ATME College of Engineering

Module-
DC-DC Converter and DC-AC Inverter

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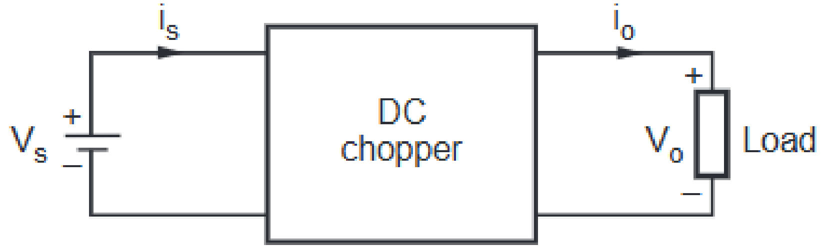
Module-5

DC-DC Converters: Introduction, principle of step down a chopper with R and RL load; the principle of step up chopper with R load, Control strategies, performance parameters, DC-DC converter classification.

DC-AC Converters: Introduction, principle of operation single phase bridge inverters, performance parameters, three-phase bridge inverters, voltage control of single phase inverters, Harmonic reductions, Current source inverters

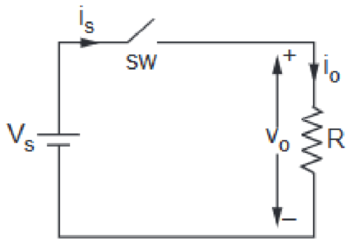
Introduction:

The DC choppers convert the input DC voltage into fixed or variable DC output. The chopper has fixed or variable DC input, Vs. And the output Vo is also fixed or variable. Hence DC chopper is also called as dc to dc converter. The output Vo can be greater or less than the input. Hence the choppers can be step-down or step-up type. Choppers are used in dc traction drives, trolley cars, marine lifts etc. The dc choppers use switching principle. Hence they have high efficiency. The dynamic response of choppers is fast due to switching nature of the devices

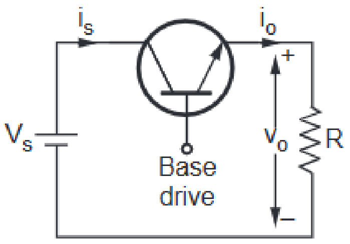


Basic inputs/outputs of DC chopper

Principle of Step-down Operation:



(a) Basic step down chopper



(b) Step - down chopper with transistor as a switch

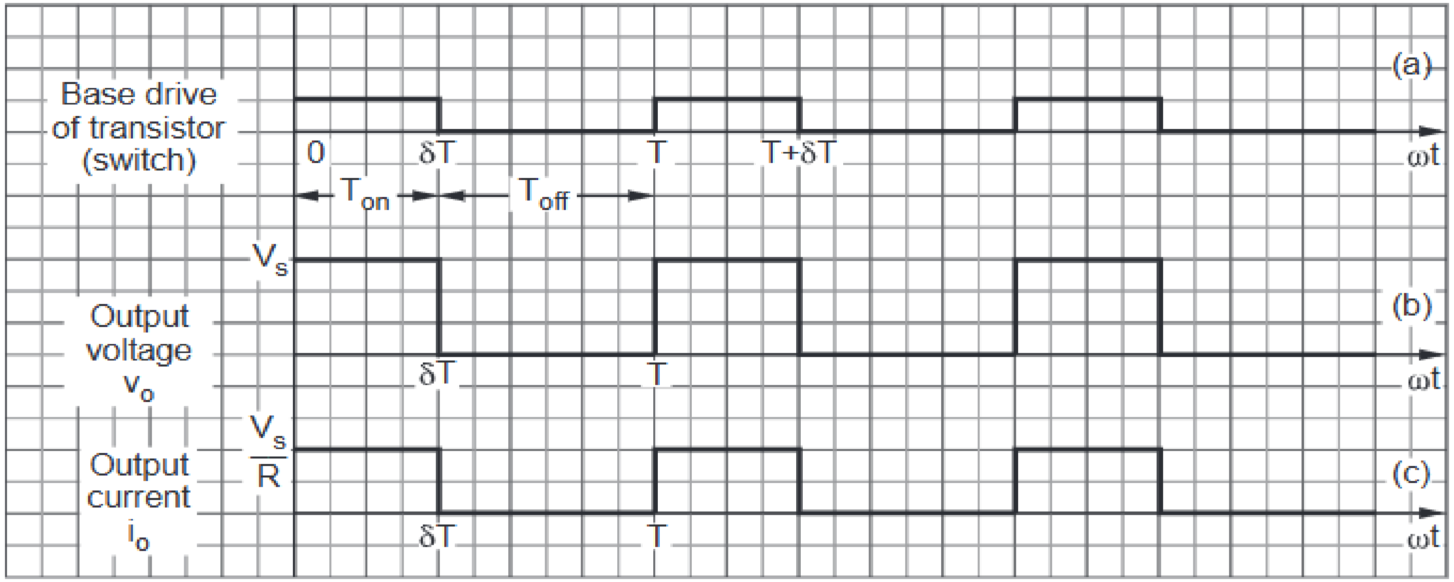


Fig. 2 Waveforms of the step-down chopper with resistive load

Chopper Control Techniques: These are also called as Time Ratio Control (TRC) techniques.

Constant frequency operation

2. Variable frequency operation

3. Current limit control

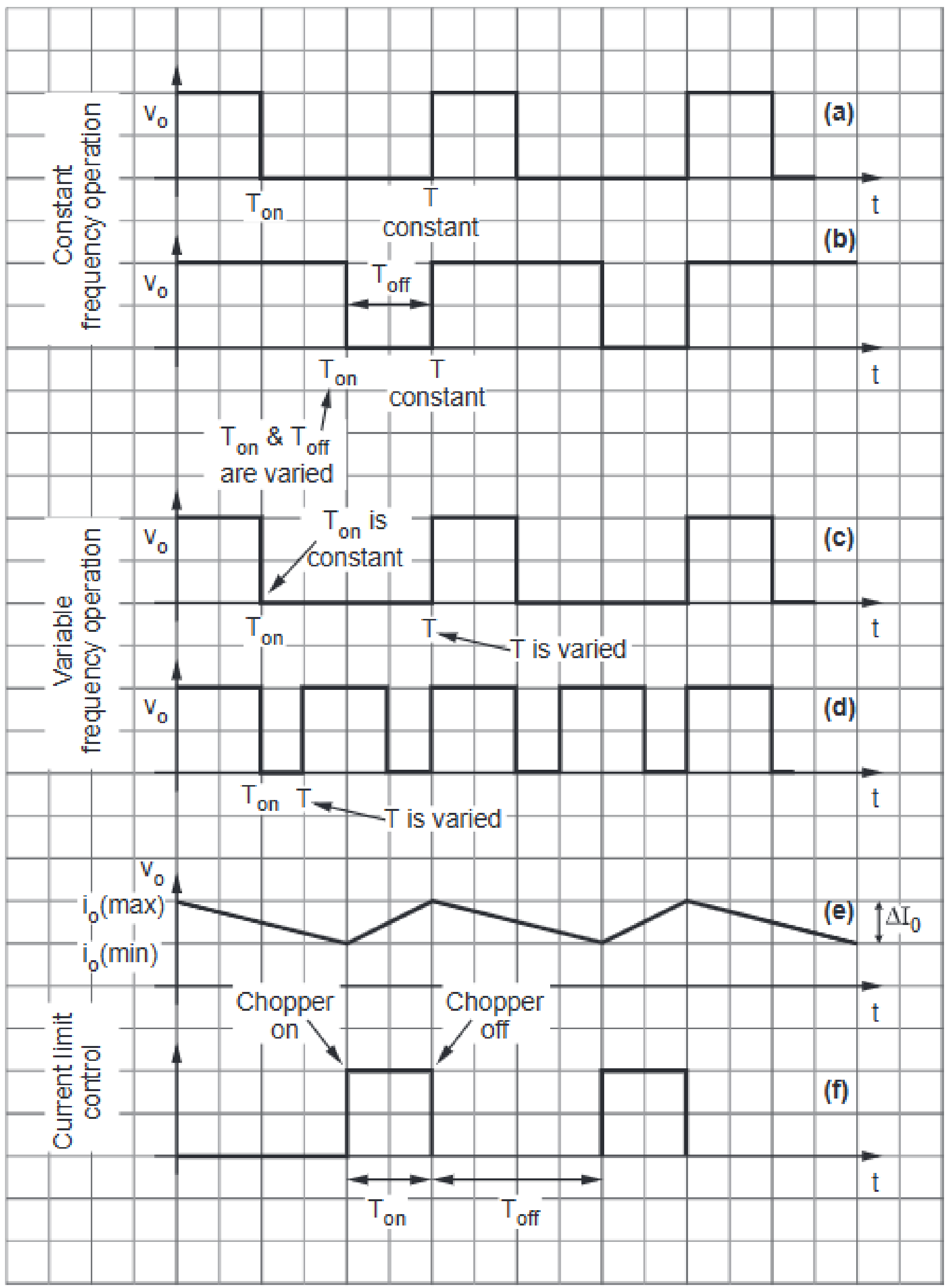


Fig. .3 Chopper control schemes

(i) **To obtain $V_{o(av)}$:**

The average value is given as,

$$V_{o(av)} = \frac{1}{T}\int_0^T v_o(t)\, dt$$

In the output voltage waveform of Fig. 6.2.2 observe that $v_o = V_s$ from 0 to δT, rest of the time v_o is zero. Hence above equation can be written as,

$$V_{o(av)} = \frac{1}{T}\int_0^{\delta T} V_s\, dt = \frac{V_s}{T}\int_0^{\delta T} dt = \frac{V_s}{T}\cdot \delta T$$

$$\therefore \quad V_{o(av)} = \delta\, V_s$$

Here $\delta = \frac{T_{on}}{T}$ is called the *duty cycle of the chopper. The value of duty cycle lies between* $0 \le \delta \le 1$.

(ii) **To obtain $V_{o(r.m.s.)}$**

The r.m.s. value of output is given as,

$$V_{o(r.m.s.)} = \left[\frac{1}{T}\int_0^T v_o^2(t)\, dt\right]^{\frac{1}{2}}$$

We know from Fig. 6.2.2 that $v_o = V_s$ from 0 to δT (i.e. when the transistor switch is on). Hence above equation becomes,

$$V_{o(r.m.s.)} = \left[\frac{1}{T}\int_0^{\delta T} V_s^2\, dt\right]^{\frac{1}{2}} = \left[\frac{V_s^2}{T}\int_0^{\delta T} dt\right]^{\frac{1}{2}} = \left[\frac{V_s^2}{T}\cdot \delta T\right]^{\frac{1}{2}}$$

$$\therefore \quad V_{o(r.m.s.)} = \sqrt{\delta}\, V_s$$

Output power

The load power can be calculated as,

$$P_o = \frac{1}{T}\int_0^{\delta T} \frac{v_o^2}{R}\,dt$$

$$= \frac{1}{T}\int_0^{\delta T} \frac{(V_s - V_{ch})^2}{R}$$

$$= \frac{1}{T}\cdot\frac{(V_s - V_{ch})^2}{R}\int_0^{\delta T} dt$$

$$= \frac{1}{T}\cdot\frac{(V_s - V_{ch})^2}{R}\cdot\delta T$$

$$= \frac{\delta (V_s - V_{ch})^2}{R}$$

If the chopper is lossless, then $V_{ch} = 0$ and output power will be,

$$P_o = \frac{\delta V_s^2}{R}$$

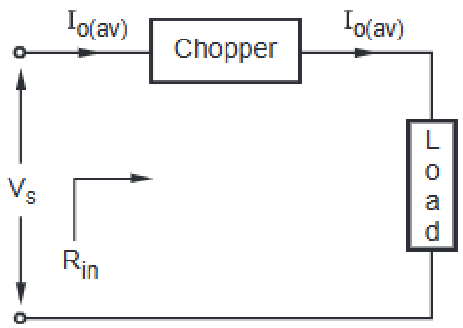


Fig Effective input resistance

(iii) Effective input resistance

Fig. shows that the average current flowing from the input is basically output average current, i.e. $I_{o(av)}$. The input voltage is supply voltage V_s. Hence effective input resistance will be,

$$R_{in} = \frac{V_s}{I_{o(av)}}$$

Putting for $I_{o(av)} = \frac{V_{o(av)}}{R}$ in above equation,

$$R_{in} = \frac{V_s}{\frac{V_{o(av)}}{R}} = R\cdot\frac{V_s}{V_{o(av)}}$$

Since $\delta = \frac{V_{o(av)}}{V_s}$, above equation becomes,

Step-down Chopper with RL Load:

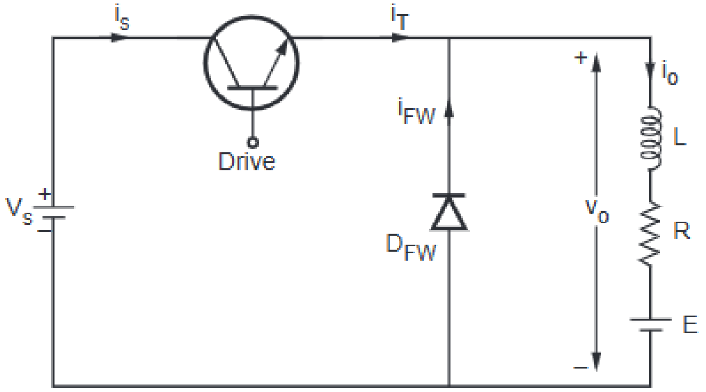
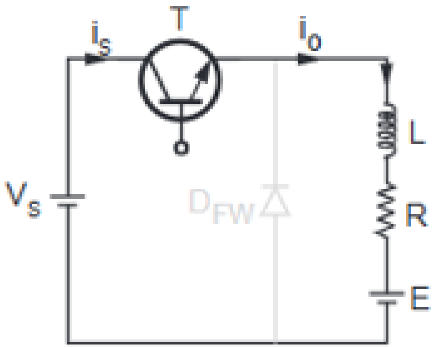
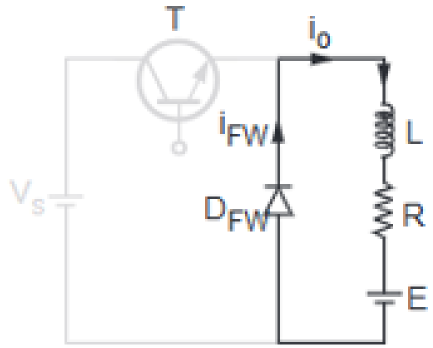


