UNIT- III

DC CHOPPERS

INTRODUCTION

A chopper is a static device which is used to obtain a variable dc voltage from a constant dc voltage source. A chopper is also known as dc-to-dc converter. The thyristor converter offers greater efficiency, faster response, lower maintenance, smaller size and smooth control. Choppers are widely used in trolley cars, battery operated vehicles, traction motor control, control of large number of dc motors, etc….. They are also used in regenerative braking of dc motors to return energy back to supply and also as dc voltage regulators.

Choppers are of two types
Step-down choppers
Step-up choppers.

In step-down choppers, the output voltage will be less than the input voltage whereas in step-up choppers output voltage will be more than the input voltage.

PRINCIPLE OF STEP-DOWN CHOPPER

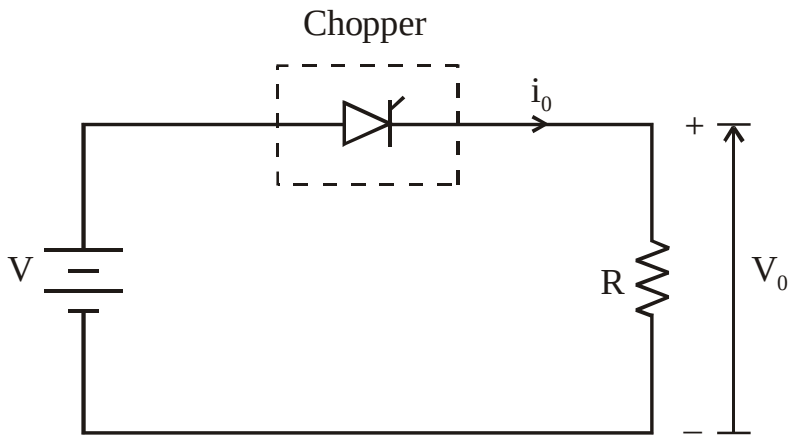


Fig. 2.1: Step-down Chopper with Resistive Load

Figure 2.1 shows a step-down chopper with resistive load. The thyristor in the circuit acts as a switch. When thyristor is ON, supply voltage appears across the load and when thyristor is OFF, the voltage across the load will be zero. The output voltage and current waveforms are as shown in figure 2.2.

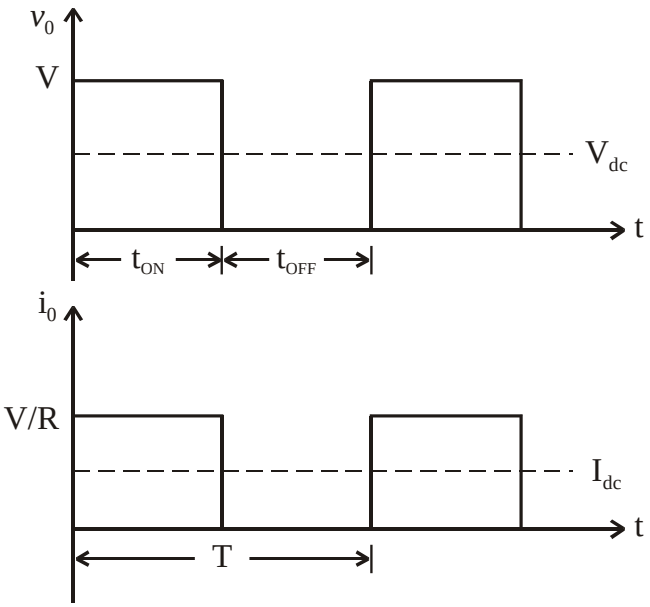


Fig. 2.2: Step-down choppers — output voltage and current waveforms

V_{dc} = average value of output or load voltage

I_{dc} = average value of output or load current

t_{ON} = time interval for which SCR conducts

t_{OFF} = time interval for which SCR is OFF.

$T = t_{ON} + t_{OFF}$ = period of switching or chopping period

$f = \frac{1}{T} =$ frequency of chopper switching or chopping frequency.

Average output voltage

$$V_{dc} = V\left(\frac{t_{ON}}{t_{ON} + t_{OFF}}\right) \qquad ...(2.1)$$

$$V_{dc} = V\left(\frac{t_{ON}}{T}\right) = V.d \qquad ...(2.2)$$

but $$\left(\frac{t_{ON}}{t}\right) = d = \text{duty cycle} \qquad ...(2.3)$$

Average output current,

$$I_{dc} = \frac{V_{dc}}{R} \qquad ...(2.4)$$

$$I_{dc} = \frac{V}{R}\left(\frac{t_{ON}}{T}\right) = \frac{V}{R}d \qquad ...(2.5)$$

RMS value of output voltage

$$V_O = \sqrt{\frac{1}{T}\int_0^{t_{ON}} v_o^2 dt}$$

But during t_{ON}, $v_o = V$

Therefore RMS output voltage

$$V_O = \sqrt{\frac{1}{T}\int_0^{t_{ON}} V^2 dt}$$

$$V_O = \sqrt{\frac{V^2}{T} t_{ON}} = \sqrt{\frac{t_{ON}}{T}}.V \qquad ...(2.6)$$

$$V_O = \sqrt{d}.V \qquad ...(2.7)$$

Output power $P_O = V_O I_O$

But $I_O = \frac{V_O}{R}$

Therefore output power $P_O = \frac{V_O^2}{R}$

$$P_O = \frac{dV^2}{R} \qquad ...(2.8)$$

Effective input resistance of chopper

$$R_i = \frac{V}{I_{dc}} \qquad ...(2.9)$$

$$R_i = \frac{R}{d} \qquad ...(2.10)$$

The output voltage can be varied by varying the duty cycle.

METHODS OF CONTROL

The output dc voltage can be varied by the following methods.
Pulse width modulation control or constant frequency operation.
Variable frequency control.

PULSE WIDTH MODULATION

In pulse width modulation the pulse width (t_{ON}) of the output waveform is varied keeping chopping frequency 'f' and hence chopping period 'T' constant. Therefore output voltage is varied by varying the ON time, t_{ON} . Figure 2.3 shows the output voltage waveforms for different ON times.

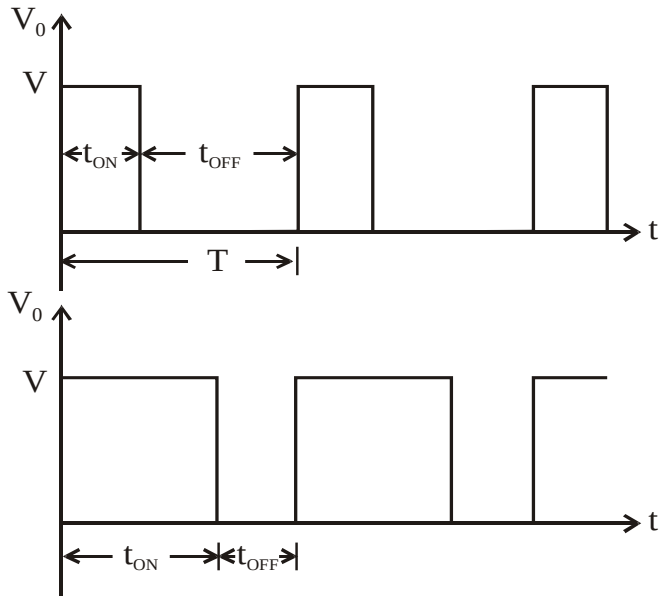


Fig. 2.3: Pulse Width Modulation Control

VARIABLE FREQUENCY CONTROL

In this method of control, chopping frequency f is varied keeping either t_{ON} or t_{OFF} constant. This method is also known as frequency modulation.

Figure 2.4 shows the output voltage waveforms for a constant t_{ON} and variable chopping period T.

In frequency modulation to obtain full output voltage, range frequency has to be varied over a wide range. This method produces harmonics in the output and for large t_{OFF} load current may become discontinuous.

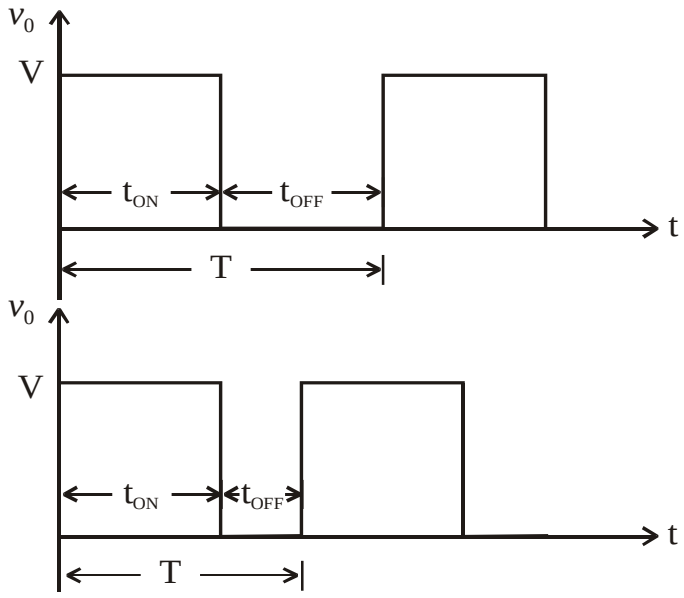


Fig. 2.4: Output Voltage Waveforms for Time Ratio Control

STEP-DOWN CHOPPER WITH R-L LOAD

Figure 2.5 shows a step-down chopper with R-L load and free wheeling diode. When chopper is ON, the supply is connected across the load. Current flows from the supply to the load. When chopper is OFF, the load current i_o continues to flow in the same direction through the free-wheeling diode due to the energy stored in the inductor L. The load current can be continuous or discontinuous depending on the values of L and duty cycle, d. For a continuous current operation the load current is assumed to vary between two limits $I_{\min}$ and $I_{\max}$.

Figure 2.6 shows the output current and output voltage waveforms for a continuous current and discontinuous current operation.

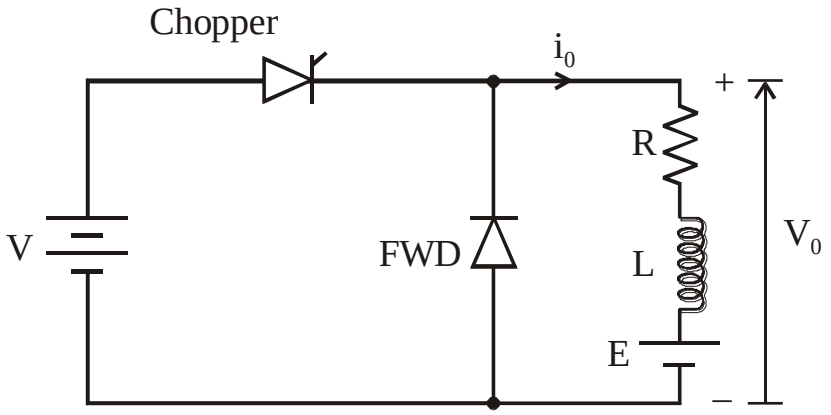


Fig. 2.5: Step Down Chopper with R-L Load

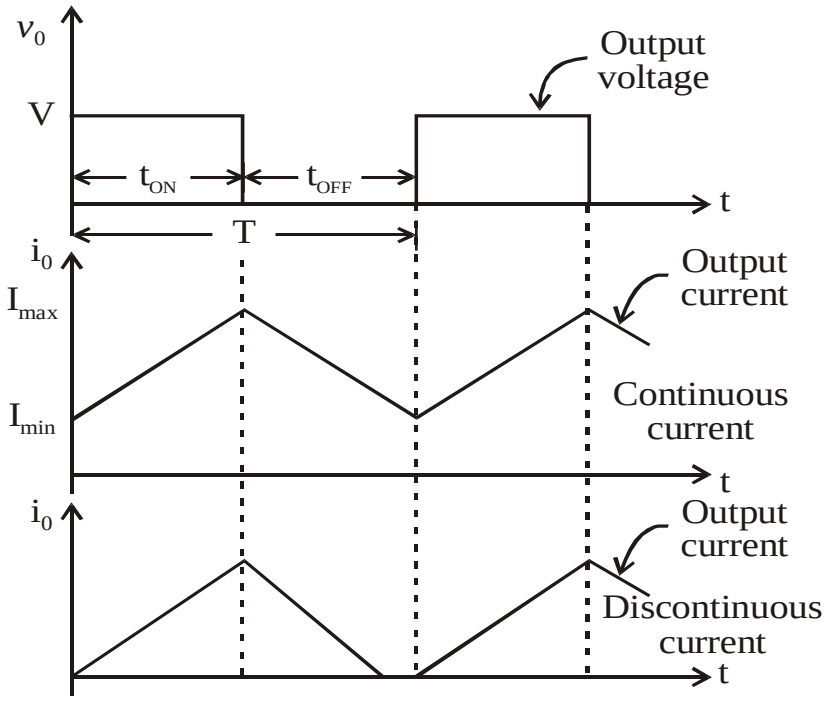


Fig. 2.6: Output Voltage and Load Current Waveforms (Continuous Current)

When the current exceeds $I_{\max}$ the chopper is turned-off and it is turned-on when current reduces to $I_{\min}$.

EXPRESSIONS FOR LOAD CURRENT i_O FOR CONTINUOUS CURRENT OPERATION WHEN CHOPPER IS ON $(0 \le t \le t_{ON})$

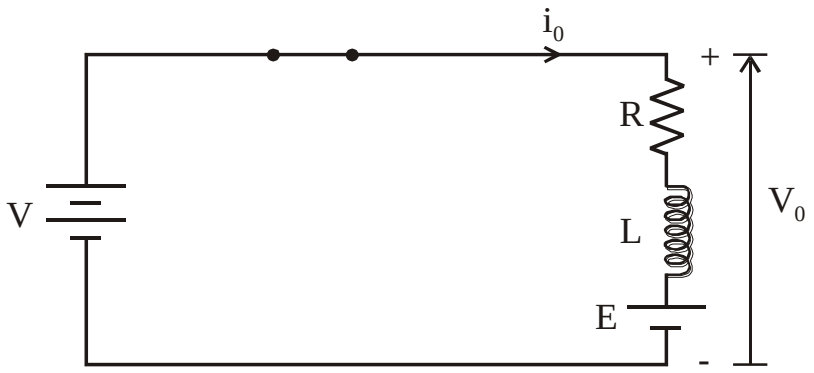


Fig. 2.5 (a)

Voltage equation for the circuit shown in figure 2.5(a) is

$$V = i_O R + L\frac{di_O}{dt} + E \qquad ...(2.11)$$

Taking Laplace Transform

$$\frac{V}{S} = RI_O(S) + L\left[S.I_O(S) - i_O(0^-)\right] + \frac{E}{S} \qquad ...(2.12)$$

At $t = 0$, initial current $i_O(0^-) = I_{\min}$

$$I_O(S) = \frac{V-E}{LS\left(S+\frac{R}{L}\right)} + \frac{I_{\min}}{S+\frac{R}{L}} \qquad ...(2.13)$$

Taking Inverse Laplace Transform

$$i_O(t) = \frac{V-E}{R}\left[1 - e^{-\left(\frac{R}{L}\right)t}\right] + I_{\min}e^{-\left(\frac{R}{L}\right)t} \qquad ...(2.14)$$

This expression is valid for $0 \le t \le t_{ON}$. i.e., during the period chopper is ON.

