Controlling of Power MOSFET using Humidity Sensor

A Dissertation submitted in fulfillment of the requirements for the Degree
of

MASTER OF ENGINEERING
in
Power Systems

Submitted by

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DECLARATION

I hereby certify that the work which is presented in dissertation entitled, "Controlling of Power MOSFET using Humidity Sensor", in partial fulfillment of the requirements for the award of the degree of Master of Engineering in Power Systems, submitted to Electrical & Instrumentation Engineering Department of Thapar University, Patiala is as authentic record of my own work carried under the supervision of Mr. Shailesh Kumar. It refers others researcher's work which are duly listed in the reference section. The matter contained in this dissertation has not been submitted, neither in part nor in full to any other degree to any other university or institute except as reported in text and references.

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It is certified that the above statement made by the student is correct to the best of my knowledge and belief.

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LIST OF SYMBOLS

ε_o	Permittivity of vacuum
ε_r	Permittivity of dielectric material
A	Area of Electrode plates
d	Distance between electrode plates
C_w	Capacitance at wet condition
C_d	Capacitance at dry condition
ε_{rw}	Permittivity of dielectric material during wet condition
ε_{rd}	Permittivity of dielectric material during dry condition
V_{gs}	Gate-Source voltage
V_{ds}	Drain-Source voltage
I_{ds}	Drain-Source current
V_{th}	Threshold voltage
ω_m	Angular speed of motor
V_{in}	Input voltage
$f_{cut\text{-}off}$	cut-off frequency
I_a	Armature current
T_e	Electromagnetic torque
φ	Flux
L_a	Armature inductance

LIST OF ABBREVIATIONS

AC	Alternating Current
BJT	Bipolar Junction Transistor
BLDC	Brushless Direct Current
C2V	Capacitance to Voltage
CDC	Conventional Direct Current
CMOS	Complementary Metal Oxide Semiconductor
CTRL	Control
DC	Duty Cycle
DIP	Dual In-Line Package
DR	Duty Ratio
EX-OR	Exclusive OR
GND	Ground
GTO	Gate Turn-off Thyristor
IC	Integrated Circuit
IGBT	Insulated Gate Bipolar Transistor
LED	Light Emitting Diode
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
PMDC	Permanent Magnet Direct Current
PWM	Pulse Width Modulated
RCT	Reverse Conducting Thyristor
RH	Relative Humidity
SCR	Silicon Controlled Rectifier
TTL	Transistor-Transistor Logic

ABSTRACT

In the dissertation work presented here, LMC555CM timers are used to generate the PWM signals on the basis of the humidity level present in the atmosphere. Here, we have designed a signal conditioning circuit for the triggering of semi-conductor devices such as BJT, MOSFET and IGBT etc. to control the power applied to the electrical load (5V PMDC motor). The circuit comprises of 555 dual timer, EX-OR gate (74LS86D), variable capacitor in the place of capacitive humidity sensor, 5v input supply and other basic electrical components. Signal conditioning circuit works on the principle that change in moisture level contributes to the change in dielectric constant of thin film Al_2O_3 based capacitive sensor used as sensing film between the two electrodes. PWM output of two dual timers is then compared by using EX-OR logic gate. The duty cycle of the logic gate output signal changes according to the change in capacitance of the capacitive sensor. For better switching performance 555 timers are used instead of other timers to get the PWM output at high frequency (near to 50 KHz). Totem-pole arrangement is used as a driver circuit for power MOSFET to reduce the switching losses at higher frequencies. These PWM signals are used as firing signals for the semi-conductor devices to control the speed of PMDC connected to the drain terminal of power MOSFET. The designed electronic circuit is simulated on NI-Multisim 12.0 software and implemented in real time on breadboard.

CHAPTER-1
INTRODUCTION

1.1 Overview

Power semi-conductor devices like IGBT, Power MOSFET etc. are generally employed in wide-ranging applications in automation industries for controlling the input power to the electrical load. Due to its low cost and high reliability, these devices have increased their demand in almost all industrial and home applications as well. These devices with high input impedance require low current signal for the triggering and thus possess low switching losses at high frequency operation [1].

Now a days, atmospheric conditions are the important process parameters for the automated industrial applications and its control. Humidity plays a vital role because its existence affects not only the working temperature but also changes the efficiency of the machine working under its influence [2]. It is quite necessary to measure its effects of existence to make the working environment safe and comfort for automated industrial applications. To fulfil all these needs, humidity sensors should be highly sensitive and must possess low response and recovery time [3].