Fig. Step-down chopper with RL load



Equivalent circuit - I

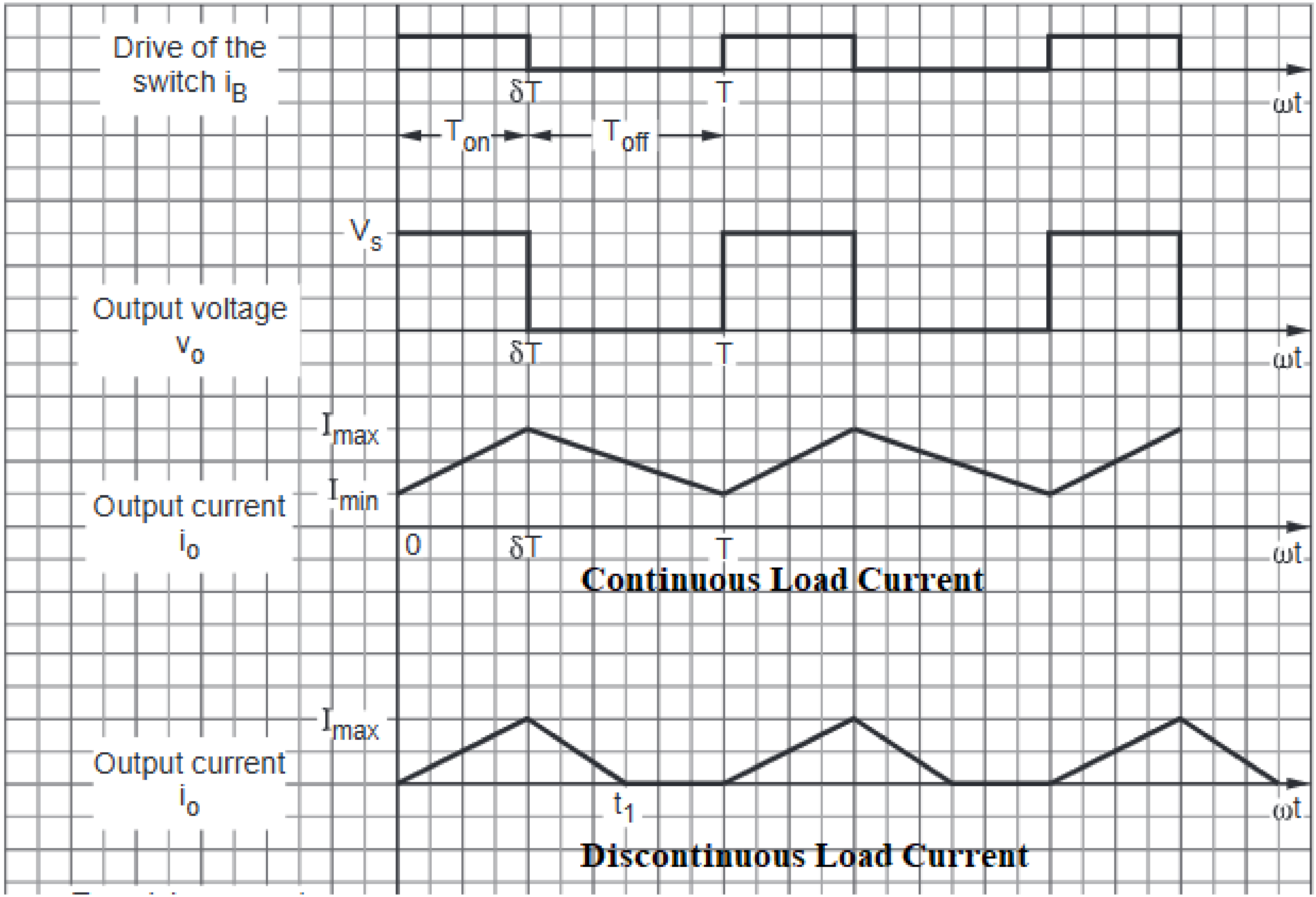
Mode-1



Equivalent circuit - II

Mode-2

Continuous and Discontinuous current in DC chopper


Drive of the switch i_B
δT
T
ωt
T_{on}
T_{off}
V_s
Output voltage v_o
δT
T
ωt
I_{max}
I_{min}
Output current i_o
0
δT
T
ωt
Continuous Load Current
I_{max}
Output current i_o
t_1
ωt
Discontinuous Load Current

Principle of Step-up Operation:

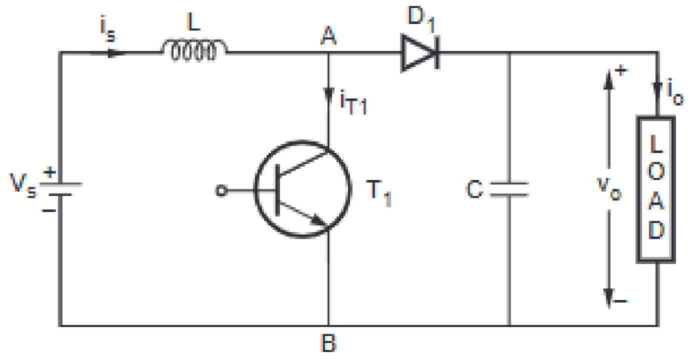
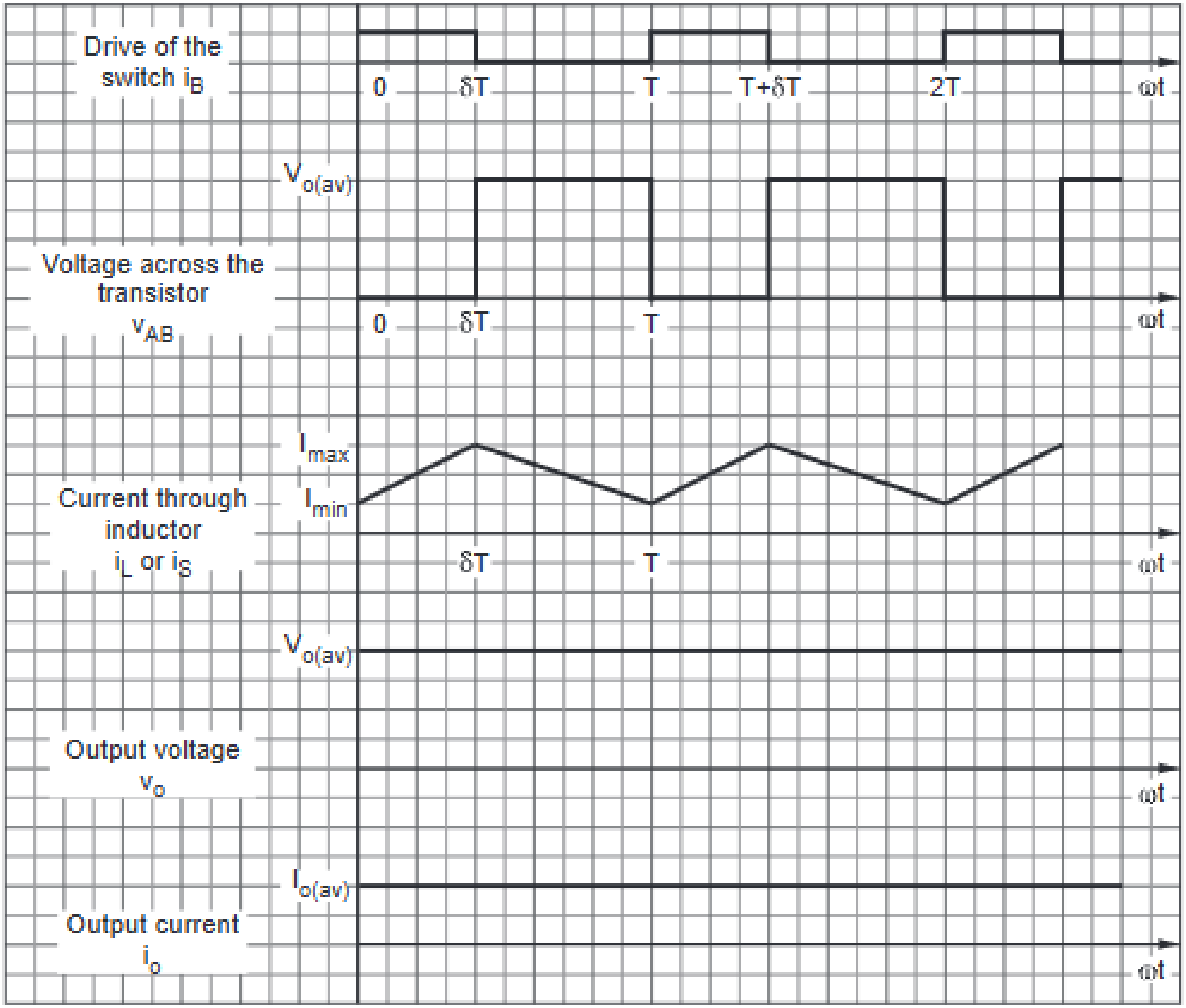


Fig. Step-up chopper having transistor as a switch



$$V_L = \frac{1}{T}\int_0^T v_L(t)\,dt$$

The inductance voltage is $v_L(t) = L\frac{di_L}{dt}$. Hence above equation will be,

$$V_L = \frac{1}{T}\int_0^T L\frac{di_L(t)}{dt}\,dt$$

$$= \frac{L}{T}\int_0^T di_L(t) \qquad \text{... (1)}$$

At $t = 0$ (lower limit), $i_L(t) = I_{min}$

and at $t = T$ (upper limit), $i_L(t) = I_{min}$

$$V_l = \frac{L}{T}\int_{I_{min}}^{I_{min}} d\, i_L(t) = \frac{L}{T}\left[i_L(t)\right]_{I_{min}}^{I_{min}}$$

$$= \frac{L}{T}\left[I_{min} - I_{min}\right] = 0 \qquad \ldots (2)$$

Thus the average voltage across the inductance is zero. The inductance stores the energy when the switch is 'ON' and supplies the energy to the load when the switch is 'OFF'.

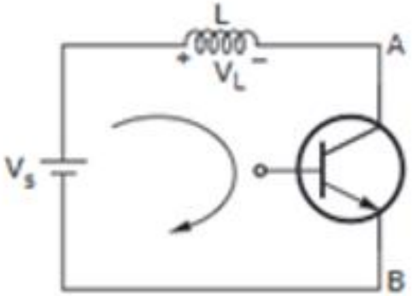


Fig. Loop formed by supply, inductance and switch in step-up chopper

$$V_{AB} = \frac{1}{T}\int_0^T v_{AB}(t)\, dt$$

In Fig. observe that $v_{AB} = V_{o(av)}$ from δT to T and rest of the period it is zero. Hence above equation becomes,

$$V_{AB} = \frac{1}{T}\int_{\delta T}^{T} V_{o(av)}\, dt = \frac{V_{o(av)}}{T}(T - \delta T)$$

$$= V_{o(av)}(1-\delta) \qquad \cdots (3)$$

By KVL to the loop shown in Fig.

$$V_s = V_L + V_{AB}$$

The above equation holds for steady state. Putting values from equation 2 and 3 in above equation,

$$V_s = 0 + V_{o(av)}(1-\delta)$$

$$\therefore \quad V_{o(av)} = \frac{V_s}{1-\delta} \qquad \cdots (4)$$

This equation gives the value of average output voltage. When $\delta = 0$, $V_{o(av)} = V_s$ and $V_{o(av)} \to \infty$ as δ approaches to unity. The value of duty cycle 'δ' lies between 0 and 1.

DC-DC Converter Classification:

There are broadly following types of choppers :

1. Class A chopper
2. Class B chopper
3. Class C chopper
4. Class D chopper
5. Class E chopper

Class A Chopper:

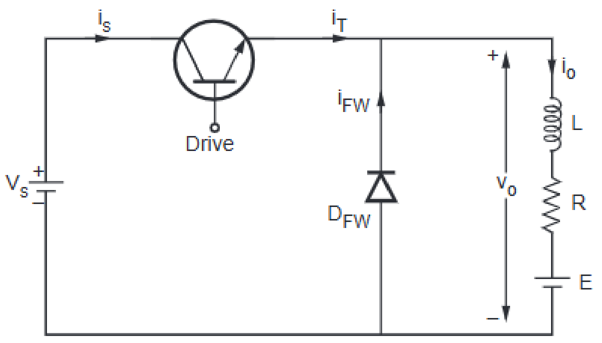


Fig. Step-down chopper with RL load

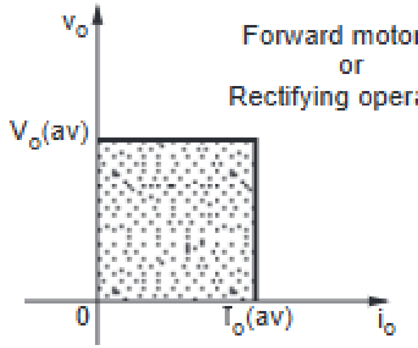
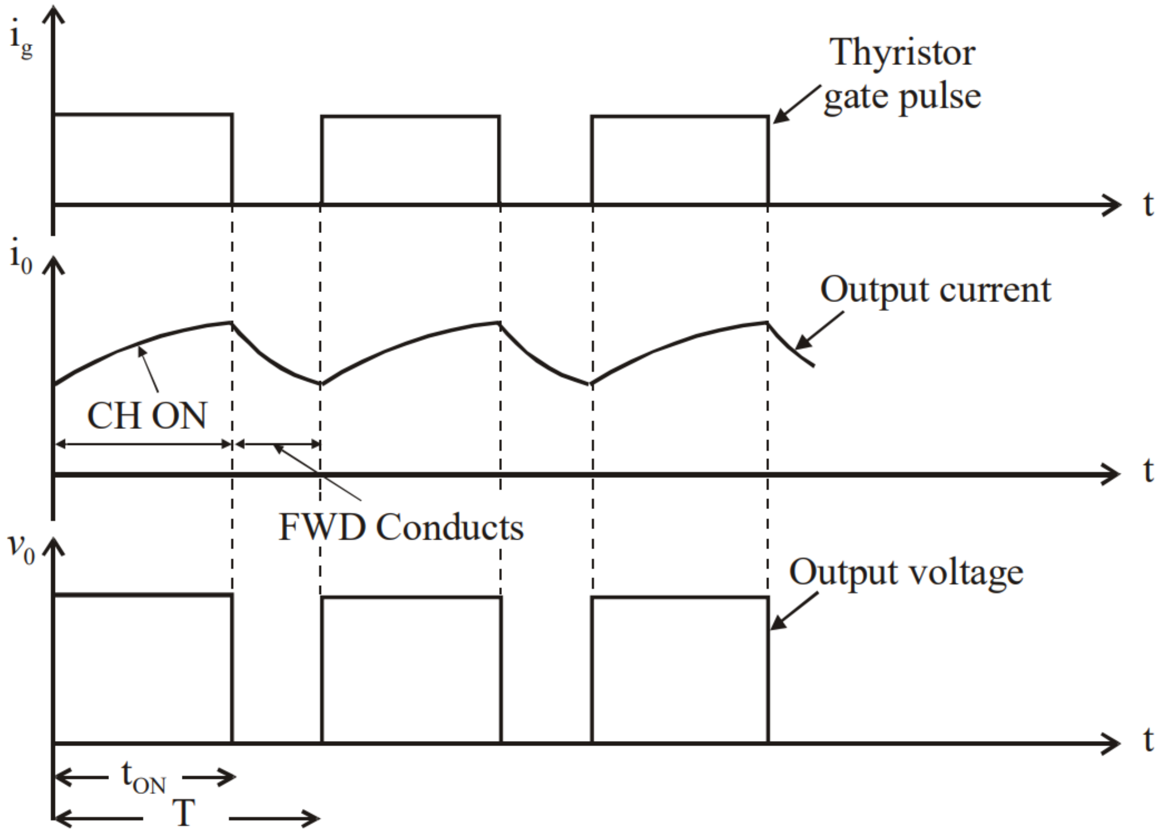


Fig. Class A chopper operates in the first quadrant



Class B Chopper:

