Palestine Polytechnic University

College of Engineering

Chopper controlled separately dc motor drive system as lap unit

Project Team

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Acknowledgement

To everyone who taught me and helped me, who got me to this scientific step, to the supervisor of the project, Dr. Abdul Karim Daud, To all the faculty members who teach me in the Department of Electricity, to my Mum, Dad, Brothers, Friends, Lovers and Relatives, we dedicate this project that may support other research in the future.

Abstract

This thesis proposes a low-cost educational approach to control the speed of DC motor. It aims to provide an educational tool for engineering students who are interested in DC motors control. The design of this project is based on the Real-time communication and control combination between LABVIEW and Arduino microcontroller.

Where the control law is computed using PID control method and transmitted using Serial port to microcontroller, which in turns converts the control signal into PWM power signal and applies it to the actuator.

As the shaft of the DC motor is rotating, the angular position of the shaft is measured and transmitted to the LABVIEW as a feedback signal. The results insure the validity of this approach in terms of Real-time communication and the ability to track the reference signal applied by the user. It is also applicable for position control, acceleration control and torque control.

الملخص

تقدم هذه الاطروحة نظام تعليمي قليل التكلفة للتحكم بسرعة محرك كهربائي ذو تيار مستمر.

تهدف لتصميم اداة تعليمية لطلاب الهندسة المهتمين بمجال التحكم بالمحركات الكهربائية.

يعتمد تصميم النظام على نظام اتصالات وتحكم ذو وقت فعلي من خلال ربط متحكم الاردوينو ببرنامج المحاكاة LABVIEW ، بحيث يتم حساب قيمة قانون التحكم في برنامج المحاكاة باستخدام المتحكمPID ، ثم يتم ارسال هذه القيمة الى الاردوينو من خلال المنفذ التسلسلي، فيقوم الاردوينو بتحويل هذه الاشارة الى اشارة مناسبة ليتم تطبيقها على المحرك .موقع الزاوي له، ويتم قياس هذه القيمة وارسالها الى عندما يقوم المحرك بالدوران، تتغير قيمة ال برنامجLABVIEW كتغذية راجعة. تؤكد النتائج صلاحية الاسلوب المستخدم من ناحية الاتصال بالوقت الحقيقي والقدرة على تتبع الاشارة المرجعية المطبقة من قبل المستخدم. هذا الاسلوب صالح ليس فقط باستخدام متحكم PIDاخرى من عو صالح ايضا للأنوا، بل ه المتحكمات. كما يمكن استخدامه ايضا للتحكم بالموقع والتسارع.

Contents

Chapter 1: Introduction

Chapter 1: DC Chopper

List of Tables

List of Figures

LIST OF SYMBOLS AND ABBREVIATIONS

Ton:on time.

Toff: off time.

D: duty cycle .
vf: Field Voltage.

If: Field Current.

Rf: Resistance field.

Lf: Self-inductance of field circuit .

va: Armature Voltage in (volts).

Ia: Armature Current in (A).

Ra: Armature Resistance in (Ω).

La: Self-inductance of armature circuit .

Ea: Back emf.

kØ: Motor voltage constant (VA).

W: Motor speed (rad/sec).

Tl: is load torque in Nm.

Td: is the torque developed in Nm.

J :is moment of inertia in kg/m².

B: is friction coefficient of the motor.

τm: mech.constant.

Ta: Armature time constant.

Lmin: minimum inductance.

CHAPTER 1
Introduction

1.1 Overview

This thesis mainly deals with controlling the speed of the DC motor using type A and C Chopper as a power transformer. The PID controller was used as the speed controller and the reference signal was applied using LABVIEW and the control signal is delivered to Arduino to control the driver voltage [3].

1.2 Objectives

1. To establish a working unit for the laboratory to conduct the required experiments to control the speed of the DC motor.
2. To study the effect of the using LABVIEW as Realtime controller .
3. To control the speed of the electric motor in four quarters using class A and C Chopper.
4. To provide a research tool that enables students and researchers to implement different types of control algorithms and to validate them with the theoretical science.

1.3Literature Review

Research [1] used a four quadrant speed control model is designed by using chopper to control the speed of DC motor in both forward and reverse directions where the PWM signal was generated by the IC LM324. This method is stable and efficient, however it does not supper digital reference signal tracking and monitoring due to the absence of the microcontroller. The study [2] shows how to use four quadrant operation and speed control of a BLDC Motor using LABVIEW, however the paper depends only on simulation without practical results.

The research [3] developed a four quadrant speed control system for a DC motor with Pulse width modulation (PWM) by the mean of a microcontroller. However, the entire control system is open loop and cannot guarantee that the desired speed will be reached with neglectable steady state error. In project [4] the modeling of BLDC motor drive system along with its control system have been presented using H-bridge type arrangement MOSFET work like a drive and for controlling purpose we use microcontroller AT 89S52. However, any change in motor's parameters requires to change the control law, which require to change these parameters programmatically, this case require an open source code and high knowledge of AT programing .

Paper [5] constructed a system which can control the speed of DC series motor by using power MOSFET chopper by the mean of closed loop control. However this study was achieved theoretically without hardware results. A reversible D.C. drive system, which employs a four-quadrant chopper with the insulated gate bipolar transistors (IGBT), is presented theoretically in [6]. [7] illustrates how the speed of a DC motor can be controlled using a chopper drive by the mean of open loop control. However the open loop control is not efficient in applications that require accuracy.

Paper [8] implements a closed loop control for DC motor using Chopper based on PI controller. However the controller gain and algorithm cannot be changed easily as the must be changed programmatically. Also [9] implements a Chopper-based speed control for DC motors using open loop Simulink. Finally, [10] depends on PIC microcontroller to generate PWM signal to control a DC motor open loop using Chopper.

In this project, a closed loop controller is designed to control the speed of a DC motor in both forward and reverse directions based on chopper of class E. The controller depends on the PID control algorithm to achieve speed control task and to guarantee that the steady state error will approach to zero after finite time. The control law is computed online using LABVIEW upon receiving the feedback signal, and transmitted to the Arduino microcontroller to achieve the task. This approach ensures the flexibility of the control system to be developed and modified for future usage and comparative studies.

CHAPTER 2 DC chopper

2.1 Introduction of DC Chopper

A chopper is a static power electronic device that converts fixed dc input voltage to a variable dc output voltage [11]. It can be step up or step down. It is also considered as a dc equivalent of an ac transformer since they behave in an identical manner. Due to its one stage conversion, choppers are more efficient and are now being used all over the world for rapid transit systems, in the hoist, in haulers and in trucks, etc. The future electric automobiles are likely to use choppers for their speed control and braking. Chopper systems offer smooth control, high efficiency, faster response and regeneration facility. The power semiconductor devices used for a chopper circuit can be force commutated thyristor, BJT, MOSFET, IGBT and GTO. Among above switches IGBT and MOSFET are widely used. These devices are generally represented by a switch. When the switch is OFF, no current will flow. Current flows through the load when the switch is ON.

2.2 Principle of chopper operation

A chopper is a high speed “on" or “off” semiconductor switch. It connects source to load and load and disconnect the load from source at a fast speed [12]. A constant dc supply of magnitude is given as input voltage and let its output voltage across load be Vo. Chopper is on and load voltage is equal to source voltage. During the period Toff, chopper is off, load voltage is zero. In this manner, a chopped DC voltage is produced at the load terminals as shown in Fig.2.1.

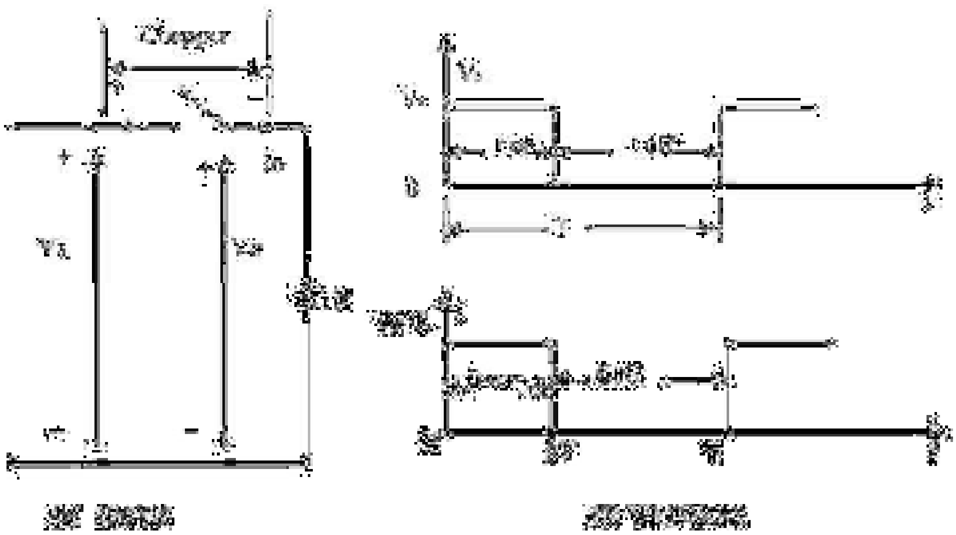


Figure 2.1:Chopper circuit diagram and its voltage and current waveform

The equations of the chopper can be expressed as,

⟹Average Voltage ,

$V_o = (T_{on} / (T_{on} + T_{off})) * V_s$ (1)

⟹Thus, the voltage can be controlled by varying duty cycle D.

$V_o = f * T_{on} * V_s$ (2)

⟹chopping frequency

$f = 1/T$ (3)

Where,

V_O is the average voltage, Ton is ON time, Toff is OFF time, T is chopping period, Vs is input voltage and D is duty cycle.

The average output voltage V_O can be controlled by varying duty cycle. There are various control strategies for varying duty cycle as will be discussed in the next section.

2.3 Classifications of Chopper

2.3.1 Step-down Chopper (Buck Converter)

In this case, the average value of the voltage at the terminals of the load is less than the voltage of the source, meaning that the operating ratio is less than one. Fig.2.2 shows the basic circuit diagram of this type, which consists from a switch, inductor, capacitor and a diode. The output voltage of this type is constrained as follows

$0 \leq V_{OUT} \leq V_S$

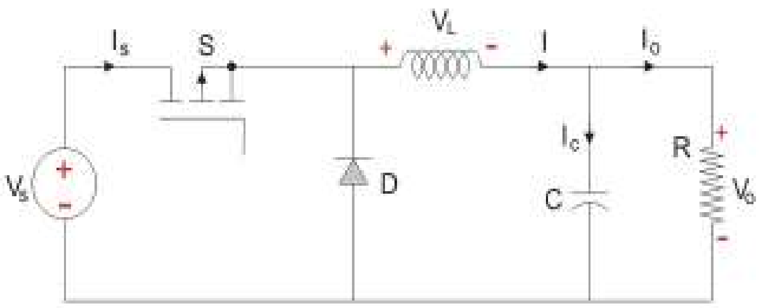


Figure 2.2.a:Buck chopper circuit

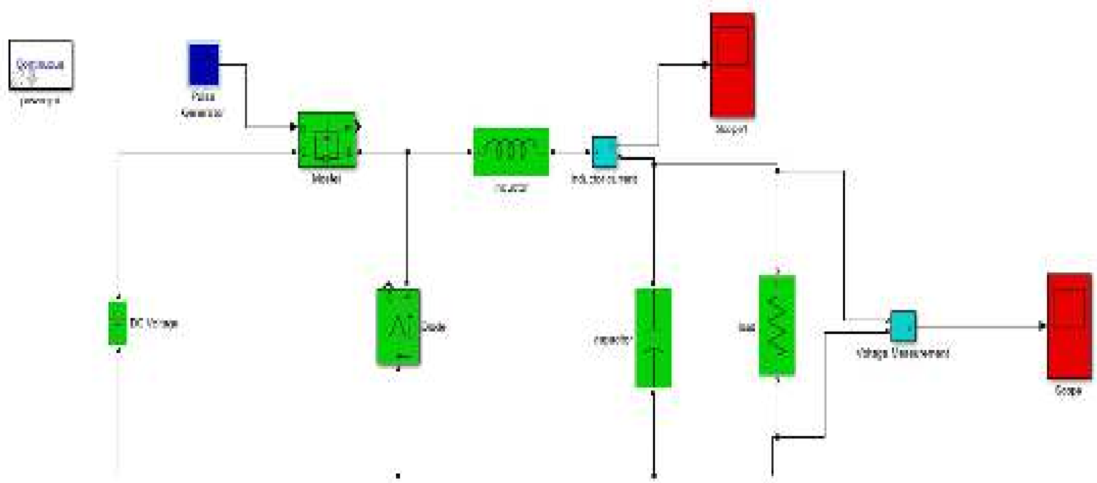


Figure 2.2.b:Buck chopper Simulink

Fig.2.3 shows the relationship between input and output voltage and the charging and discharging process in the inductor.

- When the switch is opened (S=OFF), the derivative of current (i_L) is a negative constant as follows,

$$\frac{di_L}{dt} = \frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{(1-D)T} = \frac{-V_0}{L} \qquad \textbf{(4)}$$

$$(\Delta i_L)_{opend} = \frac{-V_0}{L}(1-D)T \qquad \textbf{(5)}$$

- When the switch is closed (S=ON), the derivative of current (i_L) is a positive constant as follows,

$$\frac{di_L}{dt} = \frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{DT} = \frac{V_S-V_0}{L} \qquad \textbf{(6)}$$

$$(\Delta i_L)_{closed} = \frac{V_S-V_0}{L} DT \qquad (7)$$

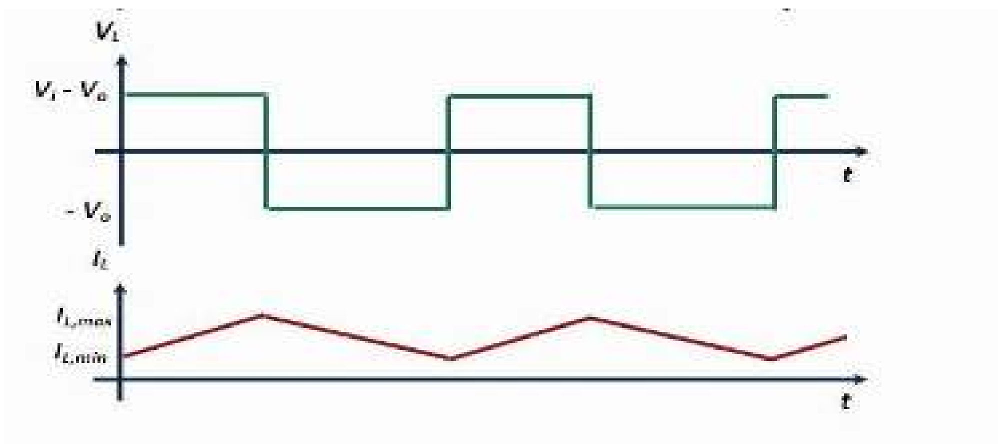


Figure 2.3.a:Buck chopper circuit output voltage and current

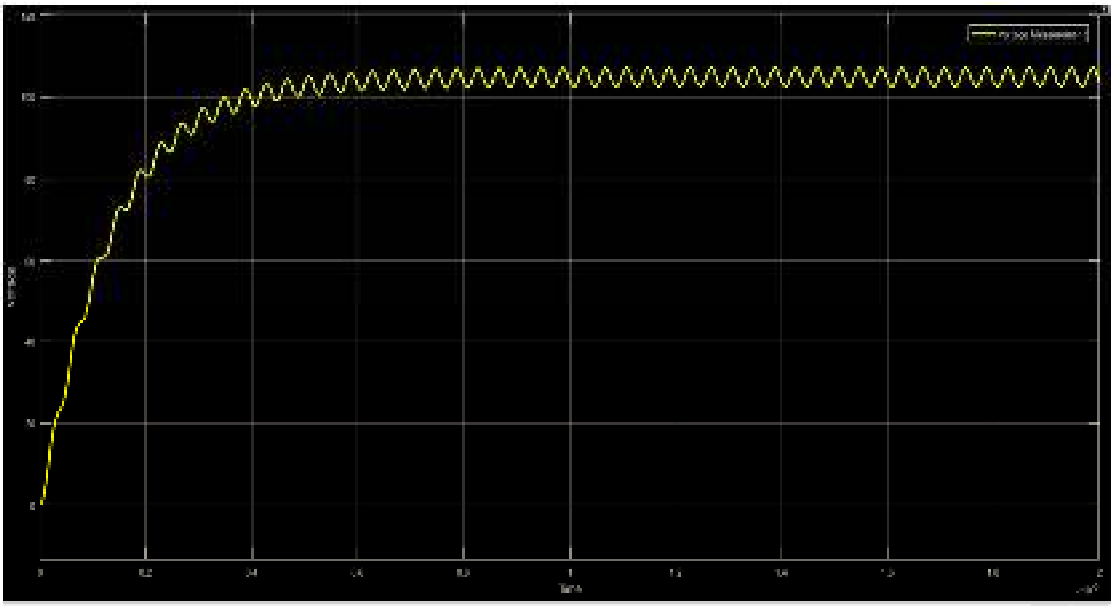


Figure 2.3.b:Buck chopper response.

2.3.2 Step-up Chopper (Boost Converter)

In this case, the average value of the voltage at the terminals of the load is greater than the voltage of the source. It consists of a switch, a highvalue coil, and a diode as shown in Fig.2.4. When the switch is turned on, the current passes for a long time in the coil and stores large amount of energy in the coil, and when the switch is turned off, it discharges its energy through the load [13]. The output voltage constraint is given by, $V_S \leq V_{out} \leq$ □.

