\zeta = 0.15$ )

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

## b) di/dt protection of SCR

4 M

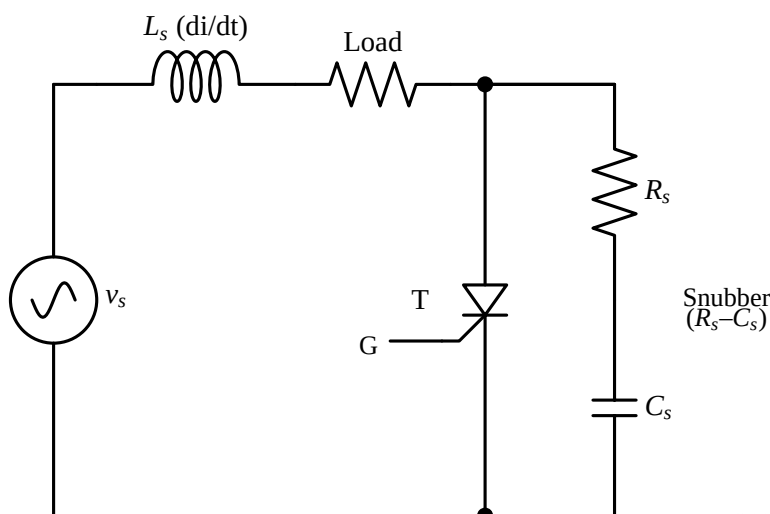


Fig.: Series inductor  $L_s$  for di/dt protection (with  $R_s$ - $C_s$  snubber)

- **Need:** when an SCR is turned ON, conduction starts only in a small area near the gate and then spreads slowly over the whole cathode area (spreading velocity  $\approx 0.1 \text{ mm}/\mu\text{s}$ ).
- If the anode current rises very fast (high di/dt), a large current flows through this small area, causing **local hot spots** and permanent damage to the junction.
- **Protection:** a small inductor  $L_s$  is connected **in series** with the SCR. Since the current through an inductor cannot change suddenly, the rate of rise is limited:  $di/dt \approx V_m/L_s$ , which is kept below the rated di/dt.
- Applying a **strong gate pulse** (large gate current, fast rise) also helps the conduction area to spread quickly.
- The snubber resistance  $R_s$  limits the capacitor discharge current at turn-ON, which also limits di/dt.

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

## c) 3- $\phi$ fully controlled bridge, R load, $\alpha = 60^\circ$ , 415 V

4 M

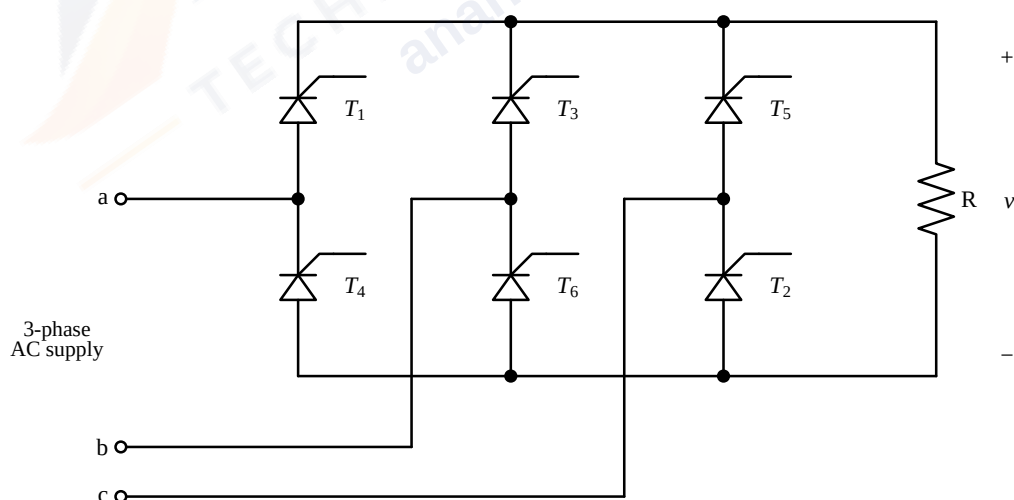


Fig.: Three phase fully controlled bridge rectifier with R load

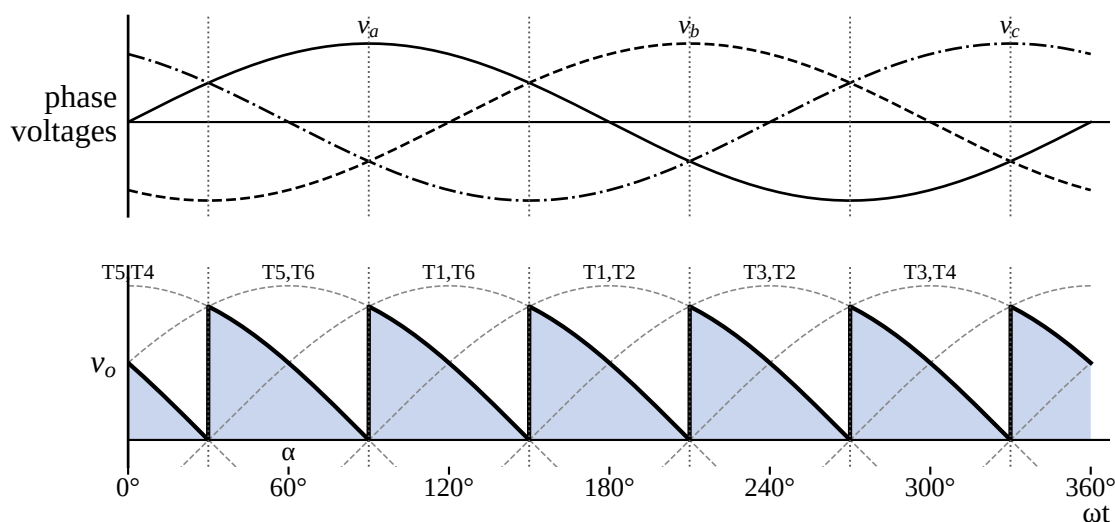


Fig.: Output voltage of 3- $\phi$  fully controlled bridge with R load ( $\alpha = 60^\circ$ ); thin dashed curves are the six line voltages

- Six SCRs are used: **T1, T3, T5** form the positive (upper) group and **T4, T6, T2** the negative (lower) group. SCRs are numbered in the order of firing.
- At any time **two SCRs conduct** — one from the upper group connected to the most positive line and one from the lower group connected to the most negative line. The output is the corresponding line voltage.
- SCRs are fired at intervals of **60°** in the sequence T1 → T2 → T3 → T4 → T5 → T6; each SCR conducts for 120°. Conducting pairs: T6T1, T1T2, T2T3, T3T4, T4T5, T5T6.
- Firing angle  $\alpha$  is measured from the **natural commutation point** (30° after the zero crossing of the phase voltage), i.e. the point where the diode in its place would start conducting.
- Output has **six pulses per cycle** (ripple frequency  $6f = 300$  Hz), so ripple is small. With R load the output is continuous for  $\alpha \leq 60^\circ$ ; for  $\alpha > 60^\circ$  it becomes discontinuous.