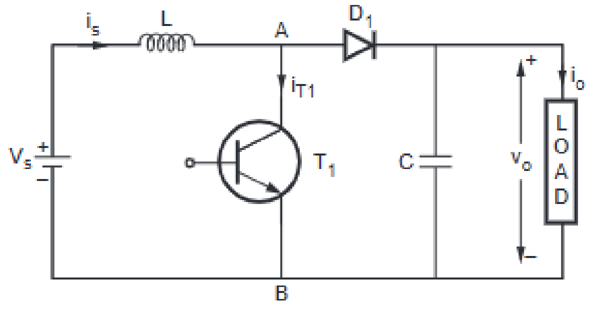


Fig. Step-up chopper having transistor as a switch

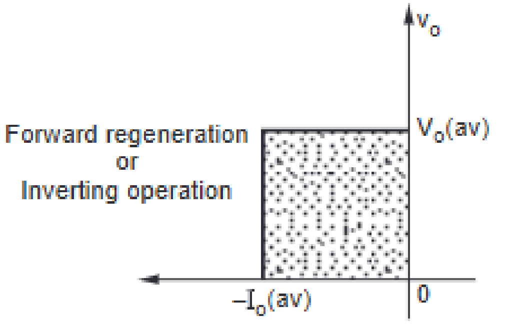
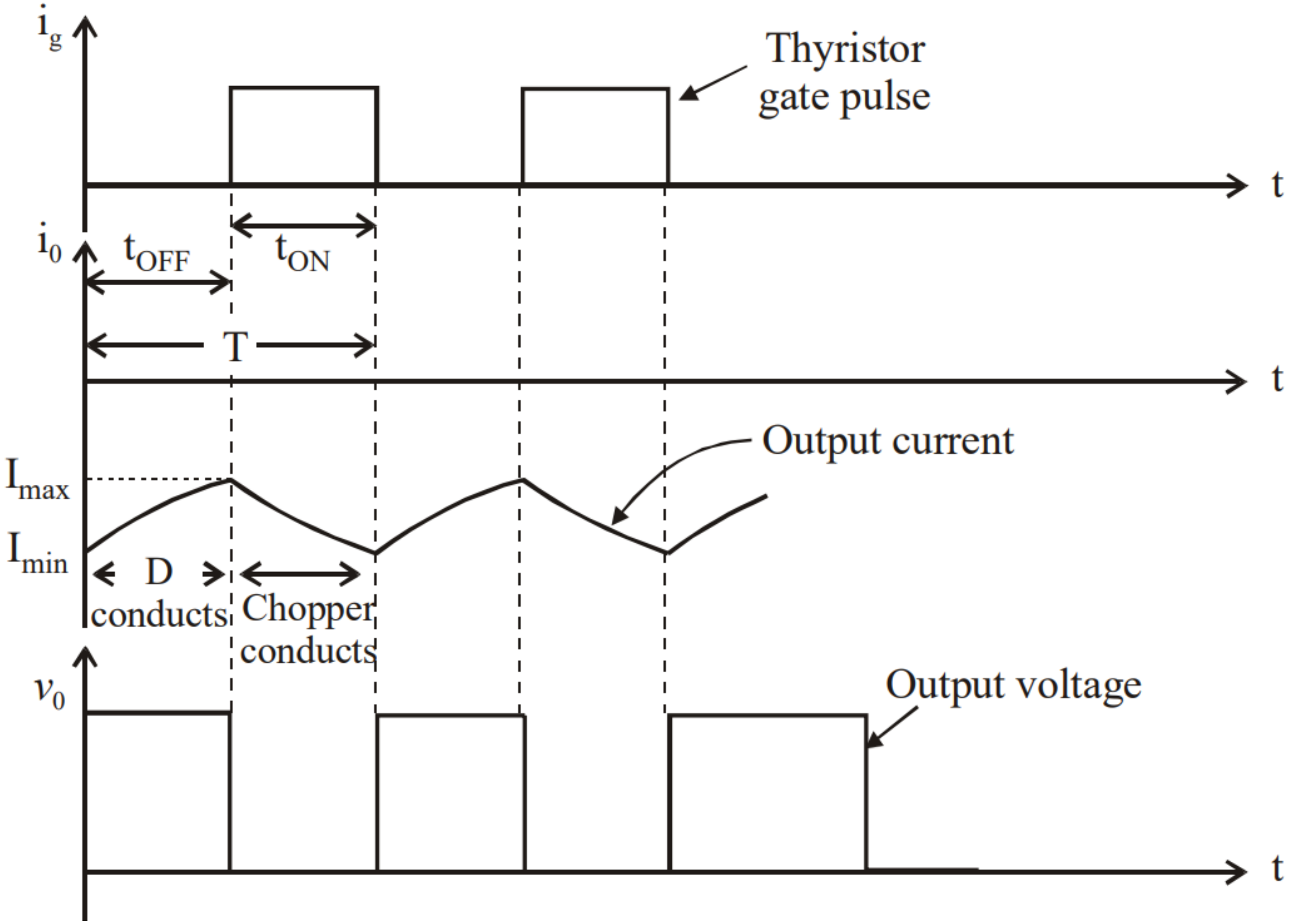


Fig. Class B chopper operates in the second quadrant



Class C Chopper:

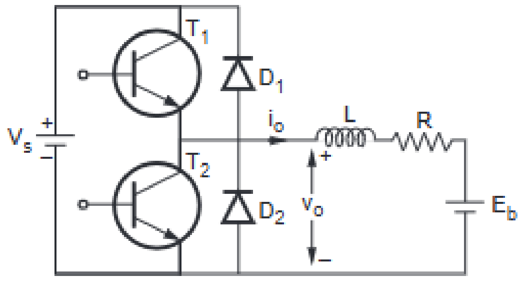


Fig. Class C chopper

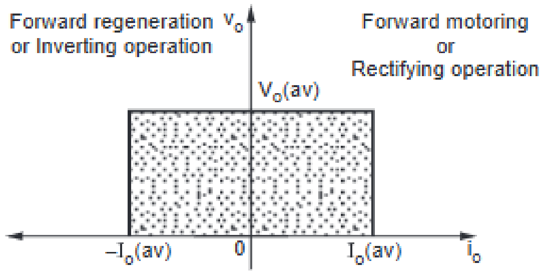
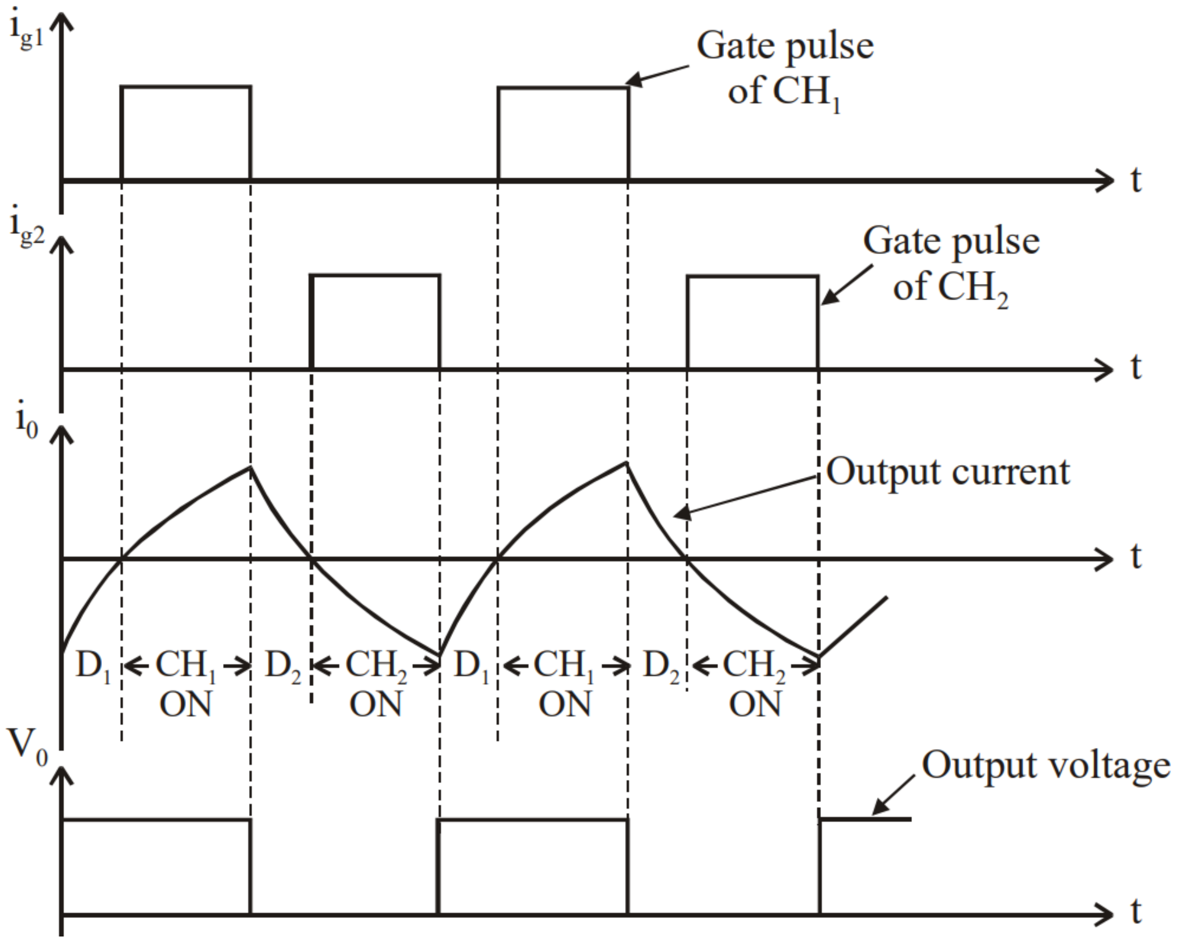
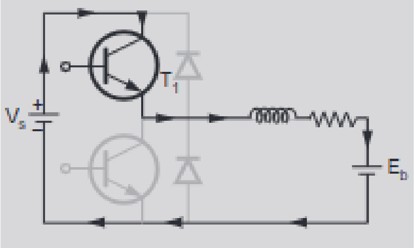
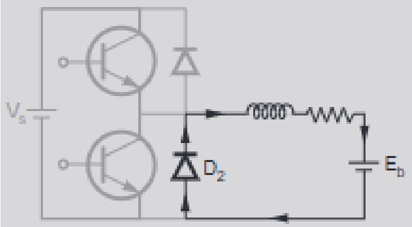
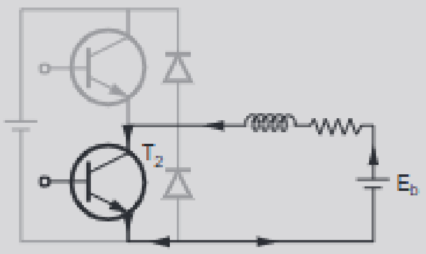
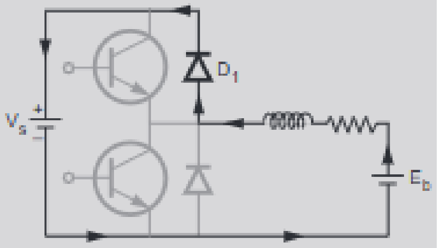


Fig. Class C chopper operates in two quadrants



Equivalent circuit	Quadrant	Description
 (a)	I Forward motoring or rectifying	T_1 conducts and energy flows from source to load. v_o and i_o are positive.
 (b)	I Forward motoring or rectifying	D_2 conducts i_o is positive and v_o is zero. Freewheeling takes place. Inductance supplies energy to the load.
 (c)	II Forward regenerative braking	T_2 conducts i_o is negative. E_b supplies energy to the Inductance v_o is zero.
 (d)	II Forward regenerative braking or inverting	D_1 conducts inductance supplies energy to the source v_o is positive and i_o is negative.

Class D Chopper:

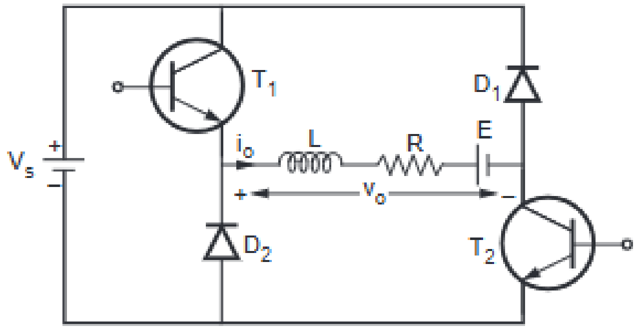


Fig. Class D chopper

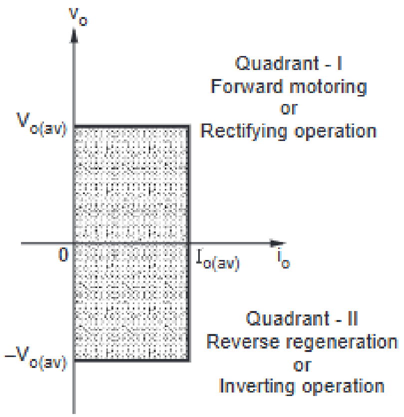
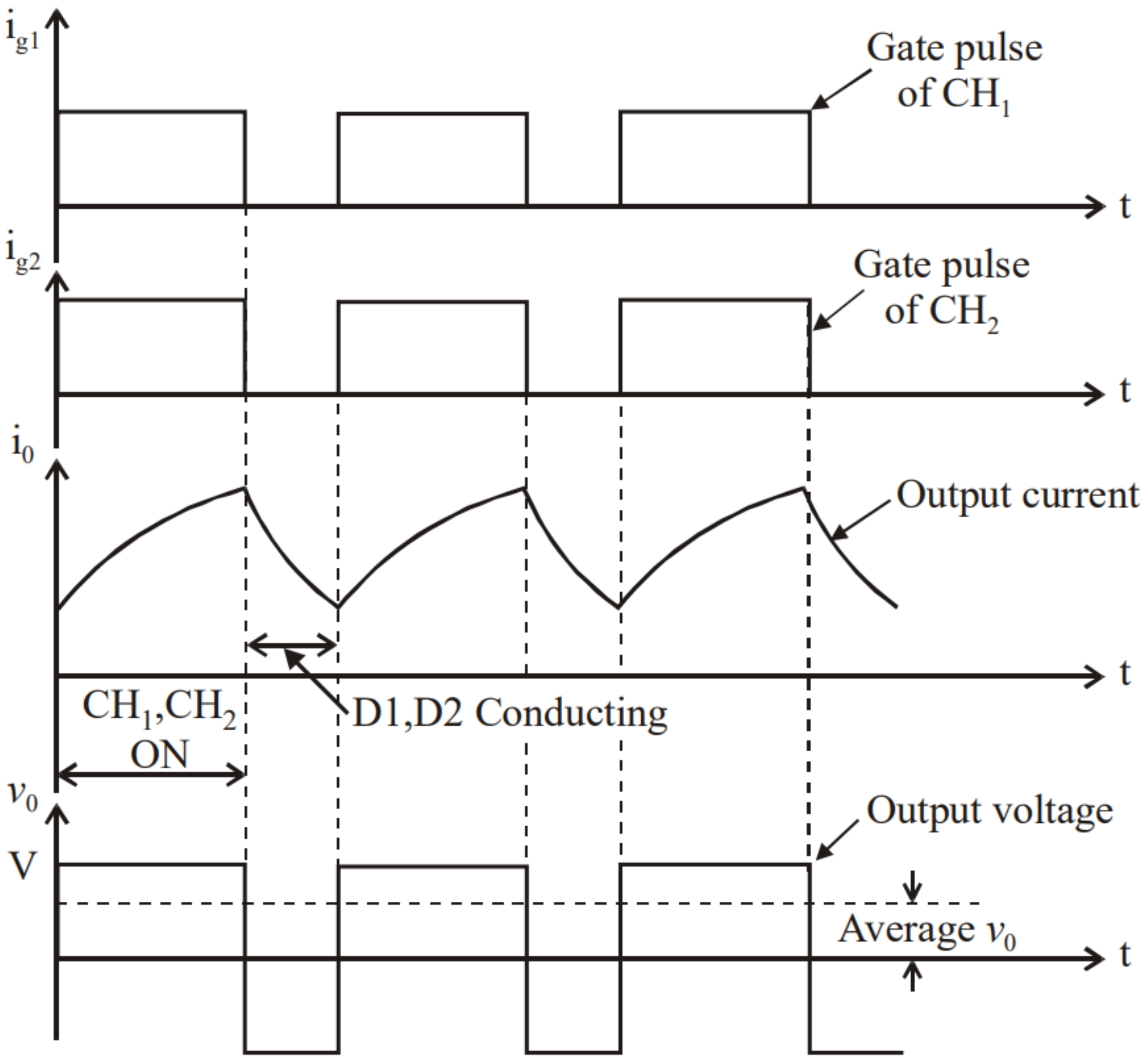


Fig. Class D chopper operates in I and IV quadrants



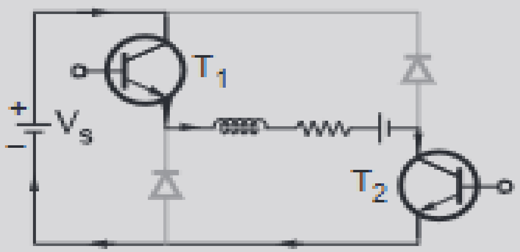
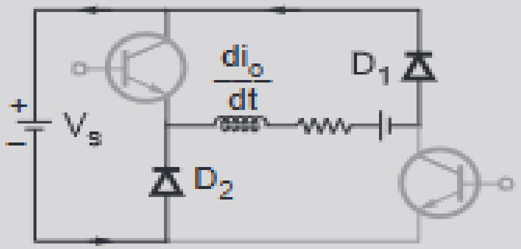
Equivalent circuit	Quadrant	Description
	I Rectifying or forward motoring	T_1, T_2 conduct power flows from source to the load
	IV Inverting or reverse regenerative braking	i_o is maintained in the same direction by inductance voltage $L\frac{d\,i_o}{dt}$. Diodes D_1 and D_2 are forward biased and conduct.

