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Performance Investigation of DC Motor Using Four Quadrant Chopper

Anamika Talukdar[1] and Tilok Baruah[2]

[1]*Post Graduate Student Jorhat Engineering College*
[2]*Jorhat Engineering College*
E-mail: [1]onlyforwork24@gmail.com, [2]tilokb@rediff.com

Abstract—*In power electronics, a chopper circuit is a combination of numerous electronic devices and circuits used in different field of application. A chopper circuit converts a fixed DC input voltage to a variable DC output voltage directly. A four quadrant chopper can be used to control a DC motor in four different operations. The speed and direction of a DC motor are controlled by using a four quadrant DC-DC chopper. Semiconductor devices such as IGBTs, MOSFETs, or GTOs can be used as switching devices. In case of four quadrant chopper it has four operations as- in the first quadrant the motor rotates in forward direction. In the second quadrant the motor operates in braking mode. The motor gets the braking mode while rotating in forward direction. Then in third quadrant the motor rotates in reverse direction i.e. anticlockwise direction. In the fourth quadrant the motor stops instantly while rotating in anticlockwise direction which is called regenerative braking. In the proposed method the whole model is simulated. Then it is implemented on hardware using microcontroller and MOSFETs from L293d IC. On the other hand the speed of DC motor can be increased or decreased by controlling the PWM. By installing the correct program in the microcontroller the motor can be controlled in four different quadrants.*

1. INTRODUCTION

From a constant DC-voltage source for charging battery, bridge rectifier, a different type of converter is used to convert a fixed voltage into a variable voltage for the speed control of a DC motor(as a armature voltage control technique). The variable DC voltage is to be controlled by chopping the input voltage by adjusting ON and OFF times (duty cycle) of a converter. The converter with this type of capability is known as a chopper which converts a fixed DC voltage into a variable voltage.

A chopper circuit consists of a semiconductor device (here it is considered as IGBT), voltage supply and a load to control such as motors. Each and every chopper based mechanism should be designed by applying the basic principle of four quadrant chopper which is explained with the help of a typical chopper circuit and its output responses shown as in Fig. 1 and Fig. 2 respectively.

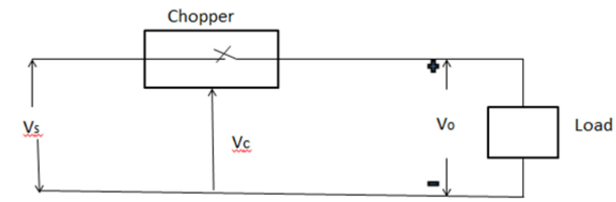

Fig. 1: Typical chopper circuit. [13]

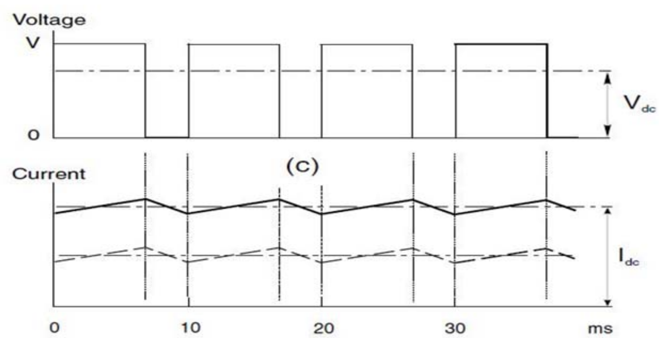

Fig. 2:Voltage waveform of a chopper circuit. [13]

Let the chopper is on for T_{on} and its on time is $T_{of\ f}$ with control voltage at the gate of the chopper V_c. Its frequency of operation can be given as [13]-

$$f_c = \frac{1}{(t_{on} + t_{off})} = \frac{1}{T} \tag{1}$$

$$\text{The duty cycle is, } d = \frac{t_{on}}{T} \tag{2}$$

During on time the output voltage across the load is equal to the difference between source voltage and the potential

drop across the power switch such as IGBT, MOSFET etc. By assuming zero voltage drop across the switch the average output voltage is given by-

$$V_{dc} = d.V_s \tag{3}$$

The duty cycle can be varied either by keeping chopping frequency constant and varying the on time or by keeping the on time constant and varying the chopping frequency.