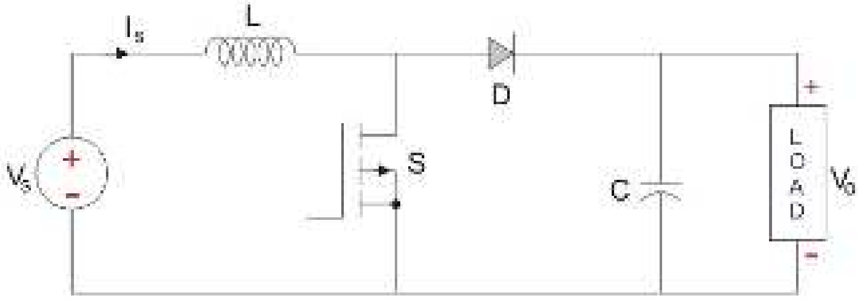


Figure 2.4.a. Boost chopper circuit.

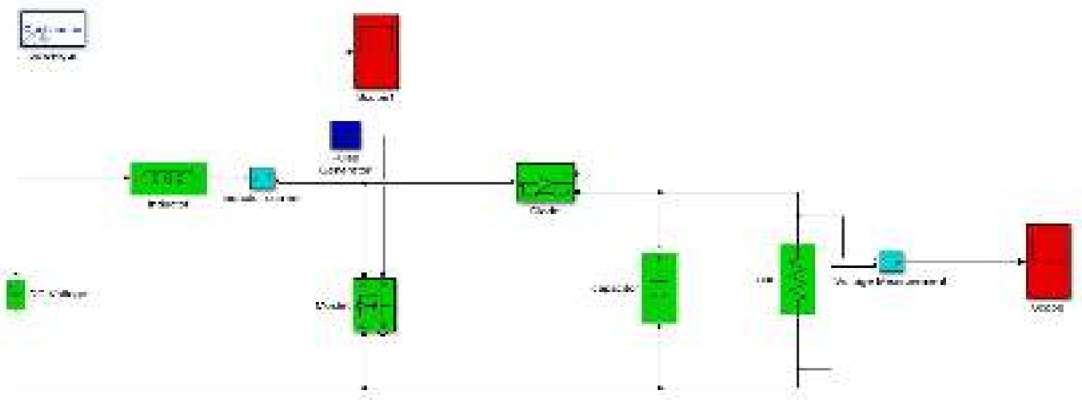


Figure 2.4.b. Boost chopper Simulink.

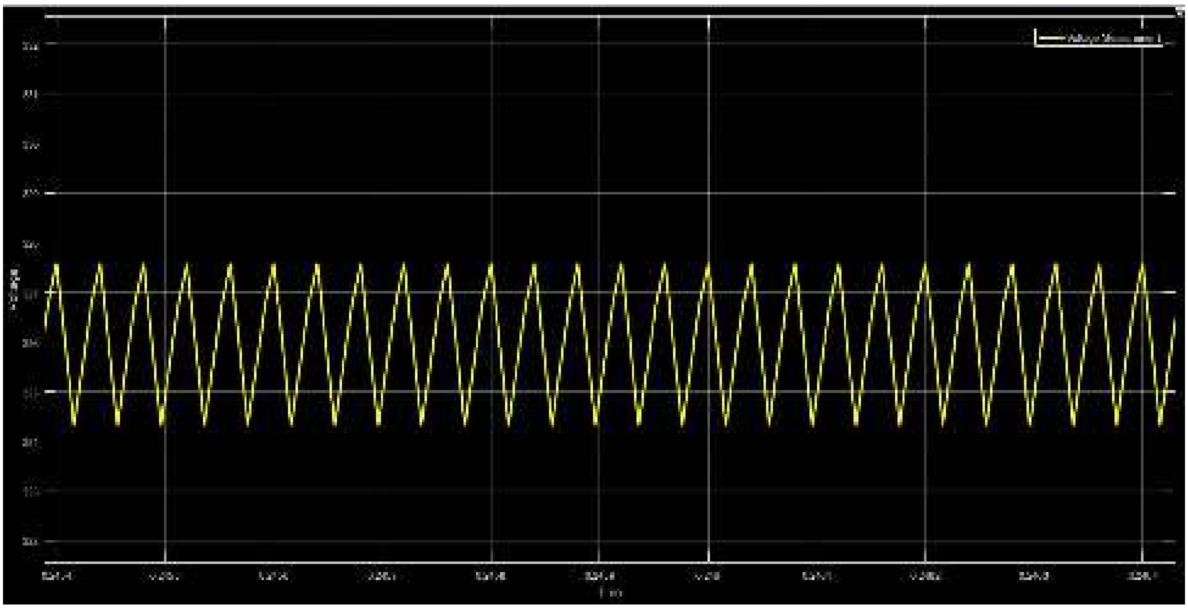


Figure 2.4.c. Boost chopper output.

- When the switch is opened (S=OFF), derivative of current (i_L) is a positive constant as follows,

$$\frac{d_i}{dt} = \frac{\Delta i_L}{\Delta t} = \frac{(\Delta i_L)}{(1 - D)T} \quad (8)$$

$$(\Delta i_L)_{opened} = \frac{V_s - V_o}{L}(1 - D)T \quad (9)$$

$$D = 1 - \frac{V_s}{V_o} \qquad (10)$$

- When the switch is closed (S=ON), the derivative of current (i_L) is a negative constant as follows,

$$\frac{di_L}{dt} = \frac{\Delta i_L}{\Delta t} = \frac{(\Delta i_L)}{DT} \qquad (11)$$

$$(\Delta i_L)_{closed} = \frac{V_s}{L} DT \qquad (12)$$

2.3.3Step-down/up Chopper (Buck-Boost converter)

In this type of direct current chopper, the output voltage value may be greater or smaller than the source voltage, depending on the Duty Cycle of the PWM signal[14].

The constraint of the output voltage can be written as the following equation, and the basic circuit is shown in Fig.2.5.

$0 \leq V_{out} \leq$ □

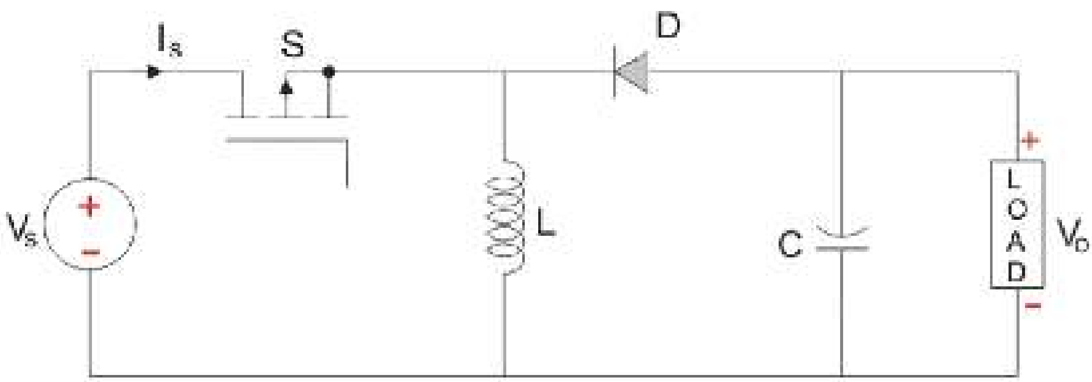


Figure 2.5. Buck boost basic circuit.

- When the switch is opened (S=OFF), the derivative of current (i_L) is a positive constant, as follows,

$$\frac{di_L}{dt} = \frac{V_s}{L} = \frac{\Delta i_L}{\Delta t} = \frac{(\Delta i_L)}{(1-D).T} \qquad (13)$$

$$(\Delta i_L)_{opened} = \frac{V_s}{L}(1-D)T \qquad (14)$$

- When the switch is closed (S=ON), the derivative of current (i_L) is a negative constant, as follows,

$$\frac{di_L}{dt} = \frac{V_d}{L} = \frac{\Delta i_L}{\Delta t} = \frac{(\Delta i_L)}{D.T} \qquad (15)$$

$$(\Delta i_L)_{closed} = \frac{V_s}{L} DT \qquad (16)$$

2.4 Pulse-Width Modulation (PWM)

2.4.1 Introduction

PWM works by pulsating DC current, and varying the amount of time that each pulse stays 'on' to control the amount of current that flows to a device such as an LED. PWM is digital, which means that it has two states: on and off (which correspond to 1 and 0 in the binary context, which will become more relevant by using microcontrollers [15].

If the PWM signal is connected to a LED, the longer each pulse is on, the brighter the LED will be. Due to the fact that the interval between pulses is so brief, the LED doesn't actually turn off. In other words, the LED's power source switches on and off so fast (thousands of times per second) that the LED actually stays on without flickering. This is called PWM dimming, and such as circuit is just called a PWM LED dimmer circuit.

2.4.2 Principle of PWM operation

The squares in the PWM shown in Fig.2.6 are the pulses which represent 'on' time, and the depressed areas represent the time that the power is 'off'. Both the squares and depressed areas are the same 'width', therefore the duty cycle is 50%. PWM signals are typically square waves.

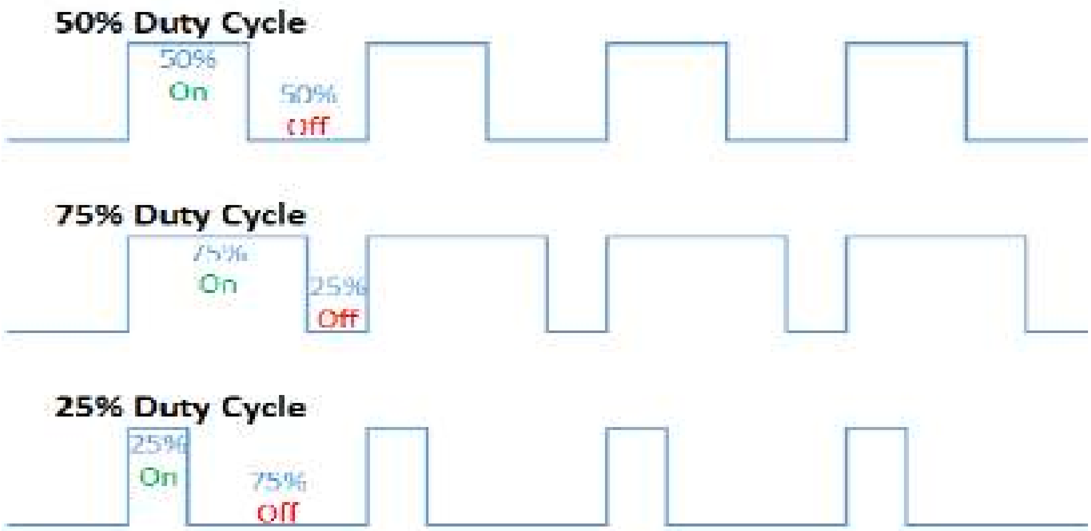


Figure 2.6:duty cycle difference.

Many projects depend on controlling the speed of a DC motor by using large variable resistances. Motor speed can be controlled by regulating the value of voltage passing through the motor terminals using a simpler method, pulse width modulation, or PWM. Speed is controlled using this method – as the name indicates – by driving the motor with a series of "ON-OFF" pulses and changing the duty cycle while the frequency remains constant The motor speed can be changed by adjusting the width of these pulses in order to control the power value applied to it, that is, changing the average value of the continuous voltage applied to the motor terminals, so the longer the pulse time (in the ON state) the longer the motor rotates, the more quickly, and correspondingly if the pulse time (in the ON state) The shorter the motor will rotate at a slower speed. In other words, the greater the pulse width, the greater the average value of the voltage applied to the motor terminals.

2.5 Pulse-Frequency Modulation (PFM)

2.5.1 Introduction

Pulse-Frequency Modulation (PFM) is a modulation method for representing an analog signal using only two levels (1 and 0). It is analogous to pulse-width modulation (PWM), in which the magnitude of an analog signal is encoded in the duty cycle of a square wave. Unlike PWM, in which the width of square pulses is varied [16].

Constant frequency, PFM fixes the width of square pulses while varying the frequency. In other words, the frequency of the pulse train is varied in accordance with the instantaneous amplitude of the modulating signal at sampling intervals. The amplitude and width of the pulses is kept constant.

2.5.2 Principle of PFM operation

While in PFM mode, the converter only operates when the output voltage is below the nominal output voltage. When this happens, the converter begins switching until the output voltage is regulated to atypical value between the nominal output voltage and 0.8% above the nominal output voltage. During the period where the converter is powered down, all unnecessary internal circuitry is turned off to reduce the IC's quiescent current. This control method significantly reduces the quiescent current to a typical value of 20µA, which results in higher efficiency at light loads In contrast to PWM mode, in which the converter is continuously switching, PFM mode allows the converter to switch in short bursts [17].

- PWM is fix frequency; pulses widen to bring more power,
- PFM send constant duration pulses that get closer to give more power

The deference between PWM and PFM are shown in Fig.2.7 and illustrated in Table

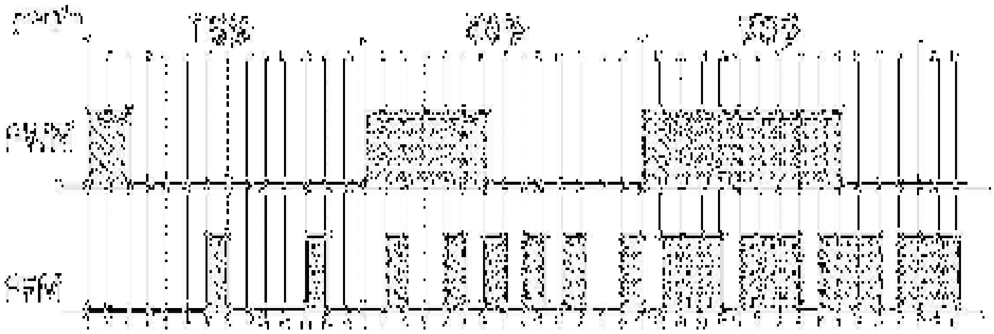


Figure 2.7:Comparison between PWM and PFM.

Table 2.1 Differences between (PWM) and (PFM)

PWM	PFM
uses a fixed-frequency oscillator to drive the power switches.	uses a variable frequency clock to drive the power switches.
Excellent efficiency under tough loading conditions.	Better efficiency under light load conditions.
When entering fixed frequency circuits, total output power levels very low.	When entering variable frequency circuits Energy saving mode, total output power levels very low.
Low noise operation	high noise operation

2.6 Four Quadrant Speed Control of dc Motor Using Chopper

2.6.1 Class A DC chopper (the first quadrant)

When chopper is ON, supply voltage V is connected across the load. When chopper is OFF, $V_O = 0$ and the load current continues to flow in the same direction through the FWD. The average values of output voltage and current are always positive. Class A Chopper is a first quadrant chopper. It is a step-down chopper in which power always flows form source to load. It can be used to control the speed of dc motor. Fig.2.8 shows its circuit diagram and Fig.2.9 Shows the output voltage and current.

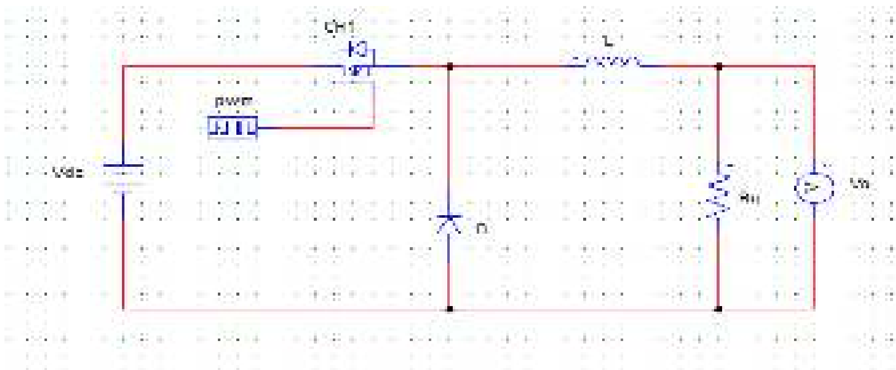


Figure 2.8.a: Class A DC chopper circuit.

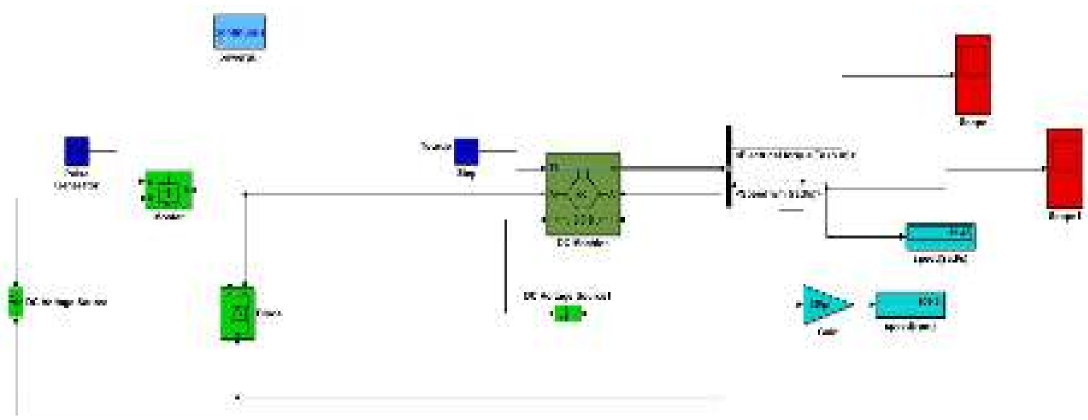


Figure 2.8.b: Class A DC chopper Simulink with DC motor.