At the instant the chopper is turned off, load current is

$$i_O(t_{ON}) = I_{\max}$$

When Chopper is OFF $\left(0 \le t \le t_{OFF}\right)$

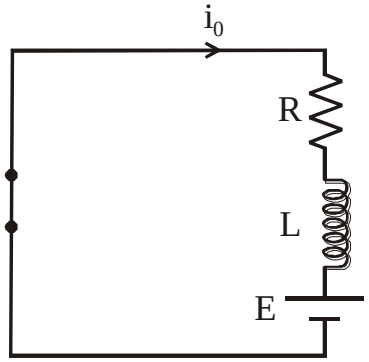


Fig. 2.5 (b)

Voltage equation for the circuit shown in figure 2.5(b) is

$$0 = Ri_O + L\frac{di_O}{dt} + E \qquad ...(2.15)$$

Taking Laplace transform

$$0 = RI_O(S) + L\left[SI_O(S) - i_O\left(0^-\right)\right] + \frac{E}{S}$$

Redefining time origin we have at $t = 0$, initial current $i_O\left(0^-\right) = I_{\max}$

Therefore $$I_O(S) = \frac{I_{\max}}{S + \frac{R}{L}} - \frac{E}{LS\left(S + \frac{R}{L}\right)}$$

Taking Inverse Laplace Transform

$$i_O(t) = I_{\max}e^{-\frac{R}{L}t} - \frac{E}{R}\left[1 - e^{-\frac{R}{L}t}\right] \qquad ...(2.16)$$

The expression is valid for $0 \le t \le t_{OFF}$, i.e., during the period chopper is OFF. At the instant the chopper is turned ON or at the end of the off period, the load current is

$$i_O\left(t_{OFF}\right) = I_{\min}$$

TO FIND $I_{\max}$ AND $I_{\min}$

From equation (2.14),

At $$t = t_{ON} = dT, \;\; i_O(t) = I_{\max}$$

Therefore $$I_{\max} = \frac{V-E}{R}\left[1-e^{-\frac{dRT}{L}}\right] + I_{\min}e^{-\frac{dRT}{L}} \qquad ...(2.17)$$

From equation (2.16),

At $$t = t_{OFF} = T - t_{ON},\ \ i_O(t) = I_{\min}$$

$$t = t_{OFF} = (1-d)T$$

Therefore $$I_{\min} = I_{\max}e^{-\frac{(1-d)RT}{L}} - \frac{E}{R}\left[1-e^{-\frac{(1-d)RT}{L}}\right] \qquad ...(2.18)$$

Substituting for $I_{\min}$ in equation (2.17) we get,

$$I_{\max} = \frac{V}{R}\left[\frac{1-e^{-\frac{dRT}{L}}}{1-e^{-\frac{RT}{L}}}\right] - \frac{E}{R} \qquad ...(2.19)$$

Substituting for $I_{\max}$ in equation (2.18) we get,

$$I_{\min} = \frac{V}{R}\left[\frac{e^{\frac{dRT}{L}}-1}{e^{\frac{RT}{L}}-1}\right] - \frac{E}{R} \qquad ...(2.20)$$

$(I_{\max} - I_{\min})$ is known as the steady state ripple.

Therefore peak-to-peak ripple current

$$\Delta I = I_{\max} - I_{\min}$$

Average output voltage

$$V_{dc} = d.V \qquad ...(2.21)$$

Average output current

$$I_{dc(approx)} = \frac{I_{\max} + I_{\min}}{2} \qquad ...(2.22)$$

Assuming load current varies linearly from $I_{\min}$ to $I_{\max}$ instantaneous load current is given by

$$i_O = I_{\min} + \frac{(\Delta I).t}{dT} \ \ for\ \ 0 \le t \le t_{ON}\ (dT)$$

$$i_O = I_{\min} + \left(\frac{I_{\max} - I_{\min}}{dT} \right) t \qquad ...(2.23)$$

RMS value of load current

$$I_{O(RMS)} = \sqrt{\frac{1}{dT} \int_0^{dT} i_0^2 dt}$$

$$I_{O(RMS)} = \sqrt{\frac{1}{dT} \int_0^{dT} \left[I_{\min} + \frac{(I_{\max} - I_{\min}) t}{dT} \right]^2 dt}$$

$$I_{O(RMS)} = \sqrt{\frac{1}{dT} \int_0^{dT} \left[I_{\min}^2 + \left(\frac{I_{\max} - I_{\min}}{dT} \right)^2 t^2 + \frac{2 I_{\min} (I_{\max} - I_{\min}) t}{dT} \right] dt}$$

RMS value of output current

$$I_{O(RMS)} = \left[I_{\min}^2 + \frac{(I_{\max} - I_{\min})^2}{3} + I_{\min} (I_{\max} - I_{\min}) \right]^{\frac{1}{2}} \qquad ...(2.24)$$

RMS chopper current

$$I_{CH} = \sqrt{\frac{1}{T} \int_0^{dT} i_0^2 dt}$$

$$I_{CH} = \sqrt{\frac{1}{T} \int_0^{dT} \left[I_{\min} + \left(\frac{I_{\max} - I_{\min}}{dT} \right) t \right]^2 dt}$$

$$I_{CH} = \sqrt{d} \left[I_{\min}^2 + \frac{(I_{\max} - I_{\min})^2}{3} + I_{\min} (I_{\max} - I_{\min}) \right]^{\frac{1}{2}}$$

$$I_{CH} = \sqrt{d}\, I_{O(RMS)} \qquad ...(2.25)$$

Effective input resistance is

$$R_i = \frac{V}{I_S}$$

Where I_S = Average source current

$$I_S = dI_{dc}$$

Therefore $$R_i = \frac{V}{dI_{dc}} \qquad ...(2.26)$$

PRINCIPLE OF STEP-UP CHOPPER

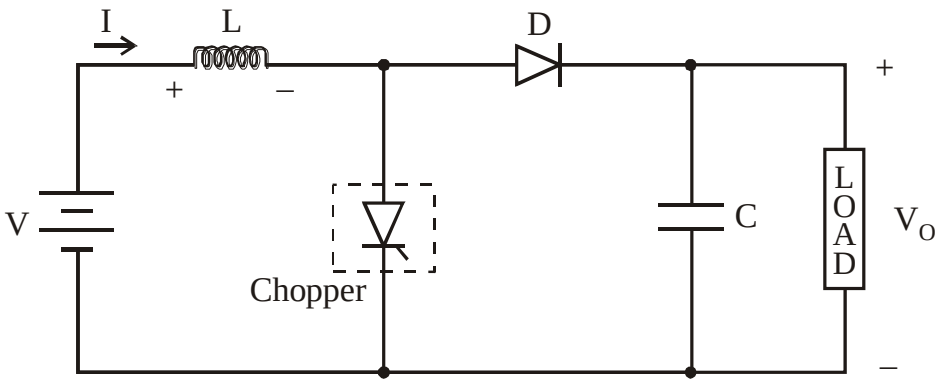


Fig. 2.13: Step-up Chopper

Figure 2.13 shows a step-up chopper to obtain a load voltage V_O higher than the input voltage *V*. The values of *L* and *C* are chosen depending upon the requirement of output voltage and current. When the chopper is *ON*, the inductor *L* is connected across the supply. The inductor current *'I'* rises and the inductor stores energy during the *ON* time of the chopper, t_{ON} . When the chopper is off, the inductor current *I* is forced to flow through the diode *D* and load for a period, t_{OFF} . The current tends to decrease resulting in reversing the polarity of induced EMF in *L*. Therefore voltage across load is given by

$$V_O = V + L\frac{dI}{dt} \quad i.e., \quad V_O > V \qquad ...(2.27)$$

If a large capacitor 'C' is connected across the load then the capacitor will provide a continuous output voltage V_O . Diode *D* prevents any current flow from capacitor to the source. Step up choppers are used for regenerative braking of dc motors.

EXPRESSION FOR OUTPUT VOLTAGE

Assume the average inductor current to be *I* during *ON* and *OFF* time of Chopper.

When Chopper is ON

Voltage across inductor $L = V$

Therefore energy stored in inductor = $V.I.t_{ON}$ $...(2.28)$,

where $t_{ON} = ON$ period of chopper.

When Chopper is OFF (energy is supplied by inductor to load)

Voltage across $L = V_O - V$

Energy supplied by inductor $L = (V_O - V) It_{OFF}$, where $t_{OFF} = OFF$ period of Chopper.

Neglecting losses, energy stored in inductor L = energy supplied by inductor L

Therefore $VIt_{ON} = (V_O - V) It_{OFF}$

$$V_O = \frac{V[t_{ON} + t_{OFF}]}{t_{OFF}}$$

$$V_O = V\left(\frac{T}{T - t_{ON}}\right)$$

Where T = Chopping period or period of switching.

$$T = t_{ON} + t_{OFF}$$

$$V_O = V\left(\frac{1}{1 - \frac{t_{ON}}{T}}\right)$$

Therefore $$V_O = V\left(\frac{1}{1-d}\right) \qquad ...(2.29)$$

Where $d = \frac{t_{ON}}{T} =$ duty cyle

For variation of duty cycle 'd' in the range of $0 < d < 1$ the output voltage V_O will vary in the range $V < V_O < \infty$.

PERFORMANCE PARAMETERS

The thyristor requires a certain minimum time to turn *ON* and turn *OFF*. Hence duty cycle *d* can be varied only between a minimum and a maximum value, limiting the minimum and maximum value of the output voltage. Ripple in the load current depends inversely on the chopping frequency, *f*. Therefore to reduce the load ripple current, frequency should be as high as possible.

CLASSIFICATION OF CHOPPERS

Choppers are classified as follows

Class A Chopper
Class B Chopper
Class C Chopper
Class D Chopper

Class E Chopper

CLASS A CHOPPER

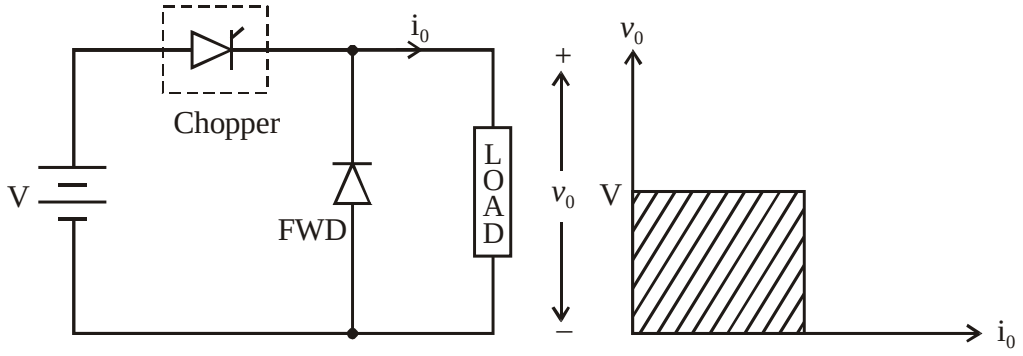


Fig. 2.14: Class A Chopper and $v_O - i_O$ Characteristic

Figure 2.14 shows a *Class A Chopper* circuit with inductive load and free-wheeling diode. When chopper is *ON*, supply voltage *V* is connected across the load i.e., $v_O = V$ and current i_0 flows as shown in figure. When chopper is OFF, v_0 = 0 and the load current i_O continues to flow in the same direction through the free wheeling diode. Therefore the average values of output voltage and current i.e., v_O and i_O are always positive. Hence, *Class A Chopper* is a first quadrant chopper (or single quadrant chopper). Figure 2.15 shows output voltage and current waveforms for a continuous load current.

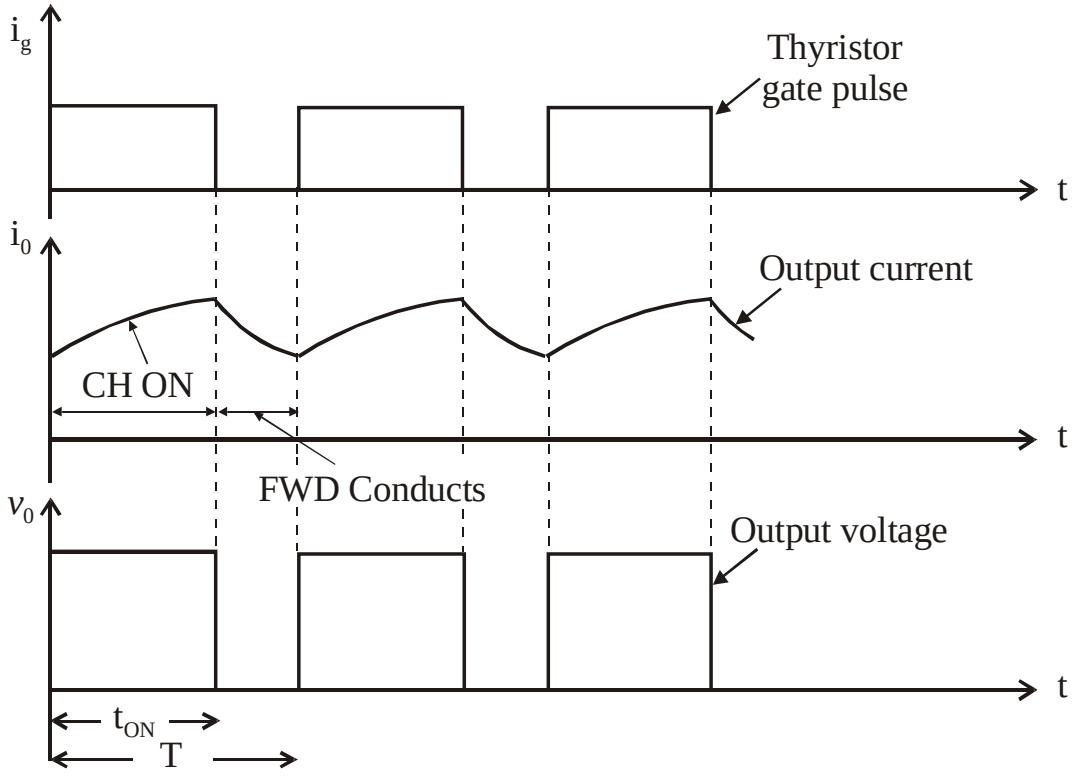


Fig. 2.15: First quadrant Chopper - Output Voltage and Current Waveforms

Class A Chopper is a step-down chopper in which power always flows from source to load. It is used to control the speed of dc motor. The output current equations obtained in step down chopper with *R-L* load can be used to study the performance of *Class A Chopper.*

CLASS B CHOPPER

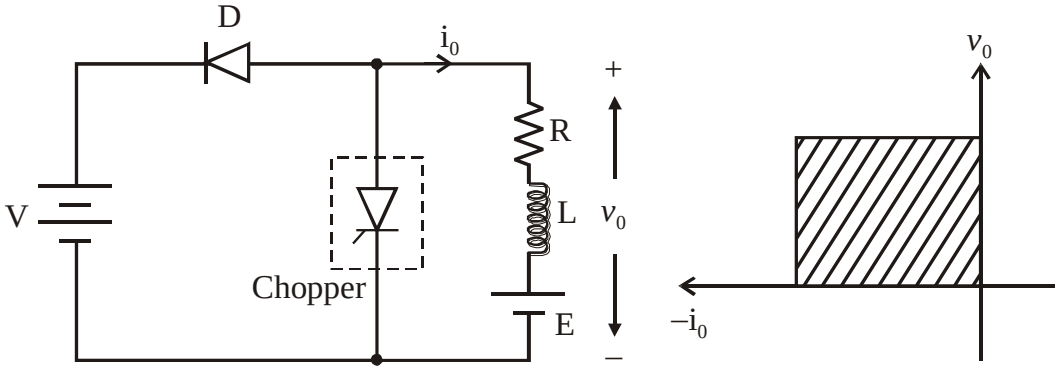
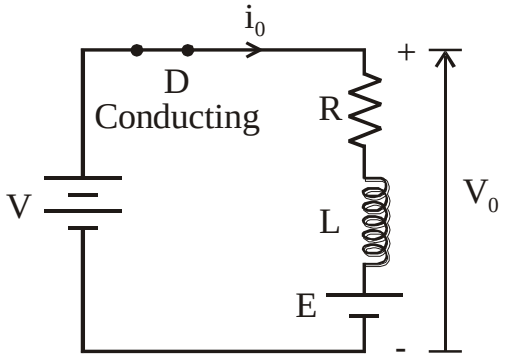


Fig. 2.16: Class B Chopper

Fig. 2.16 shows a C*lass B Chopper* circuit. When chopper is ON, $v_O = 0$ and *E* drives a current i_O through *L* and R in a direction opposite to that shown in figure 2.16. During the ON period of the chopper, the inductance *L* stores energy. When Chopper is OFF, diode *D* conducts, $v_O = V$ and part of the energy stored in inductor *L* is returned to the supply. Also the current i_O continues to flow from the load to source. Hence the average output voltage is positive and average output current is negative. Therefore C*lass B Chopper* operates in second quadrant. In this chopper, power flows from load to source. *Class B Chopper* is used for regenerative braking of dc motor. Figure 2.17 shows the output voltage and current waveforms of a C*lass B Chopper.*

The output current equations can be obtained as follows. During the interval diode 'D' conducts (chopper is off) voltage equation is given by



$$V = \frac{Ldi_O}{dt} + Ri_O + E$$

For the initial condition i.e., $i_O(t) = I_{\min}$ at $t = 0$.

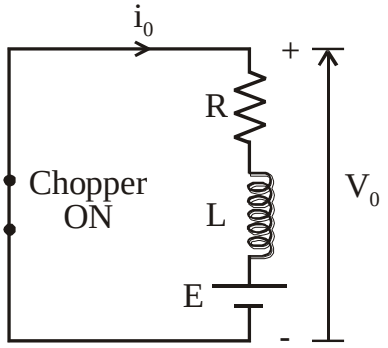
The solution of the above equation is obtained along similar lines as in step-down chopper with R-L load

Therefore $i_O(t) = \frac{V-E}{R}\left(1-e^{-\frac{R}{L}t}\right) + I_{\min}e^{-\frac{R}{L}t} \qquad 0 < t < t_{OFF}$

At $t = t_{OFF}$ $\quad i_{(O)}(t) = I_{\max}$

$$I_{\max} = \frac{V-E}{R}\left(1-e^{-\frac{R}{L}t_{OFF}}\right) + I_{\min}e^{-\frac{R}{L}t_{OFF}}$$

During the interval chopper is ON voltage equation is given by



$$0 = \frac{Ldi_O}{dt} + Ri_O + E$$

Redefining the time origin, at $t = 0$ $\quad i_O(t) = I_{\max}$.