The main aim is to develop a signal conditioning circuit which can detect the moisture content from the atmosphere efficiently and respond back electrically [4]. There are generally two types of humidity sensors used commercially are (i) Resistive and (ii) capacitive. But these, capacitive humidity sensor is preferred mostly as commercial sensor because it is highly sensitive, pore structure, very few aging effects and high stability [5]. Capacitive humidity sensor generally utilize porous thin film of γ-Al_2O_3 formed between two electrodes. This sensor generally works on the principle that whenever the moisture ingress onto its surface, results into the change in permittivity of its dielectric material and therefore changes the capacitance of the film. This is illustrated using relation between capacitance and permittivity of dielectric material,

$$\frac{C_w}{C_d} = (\frac{\varepsilon_w}{\varepsilon_d})^n \tag{1.1}$$

C_w and C_d are the capacitance value during wet and dry condition.

$\boldsymbol{\varepsilon_w}$ and $\boldsymbol{\varepsilon_d}$ are the permittivity values during wet and dry condition. ‘n’ is a constant whose value depends upon the dielectric material.

We have designed an intelligent and low cost electronic circuit to get the pulse width modulated (PWM) output whose duty ratio vary with respect to the presence of moisture content. This circuit is used to detect the humidity level from 10-98% and used to get the variable pulse width output at different humidity level. The output of this designed circuit is generally used to control the voltage applied to the electrical load connected through any semi-conductor devices like IGBT, MOSFET etc. Therefore, designed circuit will behave as a firing circuit for the semi-conductor device which is providing input/logic signal for the gate terminal of Power MOSFET. Dehumidification is a process for removing the moisture content from the atmosphere or air. Our present work deals with the designing of smart and intelligent signal conditioning circuit to detect the moisture and convert it into the electrical signal then controlling the speed of blower motor for dehumidification processes.

1.2 Literature Survey

V. Barkhordarian ***et al.*** presented the work on basics of power MOSFET, their transfer characteristics, about the switching losses and also described few applications of power MOSFET at high frequency operations with low switching time [1].

Z. Chen and C. ***Lu et al.*** represented the basic necessities humidity sensors based on several materials for both relative and absolute humidity, including ceramic, semiconducting, and polymer materials and also described the electrical properties of humidity sensors including sensitivity, response time, and their stability [2].

Z. M. Rittersma ***et al.*** described the on-chip calibration of capacitive humidity sensor by using CMOS technology to measure the relative humidity. This paper presented the principle for sensing the moisture content, about the sensor’s response and recovery time and the temperature coefficient of sensor [3].

Y. Y. Qiu ***et al.*** proposed and analysed the proper results of capacitive humidity sensor by using micro-processor based interfacing circuit. In this work, efforts had been made to describe how the capacitive humidity sensors respond back to the atmospheric effects occurring due to the ingress of moisture content onto the surface of sensor [4].

K. K. Mistry ***et al.*** proposed the work on preparation of thick film of Al_2O_3 by using sol-gel process for their application in capacitive humidity sensor and presented the different procedures to develop humidity sensors. This work also described the importance of capacitive humidity sensors among all kinds of sensors used for the same purpose of sensing the humidity [5].

F. W. Gole ***et al.*** described the basics of the term 'humidity' and different ways of expressing the moisture content of atmosphere such as relative humidity, absolute humidity and specific humidity. Also presented their mathematical formulation, and their units to measure and also described a little bit on the temperature at which 100% RH i.e. dew point [6].

T. Nitta ***et al.*** proposed the work on different materials available for manufacturing the ceramic based humidity sensors and their industrial applications as well as commercial. This work described that alumina thin films based humidity sensors and their characteristics with respect to the temperature [7].

Z. Chen ***et al.*** represented the alumina based capacitive humidity sensor for measuring relative and absolute humidity. Also described about the serious problems related to these humidity sensors of long term instability and their hysteresis losses at different temperature values or conditions [8].

U. Kang ***et al.*** successfully designed the high speed capacitive humidity sensor having a response time of around 1.0 second. The whole work of designing mainly adopts the principle of absorption and reabsorption of water molecules in alumina thin film based humidity sensors and determined the accuracy of ± 3% [9].

L. K. Baxter ***et al.*** described the electrical properties of capacitive based humidity sensor including their capacitance value of the dielectric thin film implemented for designing humidity sensors and mathematical expression about their relative permittivities at different surface conditions [10].

S. Pennisi ***et al.*** proposed a new concept of interfacing circuit for converting the capacitance of humidity sensor into other electrical quantity like current etc. The whole work is done by using CMOS technology to design the interfacing circuit with very low conversion period of around 500ns. The results obtained by the simulation of the designed interfacing circuit in PSPICE software [11].