Table Operation of class D chopper

Class E Chopper:

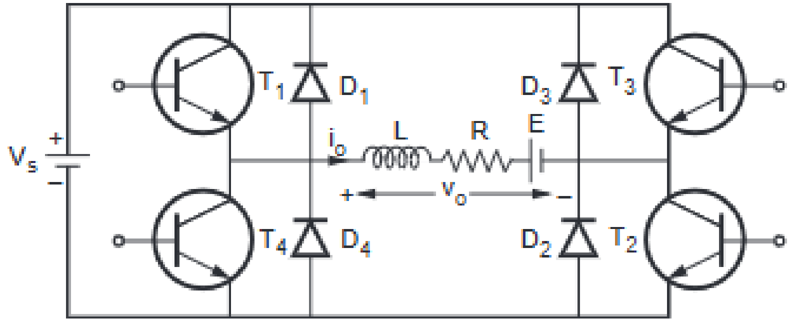
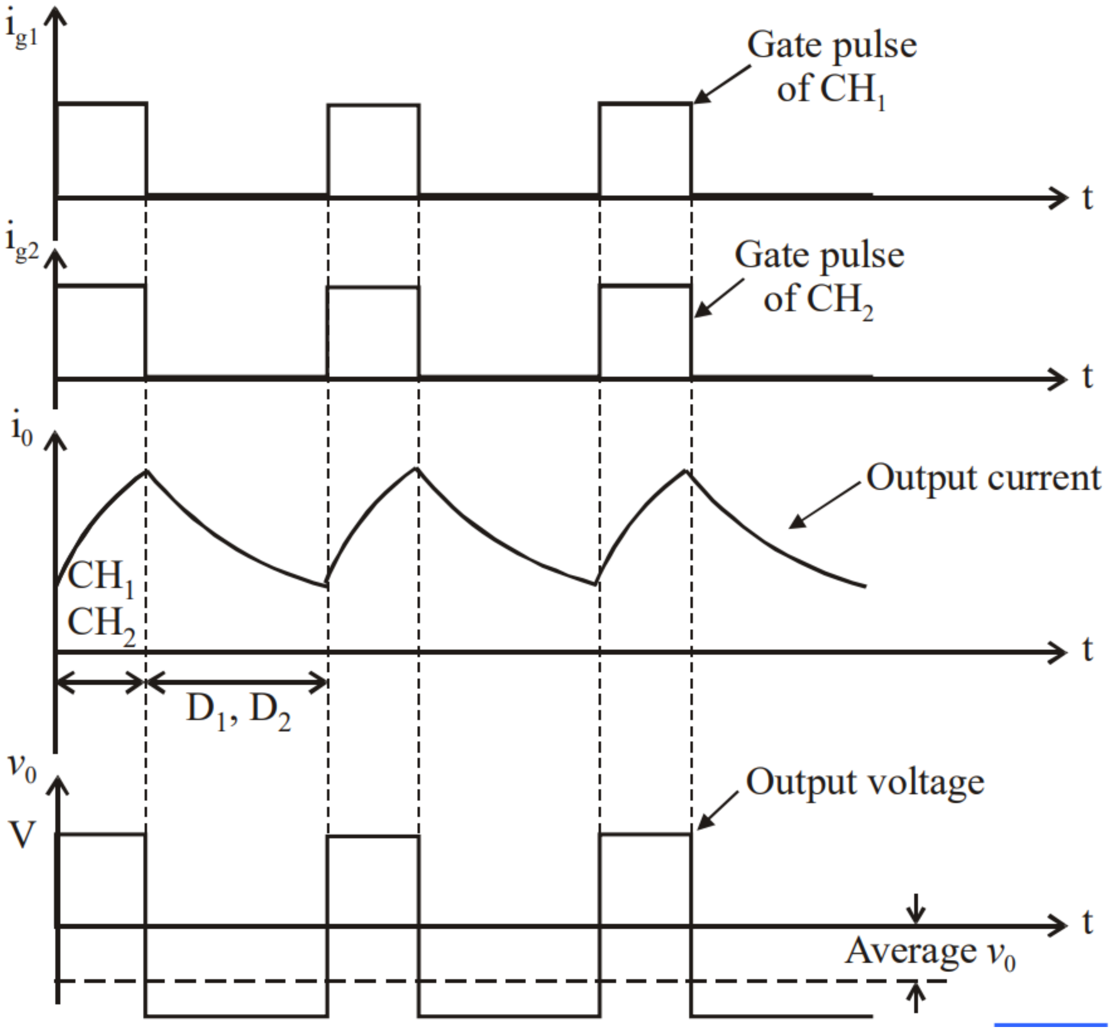
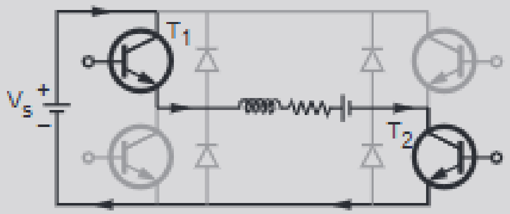
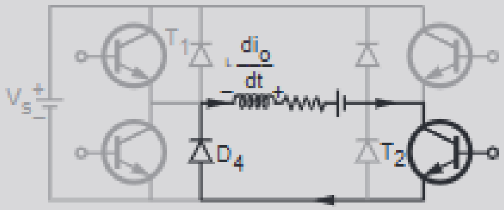
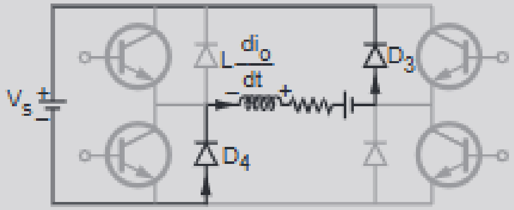
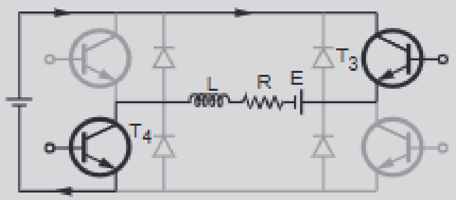
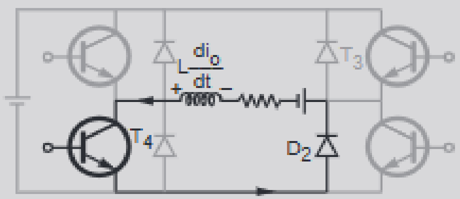
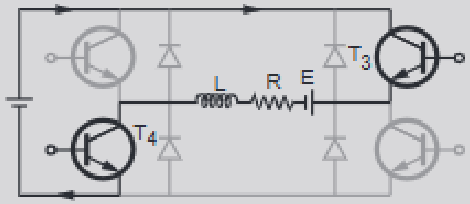
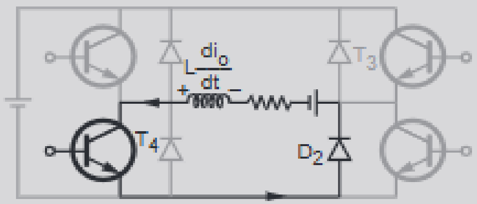


Fig. Circuit diagram of four quadrant chopper

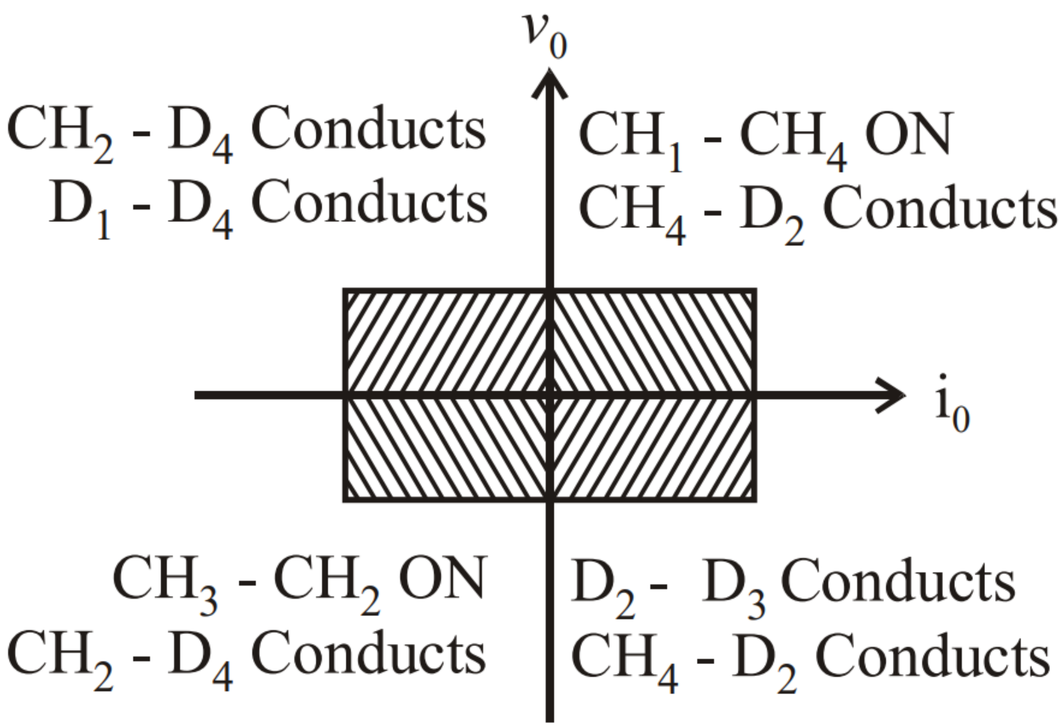


Equivalent circuit	Quadrant	Description
	I Forward motoring or rectifying	T_1 and T_2 conducts load consumes the power from the source
	I Forward motoring	T_1 turned off but T_2 conducts Hence current i_o flows through T_2 and D_4. Load inductor induces voltage as shown freewheeling action takes place.
	IV Inverting operation i_o positive V_o negative.	T_2 is turned off. Hence inductance forces current through D_3 and D_4. This current flows through supply. load energy is fed to the supply.

	III Rectifying operation motor rotates in opposite direction	To reverse the direction of rotation of the motor, T_3 and T_4 are turned on. v_o and i_o both are negative. E is shown negative since motor rotates in opposite direction.
	III Freewheeling operation motor rotates in the same direction.	T_3 is turned off, but T_4 remains on. To maintain the current in the same direction inductance generates voltage and i_o flows in same direction through D_2 and T_4. This is freewheeling action.

	III Rectifying operation motor rotates in opposite direction	To reverse the direction of rotation of the motor, T_3 and T_4 are turned on. v_o and i_o both are negative. E is shown negative since motor rotates in opposite direction.
	III Freewheeling operation motor rotates in the same direction.	T_3 is turned off, but T_4 remains on. To maintain the current in the same direction inductance generates voltage and i_o flows in same direction through D_2 and T_4. This is freewheeling action.

Four Quadrant Operation



Single Phase Bridge Inverter with R Load:

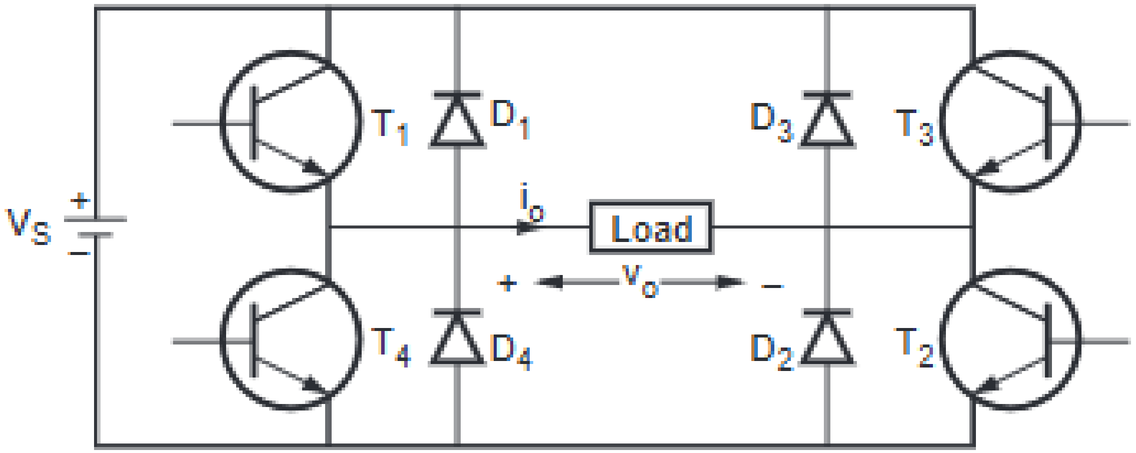
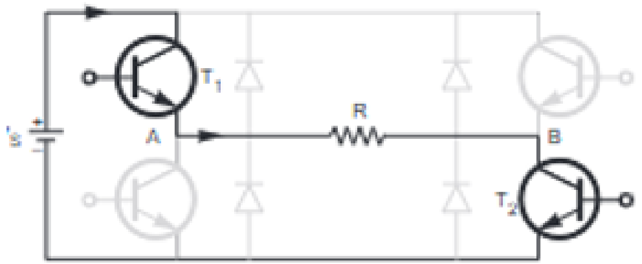
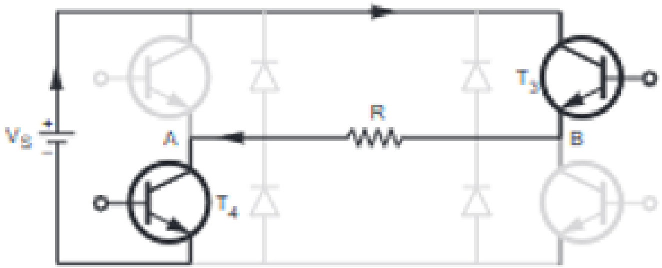