**Average output voltage:**  $V_{dc} = (3V_{ml}/\pi) \cos \alpha = 1.35 V_L \cos \alpha$  ( $\alpha \leq 60^\circ$ );  $V_{dc} = (3V_{ml}/\pi)[1 + \cos(60^\circ + \alpha)]$  ( $60^\circ \leq \alpha \leq 120^\circ$ , R load)

$$V_L = 415 \text{ V}, V_{ml} = \sqrt{2} \times 415 = 586.90 \text{ V}, \alpha = 60^\circ$$

$$V_{dc} = \mathbf{280.22 \text{ V}}$$
 (numerical average of computed waveform = 280.22 V)

(Circuit 1 M, waveform 1 M, explanation 1 M,  $V_{dc}$  1 M)

**d) 1- $\phi$  half bridge inverter, R load;  $V_s = 220$  V,  $R = 10 \Omega$**

4 M

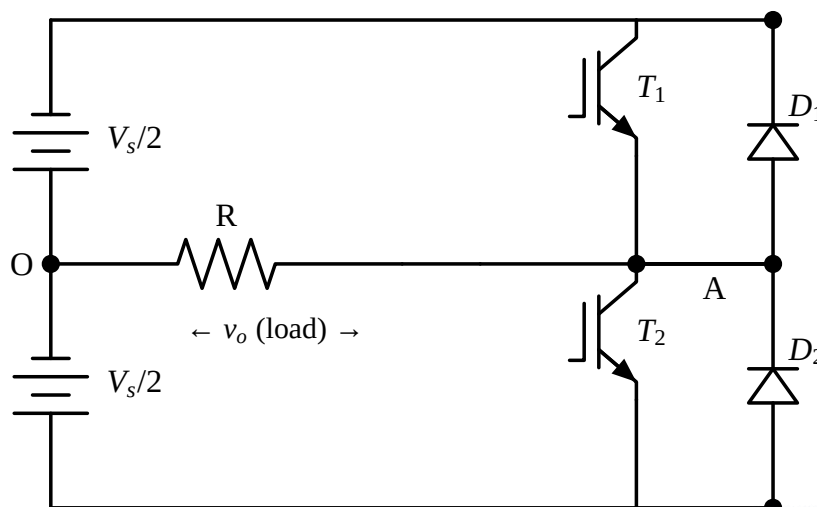


Fig.: Single phase half bridge inverter with R load

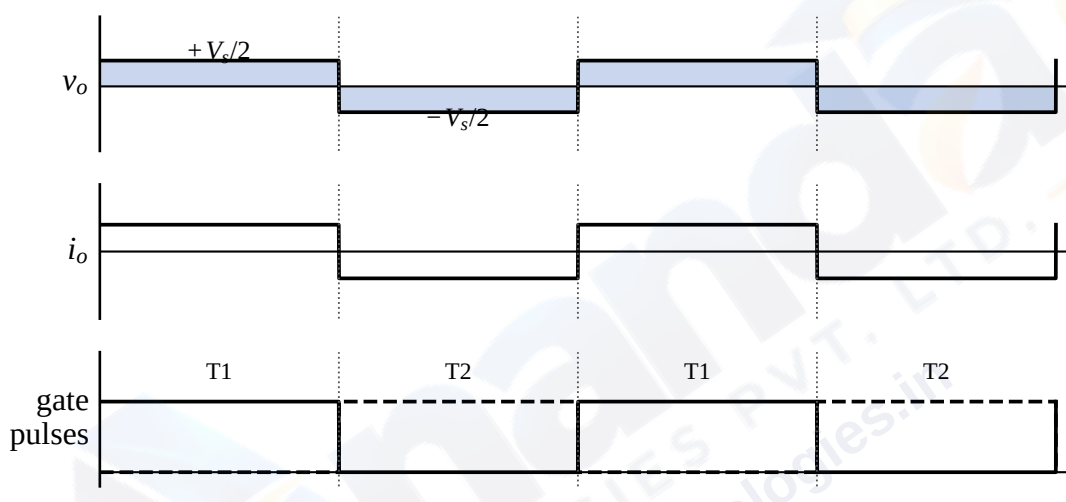


Fig.: Output waveforms of 1- $\phi$  half bridge inverter with R load

- The half bridge inverter uses **two switches T1, T2** (SCR/IGBT) and a **three-wire DC supply** (two equal sources  $V_s/2$ , or a centre-tapped capacitor divider). The load is connected between point A and the centre point O. D1, D2 are feedback diodes.
- $0 < t < T/2$ : T1 is ON, T2 OFF. The upper source drives current from A to O through the load:  $v_o = +V_s/2$ .
- $T/2 < t < T$ : T1 is turned OFF and T2 ON. The lower source drives current from O to A:  $v_o = -V_s/2$ .
- Thus a square wave AC of amplitude  $V_s/2$  is obtained. Output frequency  $f = 1/T$  is controlled by the rate of switching of T1 and T2. T1 and T2 must never be ON together (short circuit of supply).
- With R load the current is also a square wave in phase with voltage, so feedback diodes do not conduct; with R-L load they return reactive energy to the supply.

RMS output voltage  $V_{o(rms)} = V_s/2$ ; RMS value of fundamental  $V_{o1} = 2V_s/(\pi\sqrt{2}) = 0.45 V_s$ .

$$V_s = 220 \text{ V} \rightarrow V_{o(\text{rms})} = 110.0 \text{ V}, V_{o1(\text{rms})} = 0.45 \times 220 = 99.03 \text{ V}$$

$$\text{Load current } I_o = 110.0/10 = 11.00 \text{ A; power } P = V_o^2/R = 1210.0 \text{ W}$$

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

## Q.4

### a) Sinusoidal PWM

4 M

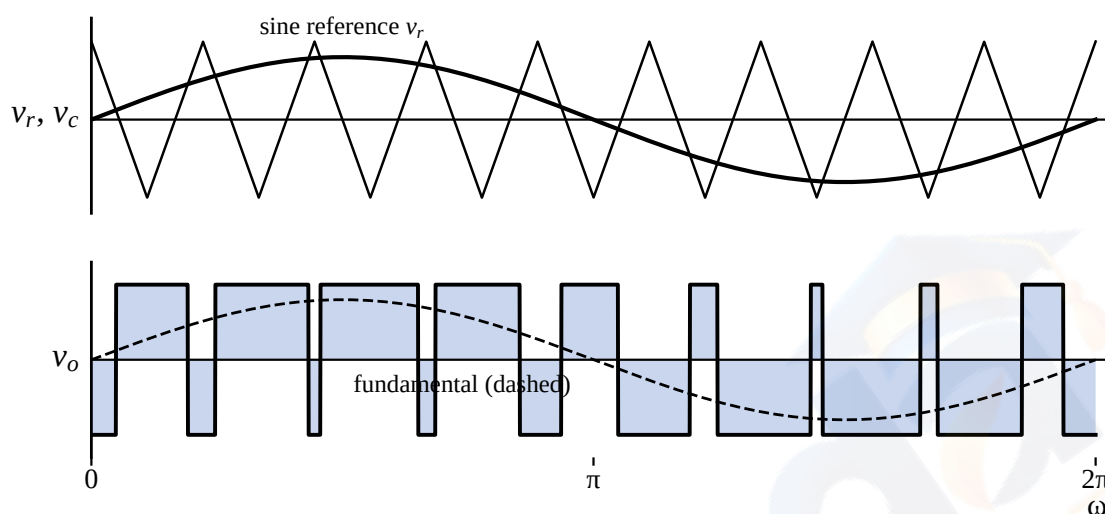


Fig.: Sinusoidal PWM — sine reference compared with triangular carrier ( $m_f = 9$ ,  $m_a = 0.8$ )