J. C. Lotters ***et al.*** designed an interfacing circuit to convert the capacitance change of sensor into the differential voltage using CMOS technology. The designed circuit is containing ac bridges, immune to parasitic capacitance that is capable of detecting the capacitance change up to at least 10Khz [12].

N. Yazdi ***et al.*** presented an interfacing circuit utilizing large variety of capacitive humidity sensor with very low voltage drop during conversion. Change in dielectric property of the sensor observe as change in its capacitance is easily converted into analogue output by using CMOS technology [13].

C. Idnani ***et al.*** describes a unique circuit known as dual timer in both astable and monostable operation modes. This paper illustrate the details of all the pins connected to the timer. The results of this work proves that the duty cycle of PWM signal varies according to the charging and discharging of capacitor connected to the threshold pin in timer [14].

B. J. Baliga ***et al.*** reviews the recent trends in power semi-conductor technologies adopted to reduce the switching losses at higher frequency applications. This paper also reveals the applications of power semi-conductor devices according to their voltage ratings. These switching devices have widen their range of application in power electronics by adopting silicon carbine material for manufacturing [15].

M. H. Rashid ***et al.*** describes the detail study of power diodes, transistors and thyristors about their threshold requirements, operating voltage and current ratings and their applications in industries as well as commercial purposes [16].

G. Belverde ***et al.*** described the basic characteristics of bipolar junction transistor (BJT) and power MOSFET in terms of their structure and electrical performances. Several experiments on these devices are done at different conditions and proves the application of IGBT and power MOSFET is considerable at higher frequency operations due to their low switching losses [17].

K. Sakamoto ***et al.*** designed an intelligent power MOSFET with in-built thermal protection for improving its reliability at higher temperature conditions. This is achieved by using

MOSFET device in place of gate resistor and this new designed circuit is known as FS-Thermal FET [18].

R. Schorner *et al.* examined the detail study of mobility of inversion layer and threshold voltage of n-channel enhancement and reveals that the channel dimensions (length and breadth) and the device material both are the deciding factor for the MOSFET voltage and current ratings [19].

K. Wilson *et al.* illustrate the basic structure of depletion mode MOSFET and develop an analytical model of depletion type MOSFET at different temperature conditions for observing their behavior from their electrical characteristics. It also illustrate about the narrowing of channel during negative gate source voltage is applied [20].

N. Mohan *et al.* describes the detail study of power electronic devices including IGBT, MOSFET's etc. about their threshold ratings and their basic structures. Threshold value mainly depends up on the material from which the device is constructed [21].

S. K. Tewksbury *et al.* presented the experimental result on the basic model of n-channel enhancement type power MOSFET and observe the characteristics between drain source voltage (V_{ds}) and drain current (I_d). These experiments were carefully done at different temperatures ranging from 10 kelvin to 300 kelvin including the essential steps taken to provide cooling effect [22].

J. Wang *et al.* presented the PSPICE model of power MOSFET to observe its characteristics to implement the results in real time applications. Simulation modeling is done at 20Khz frequency by using 10kv silicon carbide based MOSFET in dc/dc boost converter to observe its different operating regions [23].

R. Locher *et al.* illustrates the basic modelling and necessities of driver circuits used to drive power MOSFETs and their switching behavior including the switching losses. These circuits are used to reduce the switching losses at high frequency operations [24].

T. Shimizu *et al.* describes the new design for driver circuit used to trigger IGBT and power MOSFETs with reduced switching losses to increase the power density of power converters.

Several switching waveforms are observed using the designed driver circuit at both turn-on and turn-off transients [25].

L. Balogh *et al.* presented the detail study of different kinds of driver circuits and their applications in real time accordingly. Also illustrates the speed enhancing circuits for high frequency applications and methods to reduce switching losses [26].

H. K. Samitha Ransara *et al.* designed a low cost motor drive for BLDC motor with boost converter and simulate the model using MATLAB and the results were compared with conventional drives. Several mathematical expressions were given to prove the theoretical and simulation results are same [27].

D. Lin *et al.* presents an in-depth study about the flux generated by the permanent magnets and also describes torque produced due to the flow of current and flux. Detailed computation in this work proves that the torque in BLDC motor never remains constant but varies according to the load conditions [28].

B. Bose *et al.* gives a comprehensive review for the applications of variable speed drives due to the advancement in power electronics. DC motors with variable speed drives have widen their field of applications according to the recent trends [29].

