

CHAPTER-5

FOUR QUADRANT CHOPPER

5.1 Introduction

The chopper circuits described in chapter three, can operate only in two quadrants of the v_o-i_o plane. The chopper circuit shown in figure 5.1(a) can operate in all the four quadrants of the v_o-i_o plane shown in figure 5.1(b). That is the output voltage and current can be controlled both in magnitude as well as in direction. Therefore the power flow can be in either direction. In the first quadrant the power flows from the source to the load and is assumed to be (+)ve. In the second quadrant the voltage is still positive but the current is negative. The power is therefore negative. In this case power flows from the load to the source and this can happen if the load is inductive or back emf source such as a dc motor. In the third quadrant both the voltage and current are negative, but the power is positive, and the power flows from the source to the load. In the fourth quadrant voltage is negative but the current is positive. The power is therefore negative.

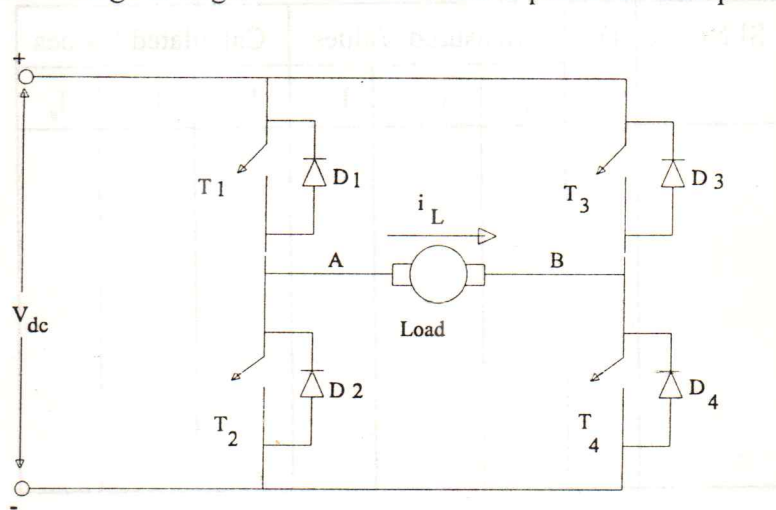


Figure 5.1(a). Four quadrant chopper circuit.

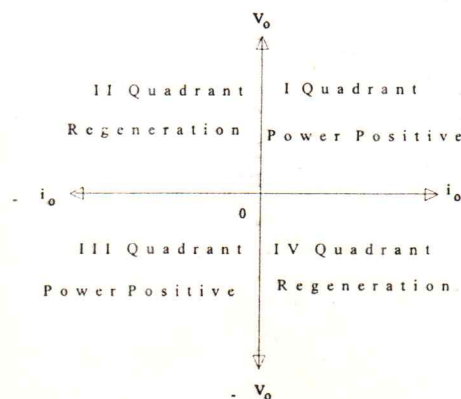


Figure 5.1(b). Four quadrant of V_o, i_o plane.

The four quadrant chopper is widely used in reversible dc motor drives. The reversible dc motor drive system requires, power flow in either direction, in order to achieve fast dynamic response. By employing four quadrant chopper it is possible to implement regeneration and dynamic braking by means of which fast dynamic response is achieved.

5.2. Circuit Description:

The four quadrant chopper, with four switching devices where diodes are connected in antiparallel with the switching devices, is also referred to as a full-bridge converter topology. The input to the full bridge converter is a fixed magnitude dc voltage V_{dc} . The output of the converter can be a variable dc voltage with either polarity. This circuit is therefore called as the four quadrant chopper circuit (or a dc-to-dc converter). The output of the full bridge converter can also be an ac voltage with variable frequency and amplitude in which case the converter is called as dc-to-ac converter (Inverter). The operation of the circuit as an inverter is explained in the chapter on inverter. The operation of circuit as a four quadrant chopper is explained in this chapter. In a full bridge converter, when a gating signal is given to a switching device either the switching device or the diode only will conduct depending on the direction of the output load current. The full bridge converter consists of two legs; Leg-1 comprising the switches T_1 , T_2 and their associated antiparallel diodes D_1 and D_2 (Refer to Fig.5.1.a), Leg-2 comprising switches the T_3 , T_4 , D_3 and D_4 . While operating the converter, the two switches in the same leg are not to be switched simultaneously, since this would cause a short circuit across the dc supply. That is only one of the device in a leg will be in the ON state and the other will be in its OFF state. In practice both the devices in a leg are made to be in OFF state for a short time interval to avoid short circuiting of the dc input.