- A **sinusoidal reference** signal  $v_r$  (frequency = desired output frequency  $f_r$ ) is compared with a high frequency **triangular carrier**  $v_c$  (frequency  $f_c$ ) in a comparator.
- When  $v_r > v_c$  the upper switch is ON ( $v_o = +V$ ); when  $v_r < v_c$  the lower switch is ON ( $v_o = -V$ ).
- The pulse width therefore varies **sinusoidally** — pulses are widest at the peak of the sine wave and narrow near zero crossing. The fundamental component of  $v_o$  is a sine wave (dashed).
- **Modulation index**  $m_a = V_r/V_c$  controls the output voltage amplitude;  $f_r$  controls output frequency;  $m_f = f_c/f_r$  decides the number of pulses.
- Lower order harmonics are eliminated; harmonics appear near the carrier frequency and are easily filtered. Used in VFDs, UPS and solar inverters.

(Waveforms 2 M, explanation 2 M)

b) Step-down chopper with  $D = 0.25$ ;  $V_s = 240$  V

4 M

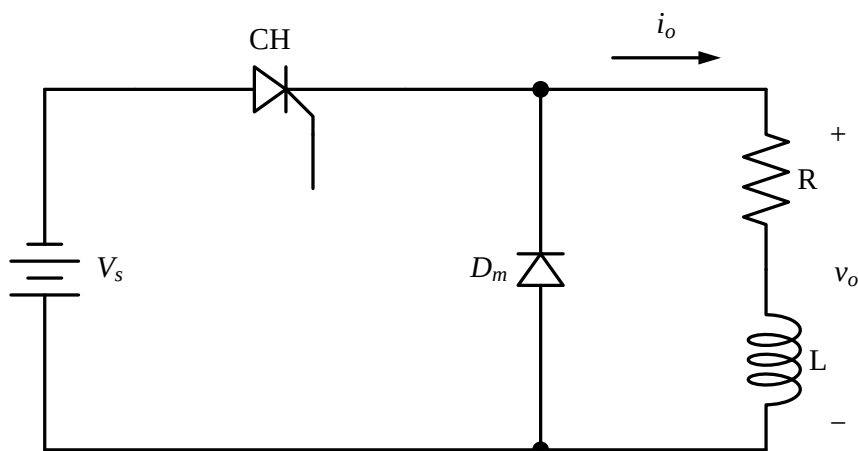


Fig.: Step-down (buck) chopper with RL load

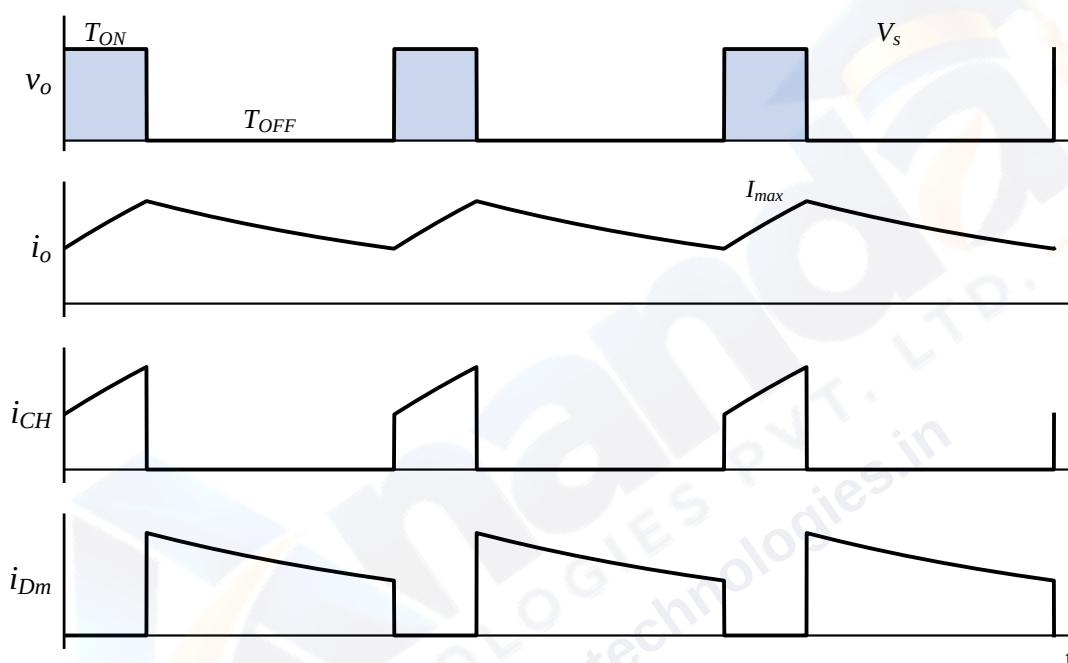


Fig.: Waveforms of step-down chopper ( $D = 0.25$ )

- A chopper CH (SCR with commutation circuit / MOSFET / IGBT) is connected in series with the load;  $D_m$  is the freewheeling diode.
- **$T_{ON}$  period:** CH is ON, the supply is connected to the load;  $v_o = V_s$ . Load current rises exponentially and energy is stored in L.  $D_m$  is reverse biased.
- **$T_{OFF}$  period:** CH is OFF; load current continues (freewheels) through  $D_m$ ;  $v_o = 0$  and the current decays.
- The output is a chopped DC; its average value is less than  $V_s$ , hence **step-down (buck) chopper**. Output is controlled by varying duty cycle.

**Output voltage:**  $V_o = (T_{ON} / (T_{ON} + T_{OFF})) \times V_s = (T_{ON}/T) V_s = D \cdot V_s$ , where  $D =$  duty cycle ( $0 \leq D \leq 1$ )

$$V_o = D \times V_s = 0.25 \times 240 = \mathbf{60 \text{ V}}$$

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

### c) Variable frequency control of chopper

4 M

In **variable frequency control** (frequency modulation) the chopping period  $T = 1/f$  is varied while either  $T_{ON}$  or  $T_{OFF}$  is kept constant. Since  $D = T_{ON}/T$ , changing  $T$  changes the duty cycle and hence the output voltage  $V_o = (T_{ON}/T)V_s$ .

- **$T_{ON}$  constant,  $T$  varied:** increasing frequency (smaller  $T$ ) increases  $D$  and  $V_o$ ; decreasing frequency reduces  $V_o$ .
- **$T_{OFF}$  constant,  $T$  varied:** increasing  $T$  (larger  $T_{ON}$ ) increases  $V_o$ .