The solution for the stated initial condition is

$$i_O(t) = I_{\max}e^{-\frac{R}{L}t} - \frac{E}{R}\left(1-e^{-\frac{R}{L}t}\right) \qquad 0 < t < t_{ON}$$

At $t = t_{ON}$ $\quad i_O(t) = I_{\min}$

Therefore $\quad I_{\min} = I_{\max}e^{-\frac{R}{L}t_{ON}} - \frac{E}{R}\left(1-e^{-\frac{R}{L}t_{ON}}\right)$

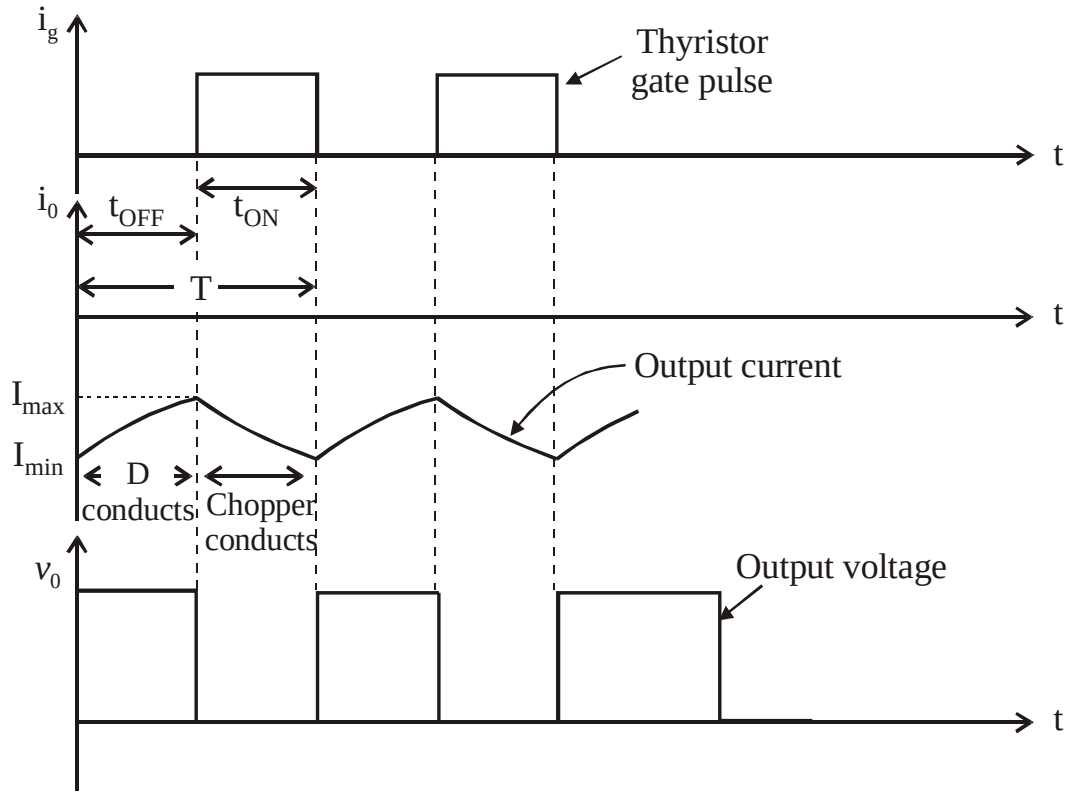


Fig. 2.17: Class B Chopper - Output Voltage and Current Waveforms

CLASS C CHOPPER

Class C Chopper is a combination of *Class A* and *Class B Choppers*. Figure 2.18 shows a *Class C* two quadrant Chopper circuit. For first quadrant operation, CH_1 is ON or D_2 conducts and for second quadrant operation, CH_2 is ON or D_1 conducts. When CH_1 is ON, the load current i_O is positive. i.e., i_O flows in the direction as shown in figure 2.18.

The output voltage is equal to $V(v_O = V)$ and the load receives power from the source.

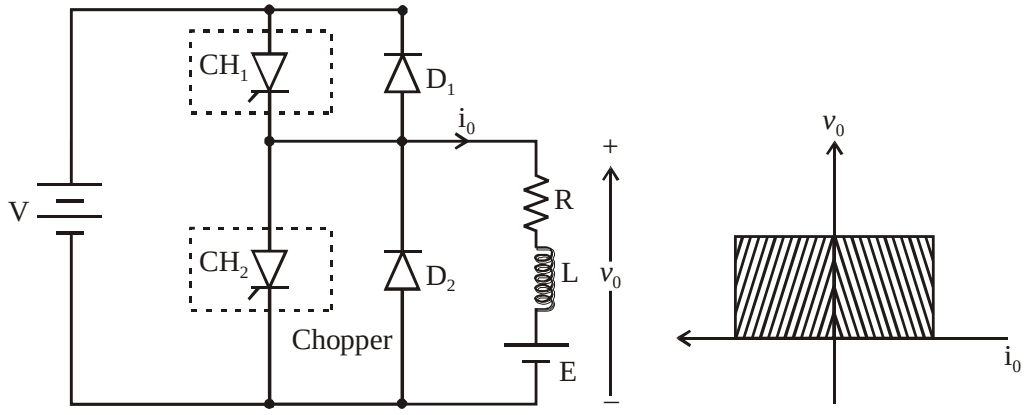


Fig. 2.18: Class C Chopper

When CH_1 is turned OFF, energy stored in inductance L forces current to flow through the diode D_2 and the output voltage $v_O = 0$, but i_O continues to flow in positive direction. When CH_2 is triggered, the voltage E forces i_O to flow in opposite direction through L and

CH_2. The output voltage $v_O = 0$. On turning OFF CH_2, the energy stored in the inductance drives current through diode D_1 and the supply; output voltage $v_O = V$ the input current becomes negative and power flows from load to source.

Thus the average output voltage v_O is positive but the average output current i_O can take both positive and negative values. Choppers CH_1 and CH_2 should not be turned ON simultaneously as it would result in short circuiting the supply. *Class C Chopper* can be used both for dc motor control and regenerative braking of dc motor. Figure 2.19 shows the output voltage and current waveforms.

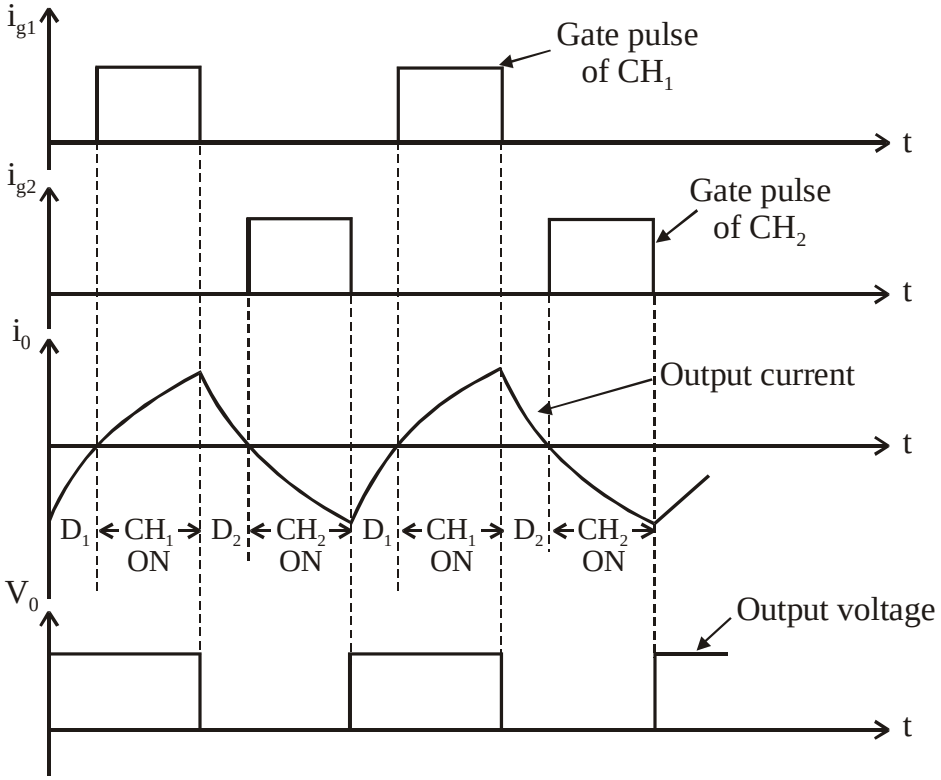


Fig. 2.19: Class C Chopper - Output Voltage and Current Waveforms

CLASS D CHOPPER

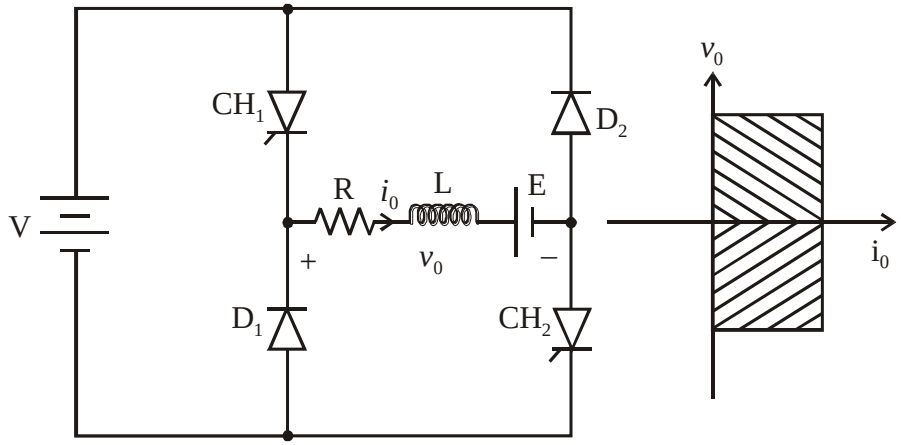


Fig. 2.20: Class D Chopper

Figure 2.20 shows a class D two quadrant chopper circuit. When both CH_1 and CH_2 are triggered simultaneously, the output voltage $v_O = V$ and output current i_O flows through

the load in the direction shown in figure 2.20. When CH_1 and CH_2 are turned OFF, the load current i_O continues to flow in the same direction through load, D_1 and D_2, due to the energy stored in the inductor L, but output voltage $v_O = -V$. The average load voltage v_O is positive if chopper ON-time (t_{ON}) is more than their OFF-time (t_{OFF}) and average output voltage becomes negative if $t_{ON} < t_{OFF}$. Hence the direction of load current is always positive but load voltage can be positive or negative. Waveforms are shown in figures 2.21 and 2.22.