5.3 Switching Modes of Four-Quadrant Chopper:

The switches in the four-quadrant chopper can be switched in two different modes such that

- i. The output voltage swings in both directions; i.e., from $+V_{dc}$ to $-V_{dc}$. This mode of switching is referred to as PWM with bipolar voltage switching.
- ii. The output voltage swings either, from zero to $+V_{dc}$ or zero to $-V_{dc}$. This mode of switching is referred to as PWM with unipolar voltage switching.

In the bipolar voltage switching mode the switches (T_1 , T_4) and (T_3 , T_2) are treated as two switch pairs and each pair are turned on and turned off simultaneously. In the unipolar voltage switching mode, the switches in each leg are controlled independently of the other leg.

5.4. Operation of the Four-quadrant chopper with bipolar Voltage Switching.

The operation of the circuit as a four quadrant chopper with bipolar voltage switching is explained, referring to the circuit diagram of fig.5.1. When the switches T1 and T4 are turned ON by applying gating signals simultaneously, the load voltage is V_{dc} with terminal 'A' positive and the load current i_L flows in the direction of A to B. The load current flows from source through T1, the load circuit and T4. Now, suppose T1 and T4 are turned OFF by removing the gating signals. Because of the load inductance, the current cannot change instantaneously. The load current i_L will now start flowing through D3, the dc source and D2. The load voltage v_L will now be $-V_{dc}$, since the conduction of the diode D3 will connect the load terminal B to the (+)ve terminal of the source. As the load voltage is negative and the current is still positive, the power is negative. The power now flows from the load to the source. The stored energy in the load inductance is now being returned to the source. This corresponds to the operation of chopper circuit in the fourth quadrant. This operation in the fourth quadrant will continue as long as the current is positive. When T₁ and T₄ are turned off, the switches T₃ and T₂ can be switched ON. Switching of T₃ and T₂ by applying a gating signals to them, would also have resulted the operation of the circuit in the fourth quadrant, because the current being positive and cannot change in direction instantaneously.

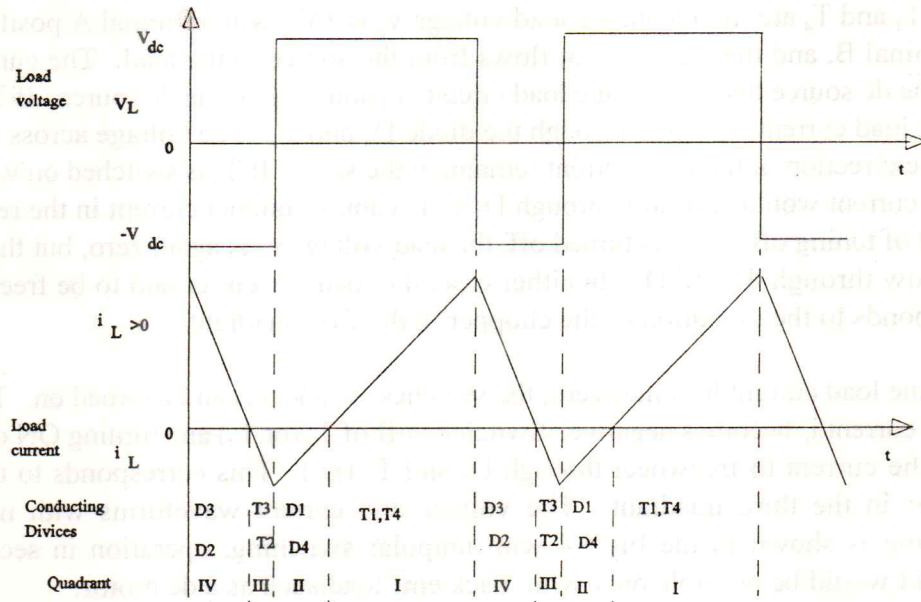
When the current passes through zero, the devices T₃ and T₂ can be turned on, and the load current becomes negative. The load current now passes through T₃ and T₂ with current direction in the load as from B to A. This brings the operation of the chopper in the third quadrant. Turning off of T₃ and T₂, will bring in the conduction of the diodes D₁ and D₄ and the operation of the chopper circuit in the second quadrant.