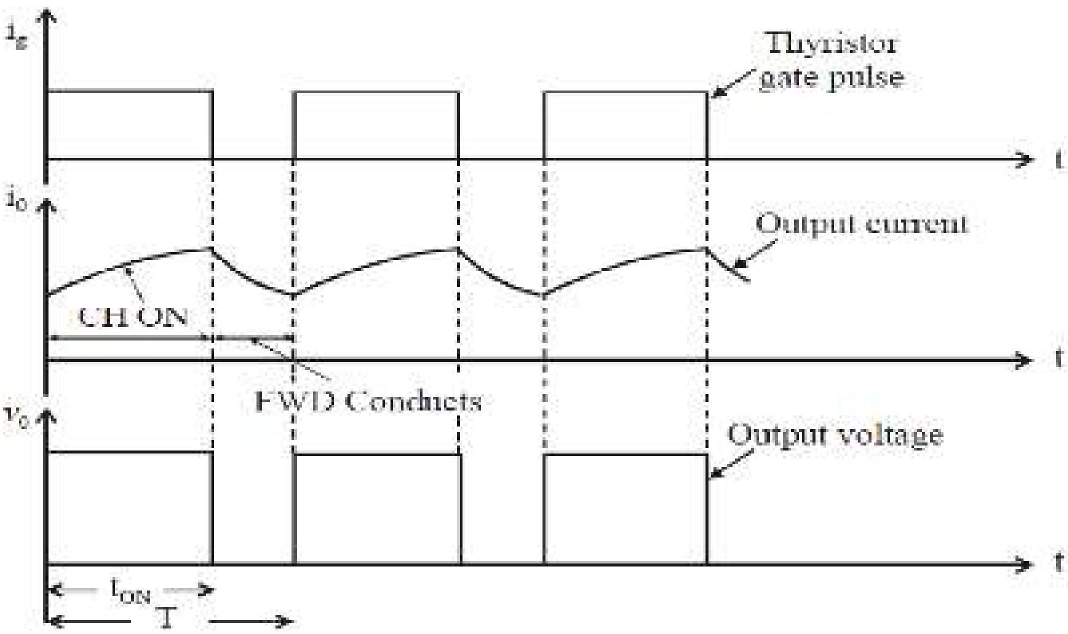


Figure 2.9.a:output voltage and current class A dc chopper.

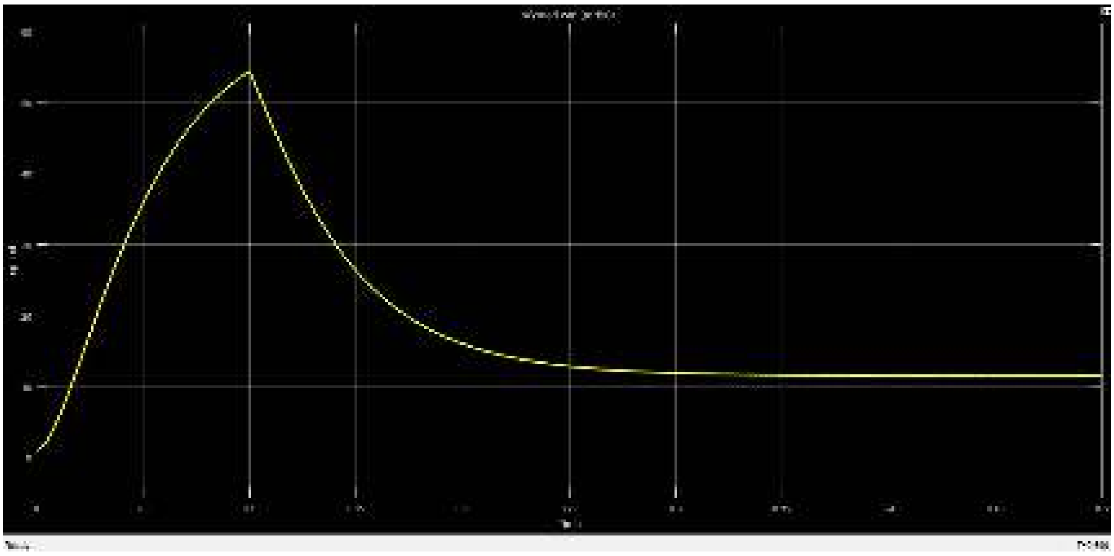


Figure 2.9.b:Response of class A dc chopper.

2.6.2 Class B DC chopper (the second quadrant)

The circuit diagram of this chopper type is shown in Fig.2.10. When chopper is ON, E drives a current through L and R in the opposite direction as shown in Fig.2.11. During the ON period of the chopper, the inductance L stores energy. When chopper is OFF, diode D conducts, and part of the energy stored in inductor

L is returned to the supply. The average output voltage is positive, while the average output current is negative.

Class B Chopper is a step-up chopper, operates in second quadrant and is used for regenerative braking of dc motor. In this chopper, power flows from load to source.

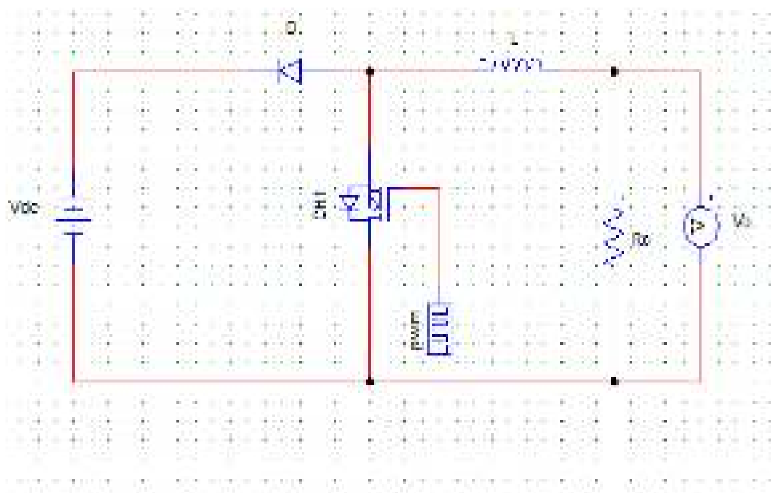


Figure 2.10.a:Class B DC chopper.

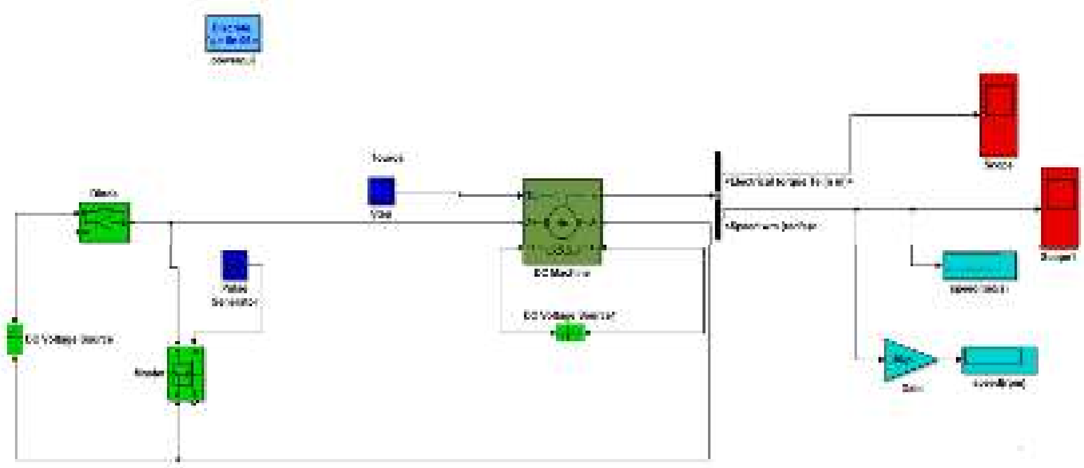


Figure 2.10.b:Class B DC chopper Simulink with DC motor.

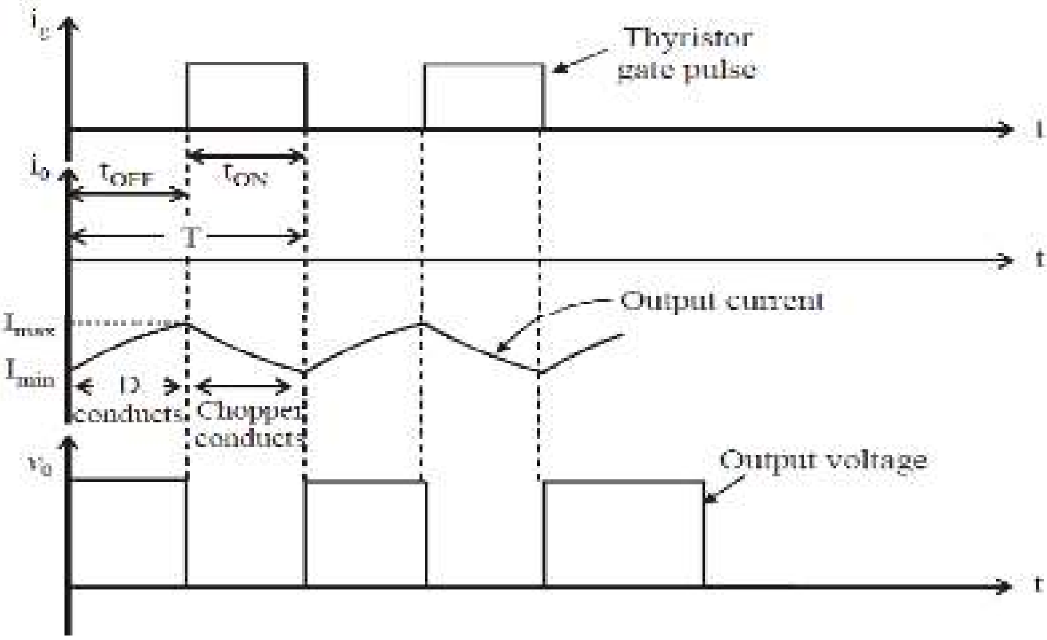


Figure 2.11.a: Output voltage and current class b dc chopper.

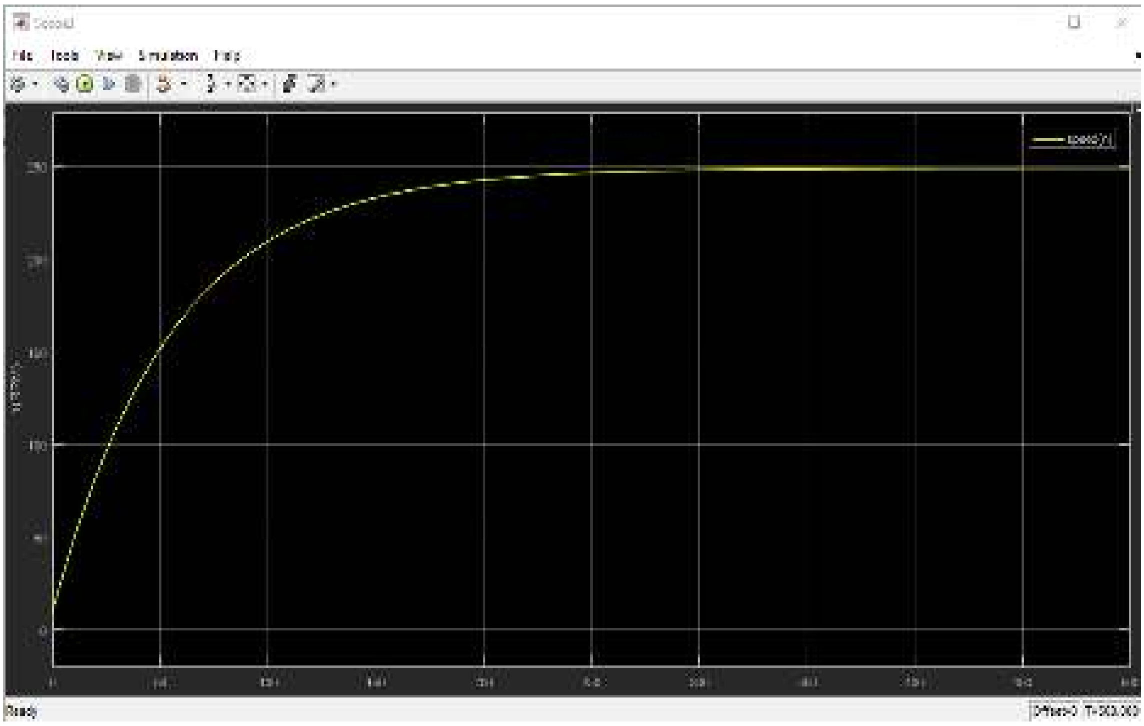


Figure 2.11.b: Output Speed Class B Chopper dc Motor.

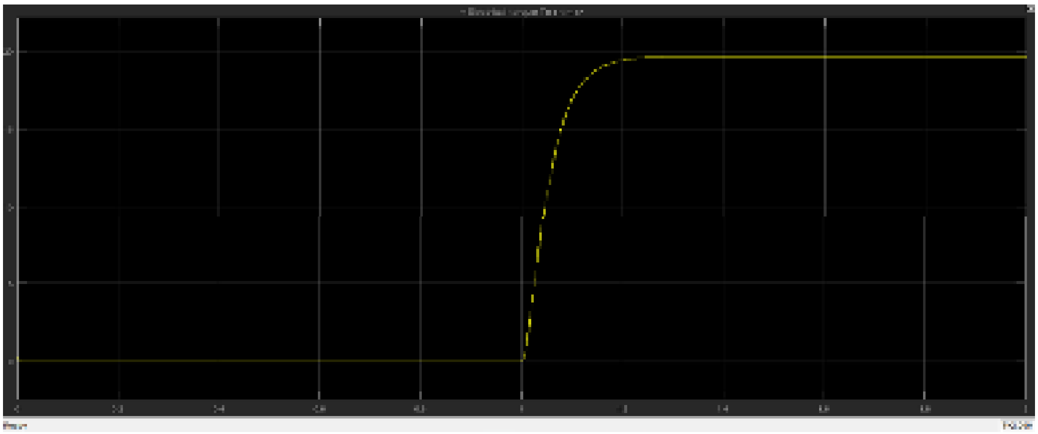


Figure 2.12.c:Output Torque Class B Chopper dc Motor

2.6.3 Class C DC chopper (the two quadrants operation) Class C Chopper is a combination of Class A and Class B Choppers. For first quadrant operation, CH1 is ON or D2 conducts. For second quadrant operation, CH2 is ON or D1 conducts. When CH1 is ON, the load current is positive. The output voltage is equal to 'V' and the load receives power from the source.

- When CH1 is turned OFF, energy stored in inductance L forces current to flow through the diode. Current continues to flow in positive direction.
- When CH2 is triggered, the voltage E forces current to flow in opposite direction through L and CH2 and the output voltage is zero.
- On turning OFF CH2, the energy stored in the inductance drives current through diode D1 and the supply and the output voltage is V, the input current becomes negative and power flows from load to source.de D2 and the output voltage is zero. And the average output voltage is positive

Average output current can take both positive and negative values. Chopper's CH1 and CH2 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 for regenerative braking of dc motor. It can be also used as a step-up or step-down chopper. The circuit diagram of this type is shown in Fig.2.12 and it output current and voltage is shown in Fig.2.13.

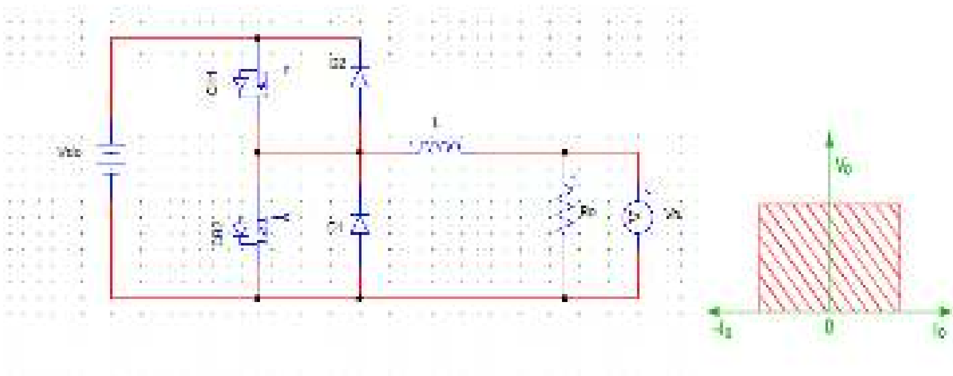


Figure 2.12.a:Class C DC chopper.