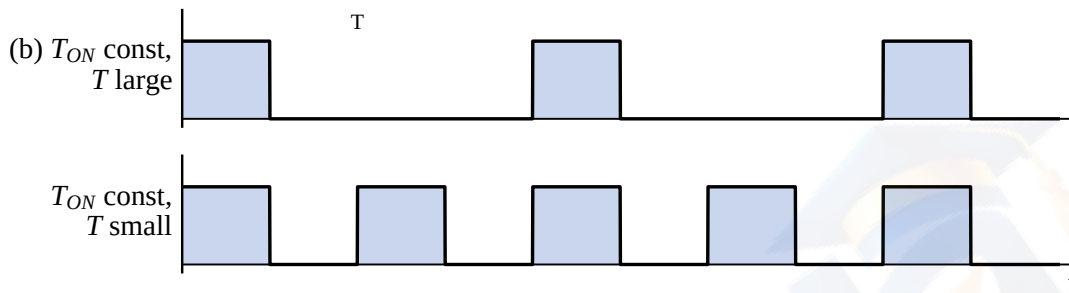


Fig.: Variable frequency control —  $T_{ON}$  constant,  $T$  varied (upper: low frequency, low output; lower: high frequency, high output)

**Disadvantages:** (i) frequency varies over a wide range, so **filter design is difficult**; (ii) harmonics of varying frequency may interfere with signalling/telephone lines; (iii) at low output (large  $T_{OFF}$ ) load current may become discontinuous. Hence constant frequency (PWM) control is generally preferred.

(Explanation with waveform 3 M, drawbacks 1 M)

### d) Converter station in HVDC

4 M

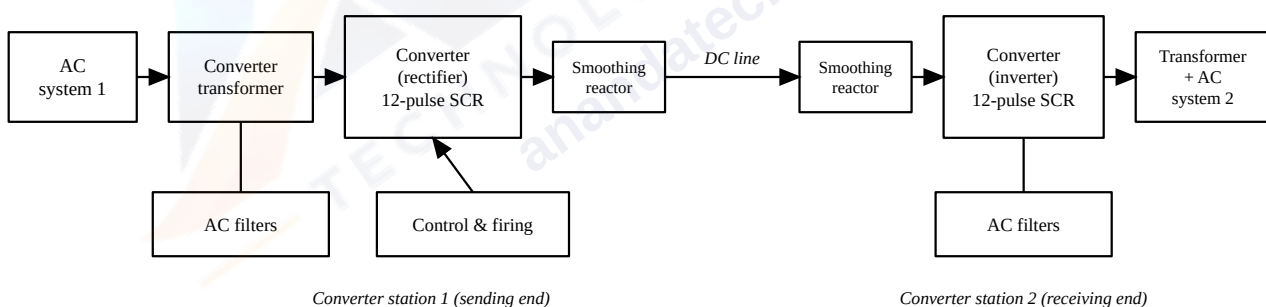


Fig.: HVDC link — converter stations at both ends (monopolar, simplified)

- At the sending end the converter station works as a **rectifier** ( $AC \rightarrow DC$ ); at the receiving end the station works as an **inverter** ( $DC \rightarrow AC$ ). Power flow and DC voltage are controlled by the firing angle of the thyristor valves.
- **Converter transformers:** step the AC voltage to the required level and give  $30^\circ$  phase shift (star–star and star–delta) for 12-pulse operation.
- **Thyristor valves (12-pulse bridges):** series-connected SCRs (often light-triggered) perform the conversion.

- **Smoothing reactor:** reduces ripple in DC current and limits fault current.
- **AC and DC filters:** remove harmonics produced by the converters; shunt capacitors supply reactive power needed by the converters.
- **Control and protection system:** firing control, current/voltage control and protection of the link.

(Diagram 2 M, functions 2 M)

### e) Fan regulator using TRIAC and DIAC

4 M

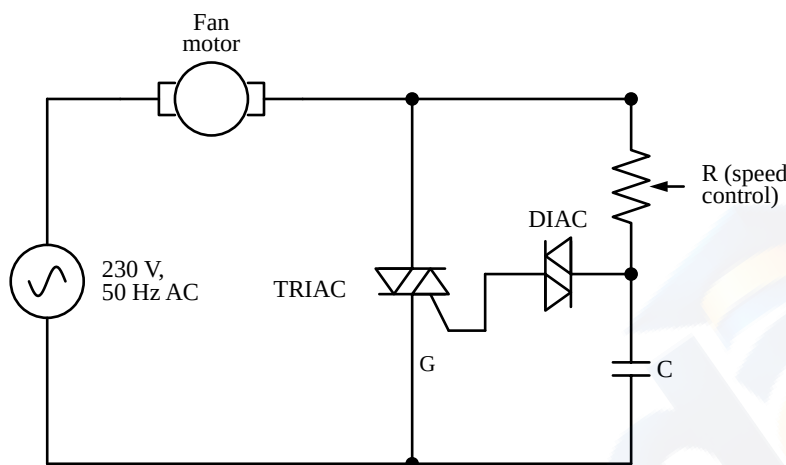


Fig.: Fan speed regulator using TRIAC and DIAC

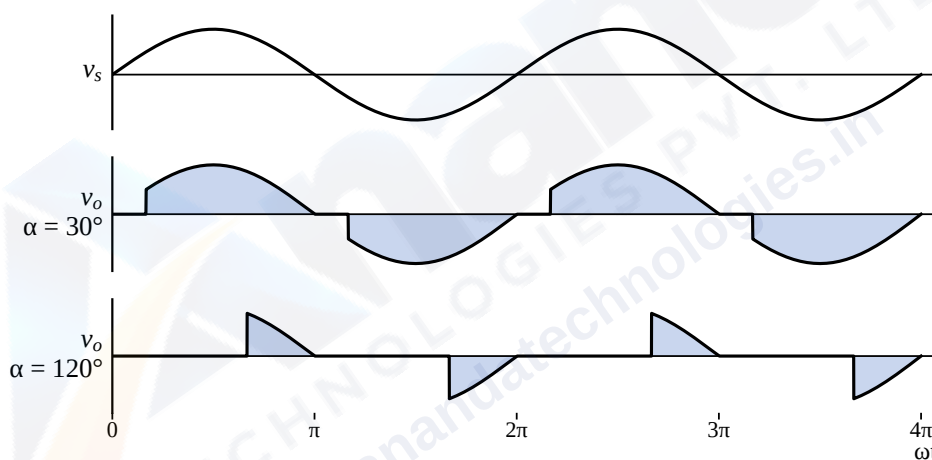


Fig.: Voltage across fan for two firing angles (small  $\alpha$  = high speed, large  $\alpha$  = low speed)

- The TRIAC is connected in series with the fan motor across the 230 V AC supply. An R-C network (R = speed control potentiometer) is connected across the TRIAC and a DIAC connects the R-C junction to the TRIAC gate.
- In each half cycle capacitor C charges through R. When the capacitor voltage reaches the **breakover voltage of the DIAC ( $\approx 30$  V)**, the DIAC conducts and gives a gate pulse to the TRIAC.
- The TRIAC turns ON and applies the supply voltage to the fan for the rest of the half cycle; it turns OFF at current zero. Since TRIAC and DIAC are bidirectional, this happens in **both half cycles**.
- **Increasing R**  $\rightarrow$  capacitor charges slowly  $\rightarrow$  firing angle  $\alpha$  increases  $\rightarrow$  RMS voltage across fan decreases  $\rightarrow$  **speed decreases**. Decreasing R increases speed. Thus smooth (stepless) speed

control is obtained.