The operation of the chopper in the first and third quadrant corresponds to power flow from the source to the load, and is considered to be forward power flow. The operation in fourth and second quadrant corresponds to reverse power flow (power flows from the load to the source). The relevant waveforms showing the operation of the full bridge converter in all the four quadrants are shown in Fig.5.3 assuming that the load is inductive.

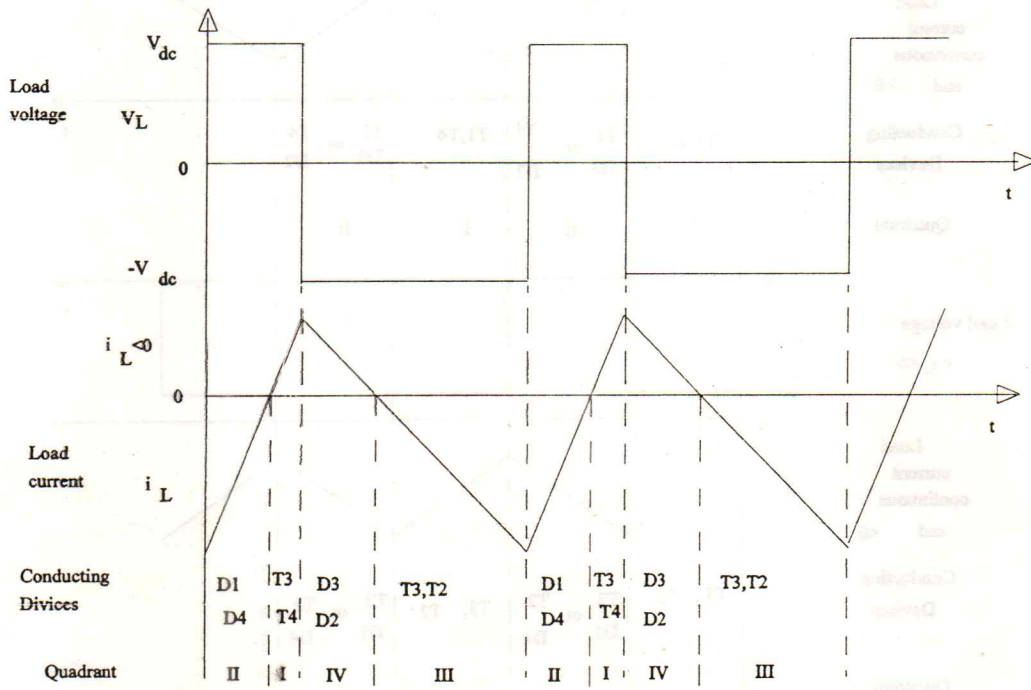
5.5 Operation of the Four-quadrant chopper with unipolar voltage switching.

Inspection of the chopper circuit of fig.5.1. shows that regardless of the direction the load current i_L , the load voltage v_o is zero if T₁ and T₃ are both on. Similarly $v_o = 0$, if T₂ and T₄ are both on. This property is utilised to improve the output voltage waveform.