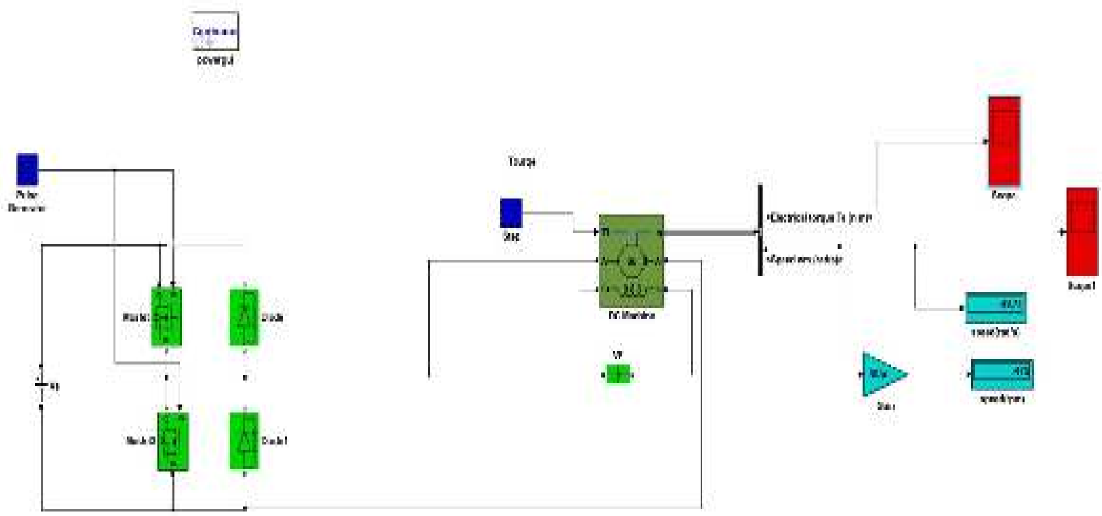


Figure 2.12.b:Class C DC chopper Simulink with DC motor2 0

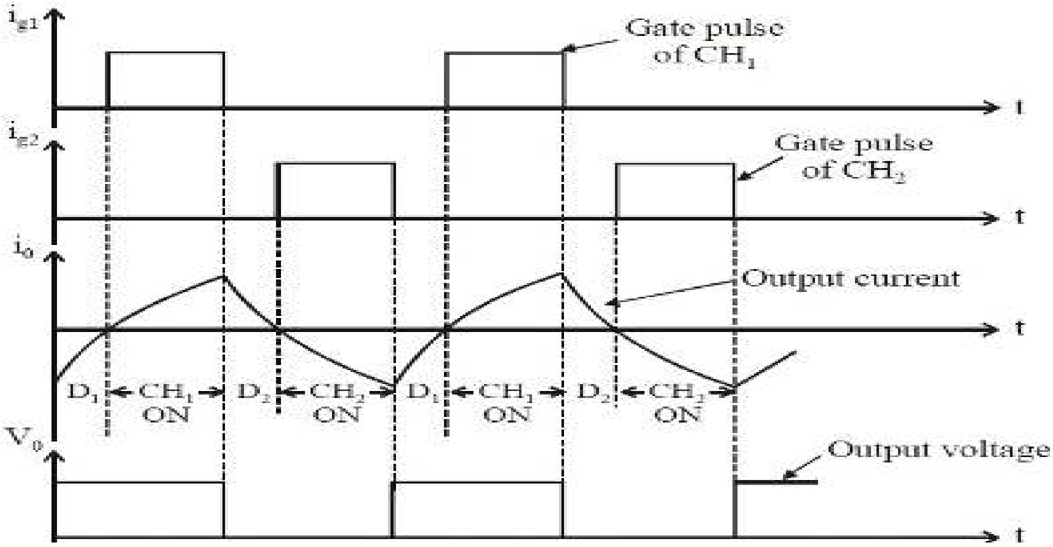


Figure 2.13.a:output voltage and current class c dc chopper.

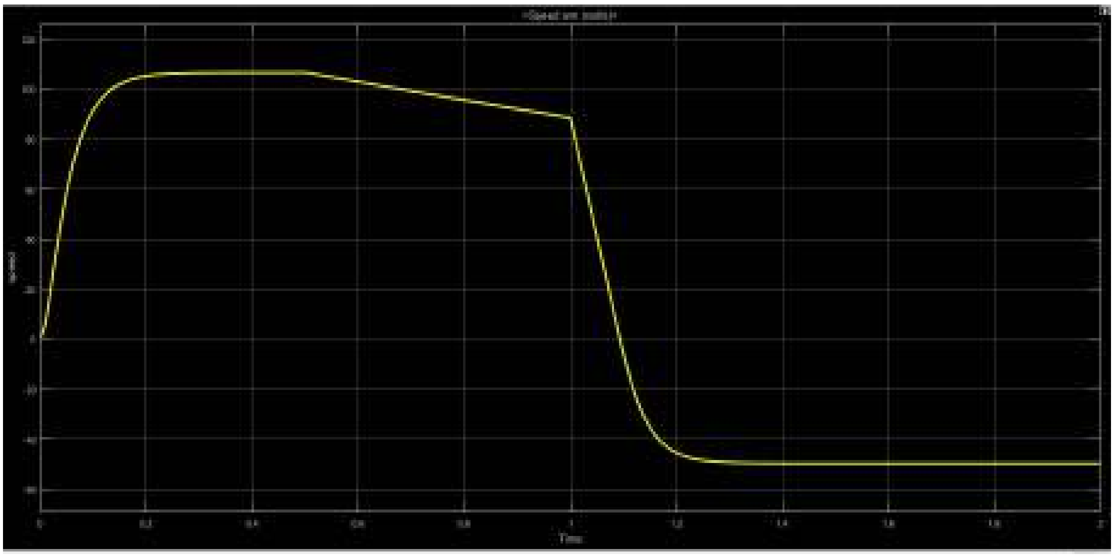


Figure 2.13.b:Output Speed Class C Chopper dc Motor.

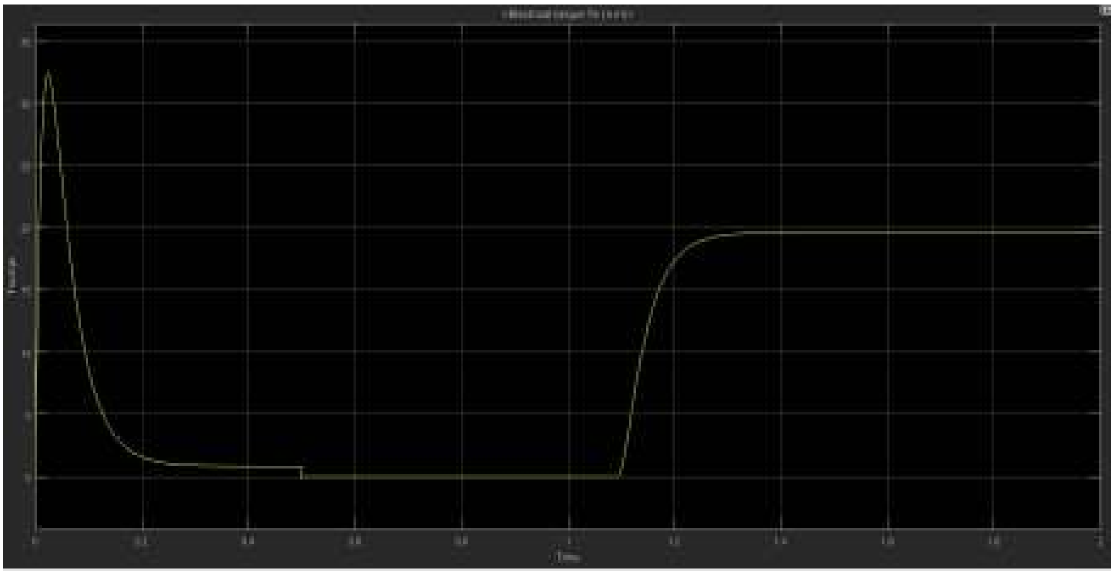


Figure 2.13.b:Output Tourqe Class C Chopper dc Motor.

2.6.4 Class D DC chopper (the two quadrants operation)

Class D is a two-quadrant chopper.

- When both CH1 and CH2 are triggered simultaneously, the output voltage $V_O = V$, and output current flows through the load.
- When CH1 and CH2 are turned OFF, the load current continues to flow in the same direction through load, D1 and D2, due to the energy stored in the inductor L and the output voltage is $V_O = - V$.

The average load voltage is positive if chopper ON time is more than the OFF time, on the other hand, the average output voltage becomes negative if $T_{on} < T_{off}$.

Which means that the direction of load current is always positive but load voltage can be positive or negative as shown in the following equations,

$$V_0 = (V_s T_{on} - V_s T_{off}) / T \quad \textbf{(17)}$$

$$V_0 = V_s . (T_{on} - T_{off}) / T \quad \textbf{(18)}$$

The circuit diagram of this type is shown in Fig.214 and its output curves are shown in Fig.2.15.

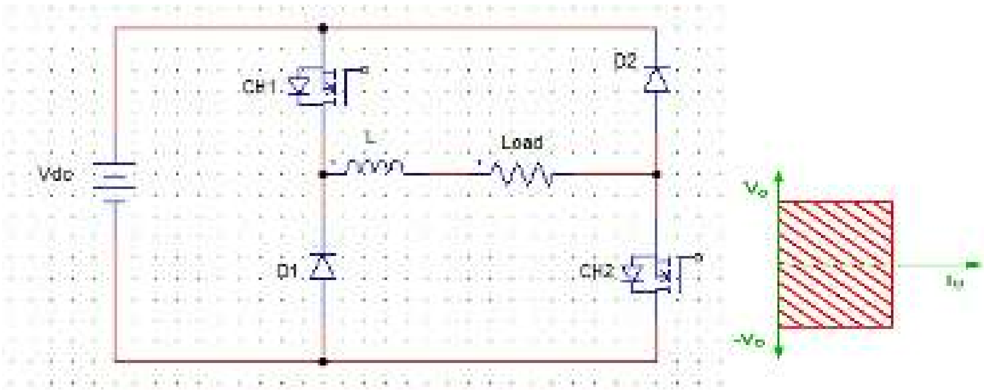


Figure 2.14.a: Class D DC chopper.

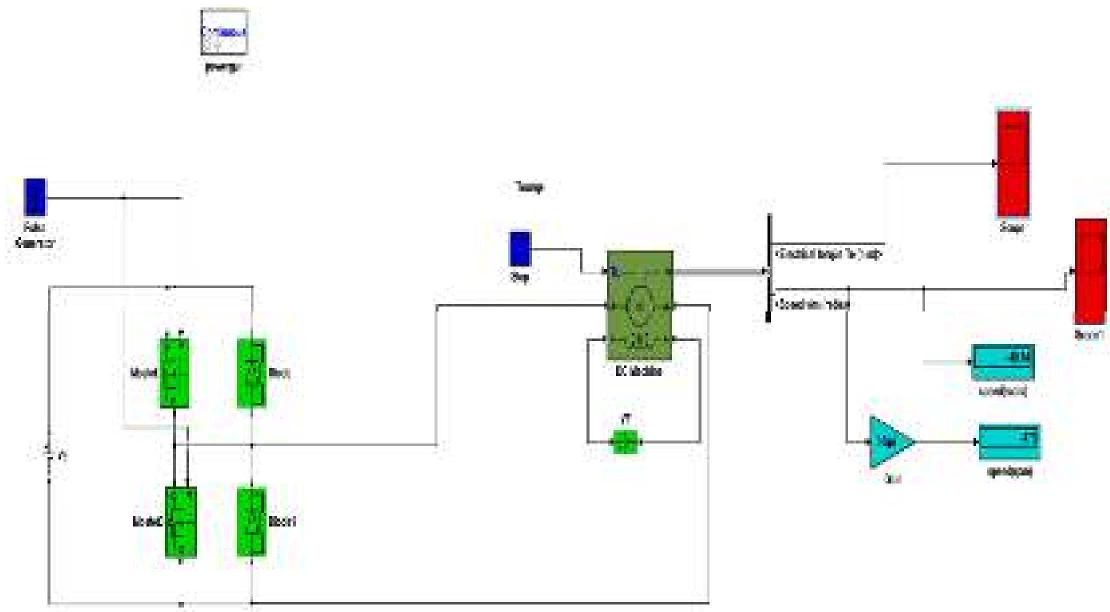


Figure 2.14.b: Class D DC chopper Simulink with DC motor.

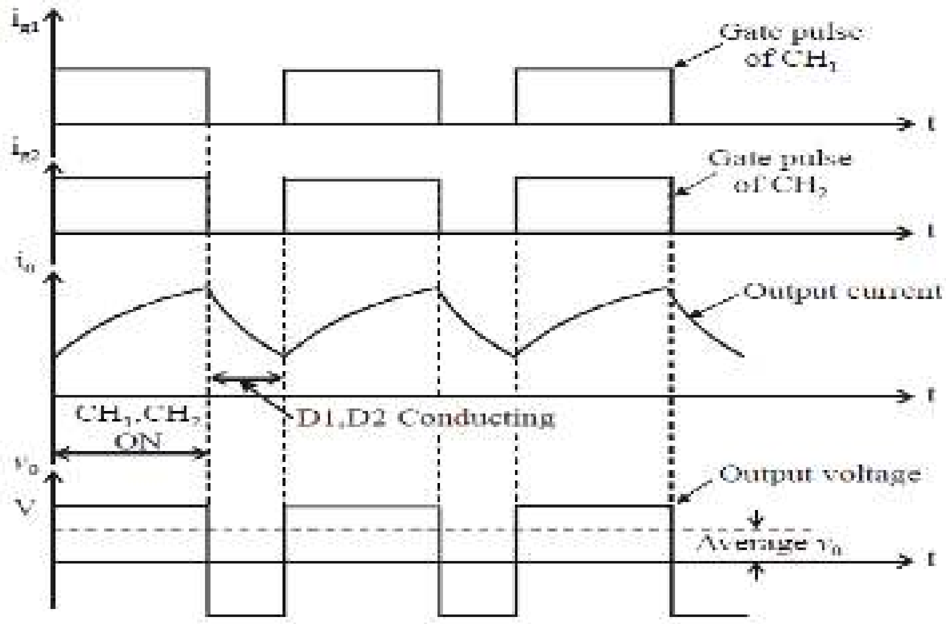


Figure 2.15.a :output voltage and current class d dc chopper.

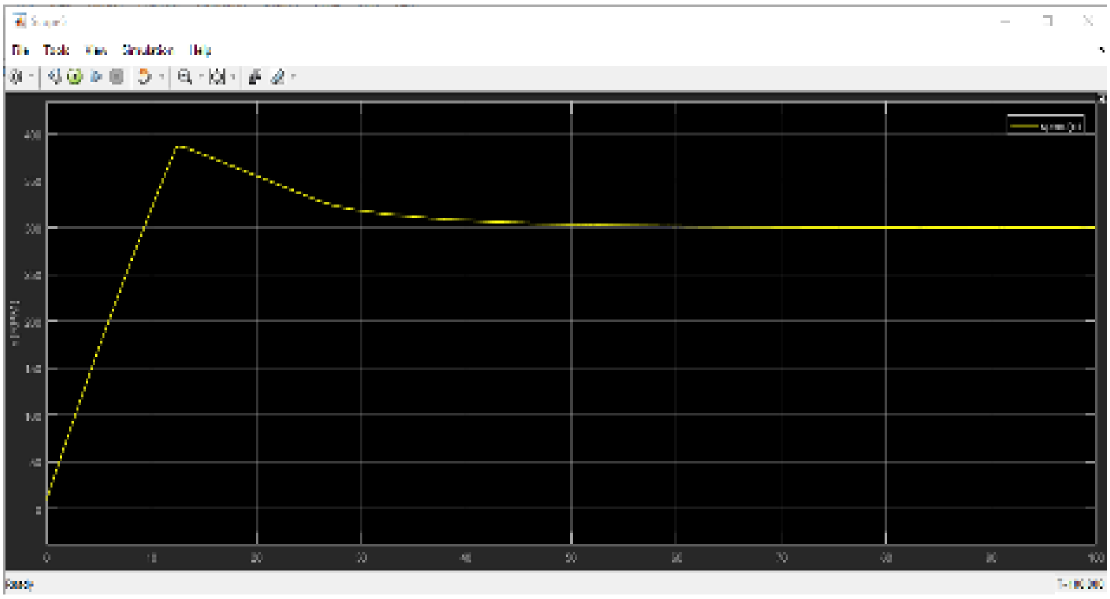


Figure 2.15.b:Output Speed Class D Chopper dc Motor.

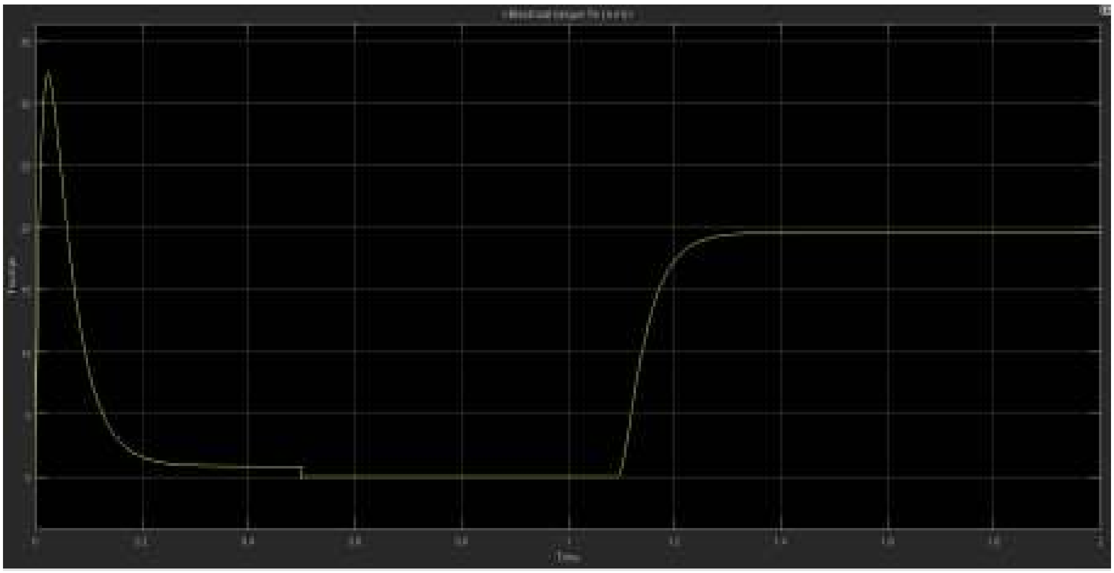


Figure 2.15.c: Output Tourqe Class D Chopper dc Motor.

2.6.5 Class E DC chopper (the four quadrants operation)

Class E is a four-quadrant chopper, when CH1 and CH4 are triggered, output current Io flows in positive direction through CH1 and CH4, and with output voltage Vo = V. This gives the first quadrant operation. When both CH1 and CH4 are OFF, the energy stored in the inductor L drives Io through D2 and D3 in the same direction, but output voltage Vo= -V. Therefore the chopper operates in the fourth quadrant.

When CH2 and CH3 are triggered, the load current Io flows in opposite direction and output voltage Vo = -V. Since both Io and Vo are negative, the chopper operates in third quadrant. When both CH2 and CH3 are OFF, the load current Io continues to flow in the same direction D1 and D4 and the output voltage Vo = V. Therefore the chopper operates in second quadrant as Vo is positive but Io is negative.