(Circuit 2 M, working 2 M)

## Q.5

### a) V-I characteristics of SCR ( $I_{G2} > I_{G1} > 0$ )

6 M

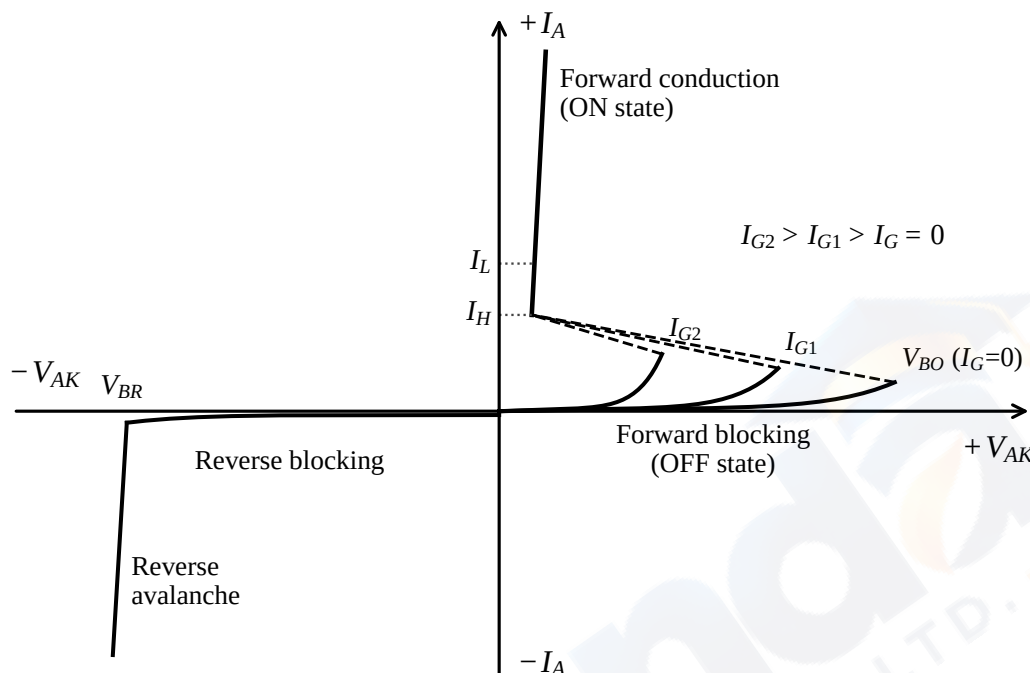


Fig.: V-I characteristics of SCR

- **Reverse blocking region:** Anode is negative w.r.t. cathode. Junctions J1 and J3 are reverse biased, so only a small reverse leakage current flows. If reverse voltage exceeds the reverse breakdown voltage  $V_{BR}$ , avalanche breakdown occurs and the SCR may be damaged.
- **Forward blocking (OFF) region:** Anode is positive w.r.t. cathode, gate open. J1 and J3 are forward biased but J2 is reverse biased, so only a small forward leakage current flows. The SCR is OFF.
- **Forward conduction (ON) region:** When the forward voltage reaches the forward breakover voltage  $V_{BO}$ , J2 breaks down and the SCR turns ON. The voltage across it falls to about 1–2 V and the current is limited only by the load.
- **Effect of gate current:** When gate current is applied, the SCR turns ON at a lower forward voltage. Larger gate current  $\rightarrow$  smaller breakover voltage ( $I_{G2} > I_{G1}$  gives lower  $V_{BO}$ ).

**Latching current ( $I_L$ ):** The minimum anode current that must flow through the SCR immediately after turn-ON (when the gate pulse is removed) to keep it latched in the ON state.

**Holding current ( $I_H$ ):** The minimum anode current required to keep the SCR in the ON state. If the anode current falls below  $I_H$ , the SCR turns OFF. Normally  $I_L \approx 2$  to 3 times  $I_H$ .

(Characteristics 3 M, three modes 2 M,  $I_L$ ,  $I_H$  1 M)

**b) 1- $\phi$  fully controlled bridge with R and R-L load ( $\alpha = 45^\circ$ ); FWD effect**

6 M

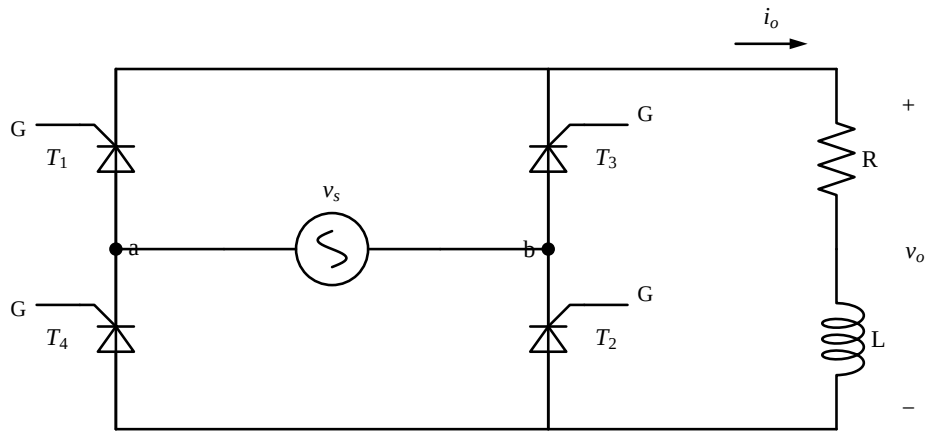


Fig.: Single phase fully controlled bridge rectifier (R-L load)

**(i) R load:** T1, T2 fire at  $\alpha$  and conduct up to  $\pi$ ; T3, T4 fire at  $\pi + \alpha$ . Output voltage is zero from 0 to  $\alpha$  in each half cycle (never negative).

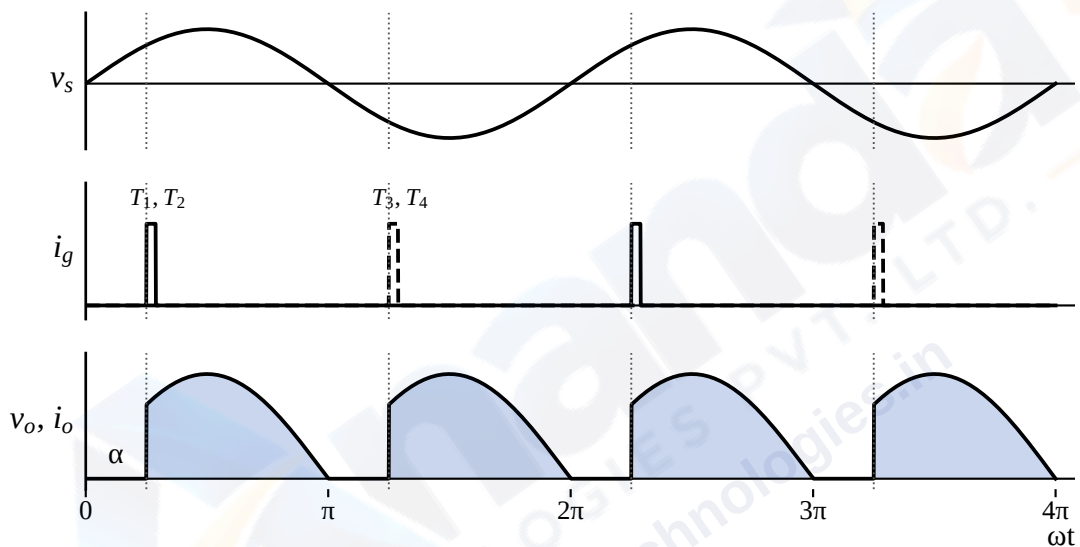


Fig.: Waveforms of 1- $\phi$  fully controlled bridge with R load ( $\alpha = 45^\circ$ )

**(ii) Highly inductive R-L load:** the load current is continuous and nearly constant ( $I_o$ ). T1, T2 continue to conduct **beyond**  $\pi$  (output goes negative) until T3, T4 are fired at  $\pi + \alpha$ , which commutates T1, T2. Each pair conducts for  $180^\circ$ .