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**Fig.5.3(a) Load Voltage and Current with inductive Load
Load Current $i_L > 0$ (Positive)**



**Fig.5.3(b) Load Voltage and Current with inductive load
Load Current $i_L < 0$ (negative)**

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When T_1 and T_4 are turned on, the load voltage v_o is $+V_{dc}$ with terminal A positive with respect to terminal B, and the load current flows from the source to the load. The current path being, from the dc source through T_1 , the load circuit, T_4 and back to the dc source. If T_4 is now turned off, the load current will flow through the diode D_3 and T_1 . The voltage across the load is zero, with the direction of the load current remaining the same. If T_3 is switched on when T_4 is turned off the current would still flow through D_3 as T_3 cannot conduct current in the reverse direction. Instead of turning off T_4 , T_1 is turned off, the load voltage v_o is again zero, but the current would now flow through T_4 and D_2 . In either case, the load current is said to be freewheeling. This corresponds to the operation of the chopper in the first quadrant.

When the load current becomes zero, the switches, T_3 and T_2 can be turned on. The load voltage V_L and current i_L becomes negative. Switching off of T_2 (or T_3) and turning ON of T_1 (or T_4) will make the current to freewheel through D_1 and T_3 (D_4). This corresponds to the operation of chopper in the third quadrant. The voltage and current waveforms with unipolar voltage switching is shown in the Fig.5.4 with unipolar switching, operation in second and fourth quadrant would be possible only with back emf load such as a dc motor.

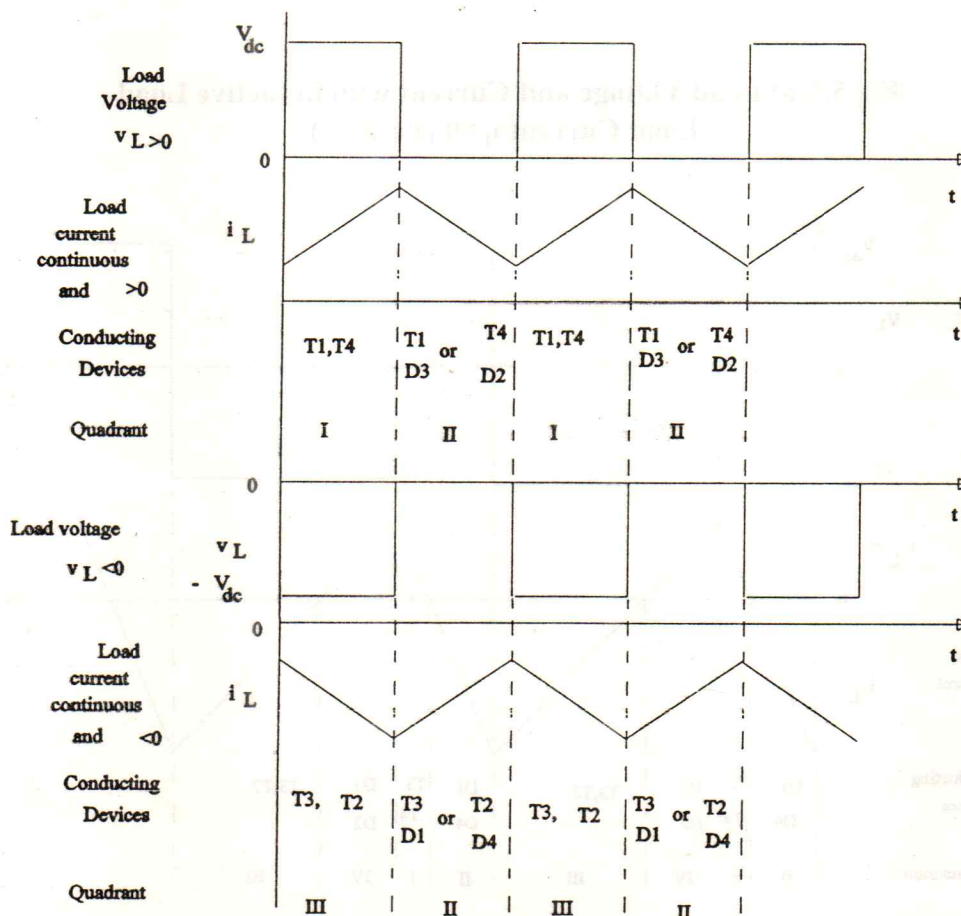


Fig.5.4 Voltage and Current with Unipolar Voltage Switching Inductive Load.