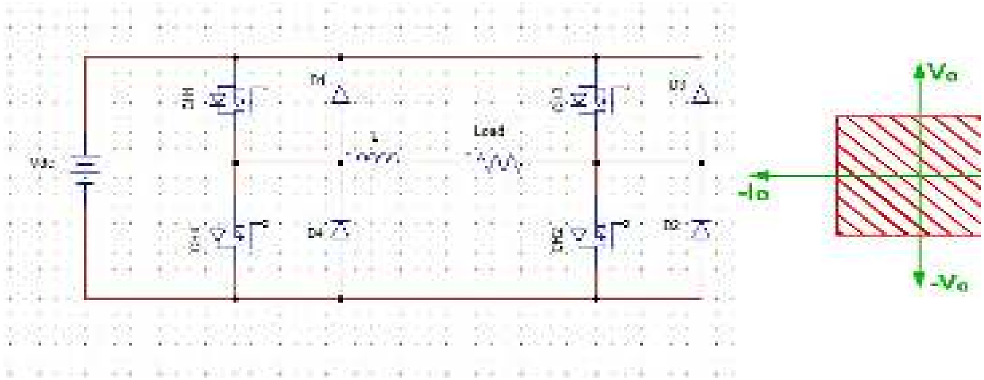


Figure 2.16:Class E DC chopper.

Working Class E DC chopper

- **First quadrant**

When chopper CH1 and chopper CH2 are switched on, the load current flows through (+)Vdc– CH1 –L– LOAD –CH2 –Vdc(–). The output voltage and current both are positive therefore it is first quadrant operation. This quadrant is shown in Fig.2.17.

- **Second quadrant:**

When chopper CH3 and chopper CH4 are switched off, the stored energy of inductor dissipates through Vdc(–) –D2–LOAD– L – D1 – (+)Vdc. The output voltage is positive but output current negative during that period therefore it is second quadrant operation. This quadrant is shown in Fig.2.18.

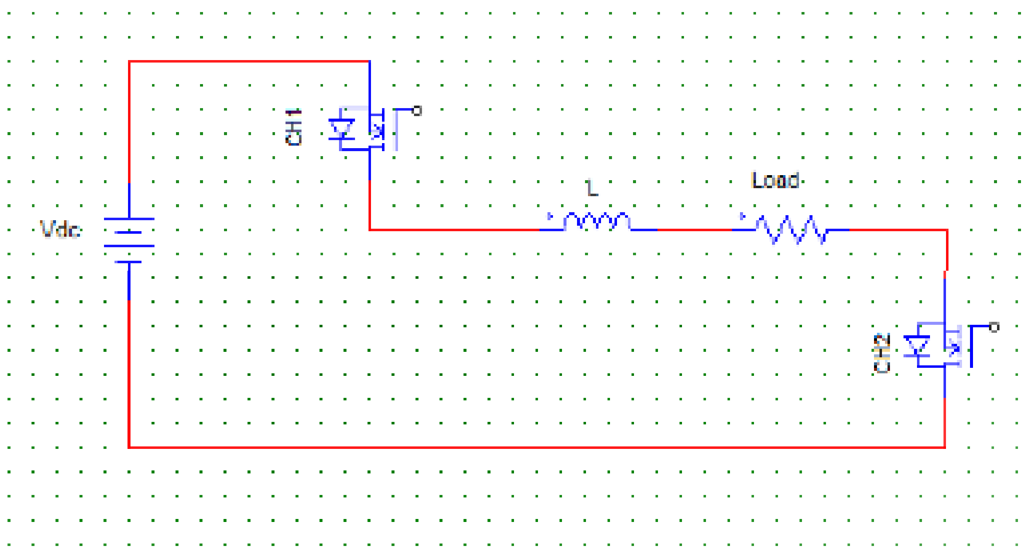


Figure 2.17:.Chopper Class E first quadrant.

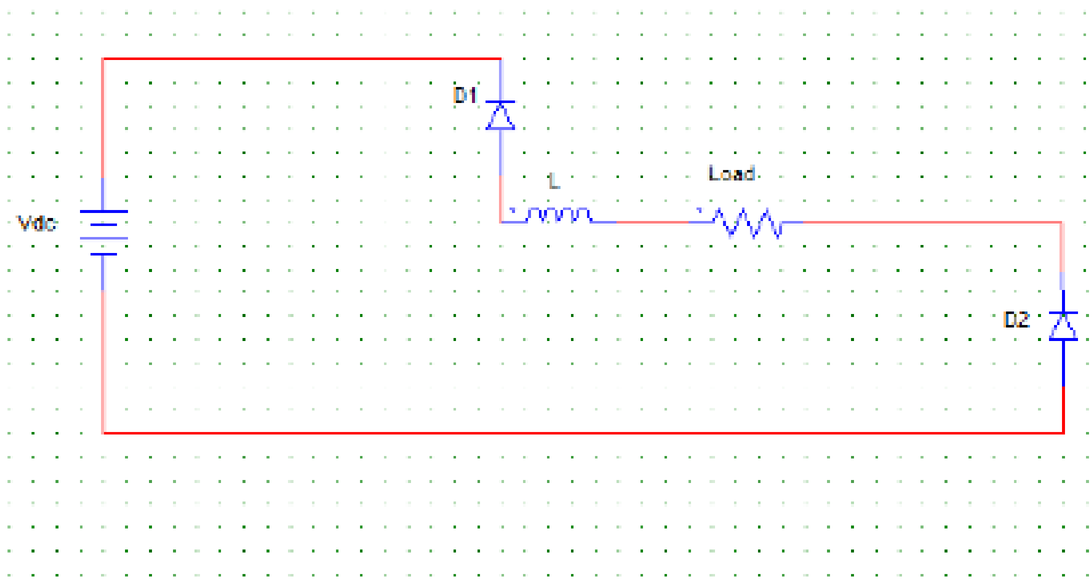


Figure 2.18:Chopper Class E second quadrant.

 Third quadrant:

When chopper CH3 and chopper CH4 are switched on, the load current flows through (+)Vdc –CH3 – L – LOAD –CH4 – Vdc(–). The output voltage and current both are negative therefore, it is third quadrant operation. This quadrant is shown in Fig.2.19.

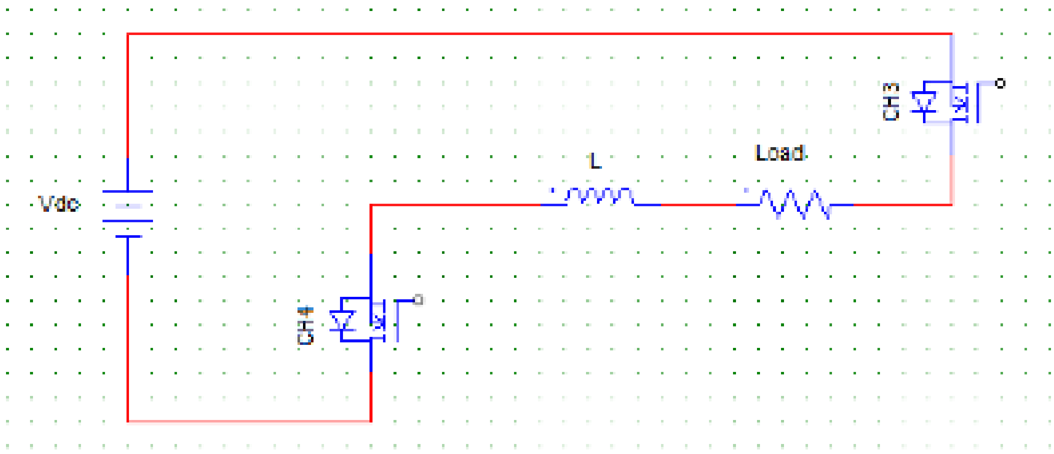


Figure 2.19:Chopper Class E third quadrant.

 Fourth quadrant:

When chopper CH1 and chopper CH2 are switched off, the stored energy of inductor dissipates through Vdc(–) –D4 – L – LOAD –D3–(+)Vdc. The output voltage is negative but output current is positive during this period therefore it is fourth quadrant chopper operation. This quadrant is shown in Fig.2.20.

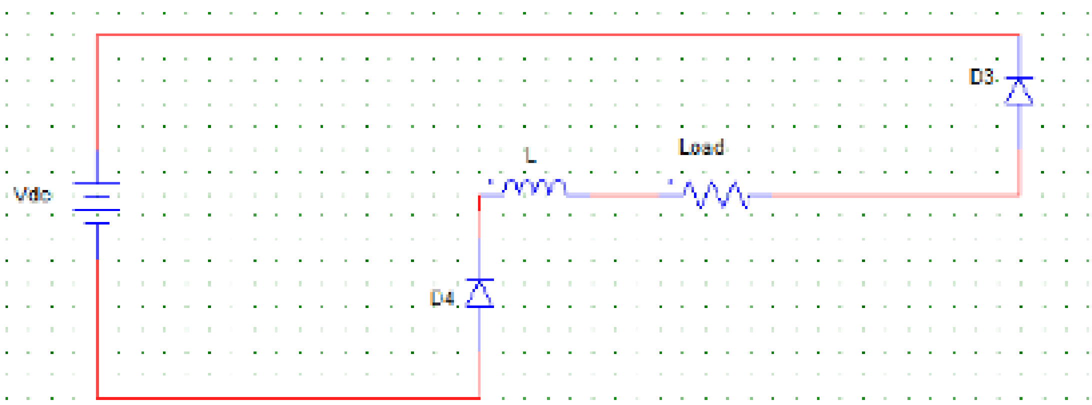
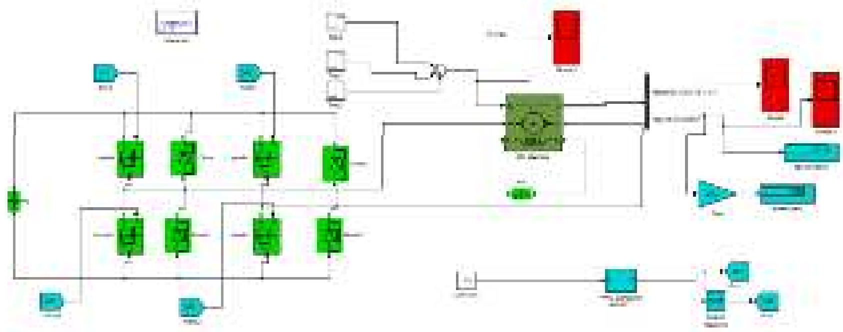
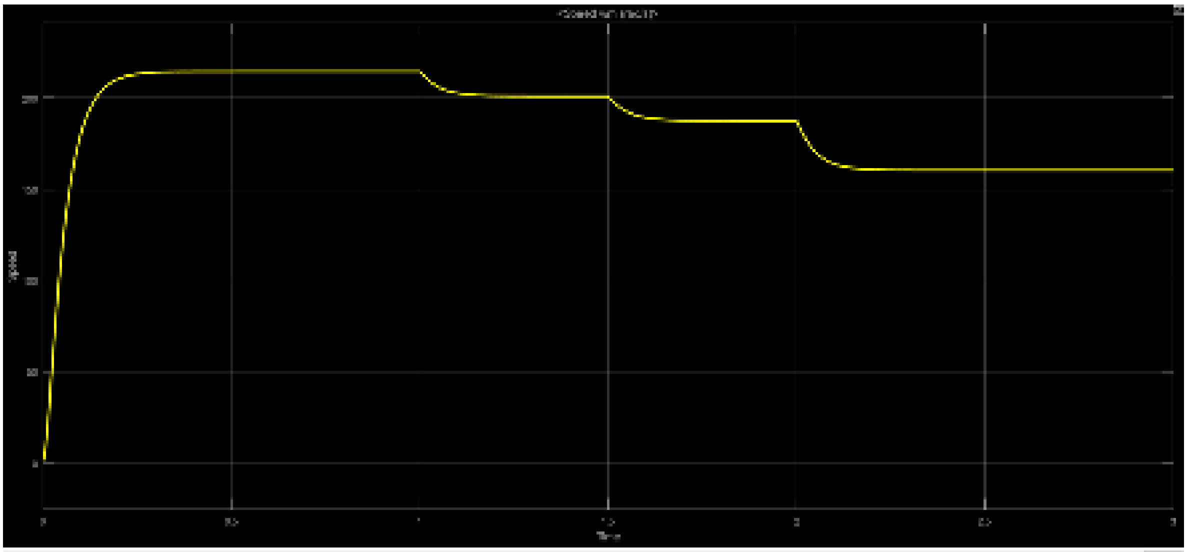


Figure 2.20: Chopper Class E fourth quadrant.

This class was used to control the motor in the Fourth quadrant using open loop control as shown in Fig.2.21. The speed and torque response are shown in Fig.2.22 and Fig.2.23 respectively.



Fiqure 2.21 Class E chopper and dc motor open loop.



Fiqure 2.22: Output Speed open loop Class E Chopper dc Motor.

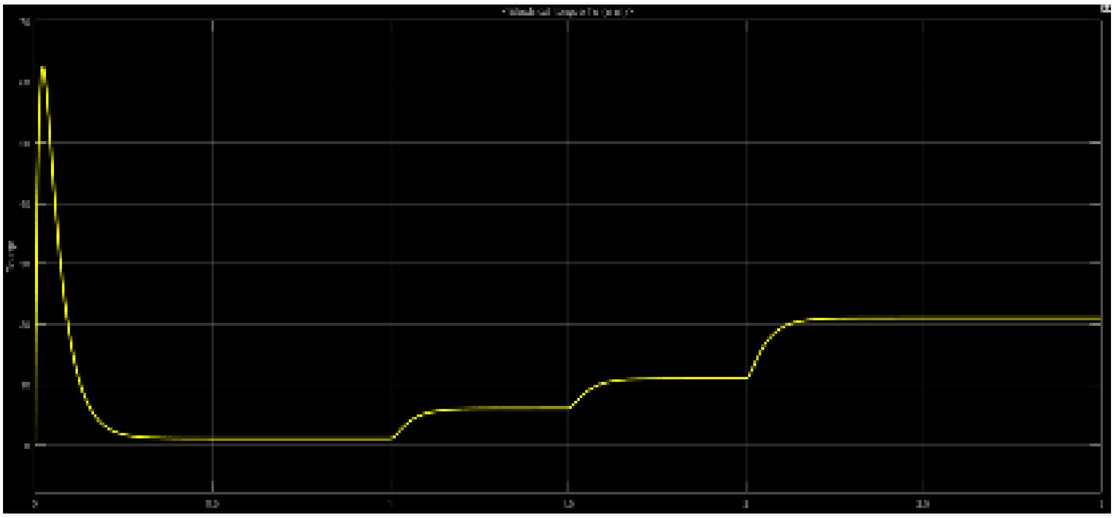


Figure 2.23: Output Tourqe open loop Class E Chopper dc Motor.

It was used again to control the motor in the Fourth quadrant closed loop as shown in Fig.2.24. The speed and torque response are shown in Fig.2.25 and Fig.2.26 respectively.

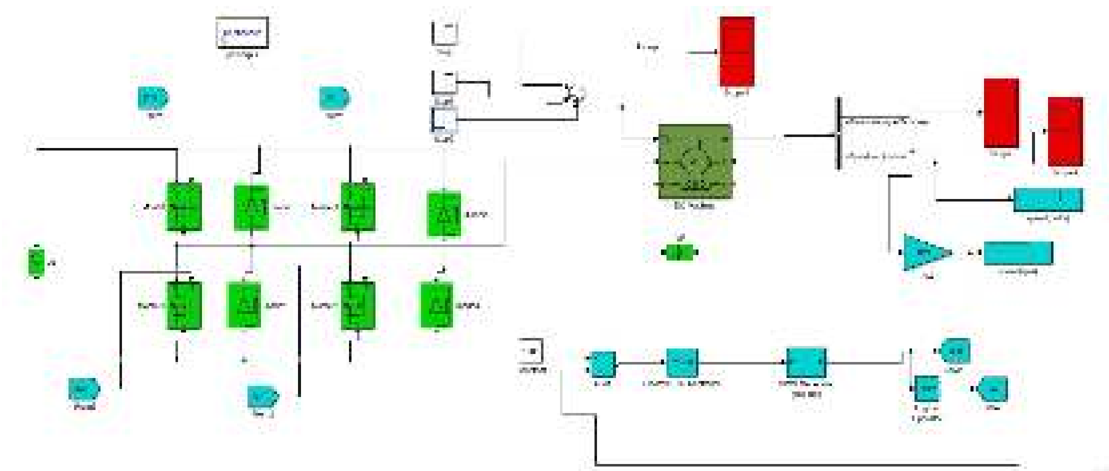


Figure 2.24: Class E chopper and dc motor closed loop.

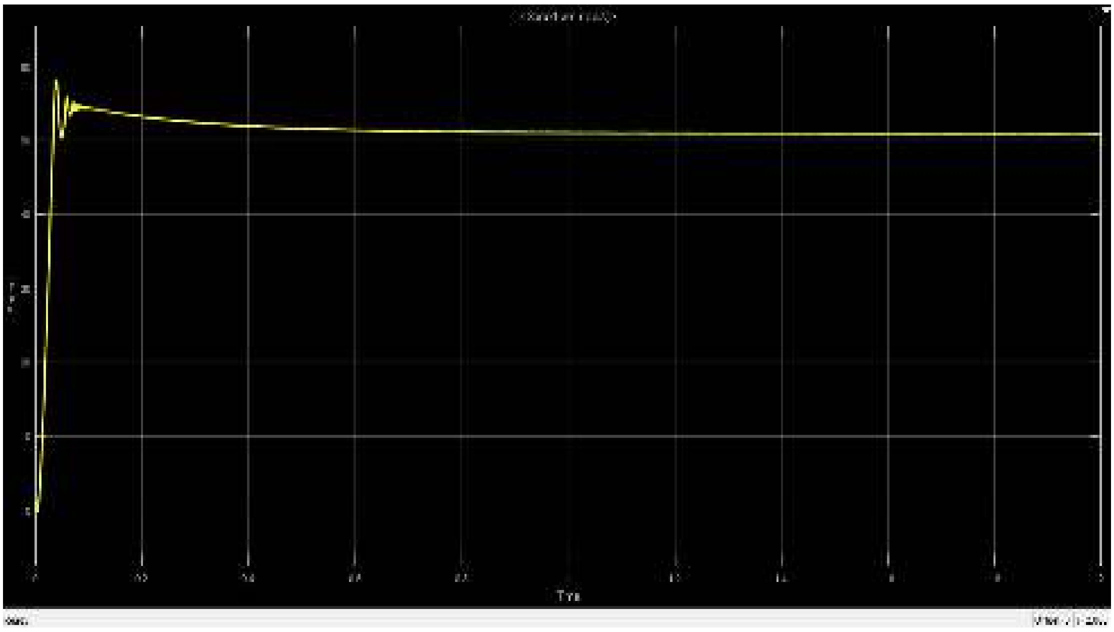


Figure 2.25: Output Speed Closed loop Class E Chopper dc Motor.