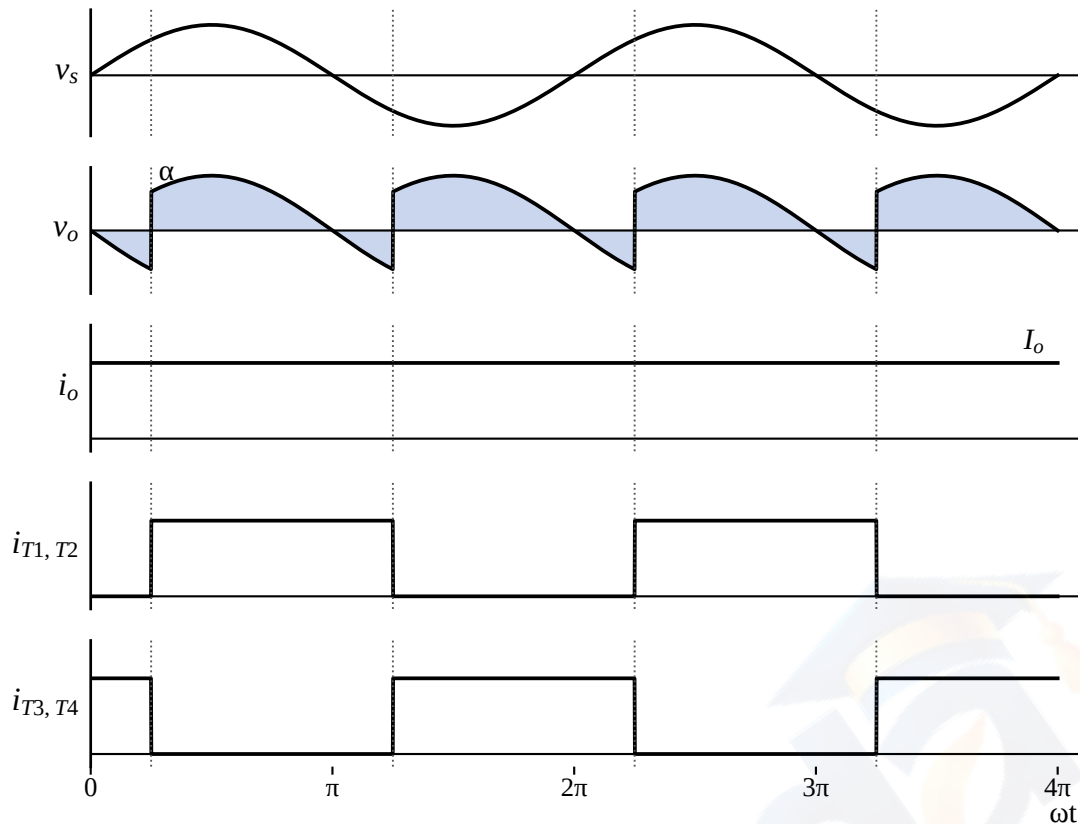


Fig.: Waveforms of 1-φ fully controlled bridge with highly inductive R-L load ( $\alpha = 45^\circ$ )

(i) R load:  $V_{dc} = (V_m/\pi)(1 + \cos \alpha) = (325.27/\pi)(1 + \cos 45^\circ) = \mathbf{176.75 \text{ V}}$

(ii) R-L load (continuous):  $V_{dc} = (2V_m/\pi) \cos \alpha = (2 \times 325.27/\pi) \cos 45^\circ = \mathbf{146.42 \text{ V}}$

(numerical averages of the computed waveforms: 176.75 V and 146.42 V)

**Effect of freewheeling diode:** with a FWD across the R-L load, the negative portions of  $v_o$  are removed (load current freewheels through the diode), so  $V_{dc}$  rises to  $(V_m/\pi)(1 + \cos \alpha) = 176.75 \text{ V}$ , the SCRs turn off at  $\pi$  and the input power factor improves.

(Circuit 1 M, waveforms 2 M, explanation 1 M, calculations 1 M, FWD effect 1 M)

### c) Class F (line) commutation

6 M

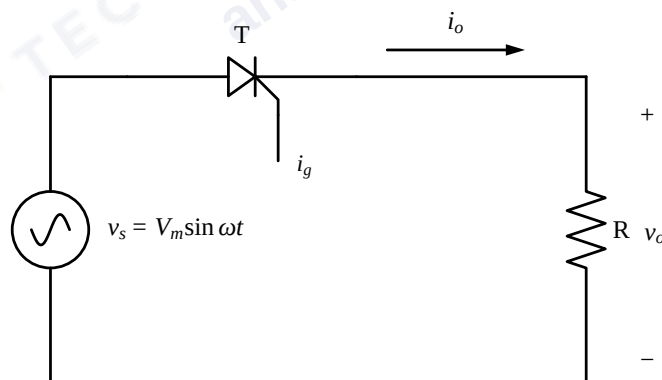


Fig.: Class F (line / natural) commutation

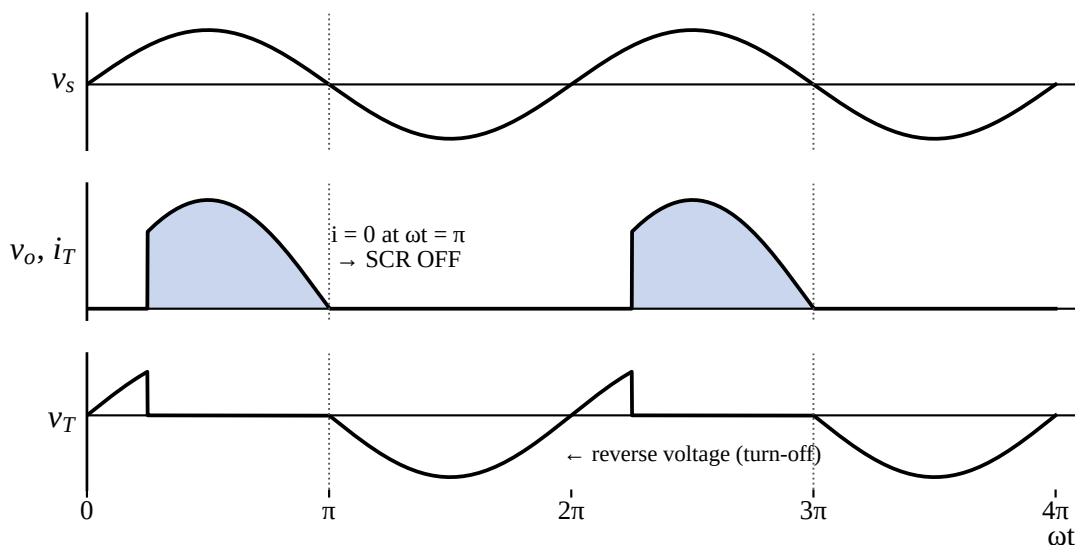


Fig.: Class F (line) commutation — supply reversal turns SCR off ( $\alpha = 45^\circ$ )