1.1 Four Quadrant Chopper Circuit

A four quadrant chopper circuit with transistor switches is shown below-

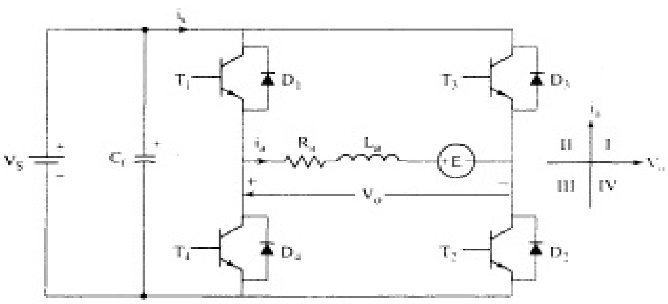

Fig. 3: Four quadrant chopper circuit. [13]

Each transistor has a freewheeling diode across it with a snubber circuit(not shown in figure) to limit the rate of rise of voltage. The load may be a DC motor or a RLE(resistance-inductance-equivalent emf) load. The source is DC and a capacitor is connected to maintain constant voltage.

2. MATHEMATICAL MODELLING OF SEPARATELY EXCITED DC MOTOR

Separately excited dc motor has field and armature winding with separate supply voltage. Field flux is supplied to armature by field winding. Current is fed to the armature winding through brushes and commutators, when DC voltage is applied to motor. Since rotor is placed in magnetic field and it is carrying current also. So a back emf and a torque to balance load torque at a particular speed are developed by the motor.

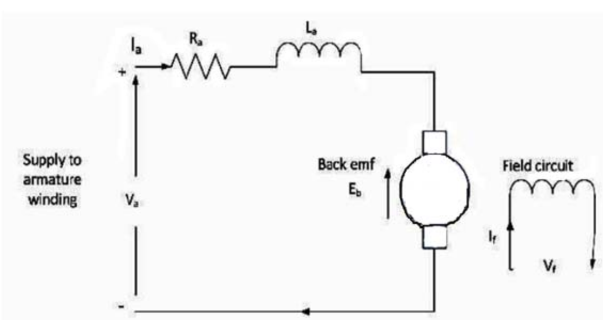

Fig. 5: Separately excited DC motor

The field current I_f is independent of the armature current I_a. The I_f is generally much less than the I_a. Suppose V_a is the armature voltage in volt, I_a is the armature current in ampere, E_b is the back emf in volt, L_a is the armature inductance in Henry, R_a is the armature resistance in ohm. The armature equation is shown below:

$$V_a = E_b + I_a R_a + L_a \frac{dI_a}{dt} \tag{4}$$

The torque equation can be given by:

$$T_e = J\frac{dw}{dt} + B + T_l \tag{5}$$

Equation for back emf is:

$$E_b = k\phi w \tag{6}$$

Also, $T_e = k\phi I_a$ (7)

Therefore, $w = (V_a - I_a R_a)/k\phi$ (8)

From equation no (8) it can be said that the speed of DC motor depends on supply voltage, armature current, armature resistance and field flux.

3. SOFTWARE IMPLEMENTATION

The software part of the model is implemented in MATLAB SIMULINK. The first step for the software implementation is the open loop test. It is called an open loop test because there is no feedback path. The pulse is not fed back to the switch. The pulse is given to the gate of the switch directly from the pulse generator. The open loop test is conducted so that one can make sure that the motor is operating properly in each quadrant or not.

3.1. First Quadrant

The open loop test for first quadrant is carried out by connecting an IGBT switch, RL load as motor and a pulse generator. Here only one IGBT switch is used to avoid equality of load voltage and source voltage. The diode provides the path for armature current continuity. The circuit simulation is given below-

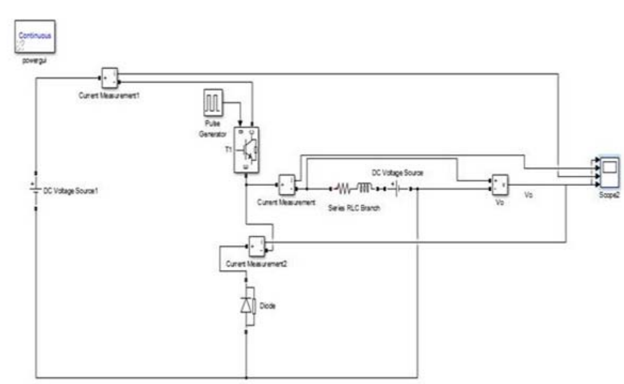

Fig. 5: First quadrant chopper circuit.