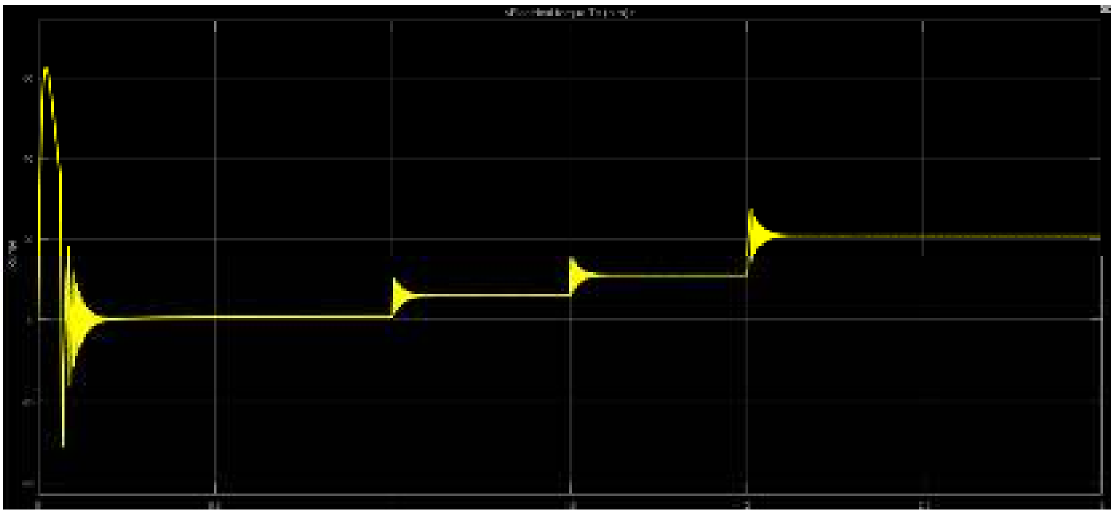


Figure 2.26:Output Tourqe Closed loop Class E Chopper dc Motor.

CHAPTER 3

Separately excited DC motor

3.1 Introduction

The dc motors are used in various applications such as industries, Robotics etc. The preferences are because of their simplicity, ease of application, reliability and favorable cost have long been a backbone of industrial applications. DC drives are less complex with a single power conversion from AC to DC. DC drives are normally less expensive for most horsepower ratings. DC motors have a long tradition used as adjustable speed machines and a wide range of options have evolved for this purpose. In these applications, the motor should be precisely controlled to give the desired performance. Many varieties of control schemes such as P, proportional integral (PI), proportional derivation integral (PID) [18].

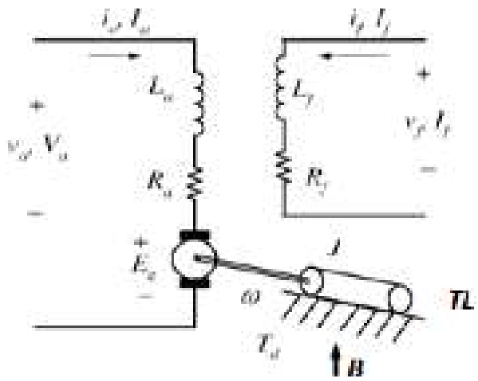


Figure 3.1 Equivalent circuit diagram of separately excited dc motor.

Separately Excited DC motor has field and armature winding with separate supply. The field windings of the dc motor are used to excite the field flux. Current in armature circuit is supplied to the rotor via brush and commutator segment for the mechanical work. The rotor torque is produced by interaction of field flux and armature current.

3.2 Operation of Separately excited DC motor

When a separately excited dc motor is excited by a field current and an armature current flows in the circuit, the motor develops a back EMF and a torque to balance the load torque at a particular speed. The field current if is independent of the armature current. Each winding is supplied separately. Any change in the armature current has no effect on the field current.

3.3 Equations of DC motor

The failed voltage is given by the relation,

$$vf = Rf * If + Lf\frac{dif}{dt} \qquad (3.1)$$

While the Armature voltage is given by,

$$va = Ra * Ia + La\frac{dia}{dt} + Ea \qquad (3.2)$$

The motor back emf, which is also Known as speed voltage, is expressed as,

$$Ea = k\emptyset * w \qquad (3.3)$$

For a fixed field current, or flux (If) the torque demand can be satisfied by varying the armature current (IA). The motor speed can be controlled by – controlling Va (voltage control) – controlling Vf (field control). These observations lead to the application of variable DC voltage for controlling the speed and torque of the DC motor [19]. The torque equation of a DC motor is given by,

$$\mathbf{T = k\emptyset * Ia} \tag{3.4}$$

$$T = J\frac{dw}{dt} + Bw + Tl \tag{3.5}$$

While the steady speed as a function of voltage is,

$$w = \frac{Va - Ia*Ra}{K\emptyset} \tag{3.6}$$

Finally, the required power is.

$$\mathbf{p = T * w} \tag{3.7}$$

3.4 DC motor transfer function

The transfer function of a separately excited DC motor can be written as follows,

$$\frac{w(s)}{Va(s)} = \frac{\frac{1/Ra}{(1 + s\tau_a)} * K * \frac{Ra/C^2}{s\tau_m}}{1 + \frac{1/Ra}{1 + s\tau_a} * K^2 * \frac{Ra/C^2}{s\tau_m}} \tag{3.8}$$

After some mathematical manipulations , Eq.3.8 can be simplified as follows,

$$\frac{w(s)}{Tl(s)} = \frac{\frac{Ra}{K^2}}{1 + \frac{Ra/C^2}{s\tau_m} * K^2 * \frac{1/Ra}{1 + s\tau_a}} \tag{3.9}$$

Further simplifying the above transfer function will yield:

$$\frac{w(s)}{va(s)} = \frac{1}{K * (1 + s\tau_m + s^2\tau_m\tau_a)} \tag{3.10}$$

$$\frac{w(s)}{Tl(s)} = -\frac{Ra}{K^2} * \frac{1 + s\tau_a}{(1 + s\tau_m + s^2\tau_m\tau_a)} \tag{3.11}$$

The transfer function shown in Eq.3.10, will be used to simulate the response of the motor under the effect of the PID controller. Fig.3.2 shows the simulation of the DC motor using MATLAB. Where the parameters of the moto and the load are shown in Table 3.1.

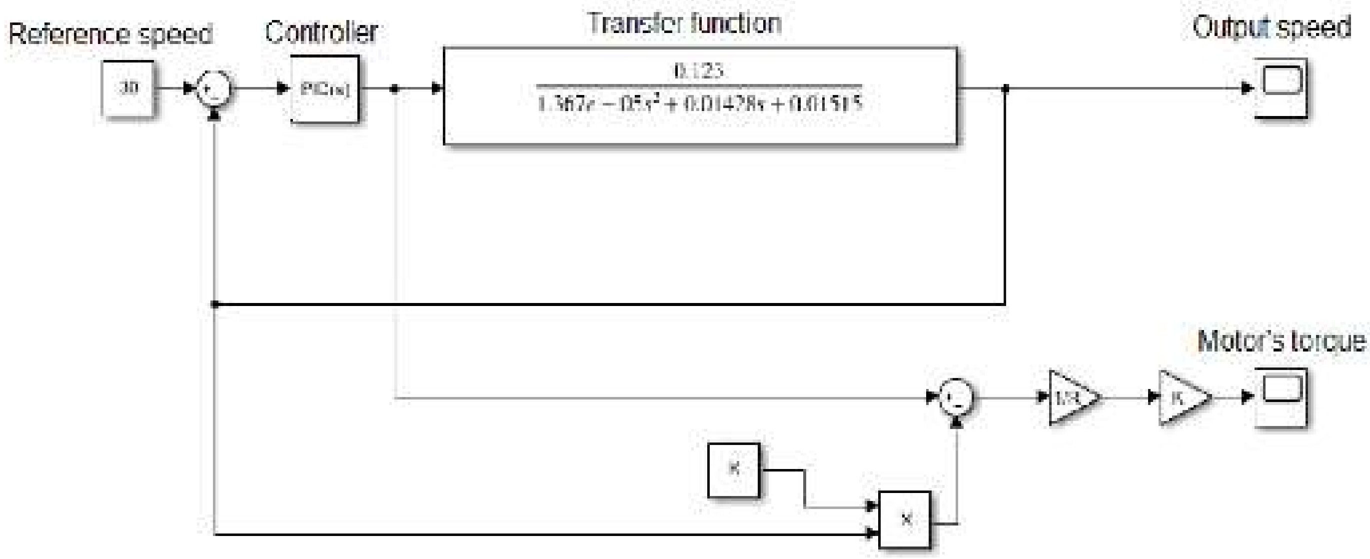


Figure 3.2. Simulation block diagram.

Table 3.1: Parameters of the DC motor and the load

Symbol	Parameter	Value
Jm	Moment of inertia of the rotor	1.54*10^-3
Jl	Moment of inertia of the load	0.5*10^-3
J	Total moment of inertia	0.0020
bm	Motor viscous friction constant	3.04*10^-6
bl	Load viscous friction constant	0.5*10^-6
b	Total viscous friction	3.5400^-6
K	Motor torque constant	0.123
R	Armature resistance	7
L	Armature inductance	6.7*10^-3

It can be noticed that the model supports the variable load that is attached to the motor. To represent any load, the inertia and the friction of this load can be added to the model, and the resulted transfer function can be added to the simulation as shown in Fig.3.2

CHAPTER 4

Conceptual design

This project consists mainly form multiple sections connected together to perform efficient closed loop speed control, these sections are,

- Hardware circuit that generates a PWM signal.
- Encoder to provide feedback signal.
- A driver to interface the motor.
- A PID controller to compute the best value of PWM.

The interfacing between these sections is shown in the block diagram in Fig.4.1.

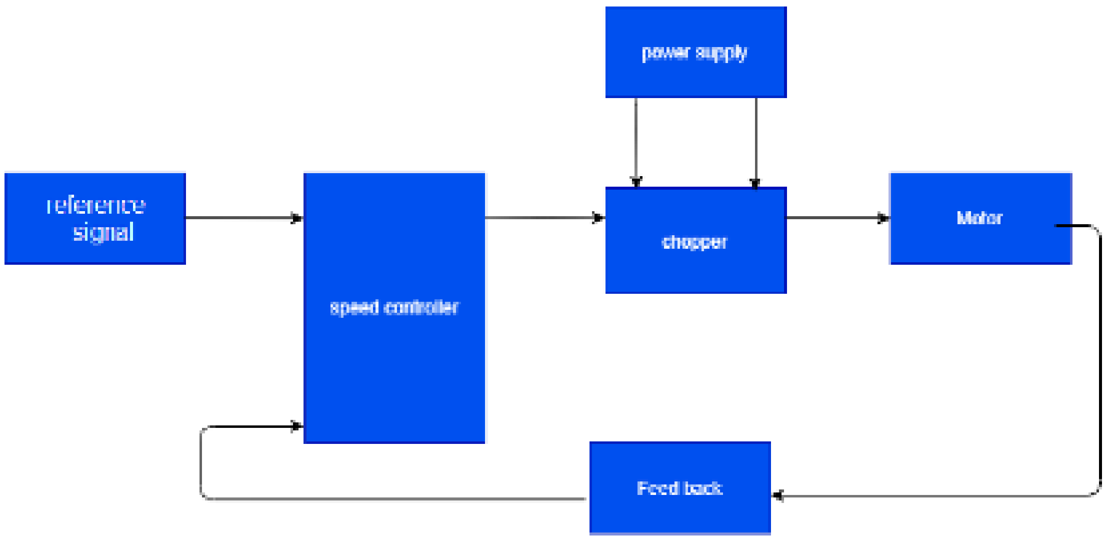


Figure 4.1: Block diagram of the entire system.

The block diagram circuit contains the following components,

1) Arduino Uno.
2) Incremental encoder.
3) Hw_095 driver.
4) Speed controller.

4.1 Electrical Components:

1. Arduino Uno

It is responsible to generate a PWM signal depending on the received value of the control law and to measure the value of the angular position of the motor's shaft. This measurement can be used to compute the angular speed by the mean of numerical derivative. Finally, the Arduino is responsible to transmit the angular speed as a feedback signal to the MATLAB. The schematic of the Arduino is shown in Fig.4.2.

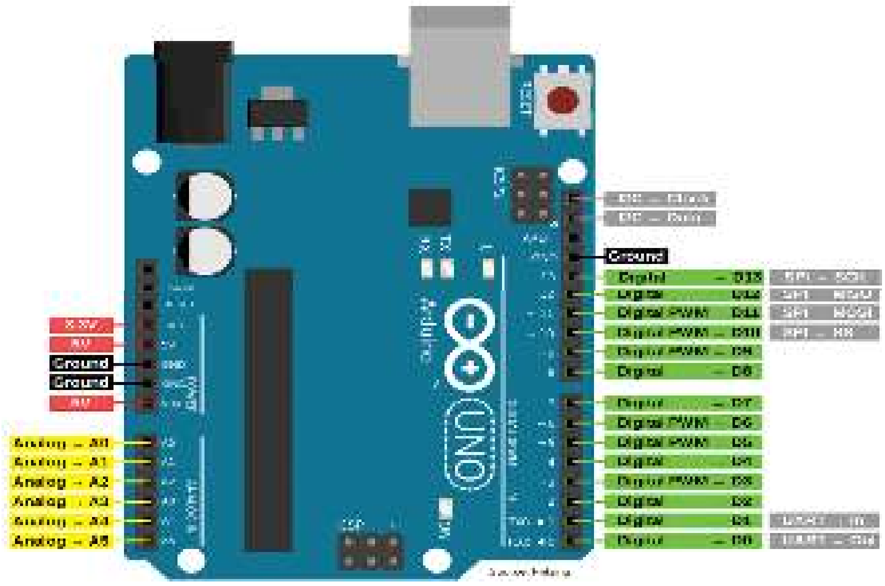


Figure 4.2: Arduino Uno.

2. Incremental encoder

It is used to measure the angular position of the motor’s shaft. It provides two signal channels, A and B. these channels provides data related to the angular position and the phase. If the phase A is activated before phase B, the motion is forward, else, the motion is backward. The incremental encoder is shown in Fig.4.3.

Figure 4.3: Incremental encoder.

3. Hw_095 driver

To control the motion of the DC motor the driver module Hw_095 was used as shown in Fig.4.4.

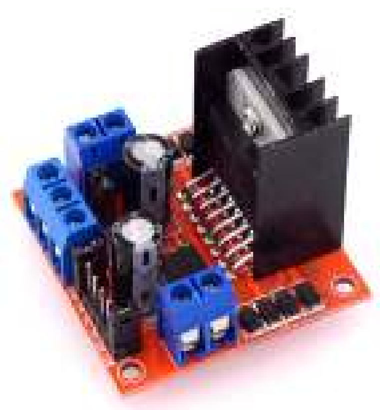


Fig.4.4 : hw_095 driver.

Hw_095 represents an inexpensive, high power motor driver based on two BTS7960 chips. This driver depends on the principle of H-Bride to control the speed and direction of a DC motor by the principle of Pulse Width Modulation (PWM). These features are compatible for the start, stop and reversing the direction of rotation functions which require relatively high current. The control signal delivered to the Hw_095 driver will affect the speed and the direction of the linear actuator as shown in Table 4.1.

- Dc Motor :

A **DC motor** is any of a class of rotary electrical motors that converts direct current electrical energy into mechanical energy. The most common types rely on the forces produced by magnetic fields. Nearly all types of DC motors have some internal mechanism, either electromechanical or electronic, to periodically change the direction of current in part of the motor.

***drive characteristics:**

MINERTIA MOTOR miniature dc MOTOR with encoder UGFMED - 03 sri11 27 v

The fuselage diameter of 61 mm, 83 mm long

The dc 21 mm shaft diameter 10 mm, gear

Fig.4.4 : hw_095 driver

\Table 4.1: hw_095 Control signal.

PWM	1-255	1-255	1-255	1-255
Right-PWM	High	Low	Low	High
Left-PWM	Low	High	Low	High
Direction	CW	CCW	Stop	Burn

The datasheet of this module provides more details such as,

- Input voltage : 6V-27V
- Maximum Current : 43A
- Output voltage : 3.3V-5V

The overall circuit diagram of the project is shown in Fig.4.5.