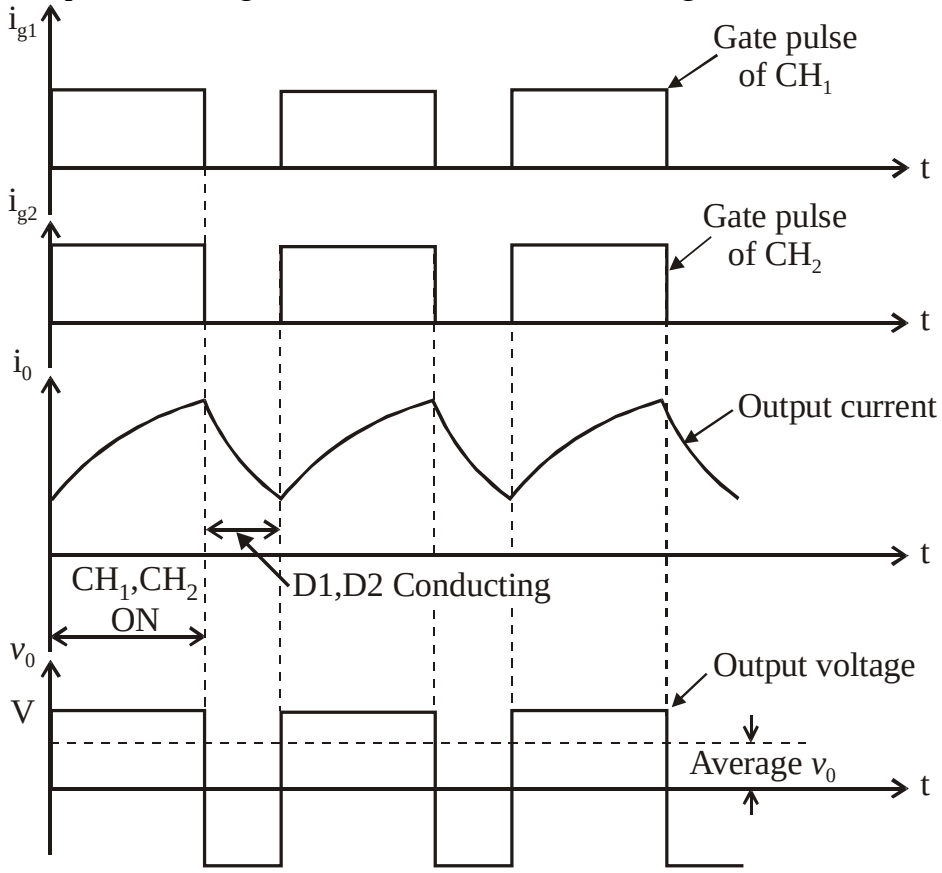


Fig. 2.21: Output Voltage and Current Waveforms for $t_{ON} > t_{OFF}$

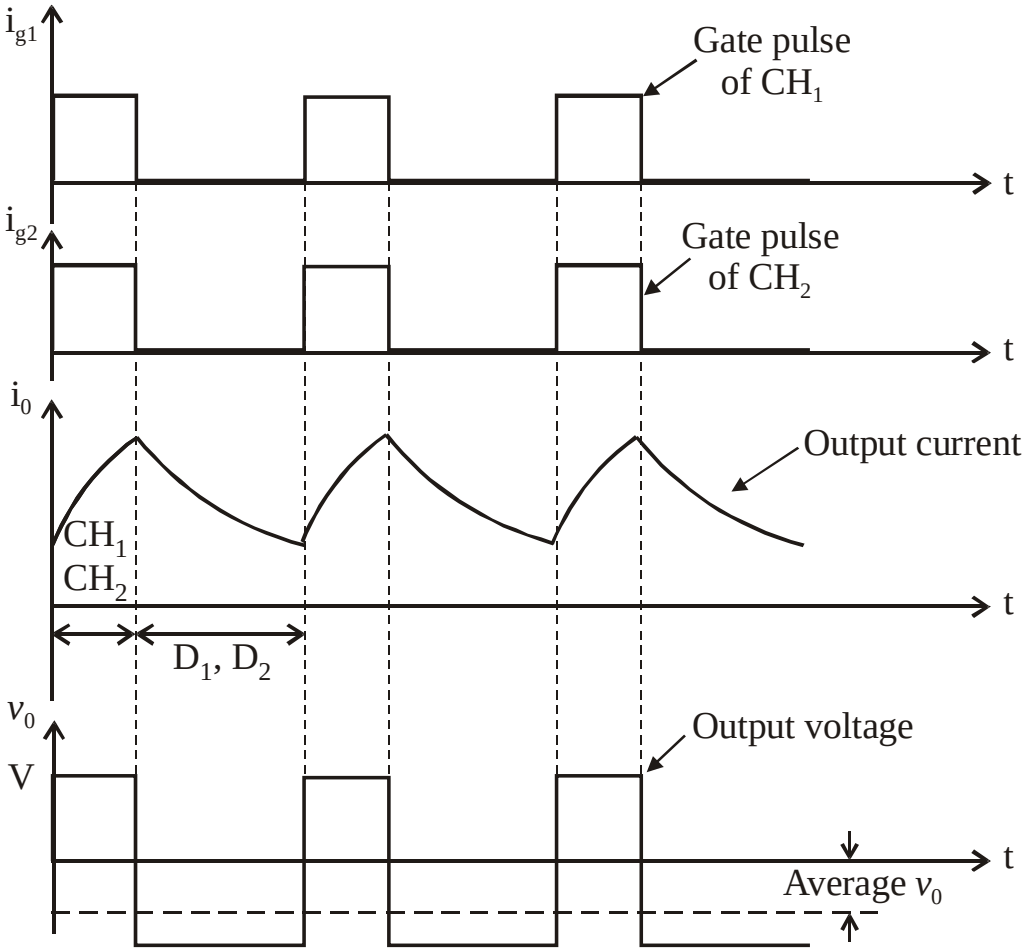


Fig. 2.22: Output Voltage and Current Waveforms for $t_{ON} < t_{OFF}$

CLASS E CHOPPER

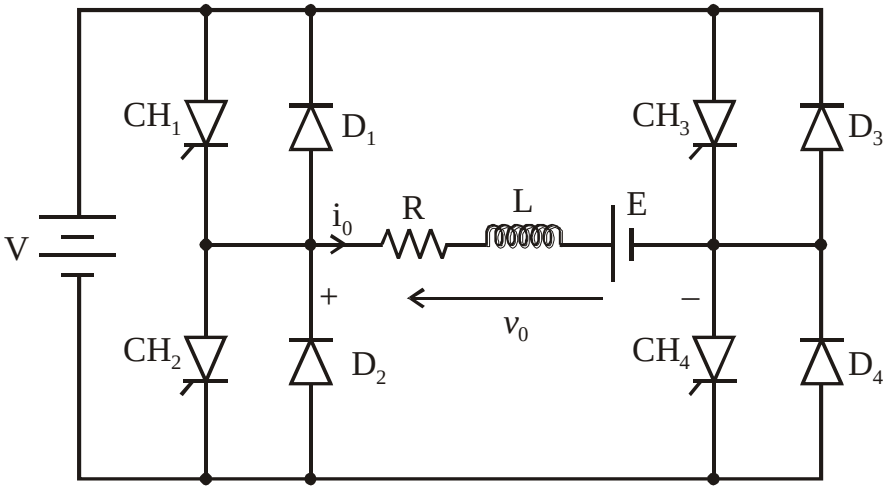


Fig. 2.23: Class E Chopper

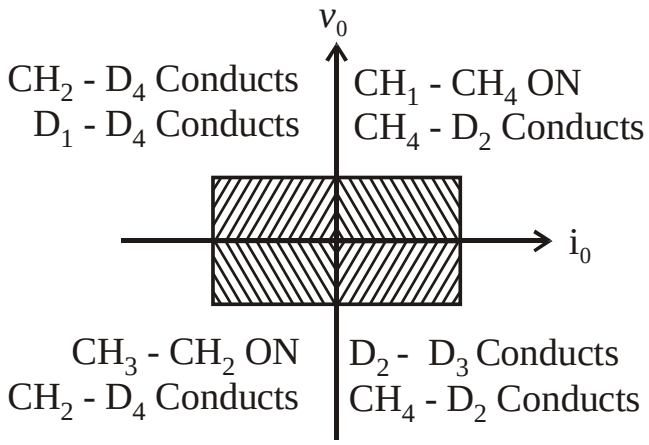


Fig. 2.23(a): Four Quadrant Operation

Figure 2.23 shows a class E 4 quadrant chopper circuit. When CH_1 and CH_4 are triggered, output current i_O flows in positive direction as shown in figure 2.23 through CH_1 and CH_4, with output voltage $v_O = V$. This gives the first quadrant operation. When both CH_1 and CH_4 are OFF, the energy stored in the inductor L drives i_O through D_3 and D_2 in the same direction, but output voltage $v_O = -V$. Therefore the chopper operates in the fourth quadrant. For fourth quadrant operation the direction of battery must be reversed. When CH_2 and CH_3 are triggered, the load current i_O flows in opposite direction and output voltage $v_O = -V$.

Since both i_O and v_O are negative, the chopper operates in third quadrant. When both CH_2 and CH_3 are OFF, the load current i_O continues to flow in the same direction through D_1 and D_4 and the output voltage $v_O = V$. Therefore the chopper operates in second quadrant as v_O is positive but i_O is negative. Figure 2.23(a) shows the devices which are operative in different quadrants.

EFFECT OF SOURCE AND LOAD INDUCTANCE

In choppers, the source inductance should be as small as possible to limit the transient voltage. Usually an input filter is used to overcome the problem of source inductance. Also source inductance may cause commutation problem for the chopper. The load ripple current is inversely proportional to load inductance and chopping frequency. Therefore the peak load current depends on load inductance. To limit the load ripple current, a smoothing inductor is connected in series with the load.

Problem 2.1 : For the first quadrant chopper shown in figure 2.24, express the following variables as functions of V, R and duty cycle 'd' in case load is resistive.
Average output voltage and current
Output current at the instant of commutation
Average and rms free wheeling diode current.
RMS value of output voltage
RMS and average thyristor currents.

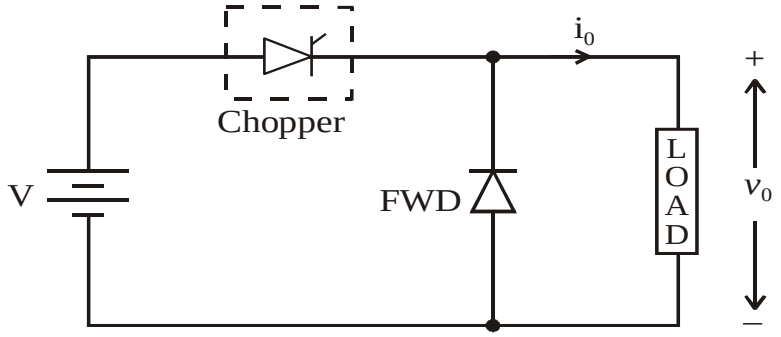


Fig. 6.24.

Solution

Average output voltage**,** $V_{dc} = \left(\frac{t_{ON}}{T}\right)V = dV$

Average output current, $I_{dc} = \frac{V_{dc}}{R} = \frac{dV}{R}$

The thyristor is commutated at the instant $t = t_{ON}$.

Therefore output current at the instant of commutation is $\frac{V}{R}$, since V is the output voltage at that instant.

Free wheeling diode (FWD) will never conduct in a resistive load. Therefore average and RMS free wheeling diode currents are zero.

RMS value of output voltage

$$V_{O(RMS)} = \sqrt{\frac{1}{T}\int_0^{t_{ON}} v_0^2 dt}$$

But $v_O = V$ during t_{ON}

$$V_{O(RMS)} = \sqrt{\frac{1}{T}\int_0^{t_{ON}} V^2 dt}$$

$$V_{O(RMS)} = \sqrt{V^2\left(\frac{t_{ON}}{T}\right)}$$

$$V_{O(RMS)} = \sqrt{d}V$$

Where duty cycle, $d = \frac{t_{ON}}{T}$

RMS value of thyristor current

= RMS value of load current

$$= \frac{V_{O(RMS)}}{R}$$

$$= \frac{\sqrt{d}V}{R}$$

Average value of thyristor current

= Average value of load current

$$= \frac{dV}{R}$$

Problem 2.2 : A Chopper circuit is operating on TRC at a frequency of 2 kHz on a 460 V supply. If the load voltage is 350 volts, calculate the conduction period of the thyristor in each cycle.

Solution

V = 460 V, V_{dc} = 350 V, f = 2 kHz

Chopping period $T = \frac{1}{f}$

$$T = \frac{1}{2\times10^{-3}} = 0.5\ m\text{sec}$$

Output voltage $V_{dc} = \left(\frac{t_{ON}}{T}\right)V$

Conduction period of thyristor

$$t_{ON} = \frac{T \times V_{dc}}{V}$$

$$t_{ON} = \frac{0.5\times10^{-3}\times350}{460}$$

$$t_{ON} = 0.38 \text{ msec}$$

Problem 2.3 : Input to the step up chopper is 200 V. The output required is 600 V. If the conducting time of thyristor is 200 μssec. Compute
Chopping frequency,
If the pulse width is halved for constant frequency of operation, find the new output voltage.

Solution

V = 200 V, $t_{ON} = 200\mu s$, $V_{dc} = 600V$

$$V_{dc} = V\left(\frac{T}{T - t_{ON}}\right)$$

$$600 = 200\left(\frac{T}{T - 200\times10^{-6}}\right)$$

Solving for T

$$T = 300\mu s$$

Chopping frequency

$$f = \frac{1}{T}$$

$$f = \frac{1}{300\times10^{-6}} = 3.33KHz$$

Pulse width is halved

Therefore $t_{ON} = \frac{200\times10^{-6}}{2} = 100\mu s$

Frequency is constant

Therefore $f = 3.33KHz$

$$T = \frac{1}{f} = 300\mu s$$

Therefore output voltage $= V\left(\frac{T}{T - t_{ON}}\right)$

$$= 200\left(\frac{300\times10^{-6}}{(300-100)10^{-6}}\right) = 300 \text{ Volts}$$

Problem 2.4: A dc chopper has a resistive load of 20Ω *and input voltage* $V_S = 220V$ *. When chopper is ON, its voltage drop is 1.5 volts and chopping frequency is 10 kHz. If the duty cycle is 80%, determine the average output voltage and the chopper on time.*

Solution

$V_S = 220V$, $R = 20\Omega$, f = 10 kHz

$d = \frac{t_{ON}}{T} = 0.80$

V_{ch} = Voltage drop across chopper = 1.5 volts

Average output voltage

$$V_{dc} = \left(\frac{t_{ON}}{T}\right)\left(V_S - V_{ch}\right)$$

$$V_{dc} = 0.80\left(220 - 1.5\right) = 174.8 \text{ Volts}$$

Chopper ON time, $t_{ON} = dT$

Chopping period, $T = \frac{1}{f}$

$$T = \frac{1}{10 \times 10^3} = 0.1 \times 10^{-3} \text{ secs} = 100 \text{ μsecs}$$

Chopper ON time,

$$t_{ON} = dT$$

$$t_{ON} = 0.80 \times 0.1 \times 10^{-3}$$

$$t_{ON} = 0.08 \times 10^{-3} = 80 \text{ μsecs}$$

Problem 2.5: In a dc chopper, the average load current is 30 Amps, chopping frequency is 250 Hz. Supply voltage is 110 volts. Calculate the ON and OFF periods of the chopper if the load resistance is 2 ohms.

Solution

$I_{dc} = 30$ Amps, f = 250 Hz, V = 110 V, $R = 2\Omega$

Chopping period, $T = \frac{1}{f} = \frac{1}{250} = 4 \times 10^{-3} = 4$ msecs

$$I_{dc} = \frac{V_{dc}}{R} \text{ and } V_{dc} = dV$$

Therefore $I_{dc} = \frac{dV}{R}$

$$d = \frac{I_{dc}R}{V} = \frac{30 \times 2}{110} = 0.545$$

Chopper ON period, $t_{ON} = dT = 0.545 \times 4 \times 10^{-3} = 2.18$ msecs

Chopper OFF period, $t_{OFF} = T - t_{ON}$

$$t_{OFF} = 4 \times 10^{-3} - 2.18 \times 10^{-3}$$

$$t_{OFF} = 1.82 \times 10^{-3} = 1.82 \text{ msec}$$

Problem 2.6: A dc chopper in figure 2.25 has a resistive load of $R = 10\Omega$ *and input voltage of V = 200 V. When chopper is ON, its voltage drop is 2 V and the chopping frequency is 1 kHz. If the duty cycle is 60%, determine*
Average output voltage
RMS value of output voltage
Effective input resistance of chopper
Chopper efficiency.

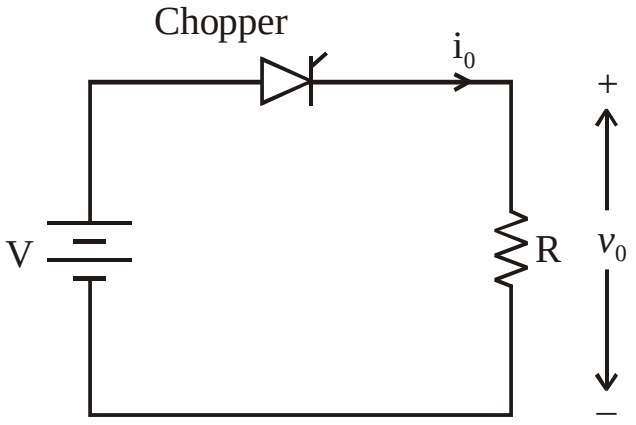


Fig. 2.25

Solution

V = 200 V, $R = 10\Omega$, Chopper voltage drop, $V_{ch} = 2V$, d = 0.60, f = 1 kHz.

Average output voltage

$$V_{dc} = d\left(V - V_{ch}\right)$$

$$V_{dc} = 0.60\left[200 - 2\right] = 118.8 \text{ Volts}$$

RMS value of output voltage

$$V_O = \sqrt{d}\left(V - V_{ch}\right)$$

$$V_O = \sqrt{0.6}\left(200 - 2\right) = 153.37 \text{ Volts}$$

Effective input resistance of chopper is

$$R_i = \frac{V}{I_S} = \frac{V}{I_{dc}}$$

$$I_{dc} = \frac{V_{dc}}{R} = \frac{118.8}{10} = 11.88 \text{ Amps}$$

$$R_i = \frac{V}{I_S} = \frac{V}{I_{dc}} = \frac{200}{11.88} = 16.83\Omega$$

Output power is

$$P_O = \frac{1}{T}\int_0^{dT} \frac{v_0^2}{R}\,dt$$

$$P_O = \frac{1}{T}\int_0^{dT} \frac{\left(V - V_{ch}\right)^2}{R}\,dt$$

$$P_O = \frac{d\left(V - V_{ch}\right)^2}{R}$$

$$P_O = \frac{0.6\left[200 - 2\right]^2}{10} = 2352.24 \text{ watts}$$

Input power, $P_i = \frac{1}{T}\int_0^{dT} V i_O\,dt$

$$P_O = \frac{1}{T}\int_0^{dT} \frac{V\left(V - V_{ch}\right)}{R}\,dt$$

$$P_O = \frac{dV\left(V - V_{ch}\right)}{R} = \frac{0.6 \times 200\left[200 - 2\right]}{10} = 2376 \text{ watts}$$

Chopper efficiency,

$$\eta = \frac{P_O}{P_i} \times 100$$

$$\eta = \frac{2352.24}{2376} \times 100 = 99\%$$

IMPULSE COMMUTATED CHOPPER

Impulse commutated choppers are widely used in high power circuits where load fluctuation is not large. This chopper is also known as parallel capacitor turn-off chopper or voltage commutated chopper or classical chopper.

Fig. 2.28 shows an impulse commutated chopper with two thyristors T_1 and T_2. We shall assume that the load current remains constant at a value I_L during the commutation process.

To start the circuit, capacitor *'C'* is initially charged with polarity (with plate 'a' positive) as shown in the fig. 2.28 by triggering the thyristor T_2. Capacitor *'C'* gets charged through *'V_S', 'C', T_2* and load. As the charging current decays to zero thyristor T_2 will be turned-off. With capacitor charged with plate 'a' positive the circuit is ready for operation. For convenience the chopper operation is divided into five modes.

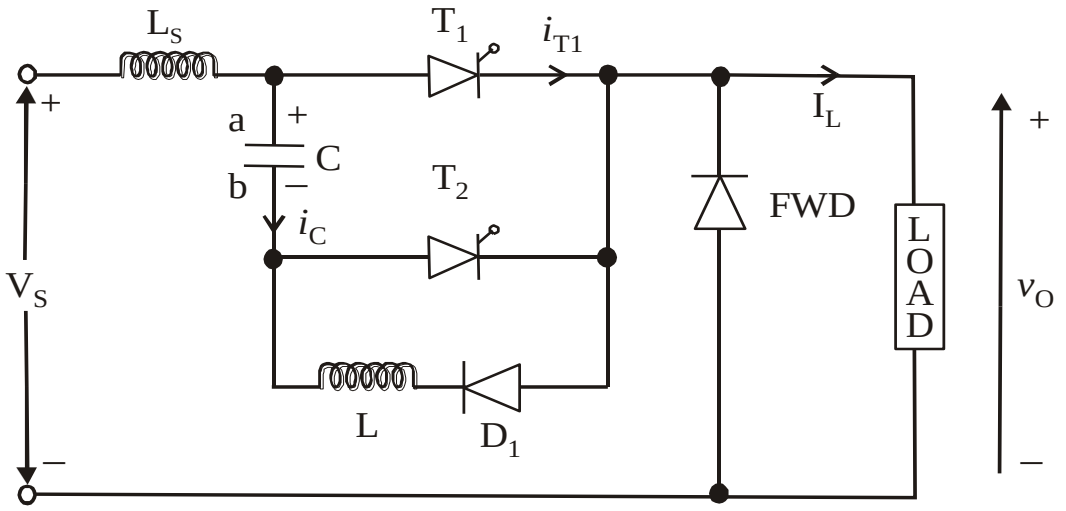


Fig. 2.28

MODE – 1

Thyristor T_1 is fired at $t = 0$. The supply voltage comes across the load. Load current I_L flows through T_1 and load. At the same time capacitor discharges through T_1, D_1, L_1, and *'C'* and the capacitor reverses its voltage. This reverse voltage on capacitor is held constant by diode D_1. Fig. 2.29 shows the equivalent circuit of Mode 1.