5.6 Generation of Gating Signals for the Four Quadrant Chopper.

The gating signals for the switches in the four-quadrant chopper are derived by comparing a triangular carrier wave with a control voltage level.

5.6.1 Gatings Signals for bipolar voltage switching.

For bipolar voltage switching the devices (T_1 and T_4) are switched ON/OFF simultaneously. When this pair of switches are OFF the other pair of switches T_3 and T_2 are switched ON and vice-versa. The gating signals are generated by comparing a switching frequency triangular waveform V_{tri} with the control voltage V_c . The pulse generated when $V_c > V_{tri}$ are used to turn on T_1 and T_4 . The complementary pulses are used to, turn on T_3 and T_2 . The waveforms of fig.5.5. Show the generation of the gating signals. The control voltage V_c is varied from $-V_{tri}$ to $+V_{tri}$. When V_c is (+)ve, the duty cycle ratio for the switches T_1 and T_4 is greater than 50% and the average output load voltage will be (+)ve. When V_c is (-)ve, the duty cycle ratio for T_3 and T_2 will be more than 50% and the average output voltage will be (-)ve.

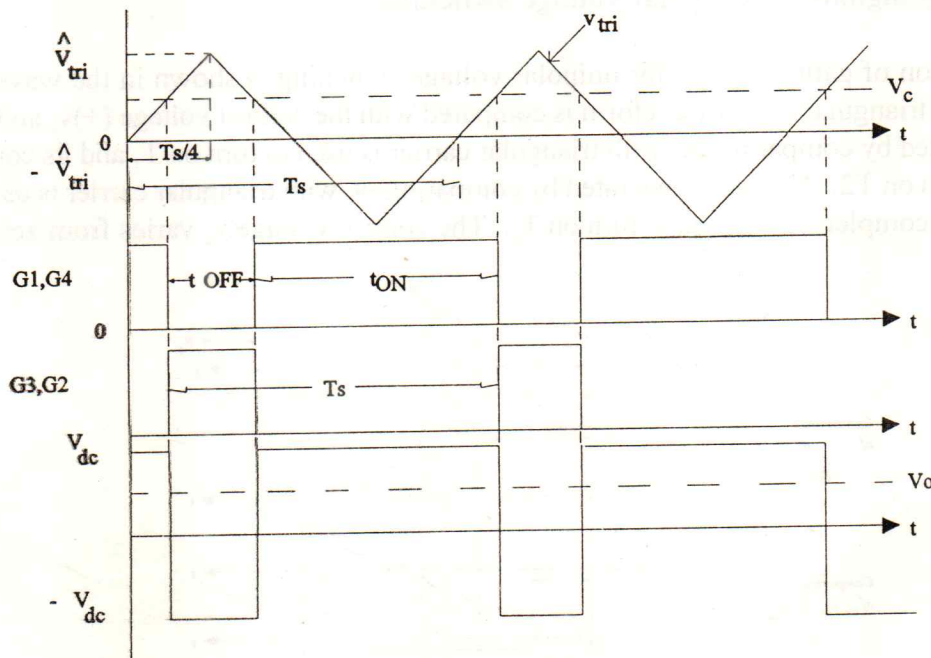


Fig.5.5 Generation of Gating Signals

When $V_c = 0$, the switches T_1, T_4 and T_3 and T_2 are switched for equal interval of time. The output voltage will then be zero.

The duty cycle ratio for the switch pair T_1 and T_4 is

$$D_1 = \frac{T_{ON}}{T_s} = \frac{1}{2} \left(1 + \frac{v_c}{V_{tri}} \right) \tag{1}$$

and duty cycle ratio for the switch pair T_3 and T_2 is

$$D_4 = 1 - D_1 \tag{2}$$

and the average output dc voltage is given by

$$V_o = \frac{V_{dc}}{V_{tri}} v_c \tag{3}$$

5.6.2 Gating Signals for Unipolar voltage Switching:

The generation of gating signals for unipolar voltage switching is shown in the waveforms of Fig.5.6. The triangular carrier waveform is compared with the control voltage $(+)v_c$ and $-v_c$. The pulse generated by comparing $+v_c$ with triangular carrier is used to turn on T_1 and its complement is used to turn on T_2 . The pulse generated by comparing $-v_c$ with triangular carrier is used to turn on T_3 and its complement is used to turn on T_4 . The control voltage v_c varies from zero to $+V_{tri}$