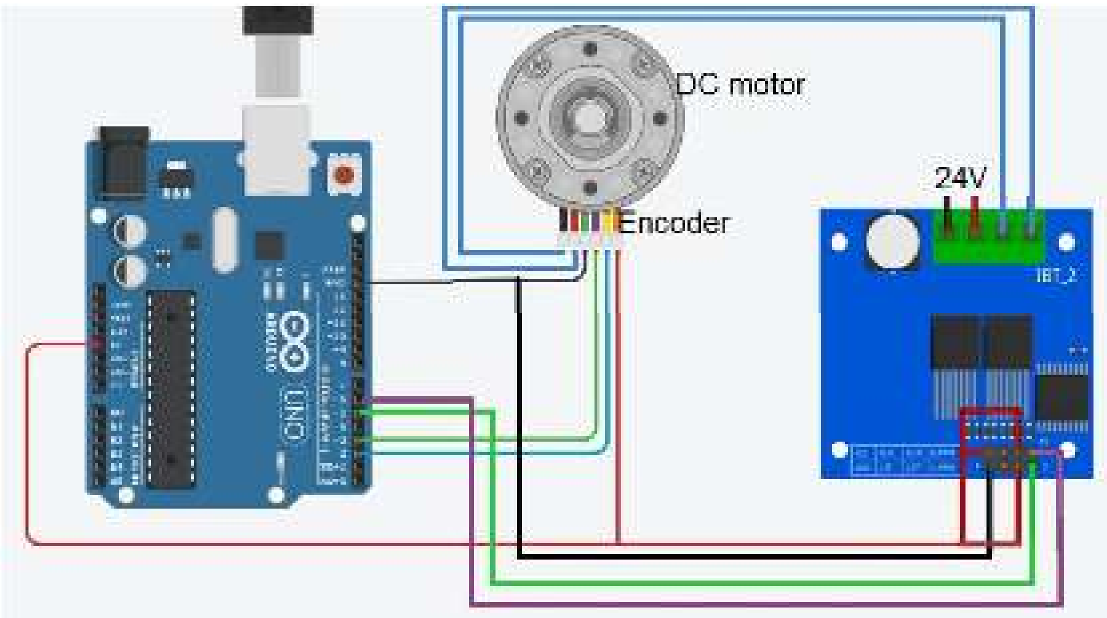


Figure 4.5: Circuit diagram.

5. Speed controller

PID controller was used to compute the value of the required PWM, the overall control diagram is shown in Fig.4.6.

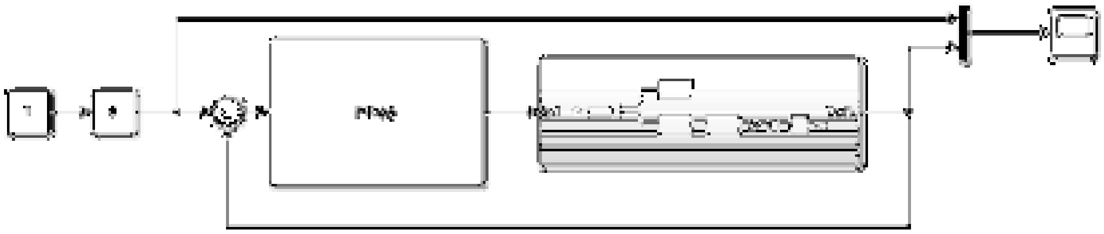


Figure 4.6: PID controller schematic

The values of controller’s gains were tuned manually to get the best performance.

CHAPTER 5

Practical implementation

5.1 Open loop speed control

In this section, multiple experiments were performed to obtain the response of the system. The first experiment was performed with a Class A open-loop speed control. applied to the motor with external load. Fig. 5.1. Shows the practical circuit connection inside the laboratory where the speed was controlled by the voltage, the speed increases with the increase in the voltage involved in it by duty cycle.

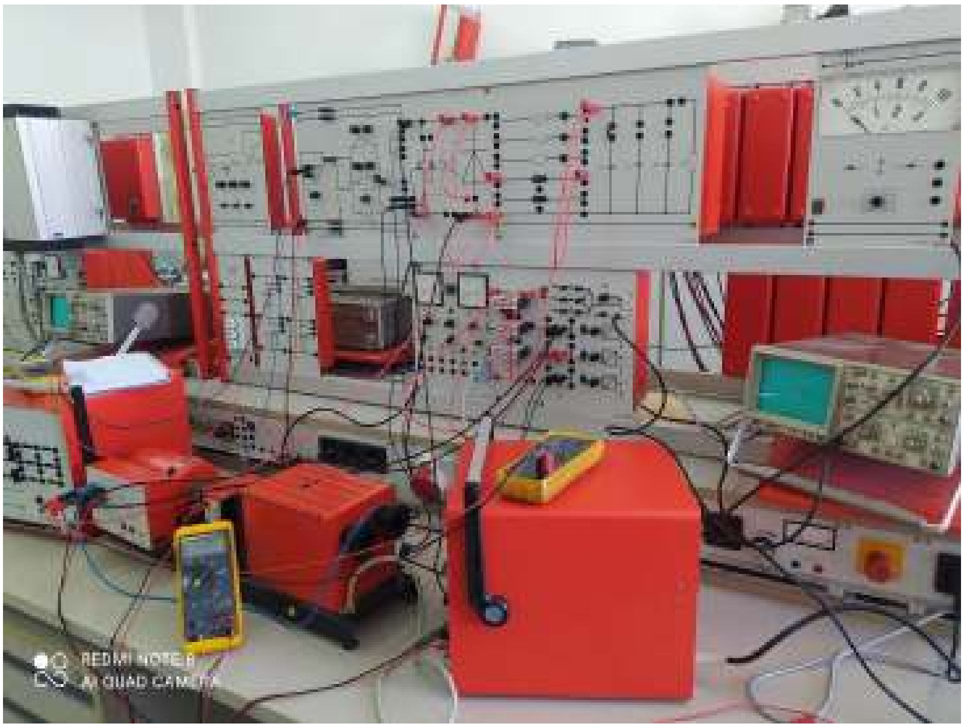


Figure 5.1: open loop speed control class (A) dc motor.

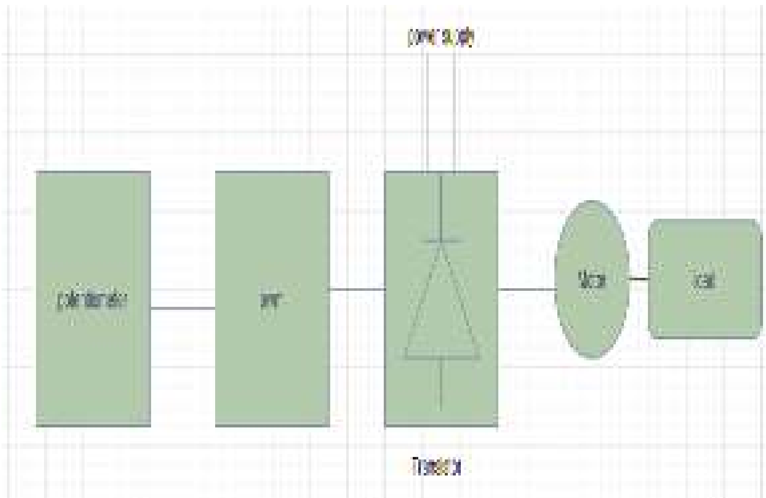


Figure 5.2: a plan open loop speed control class (A) dc motor.

Table 5.1: Practical experience values.

	Duty cycle	Vout	Speed(n)
	0.3	60	1390
Vin=200v	0.6	120	1543
	0.9	180	1883

Another experiment was conducted to control the speed by using Class D to control the first and third squares, while the motor works.

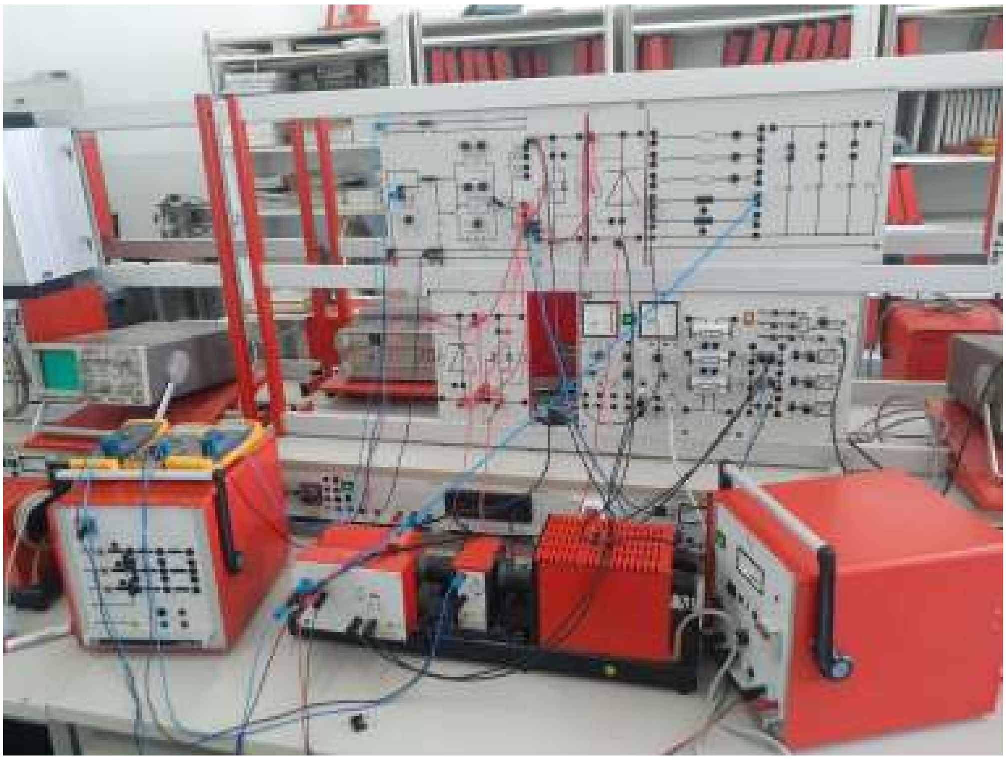


Figure 5.3: Open loop speed control Class D dc motor

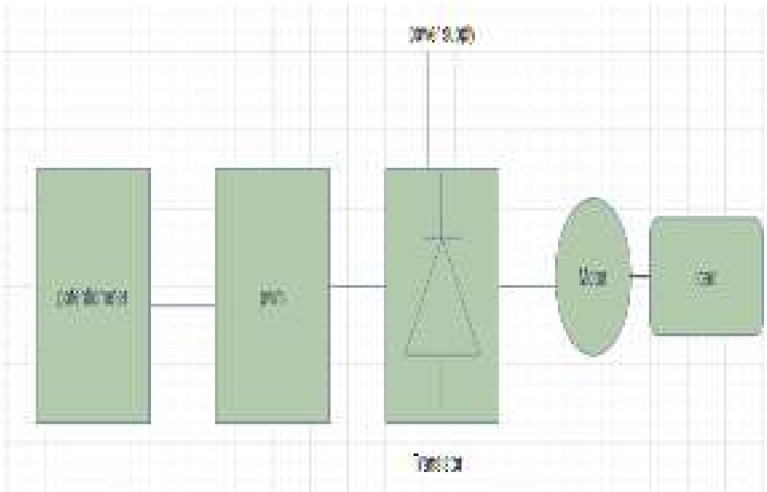


Figure 5. 4Open loop speed control Class D dc motor

5.2 Closed loop speed control

In this section, multiple experiments were conducted to obtain the response of the system. The first experiment was conducted by the mean of closed loop control using PID controller. A reference signal equals 1000 RPM . the speed curve proves that the system can track the applied reference signal effectively. The speed at steady state has about no steady state error, which proves the validity o speed control scheme. However, an overshoot occur at the transient interval. The torque developed by the motor is the largest at the beginning due to the starting process, where the motor should overcome multiple variables on the startup interval, after that it decreases to the minimum value at the steady state interval.

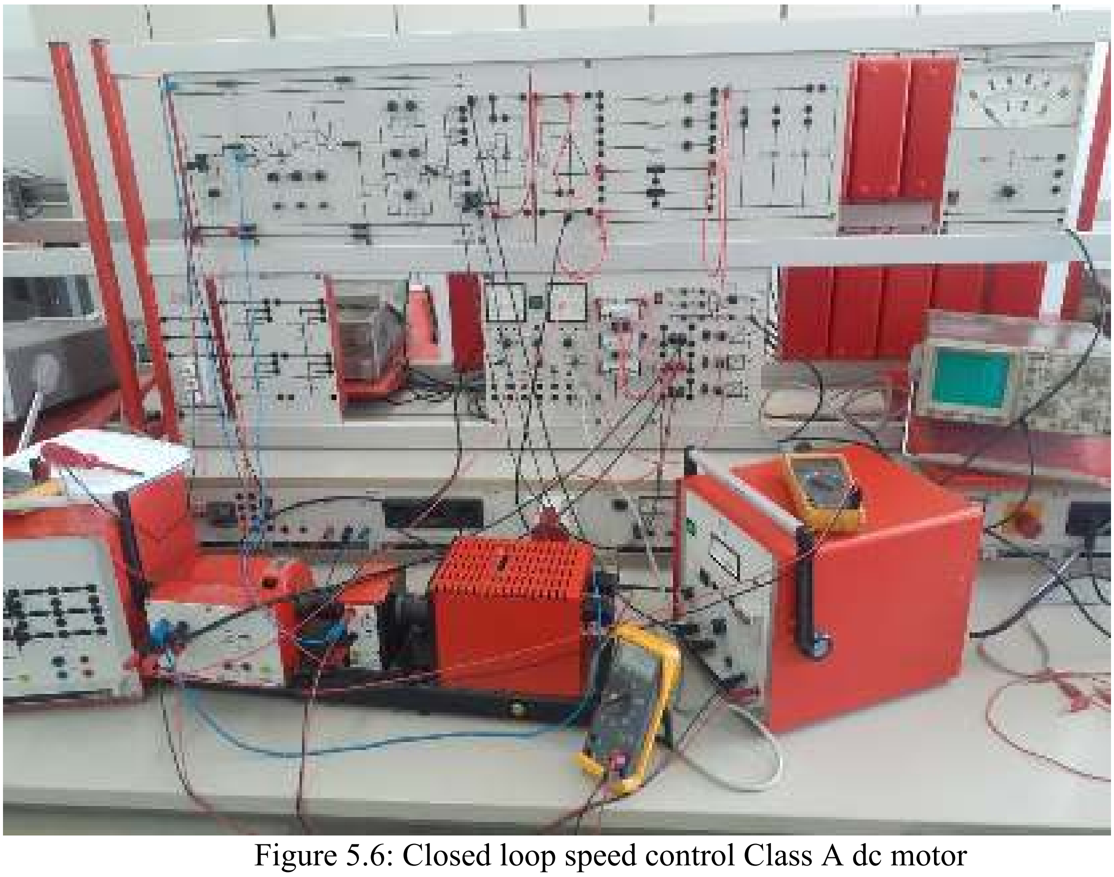


Figure 5.6: Closed loop speed control Class A dc motor

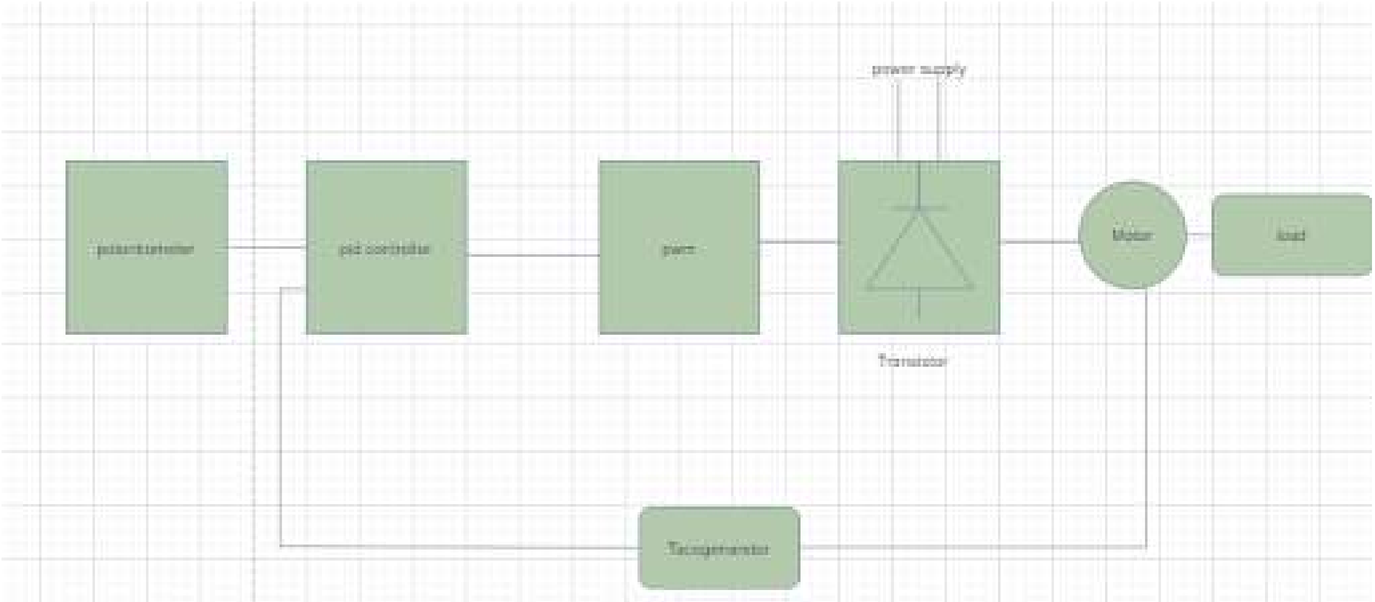


Figure 5.7: a plan Closed loop speed control Class A dc motor

Table 5.2: Practical experience values closed loop system.