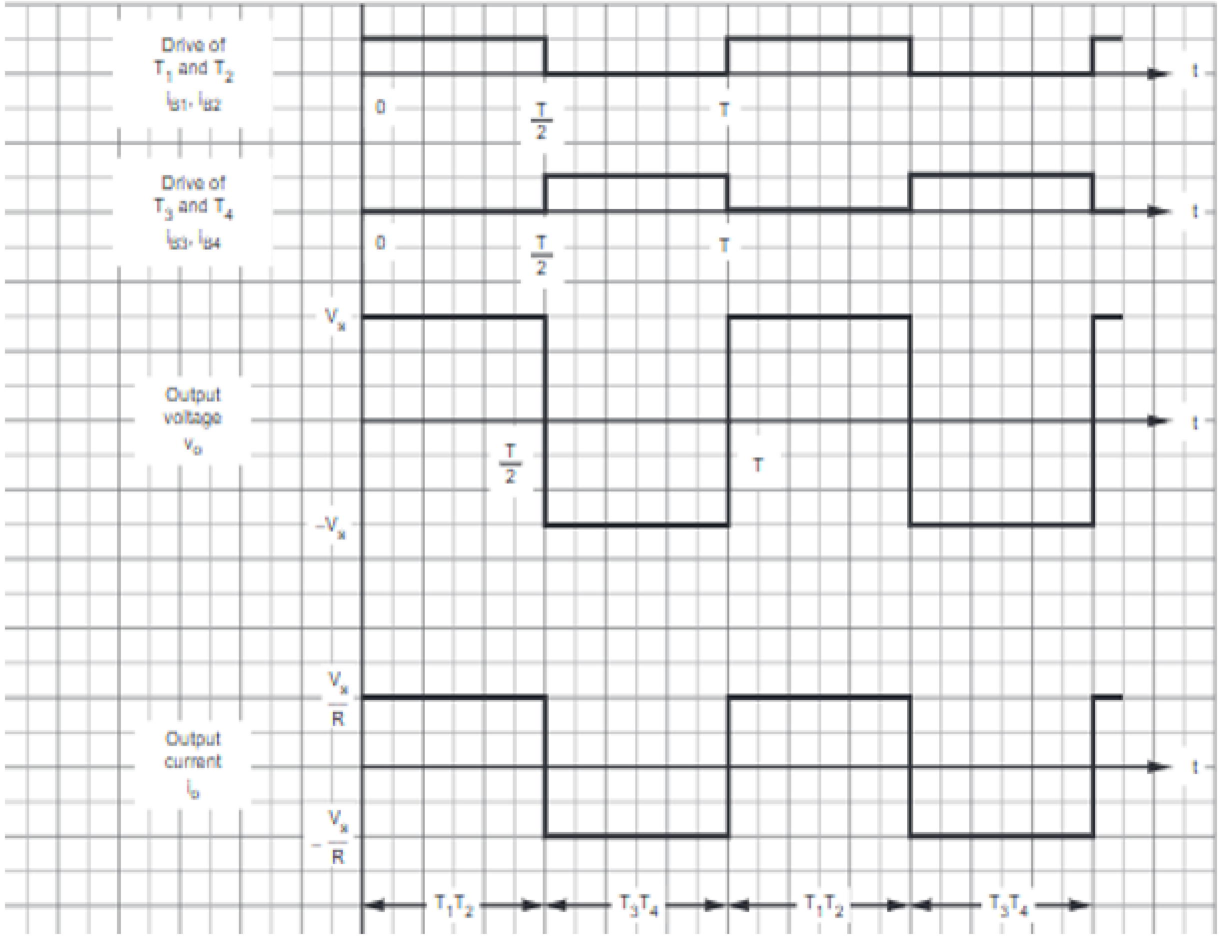
Fig. Single phase bridge inverter



Equivalent Circuit - I



Equivalent Circuit - II



Single Phase Bridge Inverter with RL Load:

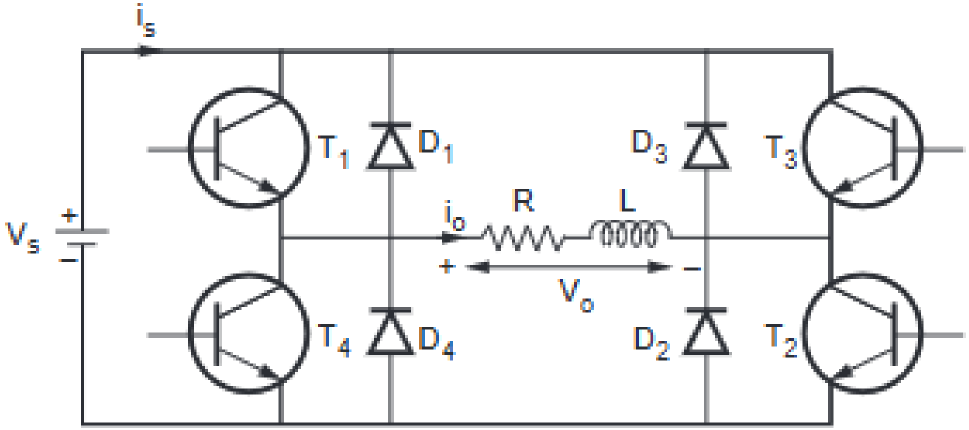


Fig. 1ϕ bridge inverter having inductive load

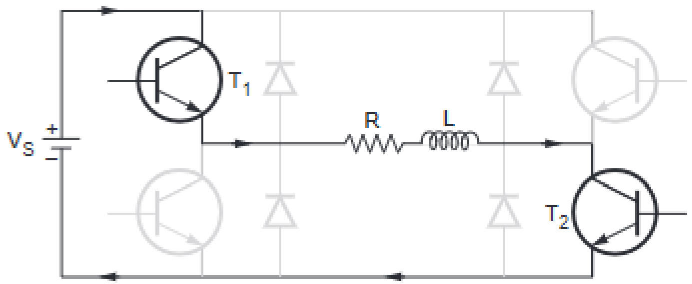


Fig. 7.4.5 T_1 and T_2 conduct from t_1 to $\frac{T}{2}$

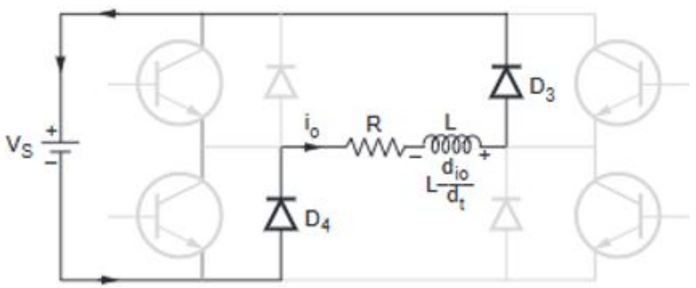
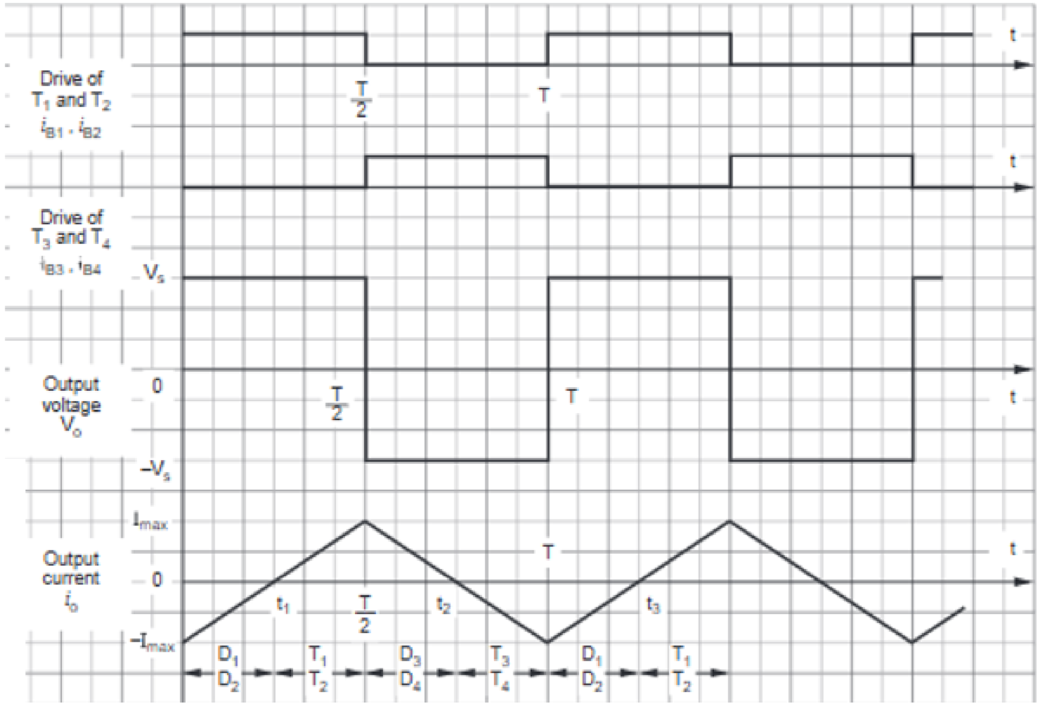


Fig. 7.4.6 D_3 and D_4 conduct from $\frac{T}{2}$ to t_2



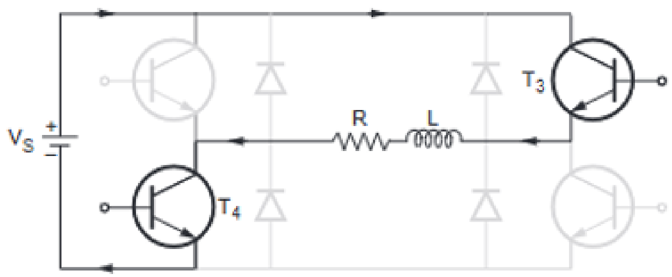


Fig. 7.4.7 T_3 and T_4 conduct from t_2 to T

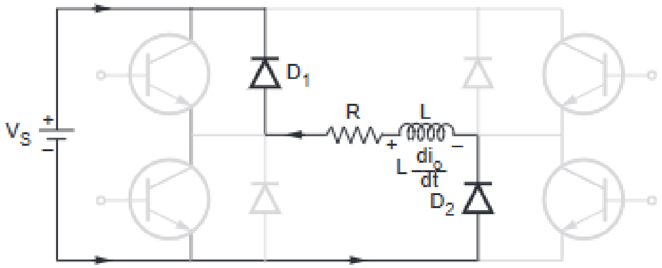
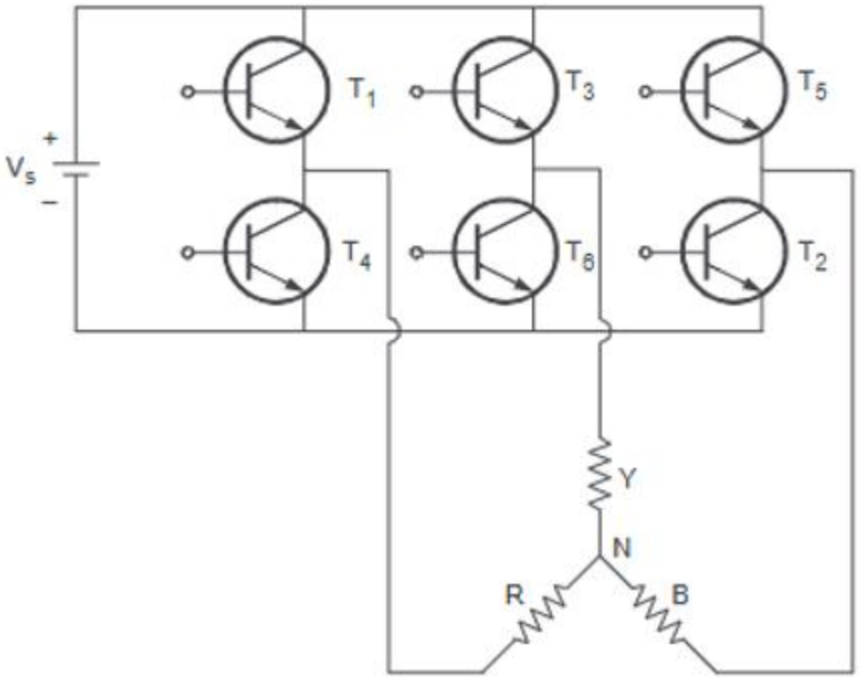
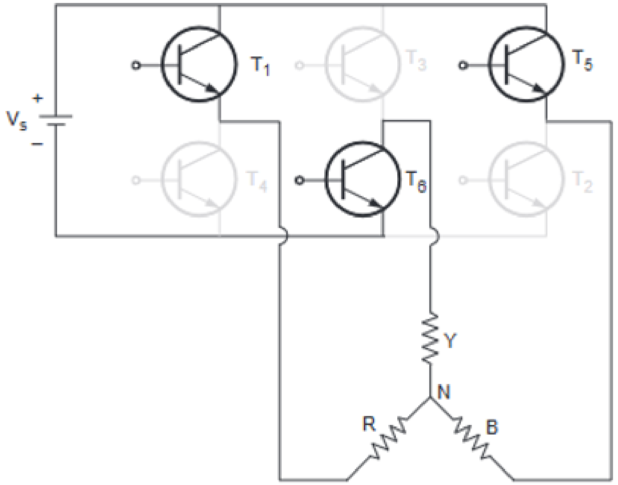


Fig. 7.4.8 D_1 and D_2 conduct from 0 to t_1 i.e. from T to t_3

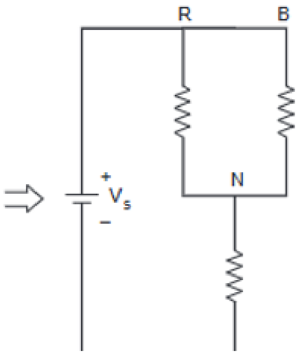
Three Phase Inverters:

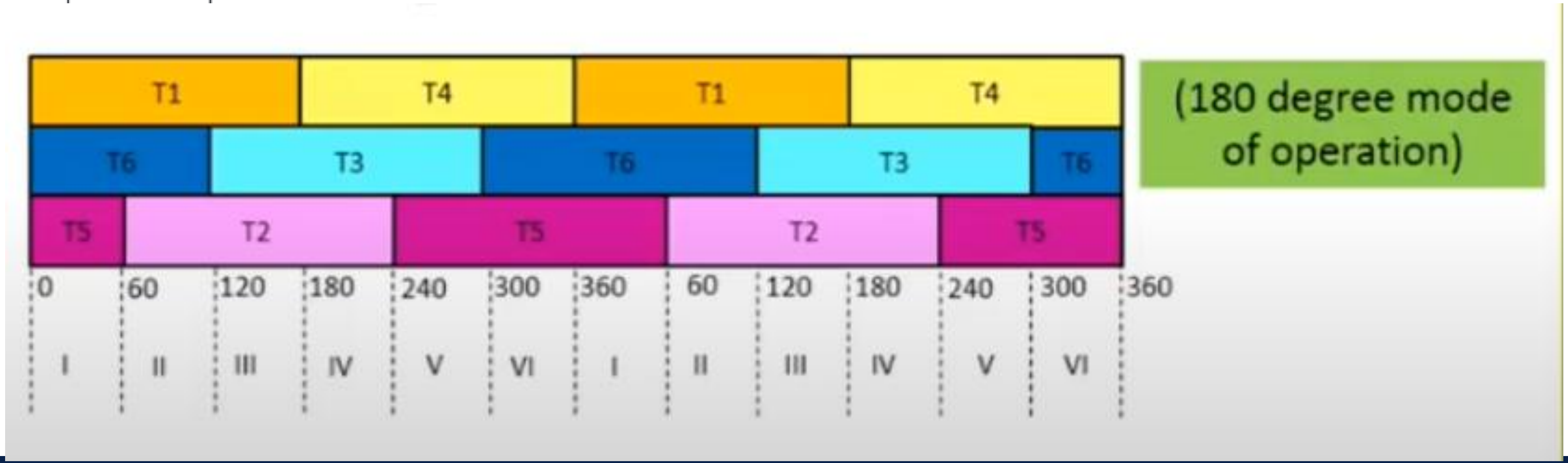


180° Conduction Type 3 ϕ Inverter



(a)