Considering the output voltage to be in X-axis and current in Y-axis, in the first quadrant the value of both output voltage and current is positive (+,+).The response of the 1st quadrant can be observed in scope as below which shows both voltage and current positive.

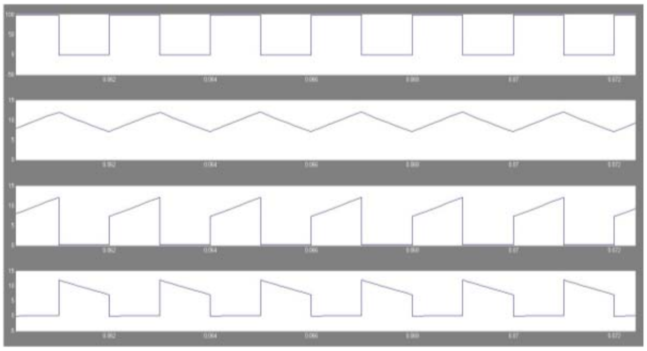

Fig. 7: Response of first quadrant.

3.2. Second Quadrant

The open loop test for second quadrant is carried out by connecting an IGBT switch, RL load as motor and a pulse generator. This quadrant corresponds to a positive current with a negative voltage across the load terminals. The circuit simulation is given below-

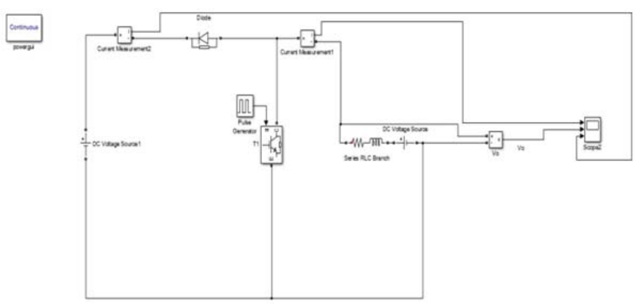

Fig. 8: Second quadrant chopper circuit.

Considering the output voltage to be in X-axis and current in Y-axis, in the second quadrant the value of output voltage is negative and current is positive (-, +). The response of the above Fig. can be observed in scope as below which shows negative value of voltage and positive current.

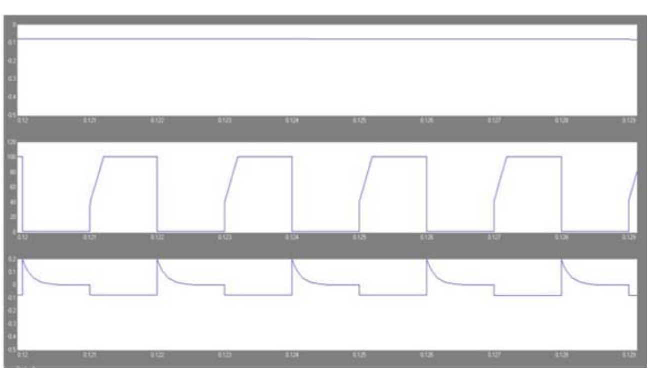

Fig. 9: Response of second quadrant.