	Torque	Vout	Speed(n)
Speed Ref = 1000 rpm	0.2	117.5	1000
	0.35	124.3	1000
	0.47	138.5	1000

5.3 Programming Code:

5.3.1 Front Panel VI:

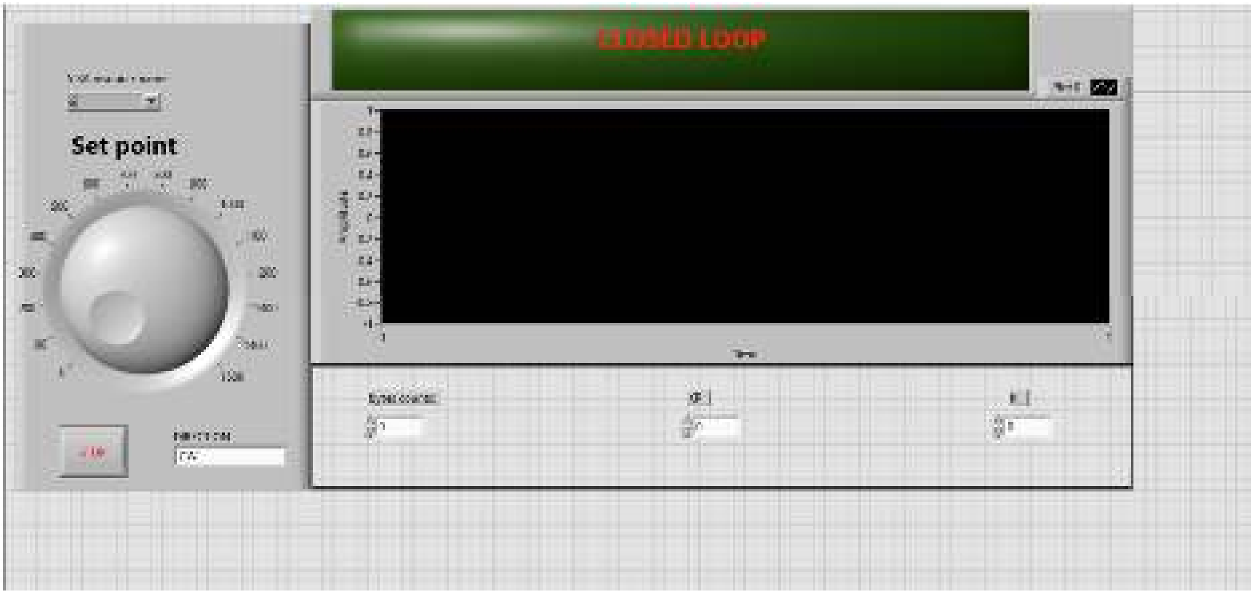


Figure 5.7: Front Panel VI

- **Closed loop speed control**

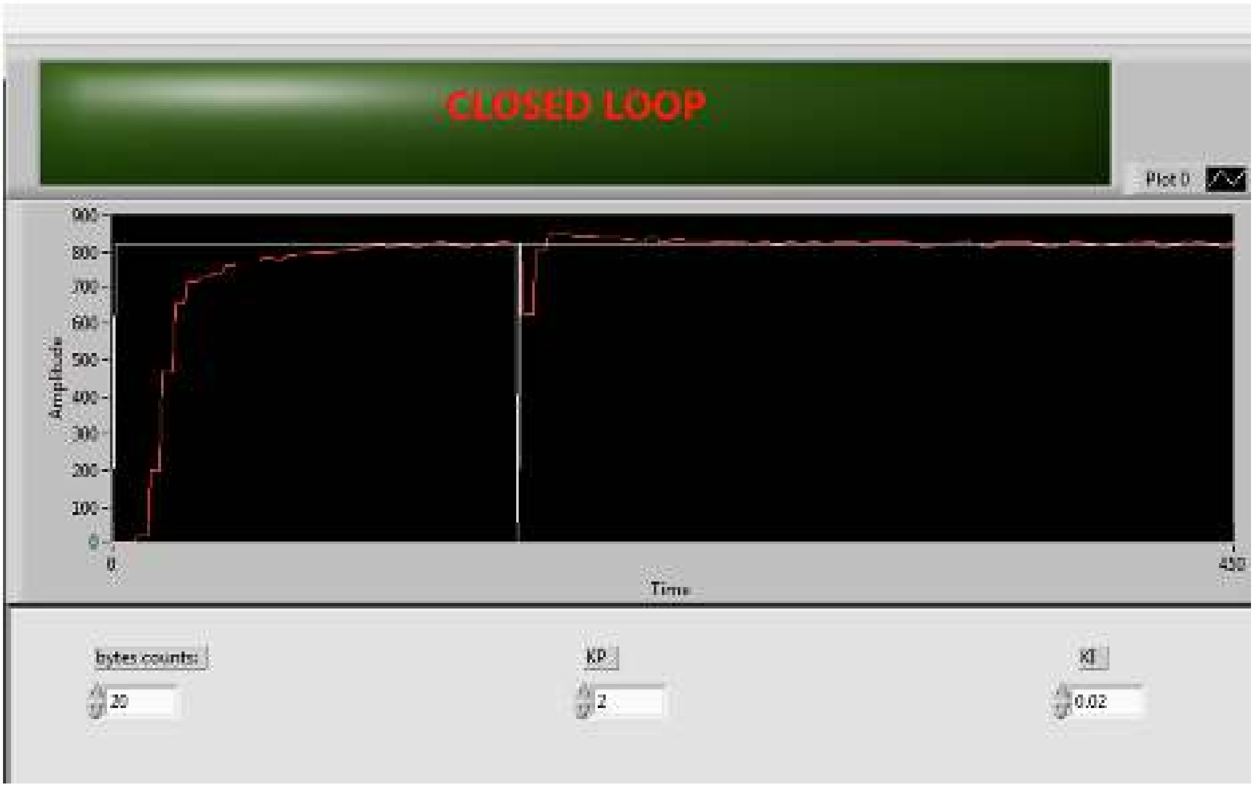


Figure 5.9 speed in close loop

- Open loop speed control

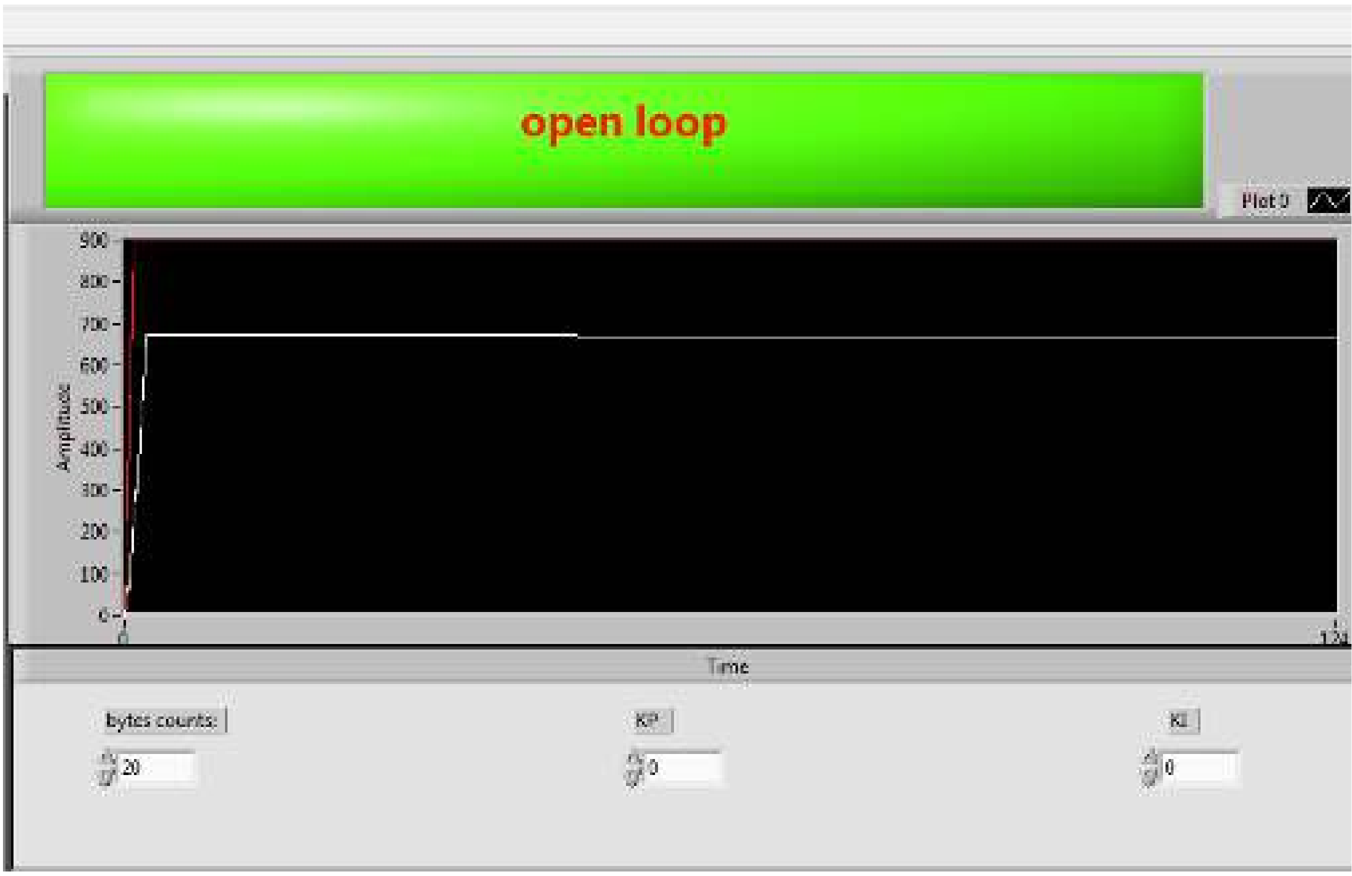


Figure 5.10 speed in open loop.

Mechanical characteristics;

$$Va = Ea + Ia * Ra$$

$$Ea = C\emptyset * Wn$$

$$Wn = 2 * \pi * \frac{n}{60}$$

$$Wn = \frac{Va}{C\emptyset} - \frac{Ra * T}{(C\emptyset)^2}$$

$$Va = 19.5V, Ra = 11.5\Omega, Ia = 0.22A, n = 1530\ RPM$$

$$19.5 = Ea + (11.5 * 0.22) \Rightarrow Ea = 16.97Volt.$$

$$Wn = \frac{2 * \pi * 1530}{60} = 160.4\ \frac{rad}{s}$$

$$Ea = C\emptyset * Wn \Rightarrow C\emptyset = 0.015$$

$$160.4 = \frac{19.5}{0.015} - \frac{11.5 * T}{0.011} \Longrightarrow 185.4 - 104.5T$$

$$when\ Wn = 160.4\frac{rad}{s}\ then\ T = 0.021\ N.m$$

$$when\ T = 0\ then\ Wn = 185.4\ rad/s$$

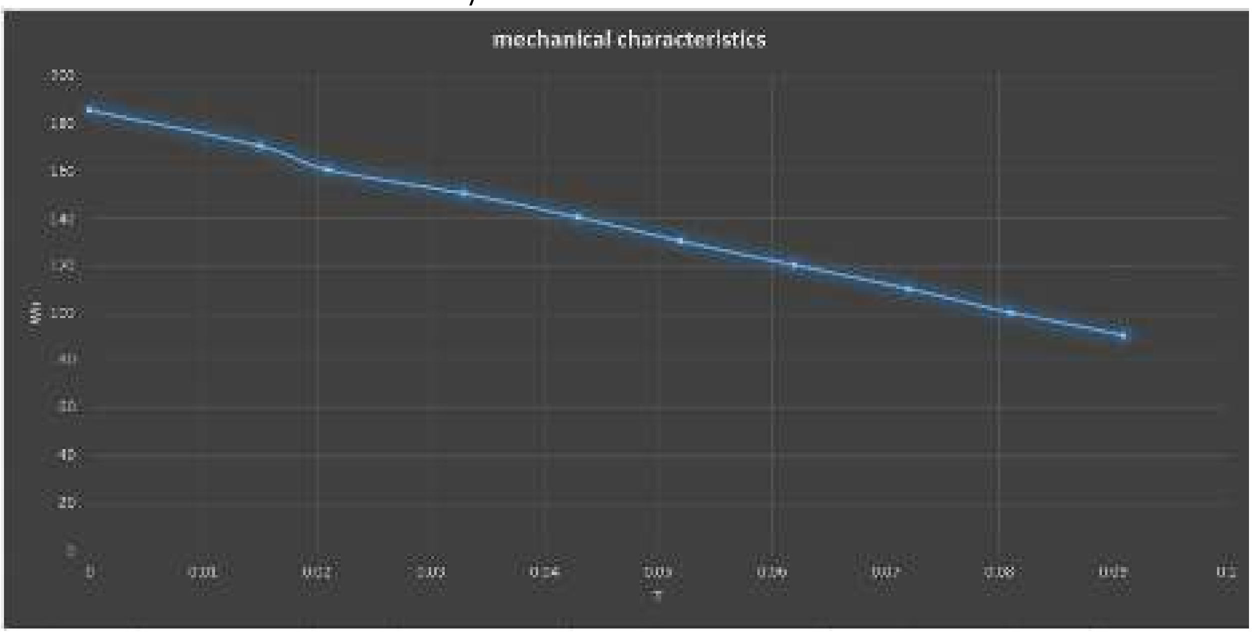


Figure 5.11 Mechanical characteristics

5.3 Conclusion:

A DC motor speed control circuit and algorithm were implemented in this project. The circuit consists of a DC motor which is supplied with an incremental encoder as a feedback supplier. The speed of the motor was controlled by the mean of the Chopper circuit of class A and C. Two control strategies were used to achieve the task. The first one is closed-loop control which provides about no steady-state error with relatively small overshoot, while the other one is open-loop which provides high steady-state error with a very smooth response.

Most industrial applications require accurate control of the speed, so the closed-loop control is better to be used to achieve the task.

5.4 Future work:

The prototype is designed to control the first and third quadrants of the motor DC, so future work will start eventually from this design, it will be developed on other types where the four quarters of the motor DC when the parts in the laboratory are sufficient to do in That, and then, the prototype will be extended to include the other.

5.5 Recommendations

Recommendations according to the project prototype:

1. Bring sufficient support for the presence of the pieces to make a comprehensive design that fits in the four quarters.

2. Work on expanding the prototype to show the entire project idea for the educational field.

3. This design should be the starting point for the fully and instructive use of dc Motor Control.

4. Using the LabVIEW dashboard in project design as an easy-to-use language.

5. Use advanced drivers compatible with LabVIEW lab, such as (DAQ, Arduino).

Appendixes:

```
#define ENC_COUNT_REV 360
#define ENC_IN 3
#define FW 6
#define RV 7
#define pwm1 9

int dir1,op=0;
char income;
String inc;
String in;
String Dir;
String kp1,ki1,op1;
volatile long encoderValue = 0;
int interval = 1000;
long previousMillis = 0;
long currentMillis = 0;
String encdir ="";
int rpm = 0;

 int currentStateCLK;
 int previousStateCLK;
 int count=0;
 int cont1;


float kp=0,ki=0.04;
float error,errorprev,integ,act,ref;
int y1=0;
void updateEncoder()
{

  encoderValue++;
}
```

Figure 5.11code arduino

```
void setup()
{

  Serial.begin(9600);

  pinMode(ENC_IN, INPUT_PULLUP);

   pinMode (FW,OUTPUT);
    pinMode (RV,OUTPUT);

  attachInterrupt(digitalPinToInterrupt(ENC_IN), updateEncoder, RISING);
  previousMillis = millis();
}

void loop()
{

     if(Serial.available()>0){inc="";  }

    while(Serial.available()>0)
    {
    income=((byte)Serial.read());

    if(income==':'){

      break;

      }else{
        inc+=income;
        }
```

Figure 5.12code arduino

```
}else{
  inc+=income;
  }
}
delay(100);

encdir=inc.substring(inc.indexOf('_')+1,inc.lastIndexOf('_'));
String en=encdir.substring(0,encdir.indexOf('_'));
int i =en.toInt();

Dir=inc.substring(0,inc.indexOf('_'));
dir1= Dir.toInt();

kp1=inc.substring(inc.indexOf('_',inc.indexOf('_')),inc.lastIndexOf('_'));
String kp2=kp1.substring(kp1.lastIndexOf('_')+1);
kp=kp2.toFloat();

ki1=inc.substring(inc.lastIndexOf('_')+1);
ki=ki1.toFloat();

op1=inc.substring(inc.indexOf(',')+1);
op=op1.toInt();


currentMillis = millis();
if (currentMillis - previousMillis > interval) {
  previousMillis = currentMillis;


  rpm = (float)(encoderValue * 60 / ENC_COUNT_REV);


  if ( rpm > 0) {
```

Figure 5.13code arduino

```
  if ( rpm > 0) {



  }

  encoderValue = 0;
 previousStateCLK = currentStateCLK;
}


act=map(rpm,0,1530,0,255);
int dir2=dir1/6;
if(op==1){
 error=dir2-act;
 integ=integ+(error*ki)+(errorprev*ki);

 error=errorprev;

 y1=(kp*error)+integ;

 if(y1>255){y1=255;}
 if(y1<0){y1=0;}

}else if(op==2){y1=dir2; }
Serial.print(dir1);
Serial.print(" ");
Serial.println(rpm);


 if(i==2){

       digitalWrite(FW,HIGH);
       digitalWrite(RV,LOW);
```

Figure 5.14code arduino

```
 if(y1>255){y1=255;}
 if(y1<0){y1=0;}

}else if(op==2){y1=dir2; }
Serial.print(dir1);
Serial.print(" ");
Serial.println(rpm);


 if(i==2){

        digitalWrite(FW,HIGH);
        digitalWrite(RV,LOW);
        analogWrite(pwm1,y1);
        delay(100);
        }
          else if(i==1){

       digitalWrite(FW,LOW);
       digitalWrite(RV,HIGH);
       analogWrite(pwm1,y1);
       delay(100);

          }else{

        digitalWrite(FW,LOW);
       digitalWrite(RV,LOW);
       analogWrite(pwm1,0);
       delay(100);

            }

 }
```

Figure 5.15code arduino

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