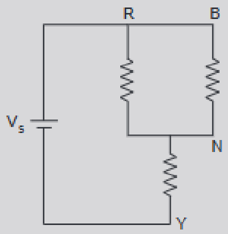
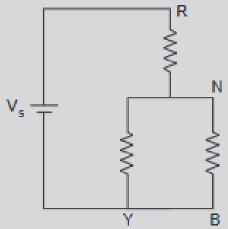
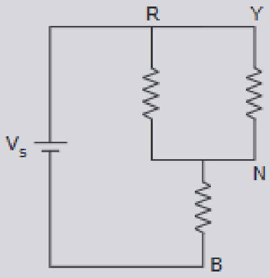
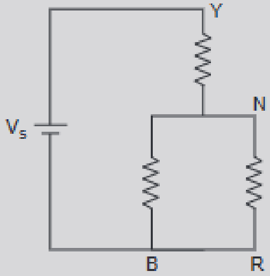
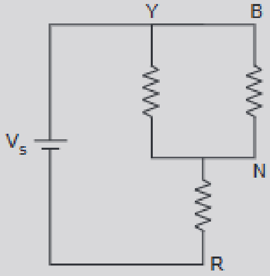
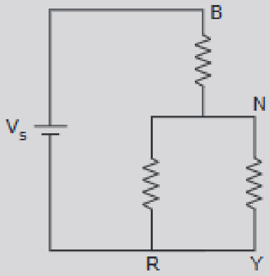
Interval	Conducting transistors	Equivalent circuit	Line voltage V_{RY}	Phase voltage, V_{RN}
I	5 6 1		V_s	$\frac{V_s}{3}$
II	6 1 2		V_s	$\frac{2V_s}{3}$
III	1 2 3		0	$\frac{V_s}{3}$
IV	2 3 4		$-V_s$	$-\frac{V_s}{3}$
V	3 4 5		$-V_s$	$-\frac{2V_s}{3}$
VI	4 5 6		0	$-\frac{V_s}{3}$

Table 7.5.1 Analysis of 3 ϕ inverter (180° conduction)

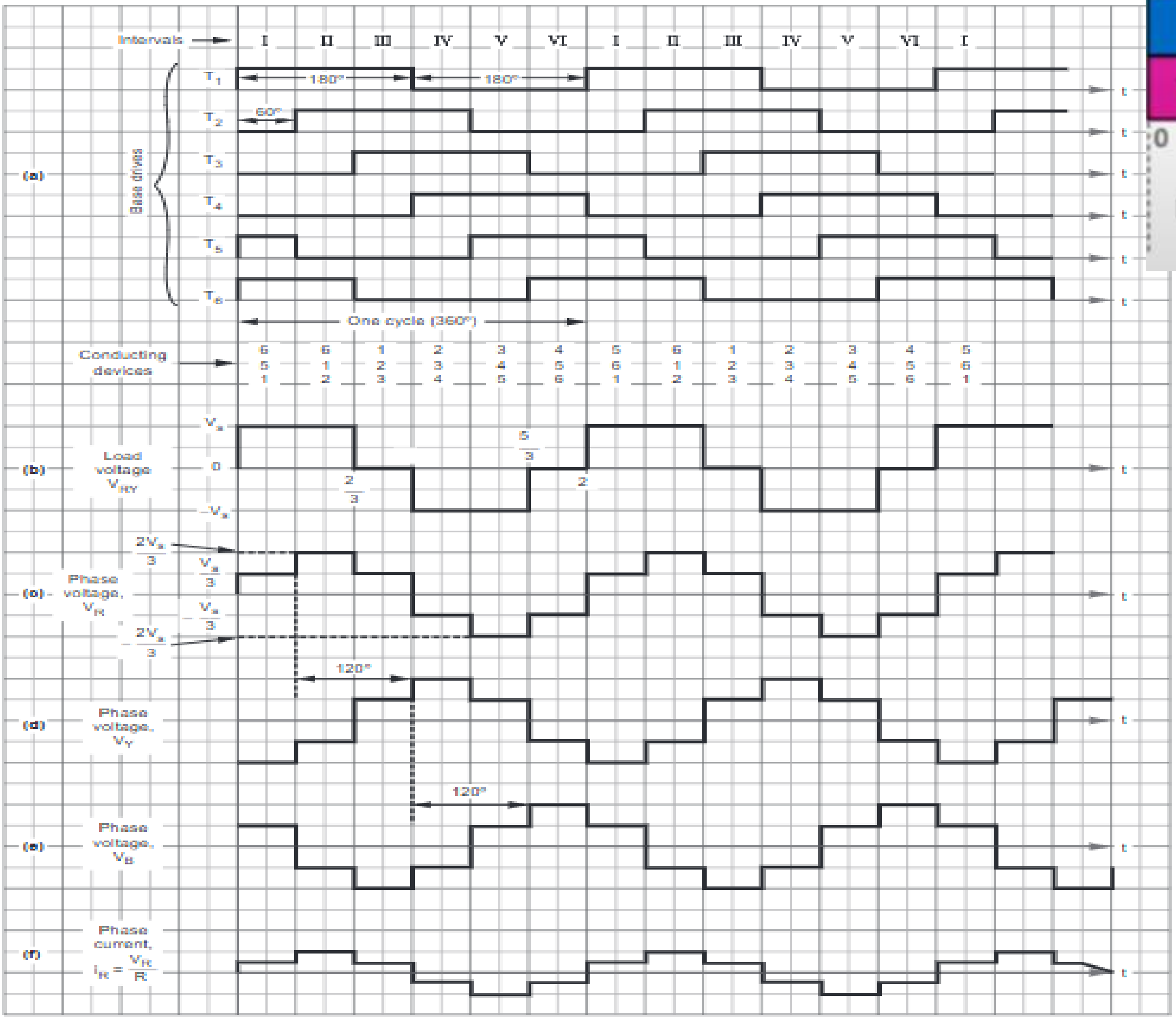
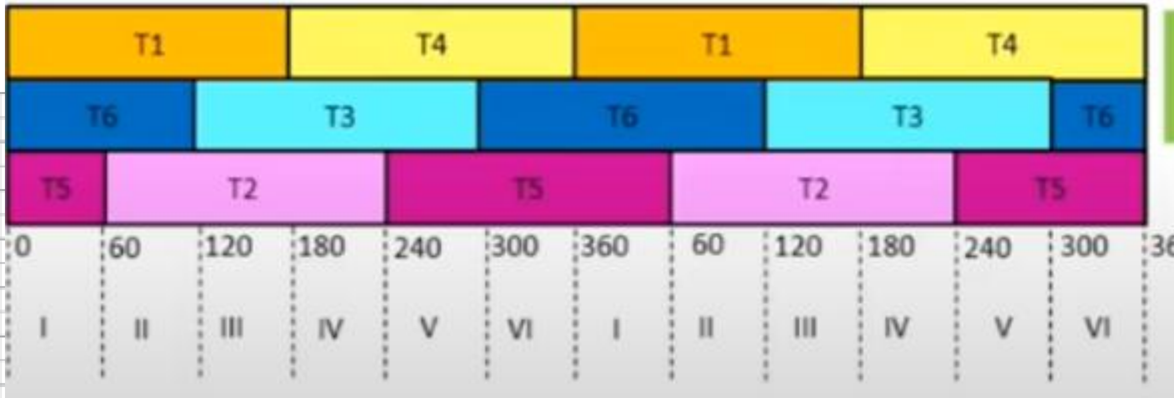
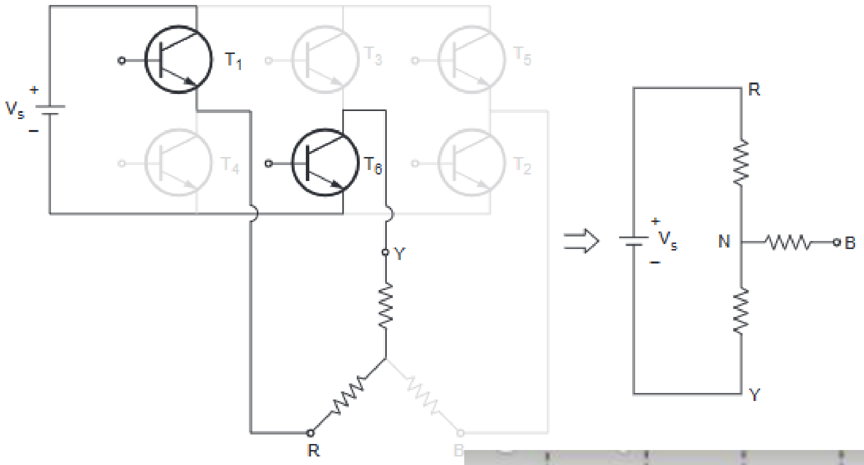


Fig. 7.5.3 Waveforms of 180° mode inverter

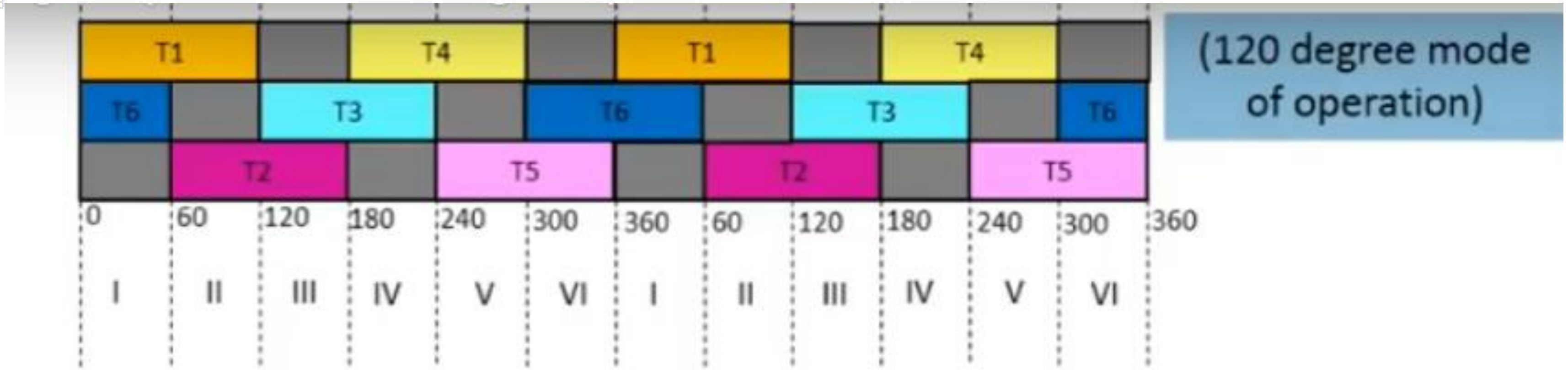


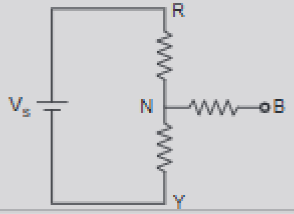
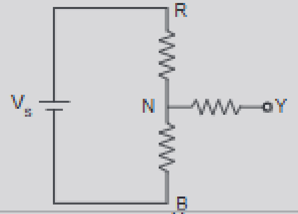
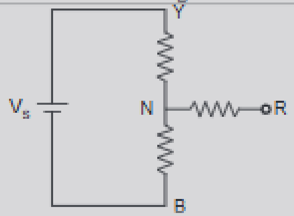
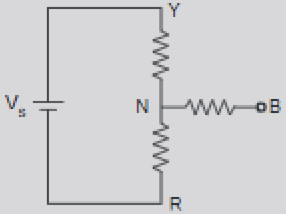
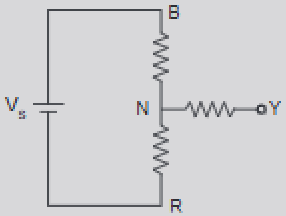
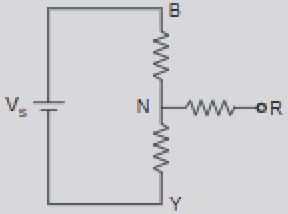
STEP	V_R	V_Y	V_B
1	$\frac{1}{3}Vs$	$\frac{-2}{3}Vs$	$\frac{1}{3}Vs$
2	$\frac{2}{3}Vs$	$\frac{-1}{3}Vs$	$\frac{-1}{3}Vs$
3	$\frac{1}{3}Vs$	$\frac{1}{3}Vs$	$\frac{-2}{3}Vs$
4	$\frac{-1}{3}Vs$	$\frac{2}{3}Vs$	$\frac{-1}{3}Vs$
5	$\frac{-2}{3}Vs$	$\frac{1}{3}Vs$	$\frac{1}{3}Vs$
6	$\frac{-1}{3}Vs$	$\frac{-1}{3}Vs$	$\frac{2}{3}Vs$