- Class F is called **line commutation or natural commutation**. It is used when the supply is AC.
- During the positive half cycle the SCR is triggered at  $\alpha$  and conducts; load current follows the supply voltage.
- At  $\omega t = \pi$  the supply voltage and load current (R load) become zero; the current falls below  $I_H$  and the SCR stops conducting.
- During the negative half cycle the SCR is **reverse biased** by the supply for a full half cycle ( $\pi$  rad), which is more than the turn-off time  $t_q$ , so it turns OFF naturally. No extra commutating components are needed.
- For R-L load the current continues beyond  $\pi$  and the SCR turns off at the extinction angle  $\beta$ , when the current becomes zero.
- **Applications:** phase controlled rectifiers, AC voltage controllers (fan regulators, dimmers), cycloconverters.

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

## Q.6

### a) TRIAC construction and V-I characteristics; DIAC

6 M

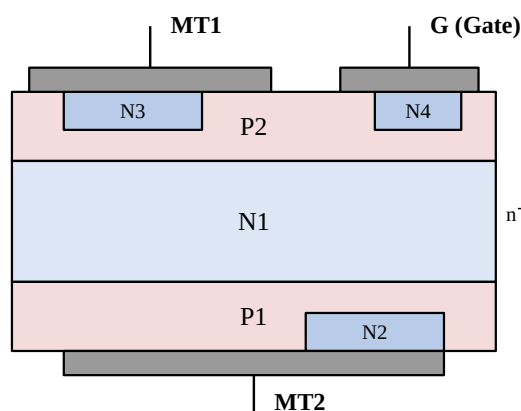


Fig.: Construction of TRIAC

- TRIAC (TRIode AC switch) is a **bidirectional** thyristor; it is equivalent to **two SCRs connected in anti-parallel** with a common gate.
- It is a five-layer device (N–P–N–P–N regions) with three terminals: **Main Terminal 1 (MT1)**, **Main Terminal 2 (MT2)** and **Gate (G)**. MT1 contacts N3 and P2; MT2 contacts P1 and N2; gate contacts P2 and N4.
- It can be turned ON in both directions by a positive or negative gate pulse (four triggering modes: I+, I–, III+, III–).

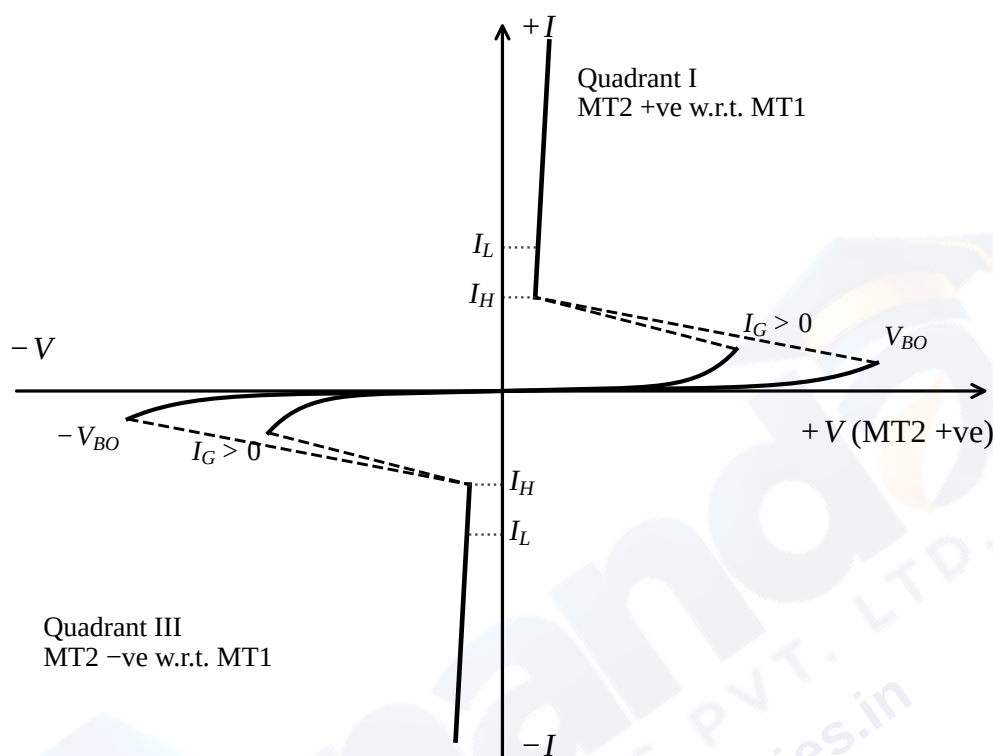


Fig.: V-I characteristics of TRIAC

- **Quadrant I:** MT2 positive w.r.t. MT1 — the TRIAC blocks up to  $V_{BO}$  and then conducts; gate current reduces the breakover voltage.
- **Quadrant III:** MT2 negative w.r.t. MT1 — identical behaviour in the reverse direction. Hence it controls power in both half cycles of AC.

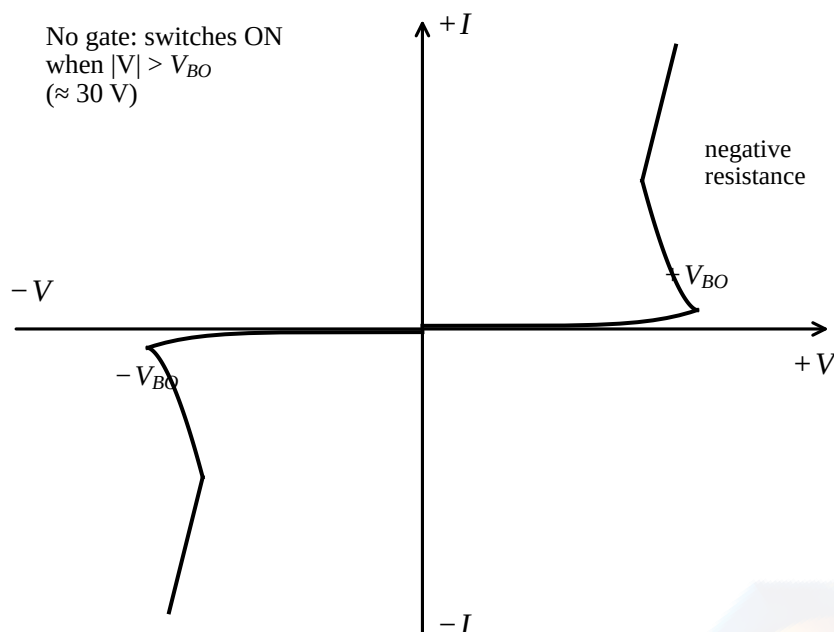


Fig.: V-I characteristics of DIAC

**DIAC** (DIode AC switch) is a two-terminal bidirectional trigger device without a gate. It conducts in either direction when the voltage exceeds its breakover voltage ( $\approx 30 \text{ V}$ ) and then shows negative resistance. **Use:** to produce sharp trigger pulses for the TRIAC gate in fan regulators, light dimmers and heater controls.