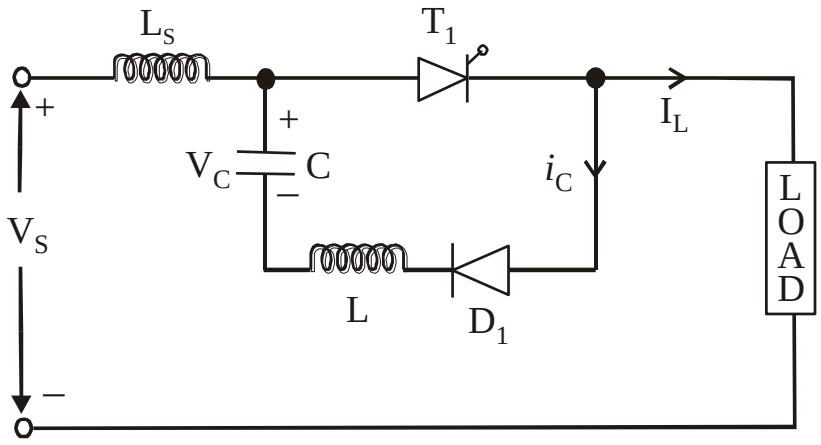


Fig. 2.29

Capacitor Discharge Current

$$i_C(t) = V\sqrt{\frac{C}{L}}\sin\omega t$$

$$i_C(t) = I_P \sin\omega t \ ; \text{where } I_P = V\sqrt{\frac{C}{L}}$$

Where $\omega = \dfrac{1}{\sqrt{LC}}$

& Capacitor Voltage

$$V_C(t) = V\cos\omega t$$

MODE – 2

Thyristor T_2 is now fired to commutate thyristor T_1. When T_2 is ON capacitor voltage reverse biases T_1 and turns it off. Now the capacitor discharges through the load from $-V_S$ to *0* and the discharge time is known as circuit turn-off time.

Circuit turn-off time is given by

$$t_C = \frac{V_C \times C}{I_L}$$

Where I_L is load current.

Since t_C depends on load current, it must be designed for the worst case condition which occur at the maximum value of load current and minimum value of capacitor voltage.

Then the capacitor recharges back to the supply voltage (with plate 'a' positive). This time is called the recharging time and is given by

$$t_d = \frac{V_S \times C}{I_L}$$

The total time required for the capacitor to discharge and recharge is called the commutation time and it is given by

$$t_r = t_C + t_d$$

At the end of Mode-2 capacitor has recharged to 'V_S' and the free wheeling diode starts conducting. The equivalent circuit for Mode-2 is shown in fig. 2.30.

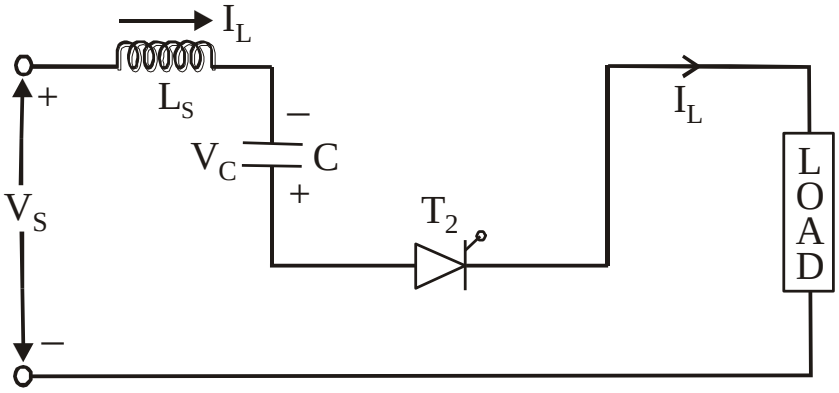


Fig. 2.30.

MODE – 3

Free wheeling diode *FWD* starts conducting and the load current decays. The energy stored in source inductance L_S is transferred to capacitor. Instantaneous current is $i(t) = I_L \cos \omega t$ Hence capacitor charges to a voltage higher than supply voltage. T_2 naturally turns-off.

The instantaneous capacitor voltage is

$$V_C(t) = V_S + I_L\sqrt{\frac{L_S}{C}}\sin\omega_S t$$

Where $\omega_S = \frac{1}{\sqrt{L_S C}}$

Fig. 2.31 shows the equivalent circuit of Mode – 3.

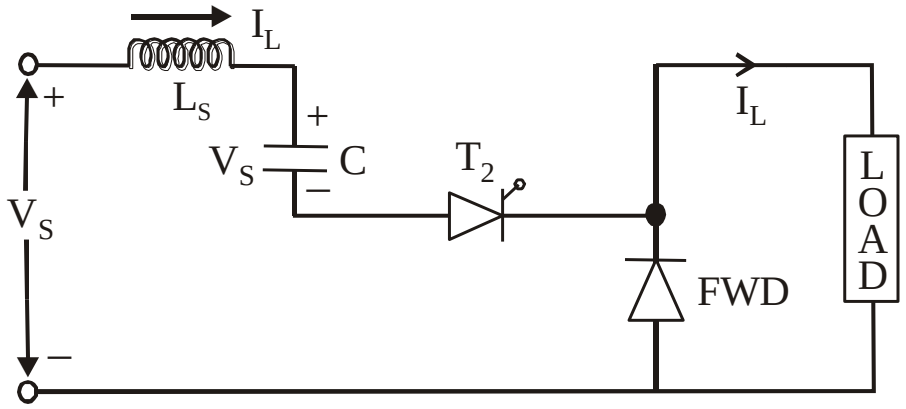


Fig. 2.31

MODE – 4

Since the capacitor has been overcharged i.e. its voltage is above supply voltage it starts discharging in reverse direction. Hence capacitor current becomes negative. The capacitor discharges through *L_S, V_S, FWD, D_1 and L*. When this current reduces to zero *D_1* will stop conducting and the capacitor voltage will be same as the supply voltage fig. 2.32 shows in equivalent circuit of Mode – 4.

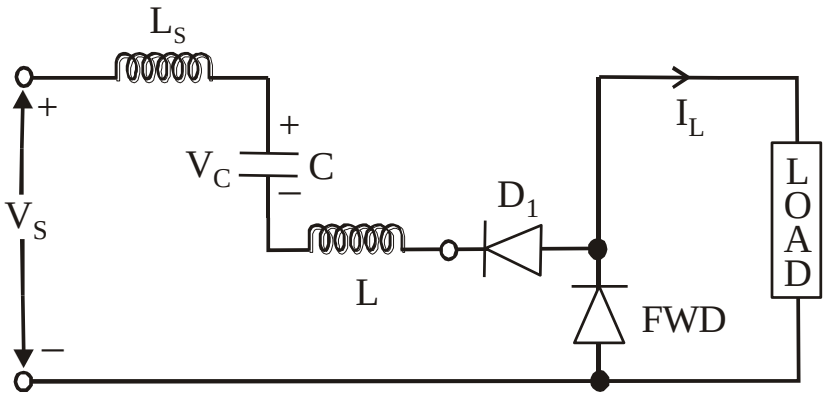


Fig. 2.32

MODE – 5

In mode 5 both thyristors are off and the load current flows through the free wheeling diode (FWD). This mode will end once thyristor *T_1* is fired. The equivalent circuit for mode 5 is shown in fig. 2.33

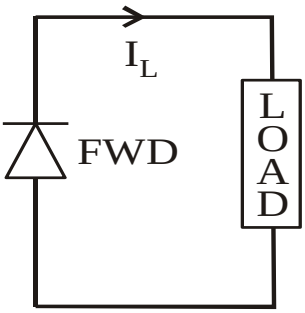


Fig. 2.33

Fig. 2.34 shows the current and voltage waveforms for a voltage commutated chopper.

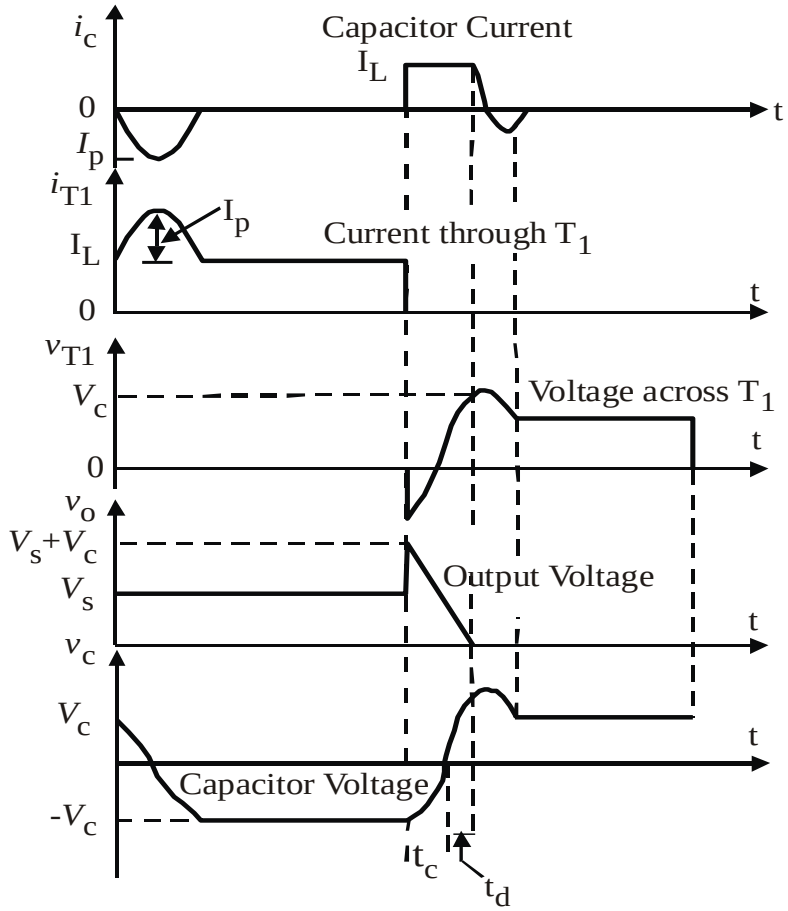


Fig. 2.34

Though voltage commutated chopper is a simple circuit it has the following disadvantages.

A starting circuit is required and the starting circuit should be such that it triggers thyristor T_2 first.

Load voltage jumps to twice the supply voltage when the commutation is initiated.

The discharging and charging time of commutation capacitor are dependent on the load current and this limits high frequency operation, especially at low load current.

Chopper cannot be tested without connecting load.

Thyristor T_1 has to carry load current as well as resonant current resulting in increasing its peak current rating.

Jone's Chopper

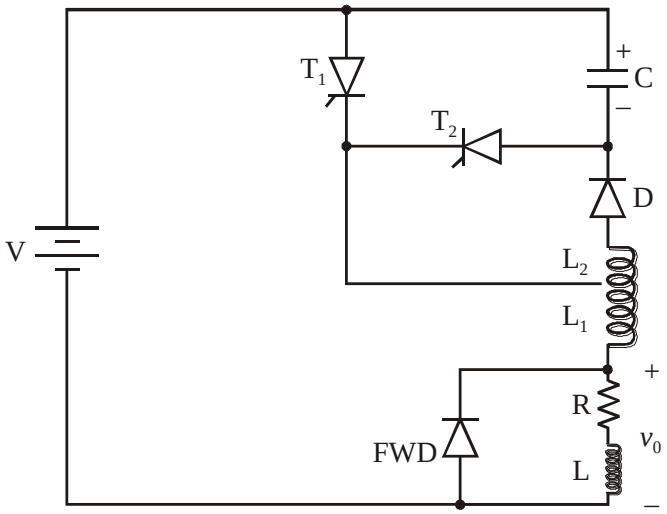


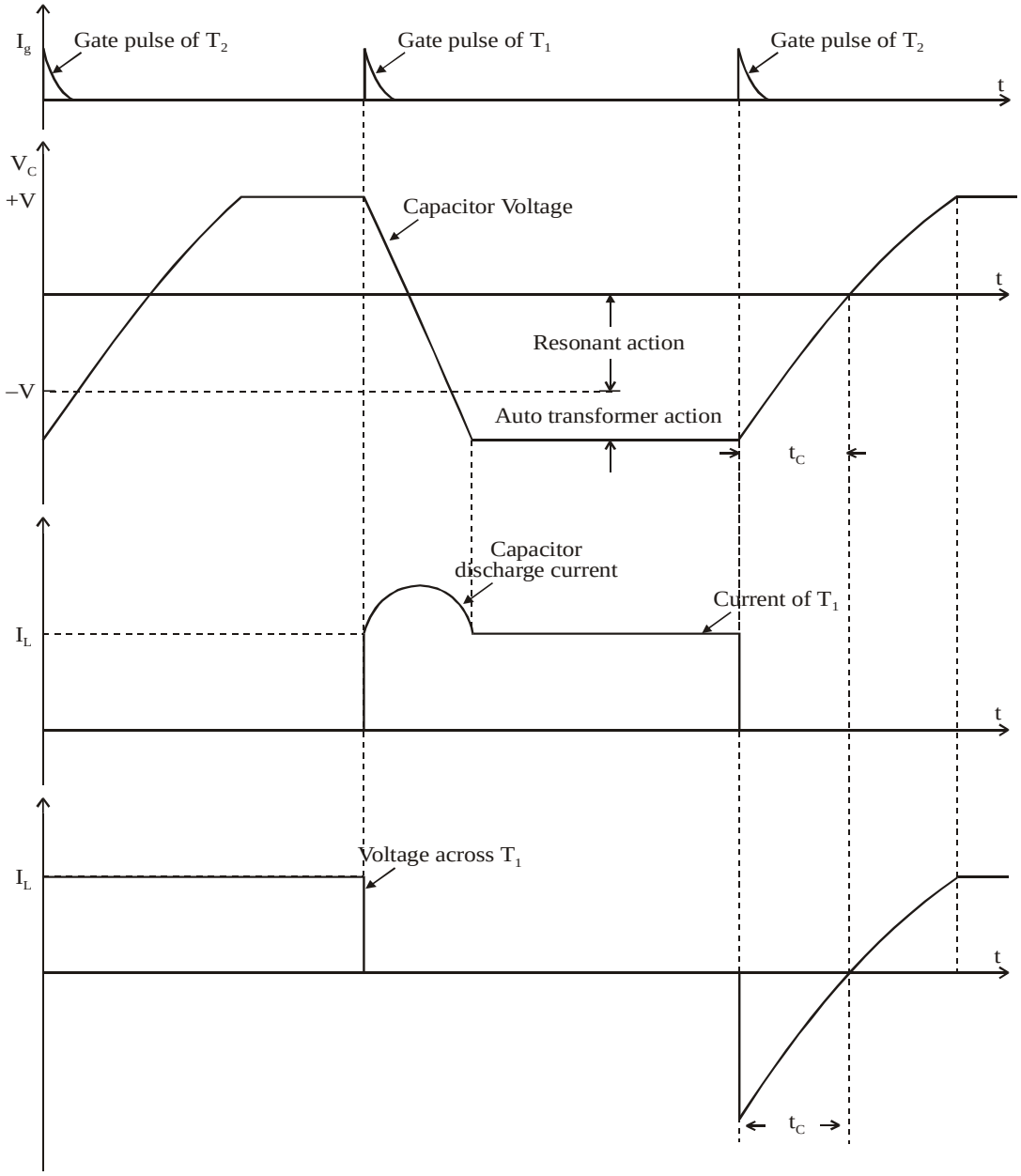
Fig. 2.35: Jone's Chopper

Figure 2.35 shows a Jone's Chopper circuit for an inductive load with free wheeling diode. Jone's Chopper is an example of class D commutation. Two thyristors are used, T_1 is the main thyristor and T_2 is the auxiliary thyristor. Commutating circuit for T_1 consists of thyristor T_2, capacitor C, diode D and autotransformer (L_1 and L_2).

Initially thyristor T_2 is turned ON and capacitor C is charged to a voltage V with a polarity as shown in figure 2.35. As C charges, the charging current through thyristor T_2 decays exponentially and when current falls below holding current level, thyristor T_2 turns OFF by itself. When thyristor T_1 is triggered, load current flows through thyristor T_1, L_2 and load. The capacitor discharges through thyristor T_1, L_1 and diode D. Due to resonant action of the auto transformer inductance L_2 and capacitance C, the voltage across the capacitor reverses after some time.