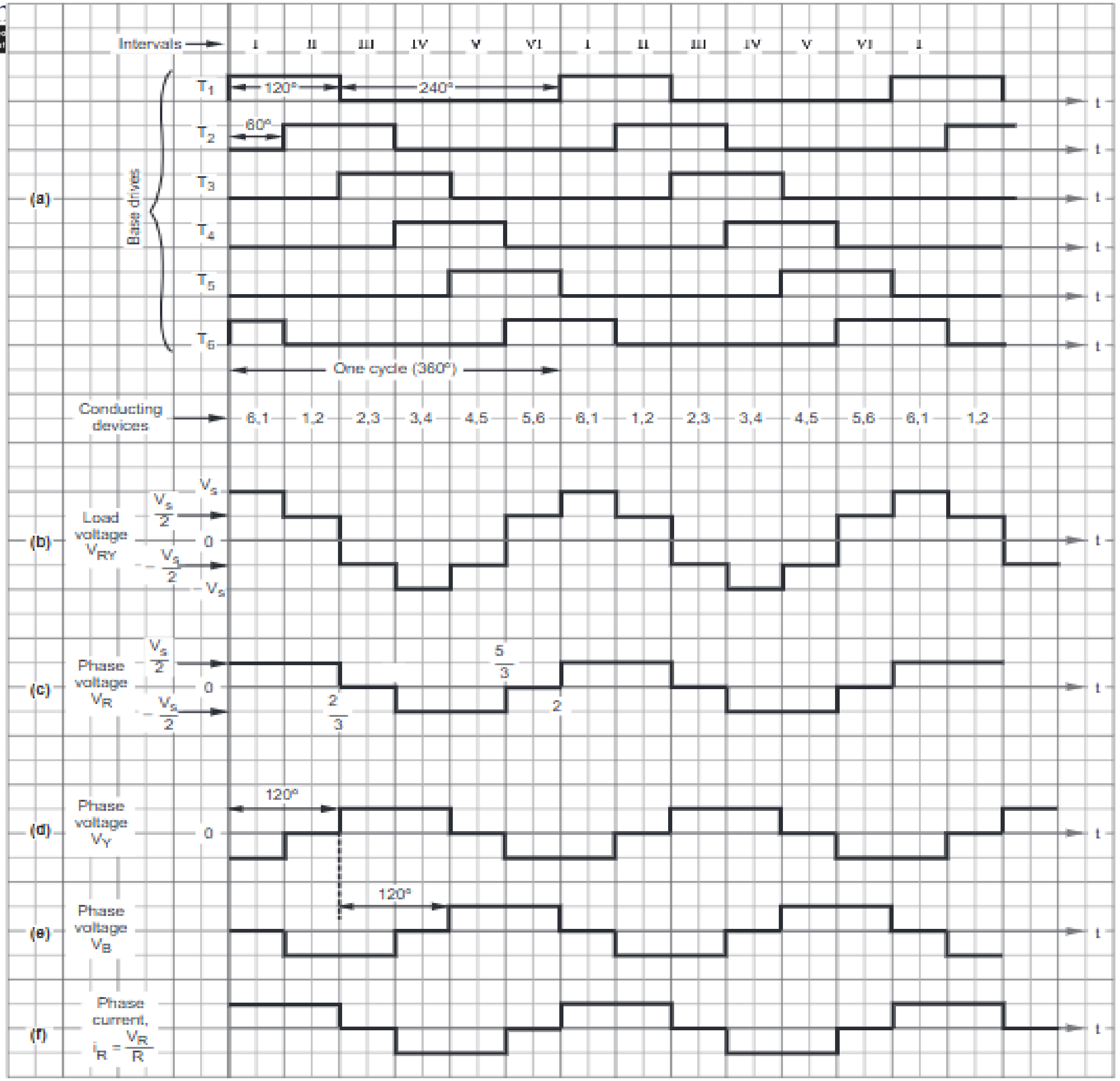
120° Conduction Type 3 ϕ Inverter

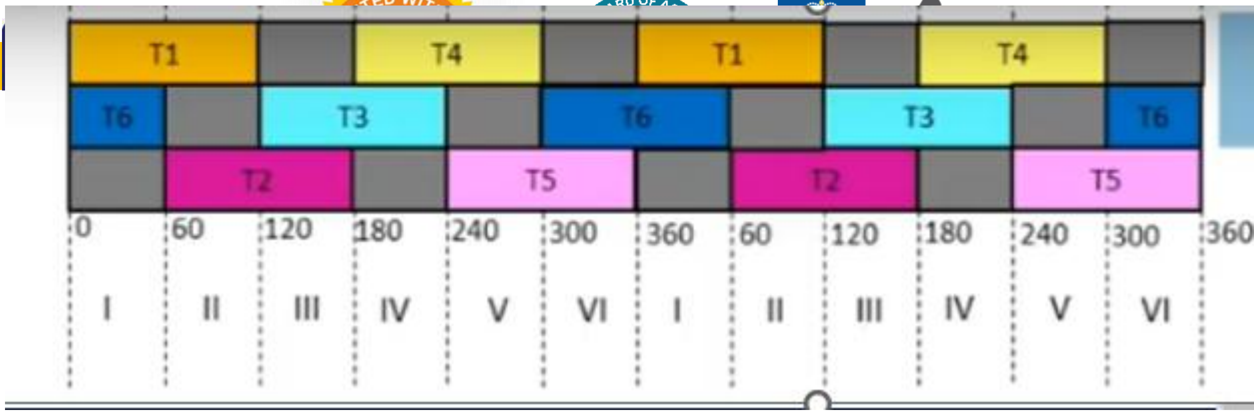


(a)



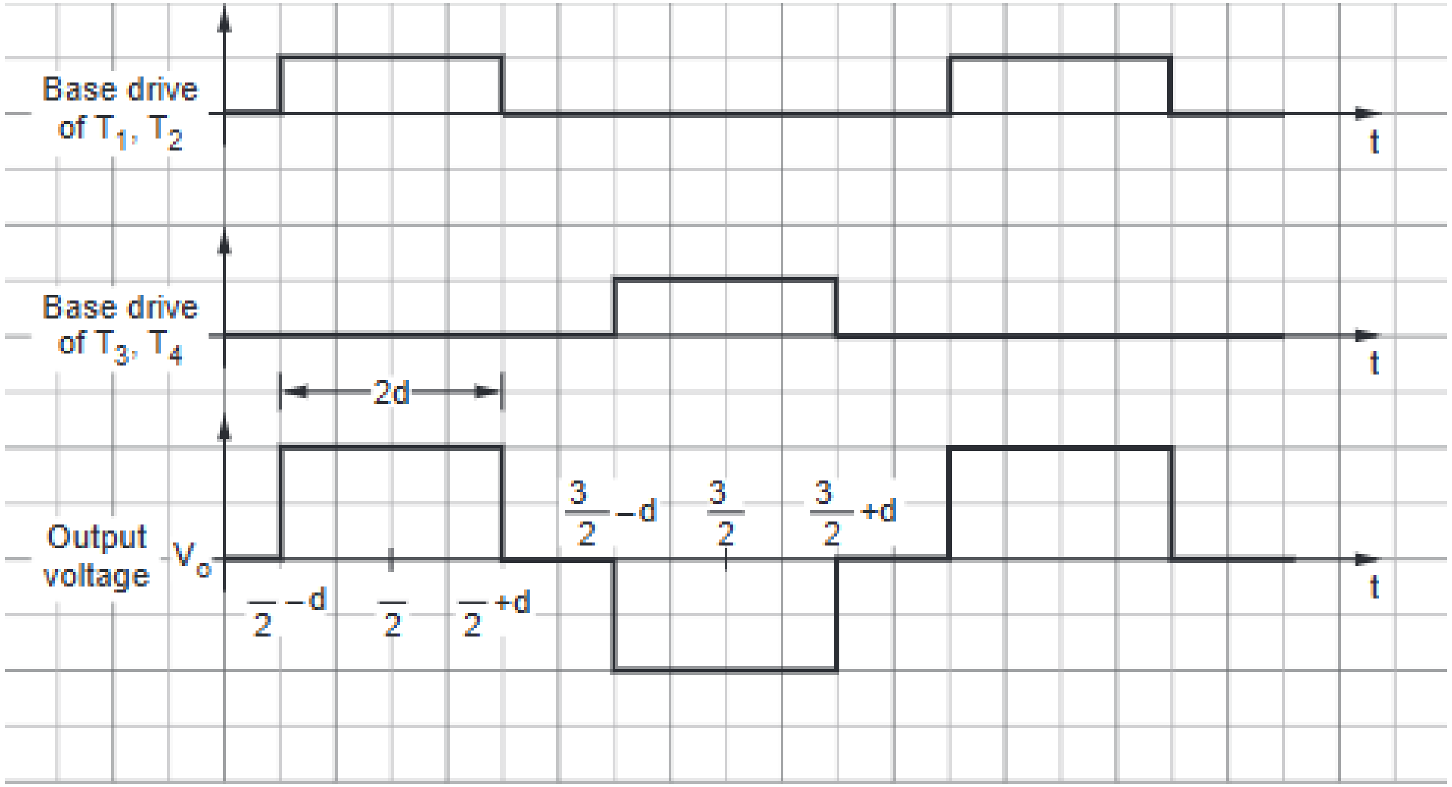
Interval	Conducting transistors	Equivalent circuit	Line voltage V_{RY}	Phase voltage V_{RN}
I	6 1		V_s	$\frac{V_s}{2}$
II	1 2		$\frac{V_s}{2}$	$\frac{V_s}{2}$
III	2 3		$-\frac{V_s}{2}$	0
IV	3 4		$-V_s$	$-\frac{V_s}{2}$
V	4 5		$-\frac{V_s}{2}$	$-\frac{V_s}{2}$
VI	5 6		$\frac{V_s}{2}$	0



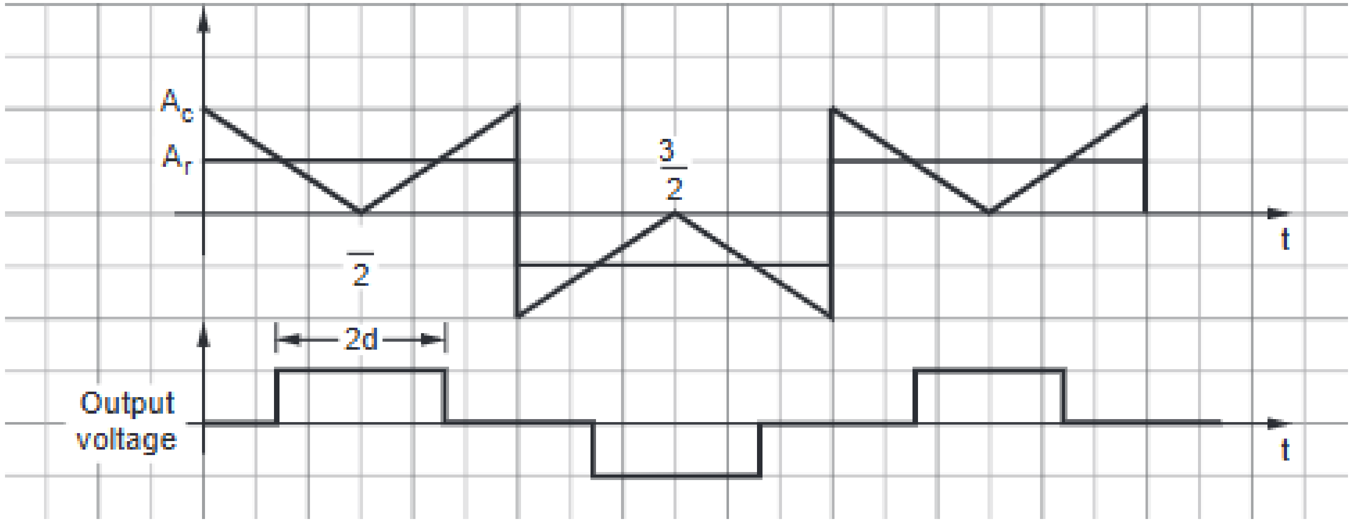


STEP	V_R	V_Y	V_B
1	$\frac{1}{2}Vs$	$\frac{-1}{2}Vs$	0
2	$\frac{1}{2}Vs$	0	$\frac{-1}{2}Vs$
3	0	$\frac{1}{2}Vs$	$\frac{-1}{2}Vs$
4	$\frac{-1}{2}Vs$	$\frac{1}{2}Vs$	0
5	$\frac{-1}{2}Vs$	0	$\frac{1}{2}Vs$
6	0	$\frac{-1}{2}Vs$	$\frac{1}{2}Vs$

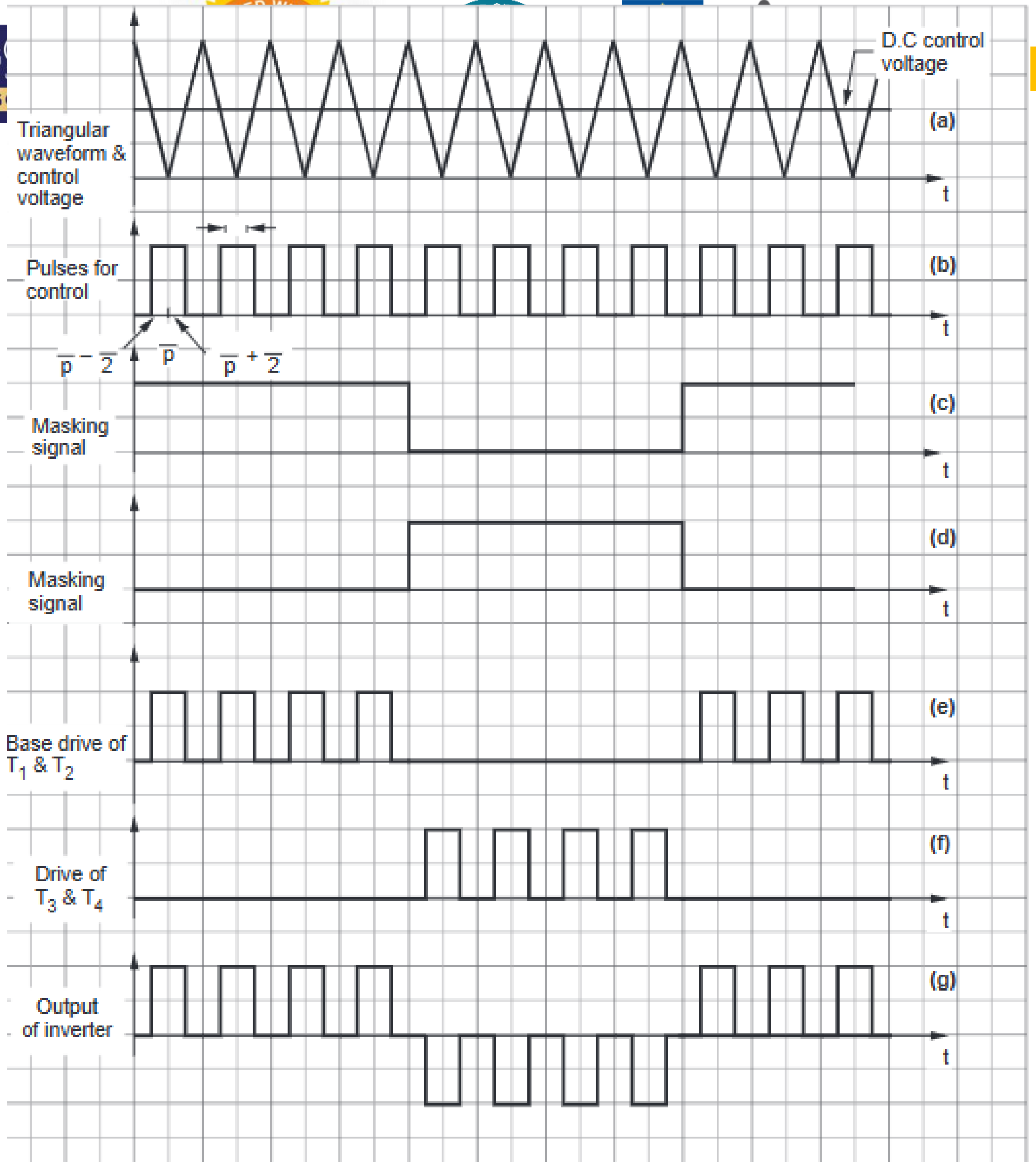
Voltage Control of Single Phase Inverters



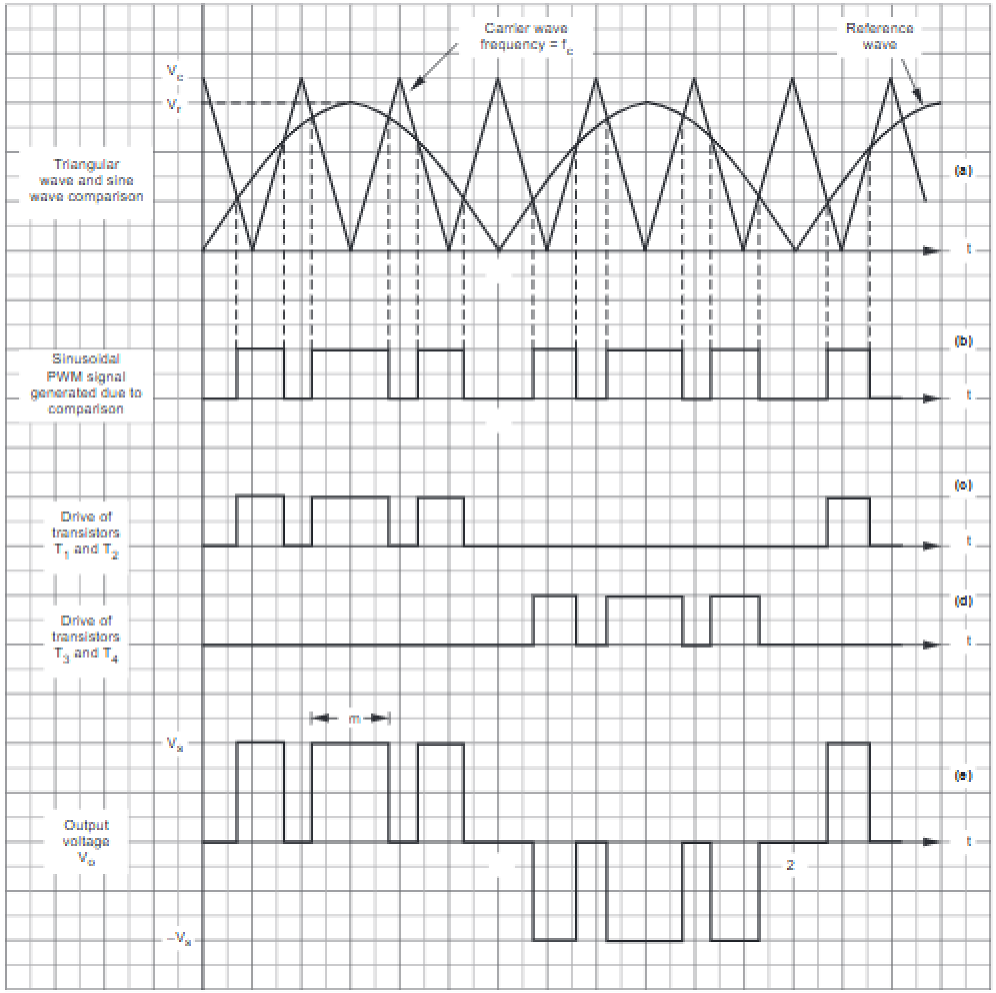
Single Pulse Modulation (SM)