(TRIAC construction 2 M, TRIAC V-I 2 M, DIAC V-I and use 2 M)

b) 1- $\phi$  full bridge inverter, R load;  $V_s = 200 \text{ V}$ ,  $R = 20 \Omega$

6 M

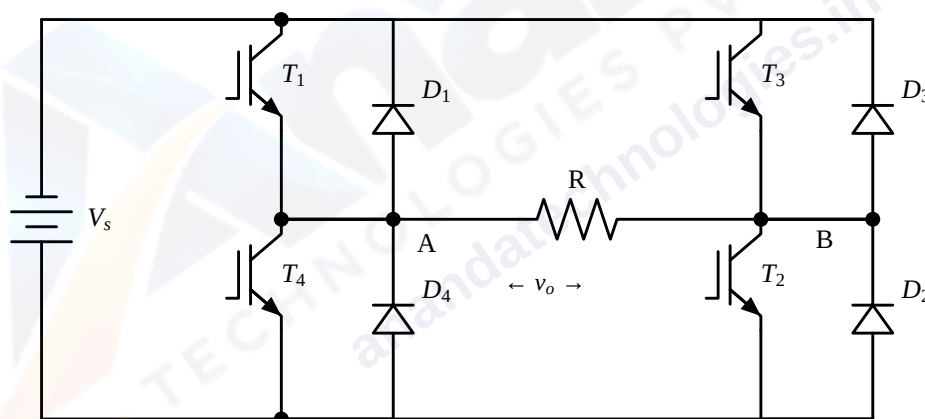


Fig.: Single phase full bridge inverter with R load

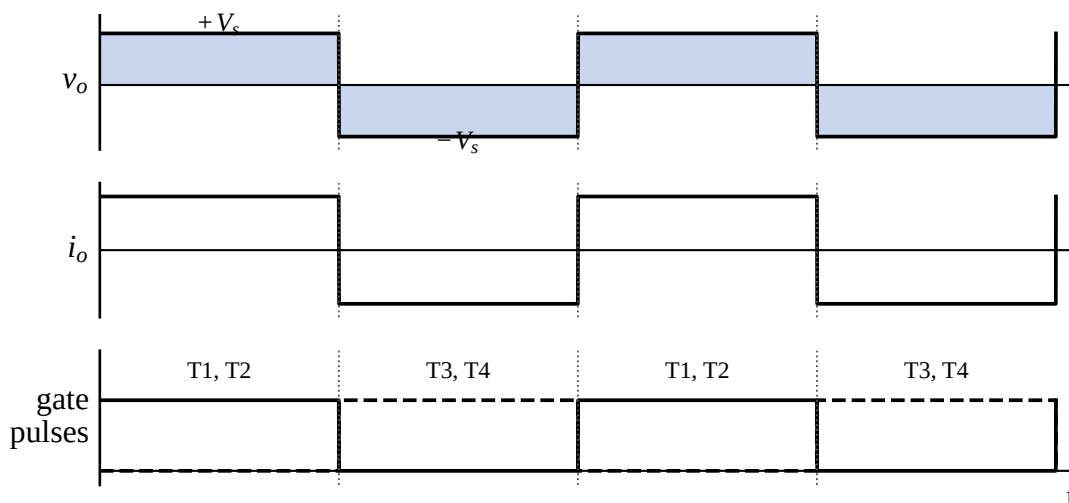


Fig.: Output waveforms of 1-φ full bridge inverter with R load

- The full bridge inverter has **four switches T1–T4** with feedback diodes D1–D4 and a two-wire DC supply  $V_s$ . The load is connected between the leg mid-points A and B.
- $0 < t < T/2$ : T1 and T2 are ON; A is connected to  $+V_s$  and B to  $-$ ;  $v_o = +V_s$ .
- $T/2 < t < T$ : T1, T2 are turned OFF and T3, T4 ON; the load voltage reverses:  $v_o = -V_s$ .
- Output is a square wave of amplitude  $V_s$  (double that of half bridge for the same supply).

Frequency is varied by changing the switching rate.

RMS output voltage =  $V_s$ ; RMS value of fundamental  $V_{o1} = 4V_s/(\pi\sqrt{2}) = 0.9 V_s$ .

$$V_s = 200 \text{ V} \rightarrow V_{o(\text{rms})} = 200 \text{ V}, V_{o1(\text{rms})} = 0.9 \times 200 = 180.06 \text{ V}$$

$$\text{R load: } I_{o(\text{rms})} = 200/20 = 10.00 \text{ A, output power } P = V_s^2/R = 2000.0 \text{ W}$$

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

### c) AC-DC-AC converter in wind power system; applications

6 M

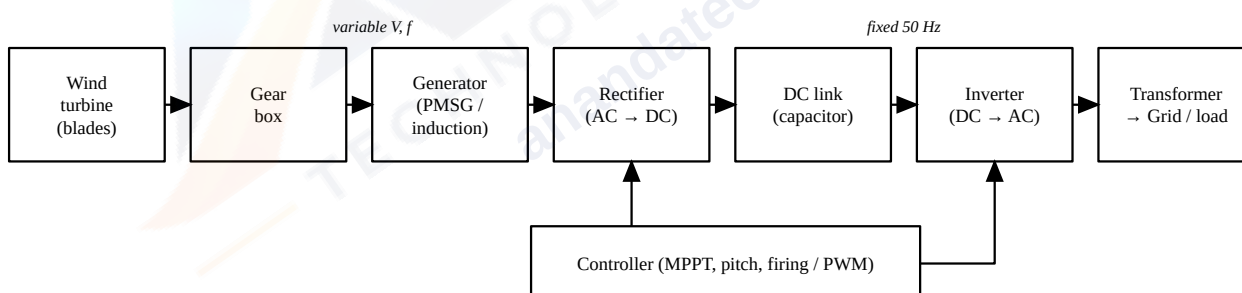


Fig.: Block diagram of variable speed wind power generation system (AC–DC–AC)

- The **wind turbine** converts the kinetic energy of wind into mechanical power; the **gear box** raises the shaft speed for the generator.
- Because wind speed keeps changing, the **generator** output voltage and frequency also vary. This variable-frequency AC cannot be connected directly to the 50 Hz grid.
- The **rectifier (AC → DC)** converts the generator output to DC; the **DC link capacitor** keeps the DC voltage steady and decouples the generator side from the grid side.

- The **PWM inverter (DC → AC)** converts DC into AC of **constant 50 Hz frequency** and grid voltage, synchronised with the grid; the transformer steps up the voltage.
- The controller performs **maximum power point tracking** (variable speed operation) and controls real and reactive power fed to the grid.

**Other applications of AC to AC converter using DC link:** (i) variable frequency drives (VFD) for induction motor speed control, (ii) UPS, (iii) induction heating, (iv) HVDC back-to-back links, (v) traction drives.

*(Block diagram 2 M, explanation 3 M, applications 1 M)*

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