It is to be noted that the load current in L_1 induces a voltage in L_2 due to autotransformer action. Due to this voltage in L_2 in the reverse direction, the capacitor charges to a voltage greater than the supply voltage. (The capacitor now tries to discharge in opposite direction but it is blocked by diode D and hence capacitor maintains the reverse voltage across it). When thyristor T_1 is to be commutated, thyristor T_2 is turned ON resulting in connecting capacitor C directly across thyristor T_1. Capacitor voltage reverse biases thyristor T_1 and turns it off. The capacitor again begins to charge through thyristor T_2 and the load for the next cycle of operation.

The various waveforms are shown in figure 2.36


I_g
Gate pulse of T_2
Gate pulse of T_1
Gate pulse of T_2
t
V_C
+V
Capacitor Voltage
t
Resonant action
–V
Auto transformer action
t_C
Capacitor
discharge current
Current of T_1
I_L
t
I_L
Voltage across T_1
t
t_C

THYRISTOR COMMUTATION TECHNIQUES

INTRODUCTION

In practice it becomes necessary to turn off a conducting thyristor. (Often thyristors are used as switches to turn on and off power to the load). The process of turning off a conducting thyristor is called commutation. The principle involved is that either the anode should be made negative with respect to cathode (voltage commutation) or the anode current should be reduced below the holding current value (current commutation).

The reverse voltage must be maintained for a time at least equal to the turn-off time of SCR otherwise a reapplication of a positive voltage will cause the thyristor to conduct even without a gate signal. On similar lines the anode current should be held at a value less than the holding current at least for a time equal to turn-off time otherwise the SCR will start conducting if the current in the circuit increases beyond the holding current level even without a gate signal. Commutation circuits have been developed to hasten the turn-off process of Thyristors. The study of commutation techniques helps in understanding the transient phenomena under switching conditions.

The reverse voltage or the small anode current condition must be maintained for a time at least equal to the TURN OFF time of SCR; Otherwise the SCR may again start conducting. The techniques to turn off a SCR can be broadly classified as

Natural Commutation

Forced Commutation.

NATURAL COMMUTATION (CLASS F)

This type of commutation takes place when supply voltage is AC, because a negative voltage will appear across the SCR in the negative half cycle of the supply voltage and the SCR turns off by itself. Hence no special circuits are required to turn off the SCR. That is the reason that this type of commutation is called Natural or Line Commutation. Figure 1.1 shows the circuit where natural commutation takes place and figure 1.2 shows the related waveforms. t_c is the time offered by the circuit within which the SCR should turn off completely. Thus t_c should be greater than t_q, the turn off time of the SCR. Otherwise, the SCR will become forward biased before it has turned off completely and will start conducting even without a gate signal.

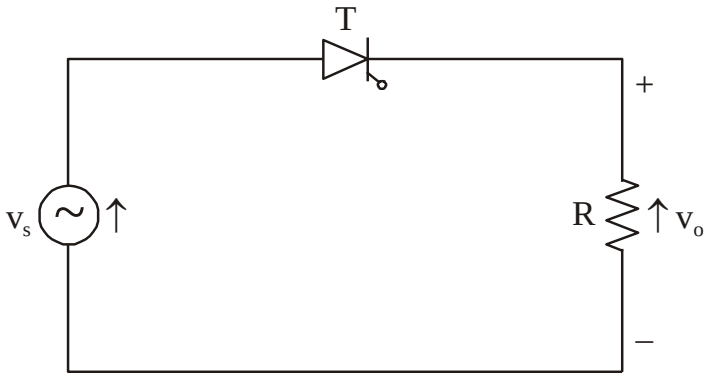


Fig. 1.1: Circuit for Natural Commutation

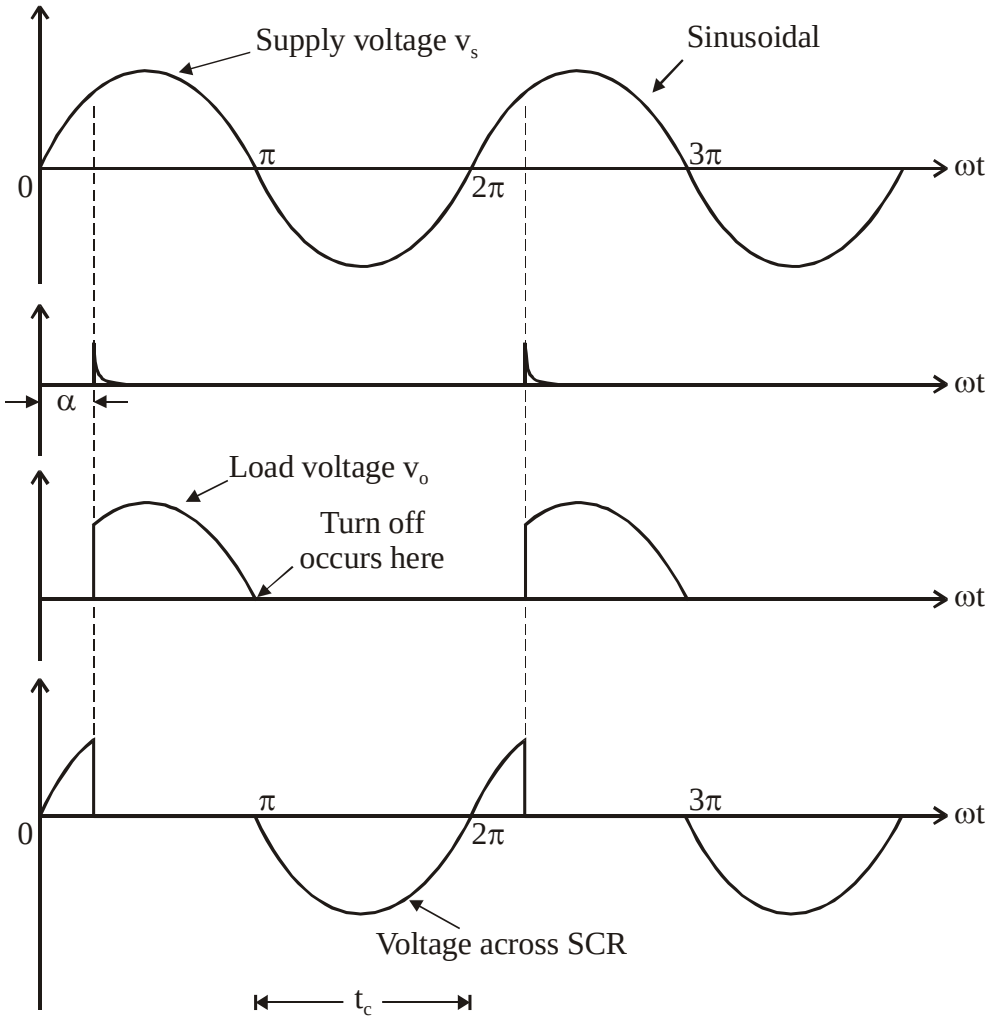


Fig. 1.2: Natural Commutation – Waveforms of Supply and Load Voltages (Resistive Load)

This type of commutation is applied in ac voltage controllers, phase controlled rectifiers and cyclo converters.

FORCED COMMUTATION

When supply is DC, natural commutation is not possible because the polarity of the supply remains unchanged. Hence special methods must be used to reduce the SCR current below the holding value or to apply a negative voltage across the SCR for a time interval greater than the turn off time of the SCR. This technique is called FORCED COMMUTATION and is applied in all circuits where the supply voltage is DC - namely, Choppers (fixed DC to variable DC), inverters (DC to AC). Forced commutation techniques are as follows:

Self Commutation
Resonant Pulse Commutation
Complementary Commutation
Impulse Commutation
External Pulse Commutation.
Load Side Commutation.
Line Side Commutation.

SELF COMMUTATION OR LOAD COMMUTATION OR CLASS A COMMUTATION: (COMMUTATION BY RESONATING THE LOAD)

In this type of commutation the current through the SCR is reduced below the holding current value by resonating the load. i.e., the load circuit is so designed that even though the supply voltage is positive, an oscillating current tends to flow and when the current through the SCR reaches zero, the device turns off. This is done by including an inductance and a capacitor in series with the load and keeping the circuit under-damped. Figure 1.3 shows the circuit.

This type of commutation is used in *Series Inverter Circuit.*

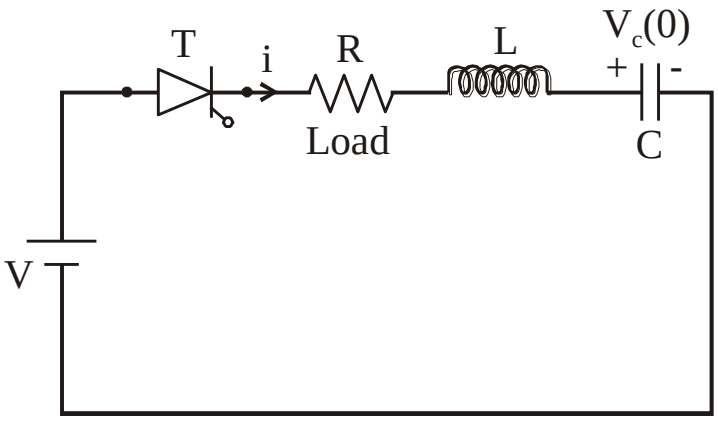


Fig. 1.3: Circuit for Self Commutation

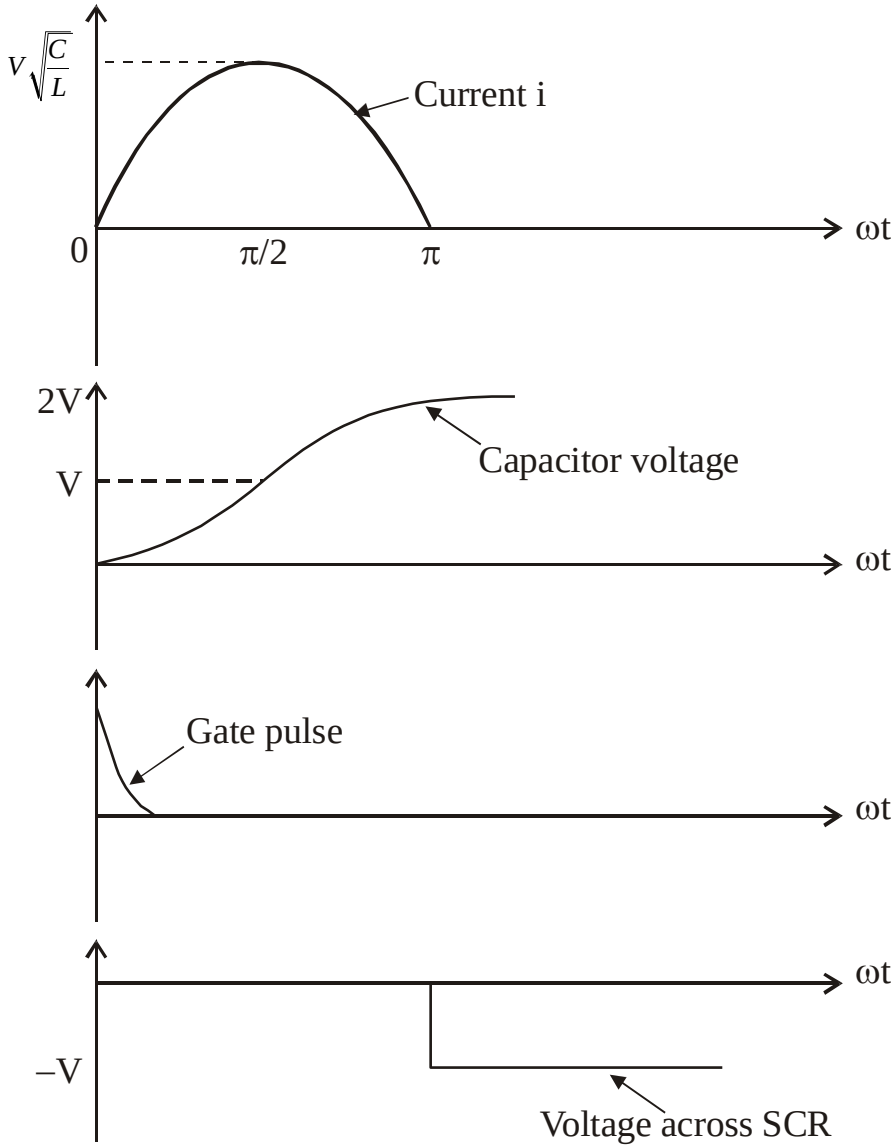


Fig. 1.5: Self Commutation – Wave forms of Current and Capacitors Voltage

RESONANT PULSE COMMUTATION (CLASS B COMMUTATION)

The circuit for resonant pulse commutation is shown in figure 1.12.

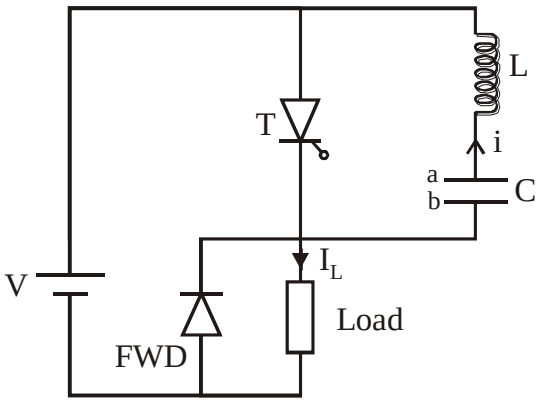


Fig. 1.12: Circuit for Resonant Pulse Commutation

This is a type of commutation in which a LC series circuit is connected across the SCR. Since the commutation circuit has negligible resistance it is always under-damped i.e., the current in LC circuit tends to oscillate whenever the SCR is on.

Initially the SCR is off and the capacitor is charged to V volts with plate 'a' being positive. Referring to figure 1.13 at $t = t_1$ the SCR is turned ON by giving a gate pulse. A current I_L flows through the load and this is assumed to be constant. At the same time SCR short circuits the LC combination which starts oscillating. A current 'i' starts flowing in the direction shown in figure. As 'i' reaches its maximum value, the capacitor voltage reduces to zero and then the polarity of the capacitor voltage reverses 'b' becomes positive). When 'i' falls to zero this reverse voltage becomes maximum, and then direction of 'i' reverses i.e., through SCR the load current I_L and 'i' flow in opposite direction. When the instantaneous value of 'i' becomes equal to I_L, the SCR current becomes zero and the SCR turns off. Now the capacitor starts charging and its voltage reaches the supply voltage with plate a being positive. The related waveforms are shown in figure 1.13.

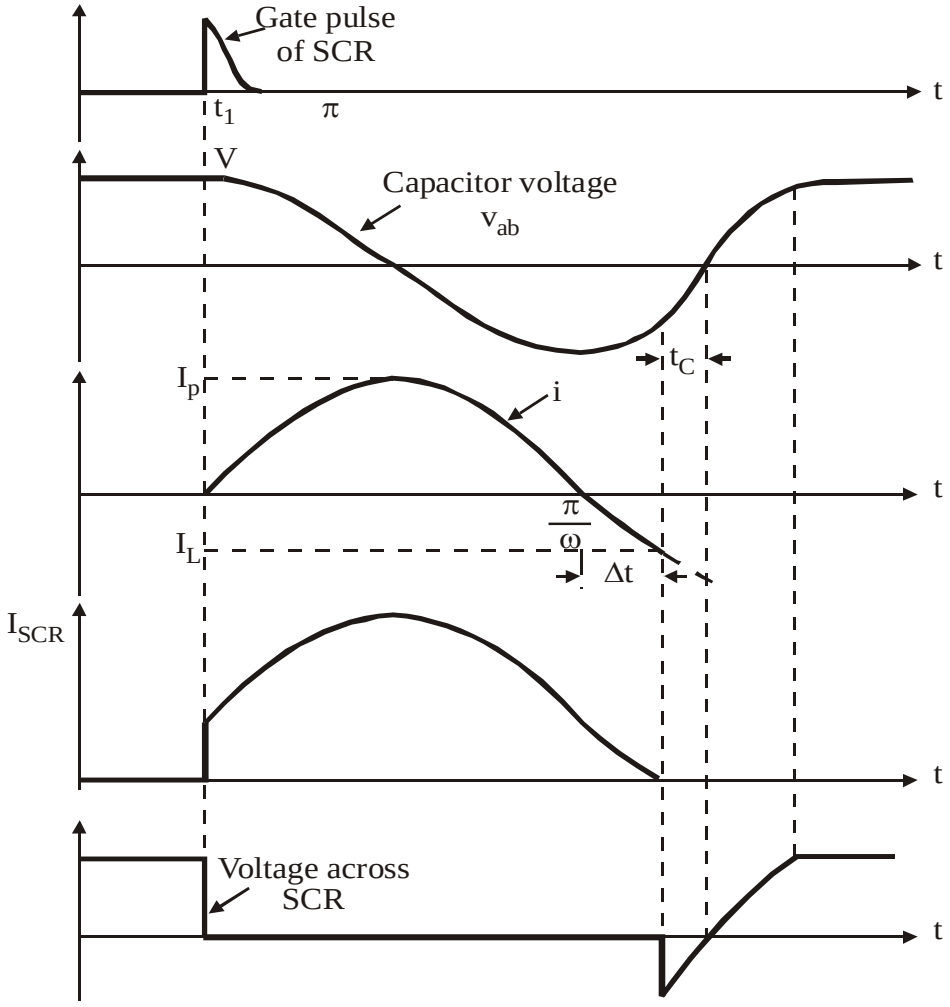


Fig. 1.13: Resonant Pulse Commutation – Various Waveforms

ALTERNATE CIRCUIT FOR RESONANT PULSE COMMUTATION

The working of the circuit can be explained as follows. The capacitor C is assumed to be charged to $V_C(0)$ with polarity as shown, T_1 is conducting and the load current I_L is a constant. To turn off T_1, T_2 is triggered. L, C, T_1 and T_2 forms a resonant circuit. A resonant current $i_c(t)$ flows in the direction shown, i.e., in a direction opposite to that of load current I_L .