3.3. Third Quadrant

The open loop test for third quadrant is carried out by connecting two IGBT switches, RL load as motor and a pulse generator. This quadrant operation provides the load with negative current and voltage. Switching of both IGBTs increases the current in the load. Thus turning of any of the two switches decrease the load current as the circuit get short circuited. Therefore two designs can be modelled in third quadrant. The circuit simulation for increase in load current is given below-

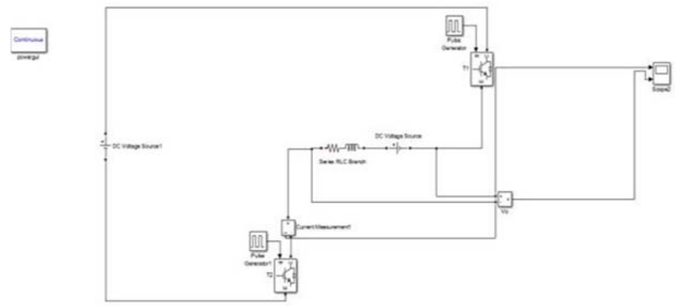

Fig. 10: Third quadrant chopper circuit (increase in LC).

The circuit simulation for decrease in load current is given below-

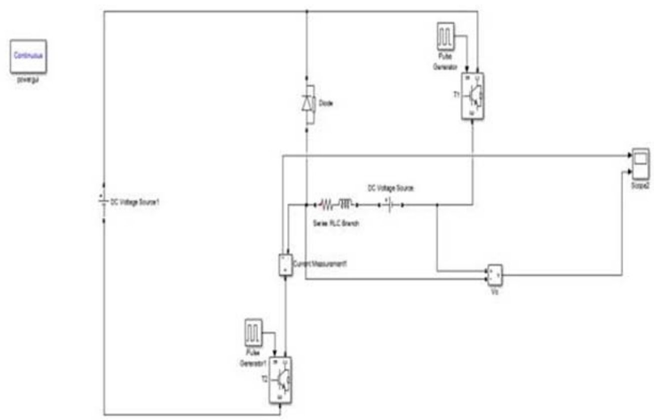

Fig. 11.Third quadrant chopper circuit (decrease in LC)

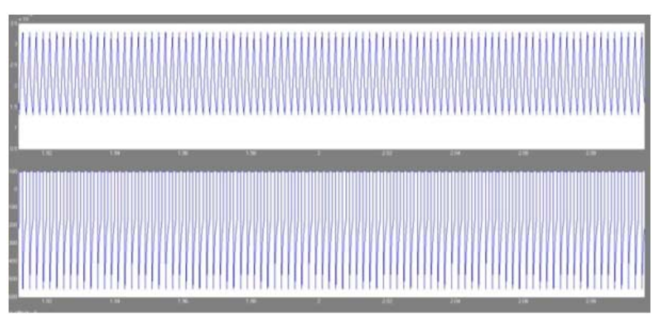

Fig. 12: Response of third quadrant (increase in LC).

Considering the output voltage to be in X-axis and current in Y-axis, in the third quadrant the value of both output voltage and current are negative since in the 3rd quadrant axes are written as(-,-).The response for both increase and decrease in LC can be observed in scope as below which shows negative value for both voltage and current.

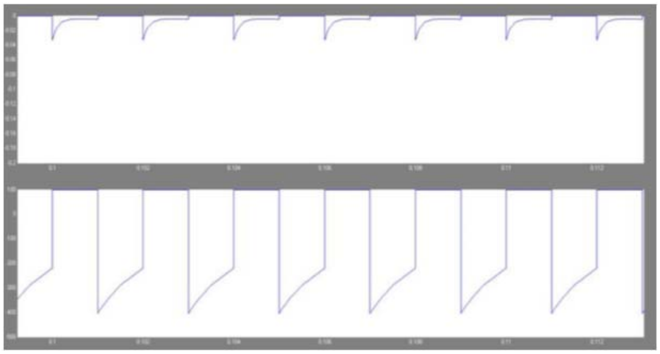

Fig. 13: Response of third quadrant (decrease in LC).

3.4 Fourth Quadrant

The open loop test for fourth quadrant is carried out by connecting four IGBT switches, four diodes, RL load as motor and a pulse generator. This quadrant operation provides positive voltage and a negative current in the load. The circuit simulation for fourth quadrant is given below.