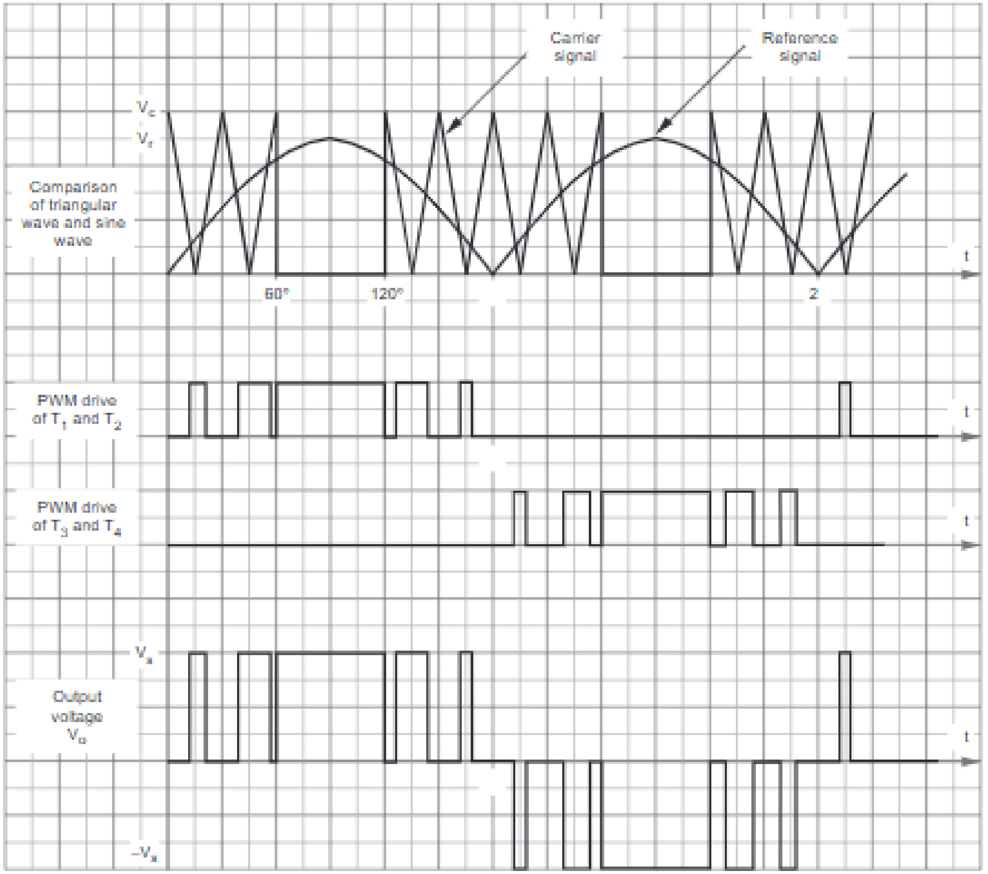
Multiple Pulse Width Modulation Technique:



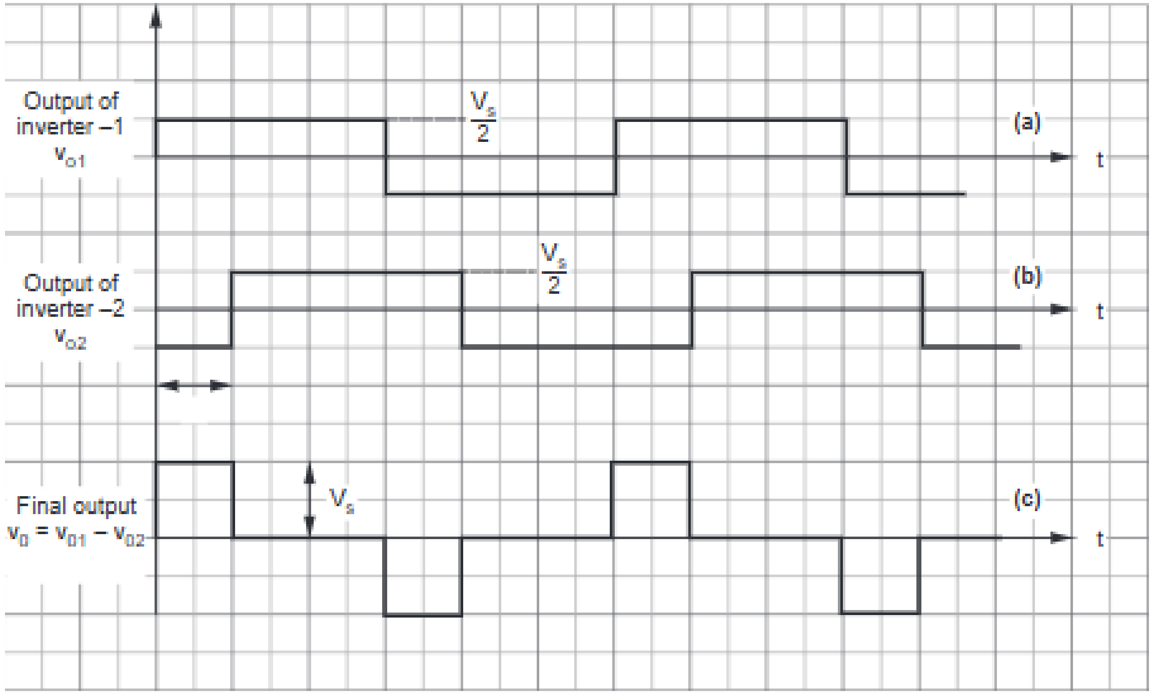
Sinusoidal PWM (SPWM)



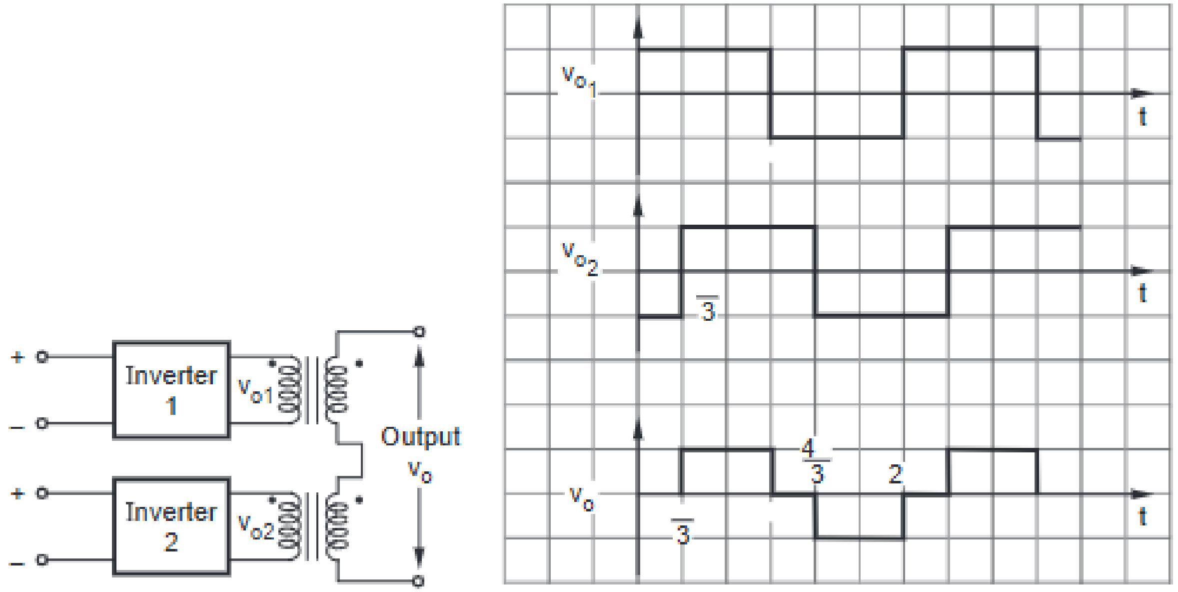
Modified Sinusoidal PWM (MSPWM)



Phase Displacement Control



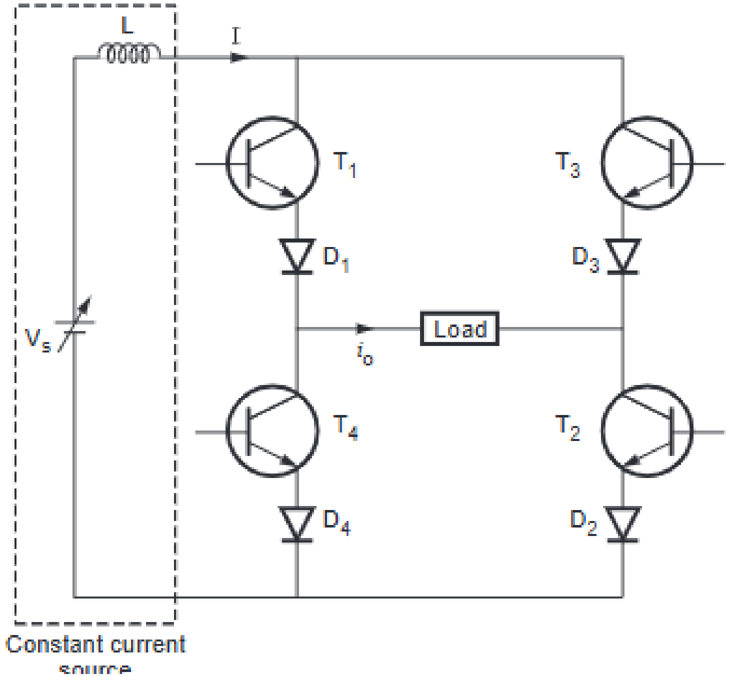
Harmonic Elimination by Transformer Connections

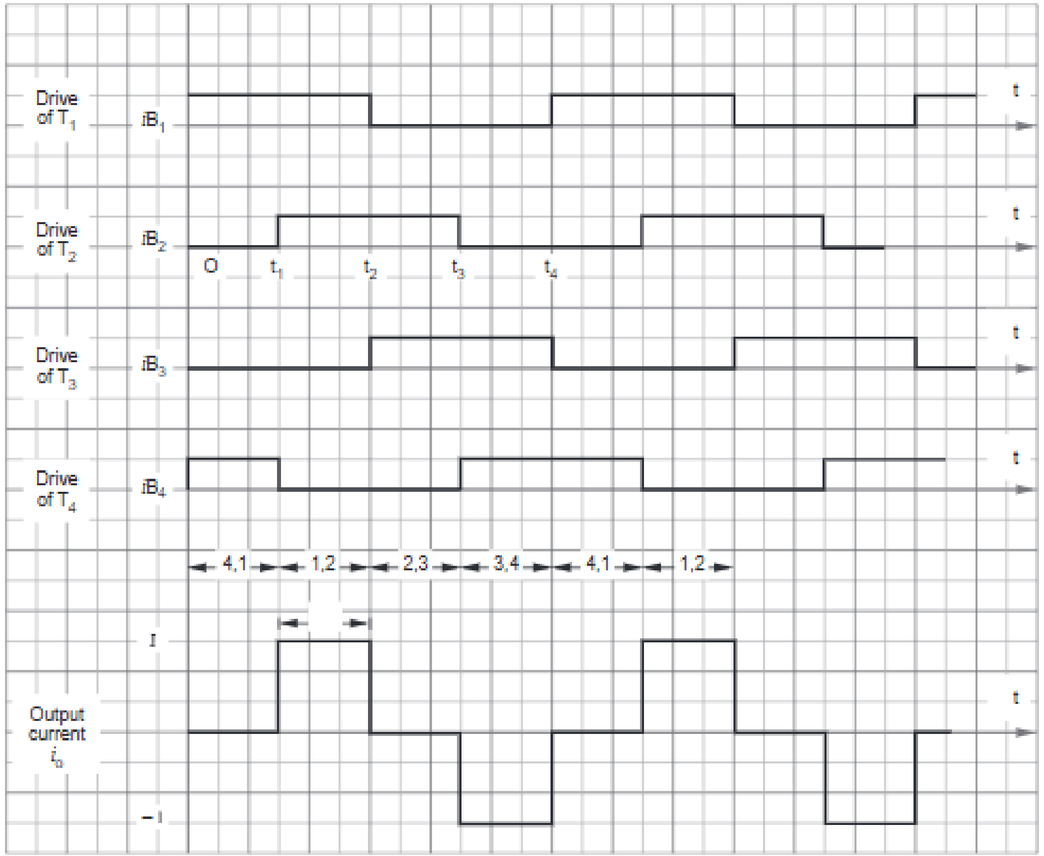


(a) Transformer connection

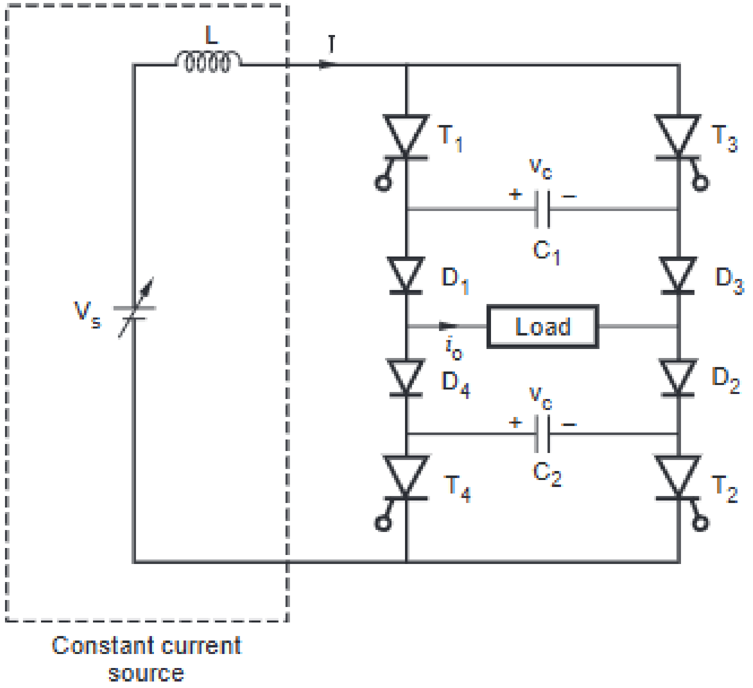
(b) Waveforms

1 phase Transistorised Current Source Inverter





Thyristorized Current Source Inverter (Capacitor Commutated Current Source Inverter)




thank
you