$i_c(t) = I_p \sin \omega t$ (refer to the previous circuit description). Where $I_p = V_C(0)\sqrt{\frac{C}{L}}$ & and the capacitor voltage is given by

$$v_c(t) = \frac{1}{C}\int i_C(t).dt$$

$$v_c(t) = \frac{1}{C}\int V_C(0)\sqrt{\frac{C}{L}} \sin \omega t.dt \text{ .}$$

$$v_c(t) = -V_C(0)\cos \omega t$$

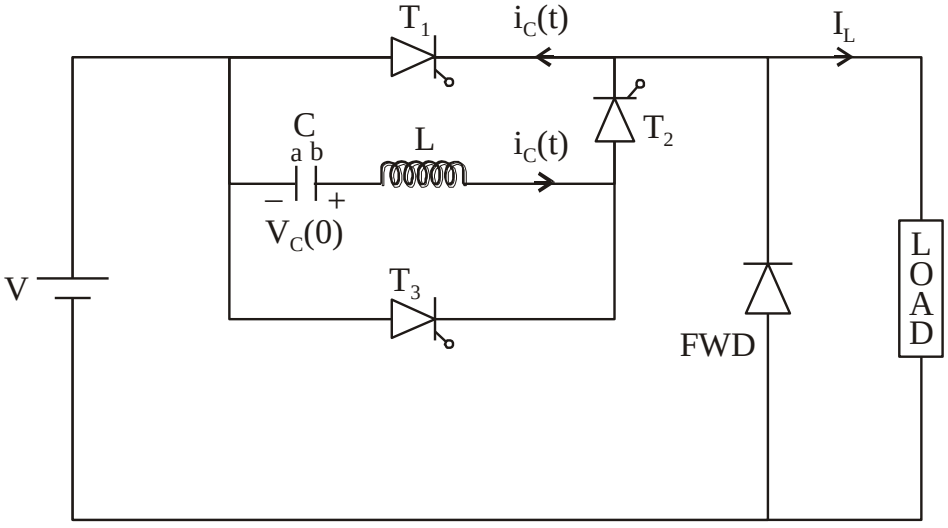


Fig. 1.16: Resonant Pulse Commutation – An Alternate Circuit

When $i_c(t)$ becomes equal to I_L (the load current), the current through T_1 becomes zero and T_1 turns off. This happens at time t_1 such that

$$I_L = I_p \sin \frac{t_1}{\sqrt{LC}}$$

$$I_p = V_C(0)\sqrt{\frac{C}{L}}$$

$$t_1 = \sqrt{LC}\sin^{-1}\left(\frac{I_L}{V_C(0)}\sqrt{\frac{L}{C}}\right)$$

and the corresponding capacitor voltage is

$$v_c(t_1) = -V_1 = -V_C(0)\cos\omega t_1$$

Once the thyristor T_1 turns off, the capacitor starts charging towards the supply voltage through T_2 and load. As the capacitor charges through the load capacitor current is same as load current I_L, which is constant. When the capacitor voltage reaches V, the supply voltage, the FWD starts conducting and the energy stored in L charges C to a still higher voltage. The triggering of T_3 reverses the polarity of the capacitor voltage and the circuit is ready for another triggering of T_1. The waveforms are shown in figure 1.17.

EXPRESSION FOR t_c

Assuming a constant load current I_L which charges the capacitor

$$t_c = \frac{CV_1}{I_L} \text{ seconds}$$

Normally $V_1 \approx V_C(0)$

For reliable commutation t_c should be greater than t_q, the turn off time of SCR T_1. It is to be noted that t_c depends upon I_L and becomes smaller for higher values of load current.

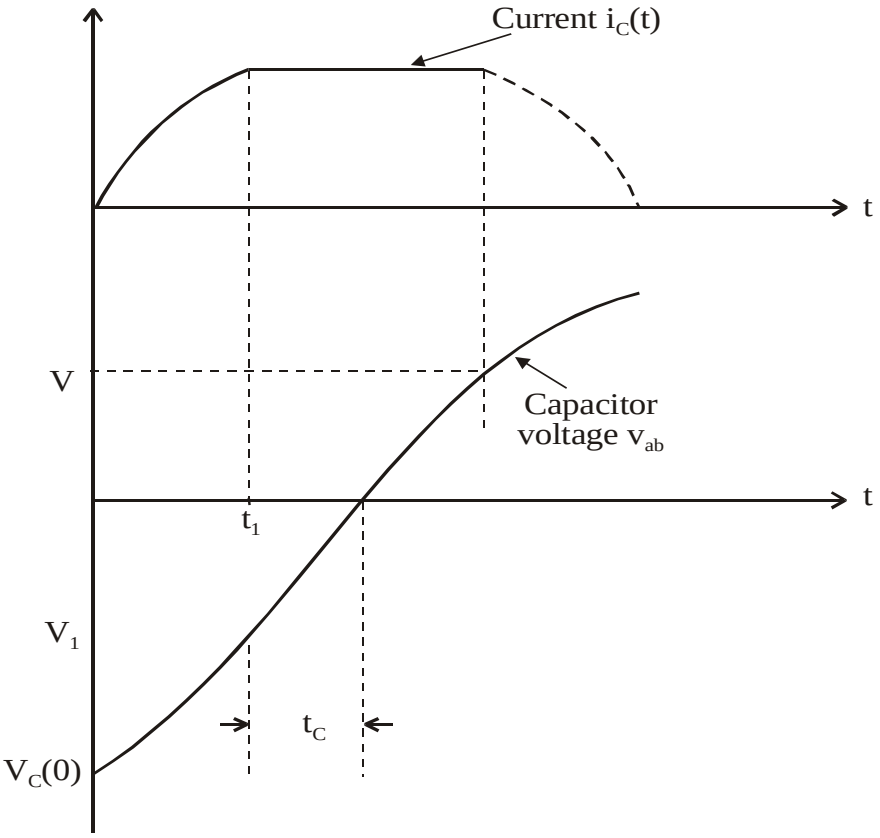


Fig. 1.17: Resonant Pulse Commutation – Alternate Circuit – Various Waveforms

RESONANT PULSE COMMUTATION WITH ACCELERATING DIODE

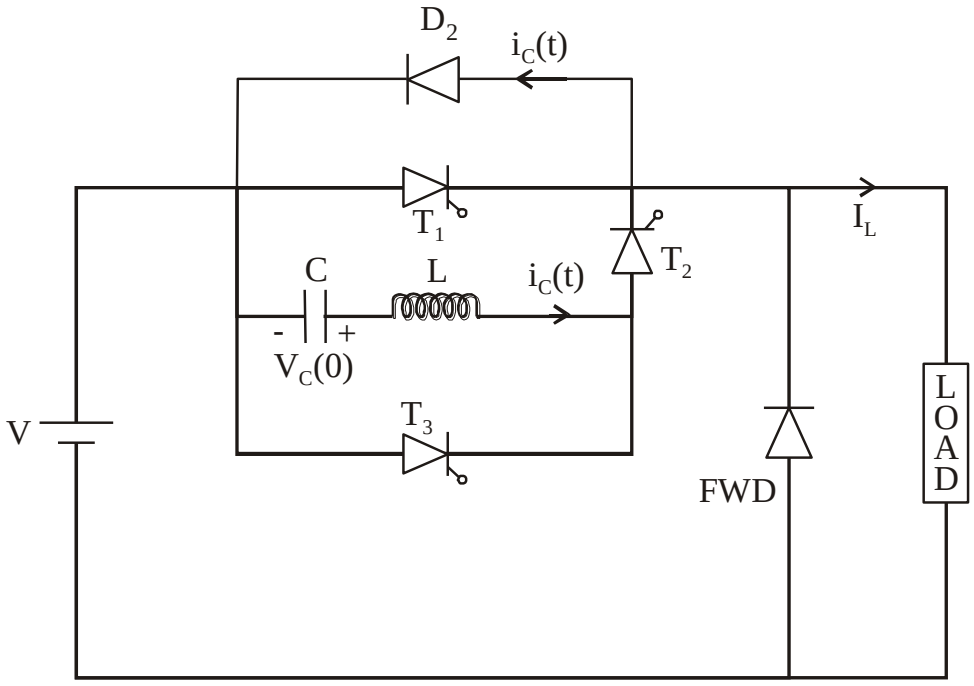


Fig. 1.17(a)

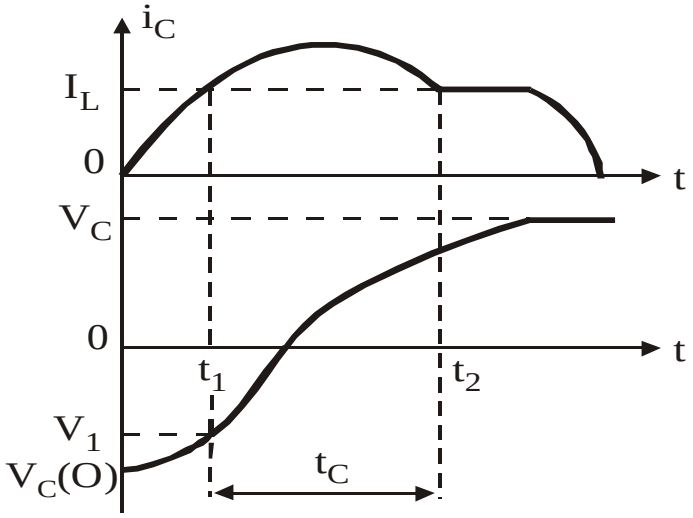


Fig. 1.17(b)

A diode D_2 is connected as shown in the figure 1.17(a) to accelerate the discharging of the capacitor 'C'. When thyristor T_2 is fired a resonant current $i_C(t)$ flows through the capacitor and thyristor T_1. At time $t = t_1$, the capacitor current $i_C(t)$ equals the load current I_L and hence current through T_1 is reduced to zero resulting in turning off of T_1. Now the capacitor current $i_C(t)$ continues to flow through the diode D_2 until it reduces to load current level I_L at time t_2. Thus the presence of D_2 has accelerated the discharge of capacitor 'C'. Now the capacitor gets charged through the load and the charging current is constant. Once capacitor is fully charged T_2 turns off by itself. But once current of thyristor T_1 reduces to zero the reverse voltage appearing across T_1 is the forward voltage drop of D_2 which is very small. This makes the thyristor recovery process very slow and it becomes necessary to provide longer reverse bias time.

From figure 1.17(b)

$$t_2 = \pi\sqrt{LC} - t_1$$

$$V_C(t_2) = -V_C(O)\cos\omega t_2$$

Circuit turn-off time $t_C = t_2 - t_1$

COMPLEMENTARY COMMUTATION (CLASS C COMMUTATION, PARALLEL CAPACITOR COMMUTATION)

In complementary commutation the current can be transferred between two loads. Two SCRs are used and firing of one SCR turns off the other. The circuit is shown in figure 1.21.

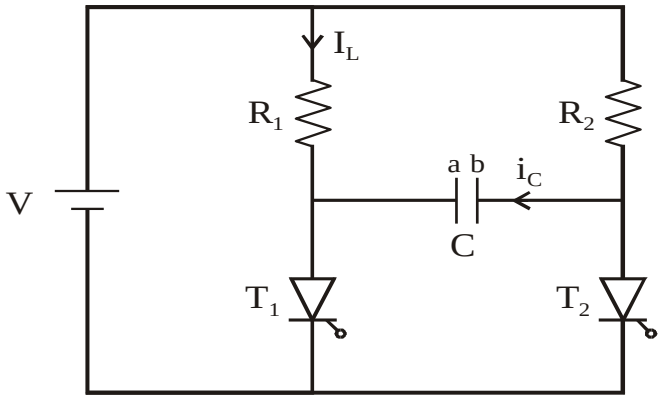
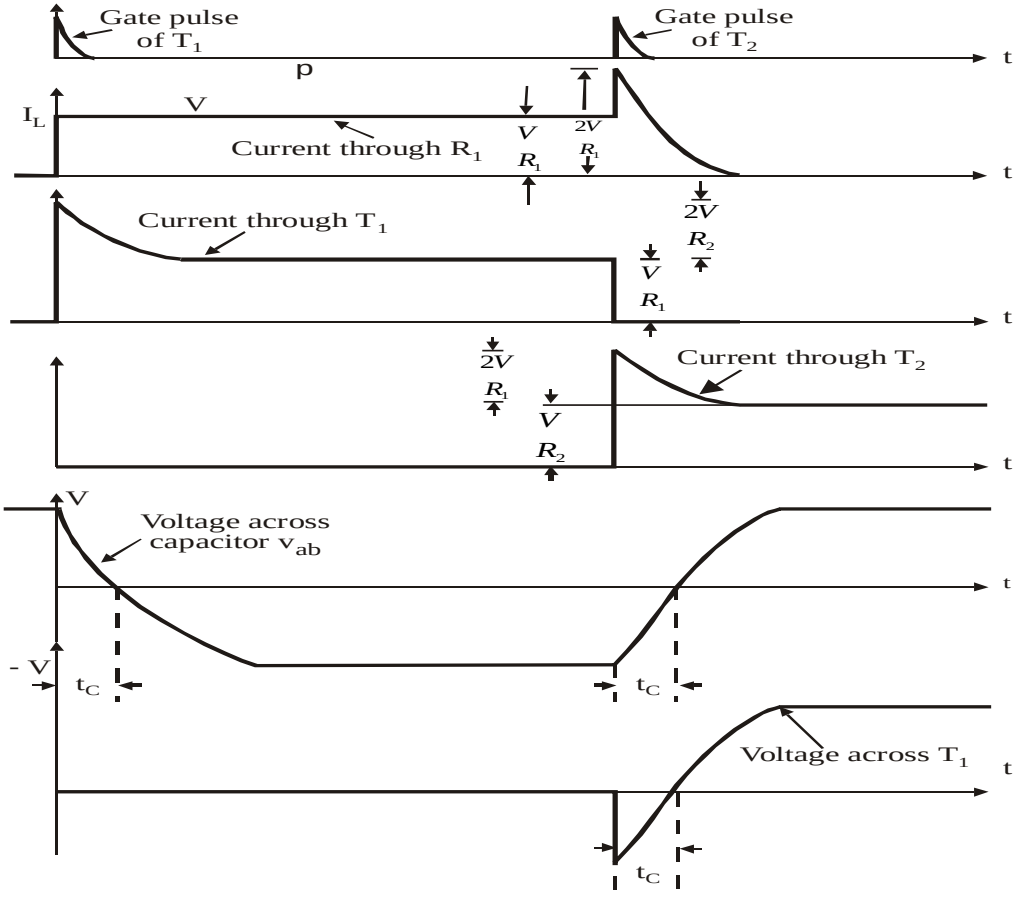


Fig. 1.21: Complementary Commutation

The working of the circuit can be explained as follows.

Initially both T_1 and T_2 are off; Now, T_1 is fired. Load current I_L flows through R_1. At the same time, the capacitor C gets charged to V volts through R_2 and T_1 ('b' becomes positive with respect to 'a'). When the capacitor gets fully charged, the capacitor current i_c becomes zero.