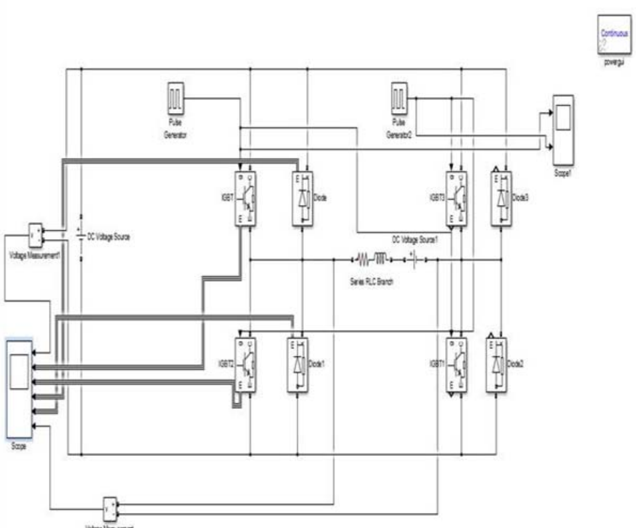

Fig. 14: Fourth Quadrant chopper circuit.

Considering the output voltage to be in X-axis and current in Y-axis, in the fourth quadrant the value of output voltage is positive and current is negative since in the 4th quadrant axes are written as(+,-).The response for this quadrant can be observed in scope as below which shows negative for current and positive voltage.

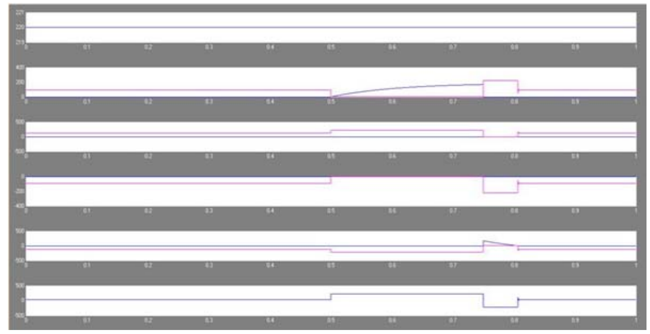

Fig. 15: Response of fourth quadrant.

3.5. Close Loop Speed Control of DC motor in First Quadrant

The speed of the DC motor can be only controlled in the first quadrant since this quadrant deals with the motoring operation of the motor. In close loop model the speed of the motor is controlled by a PI controller. The PI controller calculates the error depending upon the required speed and actual speed. Error=Actual speed-Required speed. Then it gives the error signal to the gate port of the four IGBT assembly. When the assembly receives the signal it maintains the speed of the motor at required speed by eliminating the error through PI controller. Thus one can monitor a vehicle at required speed with the help of a close loop control.

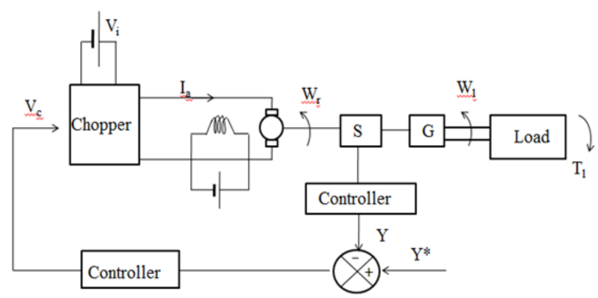

Fig. 16: Figure-Layout of speed control of DC Motor

In this design a DC motor is designed. Four IGBTs and a PI controller with value K_p =.5and K_i =1 is considered. The circuit simulation is given below-

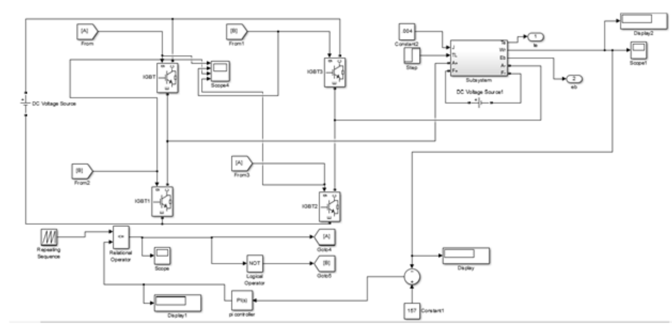

Fig. 17: Close loop speed control circuit.