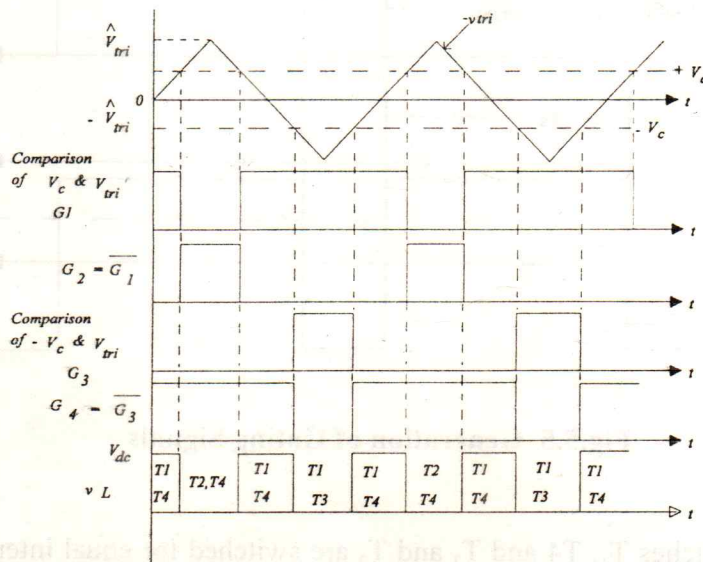


Fig.5.6 Generation of gating signals for unipolar voltage switching.

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The block diagram schematic of the gating circuit for the chopper is shown in Fig.2.4.. It consists of a triangular carrier generation whose frequency is adjustable. The gating signals for the single quadrant, two quadrant and four quadrant choppers are obtained by comparing the appropriate control voltage signal v_c with the triangular carrier, and the appropriate signals are selected through the mode selection switch SW3. The comparator output signals are applied to high speed opto isolator for the necessary isolation between the control circuit and the power circuit. The rising edges of the gating signals for the devices on the same leg are delayed to an extent of the turn-off time of the devices to avoid possible short circuit on the dc supply. The gating signals are then applied to the gate driver IC IRF2110. A single IRF 2110 can drive two MOSFETs/IGBTs in the same leg. The details of IRF 2110 is given in Appendix-I.

EXPERIMENT E.5.1:

AIM: To study the operation of four-quadrant chopper with bipolar voltage switching.

EQUIPMENTS REQUIRED:

1. MOSFET/IGBT Module
2. Chopper Control Module
3. CRO
4. R, L Load

PRECAUTION:

1. Ensure all switches are in the OFF position while doing connection.
2. Ensure pulse release ON/OFF switch is in OFF position, whenever power is switched ON to the chopper module.

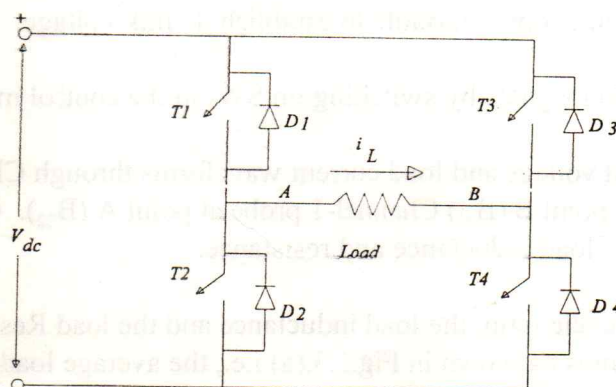


Fig.E.5.1 Four Quadrant Chopper.