To turn off T_1, T_2 is fired; the voltage across C comes across T_1 and reverse biases it, hence T_1 turns off. At the same time, the load current flows through R_2 and T_2. The capacitor 'C' charges towards V through R_1 and T_2 and is finally charged to V volts with 'a' plate positive. When the capacitor is fully charged, the capacitor current becomes zero. To turn off T_2, T_1 is triggered, the capacitor voltage (with 'a' positive) comes across T_2 and T_2 turns off. The related waveforms are shown in figure 1.22.



IMPULSE COMMUTATION (CLASS D COMMUTATION)

The circuit for impulse commutation is as shown in figure 1.25.

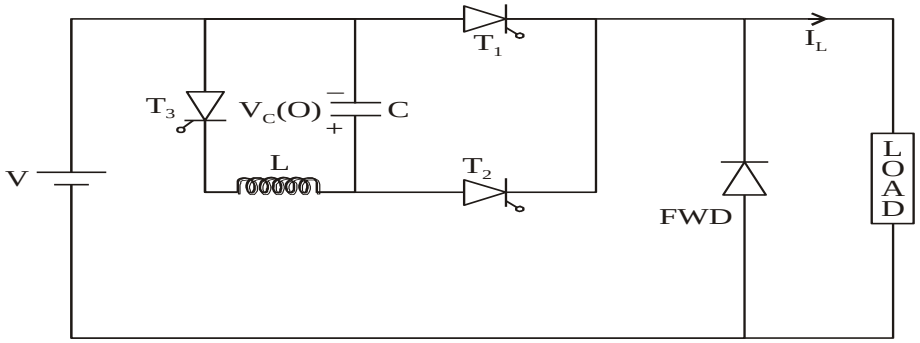


Fig. 1.25: Circuit for Impulse Commutation

The working of the circuit can be explained as follows. It is assumed that initially the capacitor C is charged to a voltage $V_C(O)$ with polarity as shown. Let the thyristor T_1 be conducting and carry a load current I_L. If the thyristor T_1 is to be turned off, T_2 is fired. The capacitor voltage comes across T_1, T_1 is reverse biased and it turns off. Now the capacitor starts charging through T_2 and the load. The capacitor voltage reaches V with top plate being positive. By this time the capacitor charging current (current through T_2) would have reduced to zero and T_2 automatically turns off. Now T_1 and T_2 are both off. Before firing T_1 again, the capacitor voltage should be reversed. This is done by turning on T_3, C discharges through T_3 and L and the capacitor voltage reverses. The waveforms are shown in figure

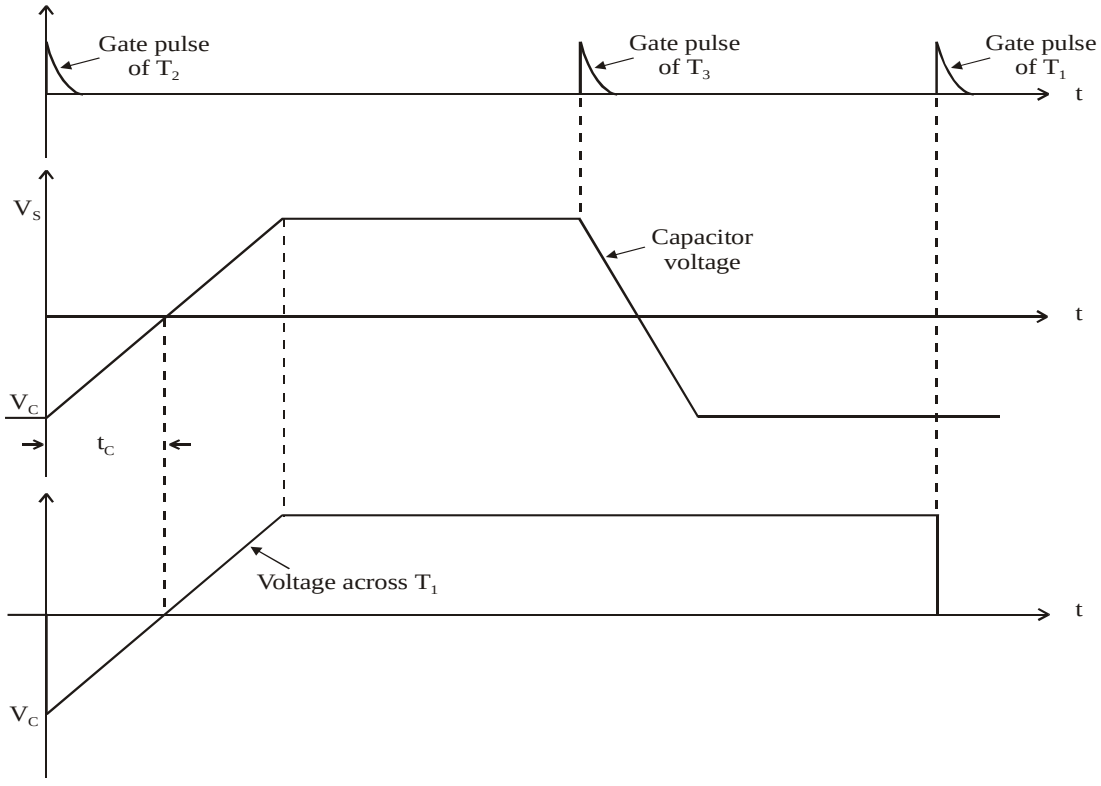


Fig. 1.26: Impulse Commutation – Waveforms of Capacitor Voltage, Voltage across T_1.

AN ALTERNATIVE CIRCUIT FOR IMPULSE COMMUTATION

Is shown in figure 1.27.

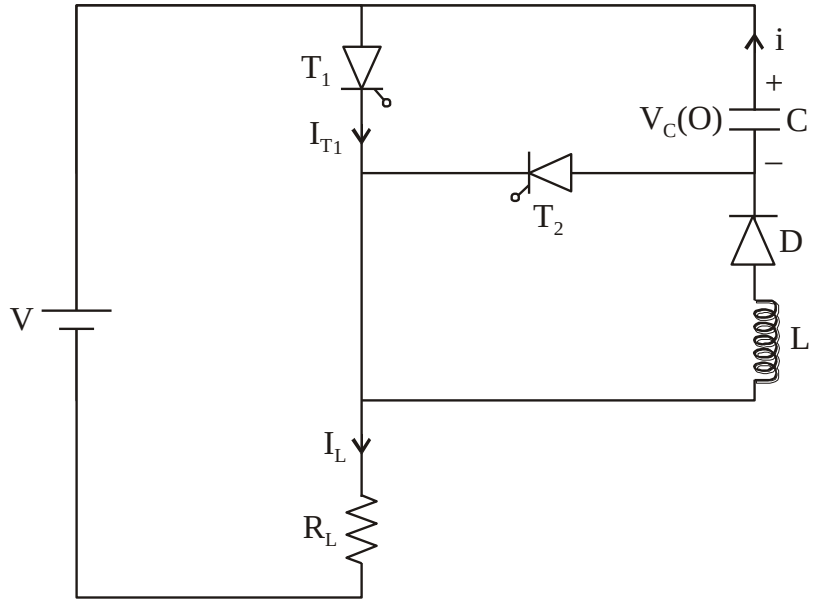


Fig. 1.27: Impulse Commutation – An Alternate Circuit

The working of the circuit can be explained as follows:

Initially let the voltage across the capacitor be $V_C(O)$ with the top plate positive. Now T_1 is triggered. Load current flows through T_1 and load. At the same time, C discharges through T_1, L and D (the current is 'i') and the voltage across C reverses i.e., the bottom plate becomes positive. The diode D ensures that the bottom plate of the capacitor remains positive.

To turn off T_1, T_2 is triggered; the voltage across the capacitor comes across T_1. T_1 is reverse biased and it turns off (voltage commutation). The capacitor now starts charging through T_2 and load. When it charges to V volts (with the top plate positive), the current through T_2 becomes zero and T_2 automatically turns off.

The related waveforms are shown in figure 1.28.

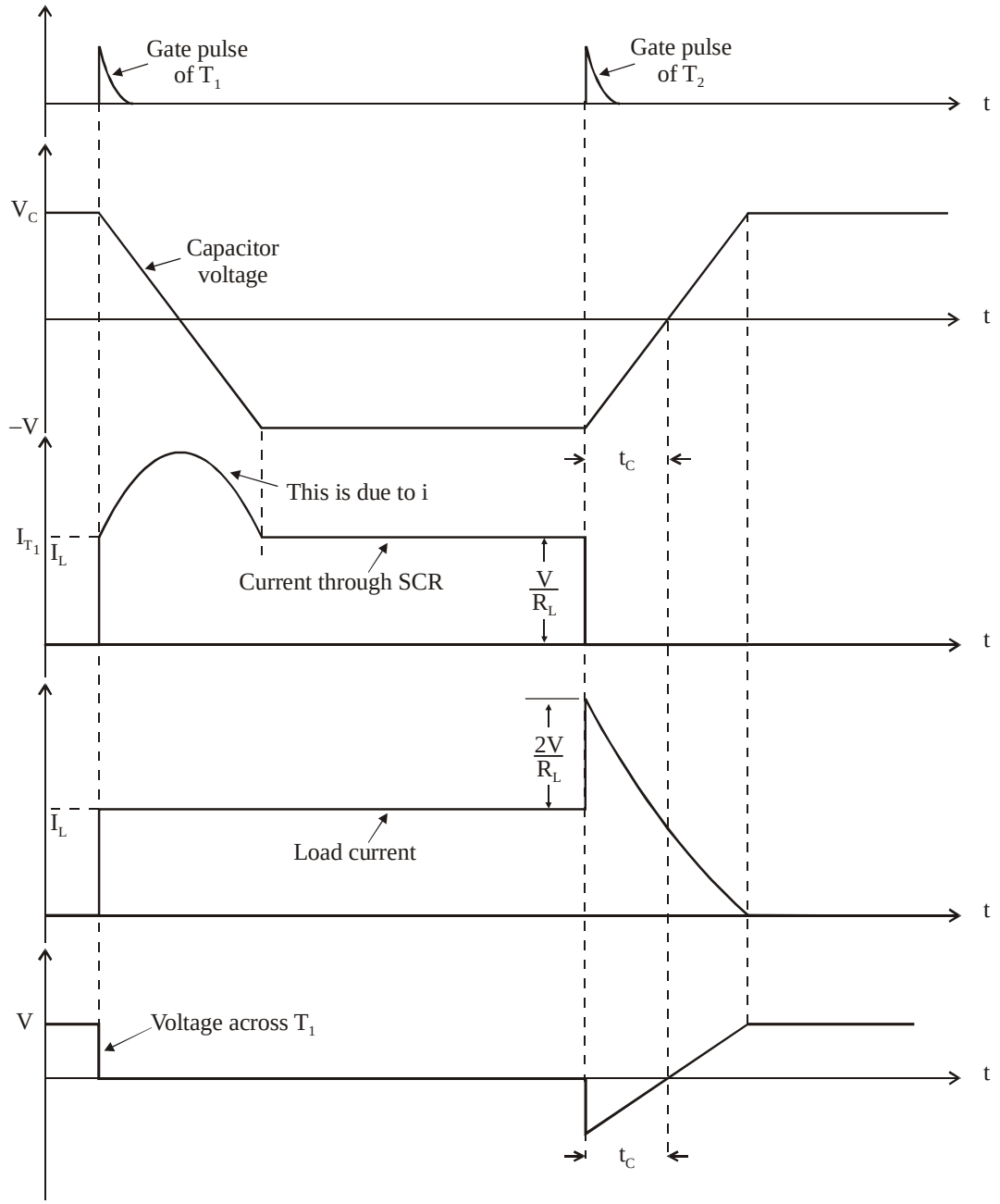


Fig. 1.28: Impulse Commutation – (Alternate Circuit) – Various Waveforms

EXTERNAL PULSE COMMUTATION (CLASS E COMMUTATION)

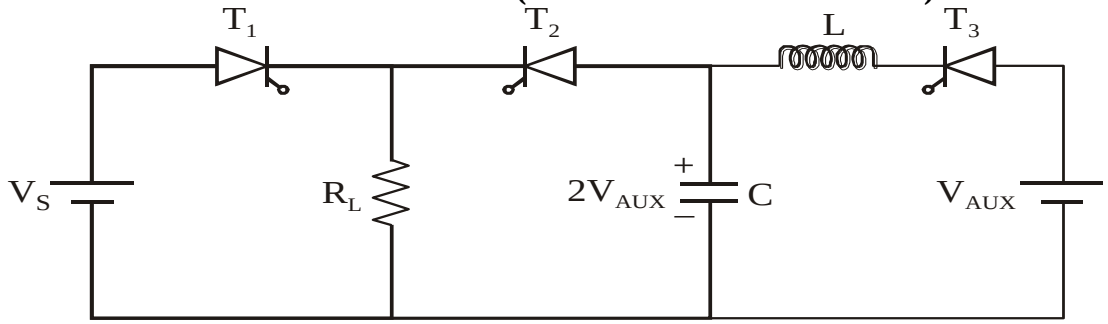


Fig. 1.34: External Pulse Commutation

In this type of commutation an additional source is required to turn-off the conducting thyristor. Figure 1.34 shows a circuit for external pulse commutation. V_S is the main voltage source and V_{AUX} is the auxiliary supply. Assume thyristor T_1 is conducting and load R_L is connected across supply V_S. When thyristor T_3 is turned ON at $t = 0$, V_{AUX}, T_3, L and C from an oscillatory circuit. Assuming capacitor is initially uncharged, capacitor C is now charged to a voltage $2V_{AUX}$ with upper plate positive at $t = \pi\sqrt{LC}$. When current through T_3 falls to zero, T_3 gets commutated. To turn-off the main thyristor T_1, thyristor T_2 is turned ON. Then T_1 is subjected to a reverse voltage equal to $V_S - 2V_{AUX}$. This results in thyristor T_1 being turned-off. Once T_1 is off capacitor 'C' discharges through the load R_L

LOAD SIDE COMMUTATION

In load side commutation the discharging and recharging of capacitor takes place through the load. Hence to test the commutation circuit the load has to be connected. Examples of load side commutation are Resonant Pulse Commutation and Impulse Commutation.

LINE SIDE COMMUTATION

In this type of commutation the discharging and recharging of capacitor takes place through the supply.

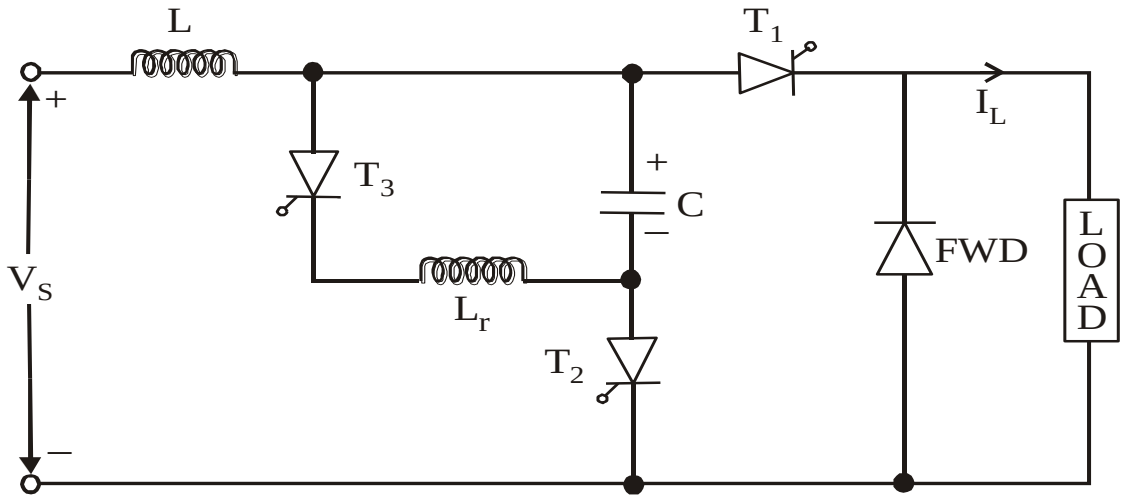


Fig.: 1.35 Line Side Commutation Circuit

Figure 1.35 shows line side commutation circuit. Thyristor T_2 is fired to charge the capacitor 'C'. When 'C' charges to a voltage of 2V, T_2 is self commutated. To reverse the voltage of capacitor to -2V, thyristor T_3 is fired and T_3 commutates by itself. Assuming that T_1 is conducting and carries a load current I_L thyristor T_2 is fired to turn off T_1. The turning ON of T_2 will result in forward biasing the diode (FWD) and applying a reverse voltage of 2V across T_1. This turns off T_1, thus the discharging and recharging of capacitor is done through the supply and the commutation circuit can be tested without load.