4. HARDWARE IMPLEMENTATION

A typical four quadrant chopper circuit consists of four switches (IGBTs, MOSFETs, GTOs or BJTs), a motor, controller devices and power supply. Here, the microcontroller plays the role of controller device. Four MOSFETs from the IC L293D have been used as switches. Then by controlling the switches with the help of microcontroller the motor is controlled in four different operations. The block diagram is represented as-

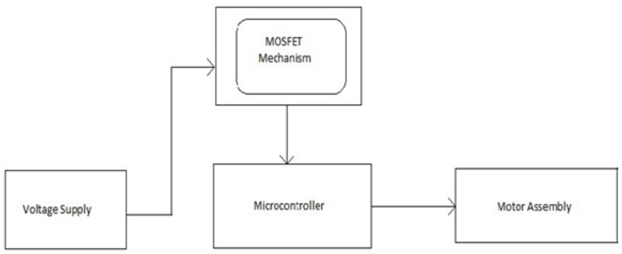

Fig. 18: Block diagram for hardware.

The block diagram in the Fig. shows the overview of the four quadrant chopper controlled DC motor. Voltage supply of satisfactory rate according to the rating of DC motor and the MOSFETs has been supplied to the MOSFET assembly. Then the signals from MOSFETs are given to the microcontroller. Depending upon the signals from the MOSFETs the controller device is programmed. The controller signal is then fed to the motor mechanism. According to the signals from four MOSFET switches the microcontroller monitors the motor in four different quadrants. The hardware consists of microcontroller AT89C51, MOSFETs, voltage regulator IC 7805 and a LCD for displaying the status.

By tapping the buttons one can operate the motor in four quadrant operations.

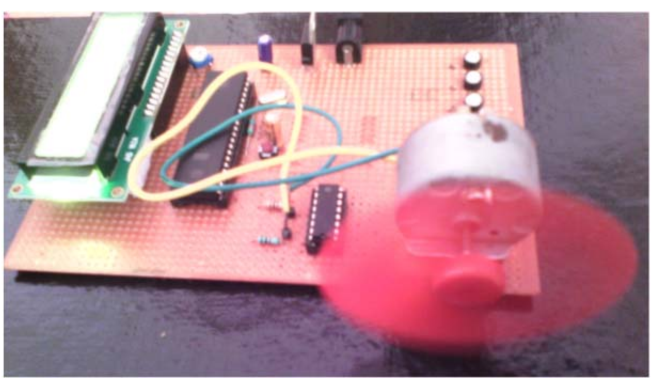

Fig. 19: Hardware model

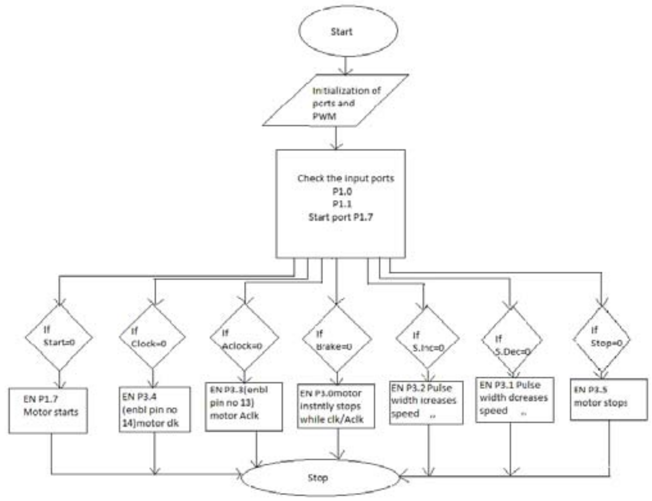

Fig. 20: Flowchart for programming.

5. CONCLUSION

Depending upon the concept of four quadrant chopper concept most of the vehicles are controlled in forward acceleration and backward acceleration. The advantages of the proposed model is only by varying duty cycle of the PWM signal from microcontroller the speed is controlled. This method reduces the use of many components as it uses microcontroller which makes the circuit compact. Microcontroller is an integration circuit of all functions which is very reliable also. This circuit suggests an efficient way of speed control of DC motors. But the circuit is not suitable for heavy motors such as in industrial applications. For this drawback we can take help of artificial intelligence (AI).

6. ACKNOWLEDGEMENT

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7. REFERENCES

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