PROCEDURE:

1. Using the chopper module, and referring to the mimic diagram of the Fig.2.1 connect the circuit diagram of Fig.E.5.1.
 - i. Connect B_{11} to V+1 using patch cords.
 - ii. Connect B_{12} to B_{21} using patch cords.
 - iii. Connect B_{23} to V-1 using patch cords.
 - iv. Connect V+2 to B_{31} using patch cords.
 - v. Connect B_{32} to B_{41} using patch cords.
 - vi. Connect V-2 to B_{43} using patch cords.
2. Connect the R-L load between B_{13} and B_{33} .
3. Connect the gating signals from the chopper control module to the chopper module using the signal cable provided.
4. Connect the power cables for both the modules.
5. Select bipolar voltage switching mode, mode-III by setting SW_3 in the control module at position III.
6. Keeping pulse release ON/OFF switch SW_4 , in the control module in the OFF position. Switch ON ac mains to CRO, control module and chopper module.
7. Observe the triangular waveform frequency at test point T_1 through CRO and adjust its frequency to above 2.2 KHz.
8. Observe the gating signals at Test Points T_{11} , T_{12} , T_{13} and T_{14} . It should be of Rectangular pulses of amplitudes about 15V.
9. Switch on SW_1 in chopper module to establish dc link voltage.
10. Release the gating signals by switching on SW_4 in the control module.
11. Observe the load voltage and load current waveforms through CRO. Connect the CRO signal ground at point B (B_{33}) Channel-1 probe at point A (B_{22}). Channel-2 probe to the junction point of load inductance and resistance.
12. Adjust the duty cycle ratio, the load inductance and the load Resistance so that the load current waveform is as shown in Fig.5.3.(a) i.e., the average load current is positive and also the chopper operates in all the four quadrants. Plot the load voltage and load current waveforms on a graph sheet to scale. Mark the conducting devices and the quadrants of operation on the graph sheet by looking at the voltage and current waveform.

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13. Vary the duty cycle ratio and study the operation of the chopper.
14. Vary the duty cycle ratio in steps. For each step measure the average dc output voltage, on period T_{ON} , off period T_{off} , the maximum and minimum load currents, through CRO and tabulate the readings as in Table E.5.1.

TABLE E.5.1. Bipolar Voltage Switching

S.No.	V _a Volts	T _{ON} (Sec)	T _{OFF} (Sec)	I _{max} (A)	I _{min} (A)	ΔI	I _o	$V_o = \frac{V_c}{\Delta} * V_{dc}$

15. Calculate the dc output voltage v_o , current ripple ΔI , and the average dc load current.

$$V_o = \frac{V_c}{\Delta} * V_{dc} \quad (1)$$

$$\Delta I = I_{max} - I_{min} \quad (2)$$

$$I_o \approx \frac{I_{max} + I_{min}}{2} \quad (3)$$

16. Adjust the duty cycle ratio such that the average load current is negative.
17. Repeat steps 12 to 15 for the negative average load current.

EXPERIMENT E.5.2: Four Quadrant Chopper with Unipolar Voltage Switching

AIM:

- i. To study the gating scheme for unipolar voltage switching.
- ii. To study the operation of the Four-Quadrant chopper with unipolar switching.

EQUIPMENTS REQUIRED:

1. MOSFET/IGBT Module.
2. Chopper Control Module.
3. CRO.
4. R-L Load.

PRECAUTION:

1. Ensure all switches are in the OFF position while doing connection.
2. Ensure pulse release ON/OFF switch is in OFF position, whenever power is switched ON to the chopper module.

PROCEDURE:

- i. To study the gating scheme for unipolar voltage switching.
 1. Connect the power cable to the chopper control module.
 2. Switch on power supply to CRO and the chopper control module. Set the mode selection switch SW₃ at position IV.
 3. Observe the triangular carrier wave at test point T₁ and the control voltage level at T₂.
 4. Observe the comparator output at the test points T₃ to T₆.
 5. Plot the waveforms on a graphs sheet as shown in Fig.5.6.
 6. Mark the conducting devices in each interval on the graph.

ii. To study the operation of the Four-Quadrant chopper with unipolar switching.

1. Follows the steps 1 to 4 given in E.5.1.
2. Select the unipolar switching mode, by setting the mode switch SW_3 at position IV in the Chopper Control Module.
3. Follow the steps 6 to 17 given in E.5.1.