M. H. Rashid *et al.* describes the detail study of dc motor drives and their chopper control for different quadrant operations in controlling the speed of brushless dc motors. It also illustrate the mathematical formulation for armature current, motor current during its running conditions [30].

P. S. Bimbhra *et al.* illustrates the detailed information regarding the applications of permanent magnet direct current (PMDC) motors in different field of operations [31].

1.3 Objective

- To design an intelligent and low cost signal conditioning circuit for converting capacitance change into the differential voltage.
- To design the highly efficient driver circuit for power MOSFET to reduce its switching losses.
- To control the speed of PMDC motor used in blowers for dehumidification processes.

- Simulation of the designed signal conditioning and driver circuit with accurate results.

1.4 Organization of Thesis

Chapter 1 mainly deals with the overview about the dissertation work, literature survey and our objective.

Chapter 2 illustrate about the humidity sensors, its basic terms and types of humidity sensor mainly capacitive humidity sensor.

Chapter 3 describes all about the power semi-conductor devices, their types, operating principles and their characteristics and applications.

Chapter 4 introduce the different types of electronic signal conditioning circuits and modes of operations of CMOS 555 timer.

Chapter 5 illuminate all about the electrical motors specifically PMDC motor, its speed controlling methods, advantages and applications.

Chapter 6 depicts the simulation and real-time implemented circuits and their correspondingly results.

Chapter 7 discusses the conclusion and the future scope of the present dissertation work.

CHAPTER-2
HUMIDITY SENSORS

2.1 Humidity and Its Basic Terms

Humidity is defined as the amount of wetness or water vapours present in the surrounding atmosphere. The partial pressure of water vapours is directly proportional to the amount of atmospheric moisture. There are different ways of expressing the moisture content in air such as (a) absolute humidity (b) specific humidity (c) relative humidity

a) Absolute humidity:

It is defined as the total mass of water vapours present per unit volume of dry air. This term is generally considered to be independent of temperature. Mathematically, it is the mass of water vapours divided by the mixture of air and vapours expressed in volume [6].

$$Absolute\ humidity = \frac{Mass\ of\ water\ vapours}{Volume\ of\ (air + water\ vapours)}$$

Units to express absolute humidity are g/m^3.

b) Specific humidity:

It is defined as a ratio of the mass of water vapours content to the total air on the mass basis. Specific humidity and mixing ratio bot are the same terms with only one difference that is given in their mathematical expressions [6],

$$Specific\ humidity = \frac{Mass\ of\ water\ vapours}{Mass\ of\ total\ air}$$

$$Mixing\ Ratio = \frac{Mass\ of\ water\ vapours}{Mass\ of\ dry\ air}$$

c) Relative humidity:

It is defined as the ratio of partial water vapour pressure at specific temperature to the water vapour pressure at saturation provided that temperature remain same. This term is generally expressed in percentage (%). It is a temperature dependent term.

$$Relative\ humidity = \frac{water\ vapour\ pressure}{water\ vapour\ pressure\ at\ saturation}$$

Dew-point temperature is one more humidity linked parameter that is well-defined as the temperature to which the air should be conditioned to reach the level of saturation, where the moisture content remains constant. In other words, the temperature at which the relative humidity reaches to 100% due to the decrease in the saturation vapour pressure during cooling down. This temperature gives a quantity of the absolute humidity present in the air and it corresponds to the saturation vapour density at that temperature.

2.2 Industrial Application of Humidity Sensors

Now-a-days atmospheric conditions play a vital role for the efficient operations in automated industrial applications. That is why humidity sensors have gained their applications for both industrial as well as domestic purposes. Humidity sensors generally follows the principle of any change in physical property will results into the electrical change. Humidity sensors can measure the humidity level simply by absorbing or releasing moisture, which can make change in its physical properties. These humidity sensors are used in industries not only to determine or monitor the moisture content but widen their range of application in some electronic designed circuit to control the moisture content by switching the blower motors as in case of air-conditioners. These sensors have their wide range of applications in semi-conductor industries. At the present time, a lot of research work has been done on the materials used for developing these humidity sensors such as polymers, ceramic materials, alumina thin films and other metal oxides [7]. But in spite use of these materials for the humidity sensors, they are going through many serious problems [8] illustrated as: (i) slow response (ii) long time stability and reproducibility and (ii) hysteresis losses in these sensors. Based on different techniques available to measure the humidity, these sensors are categorized into two (i) Absolute humidity sensor and (ii) Relative humidity sensor . Basic flowchart of humidity sensors is shown in Fig. 2.1

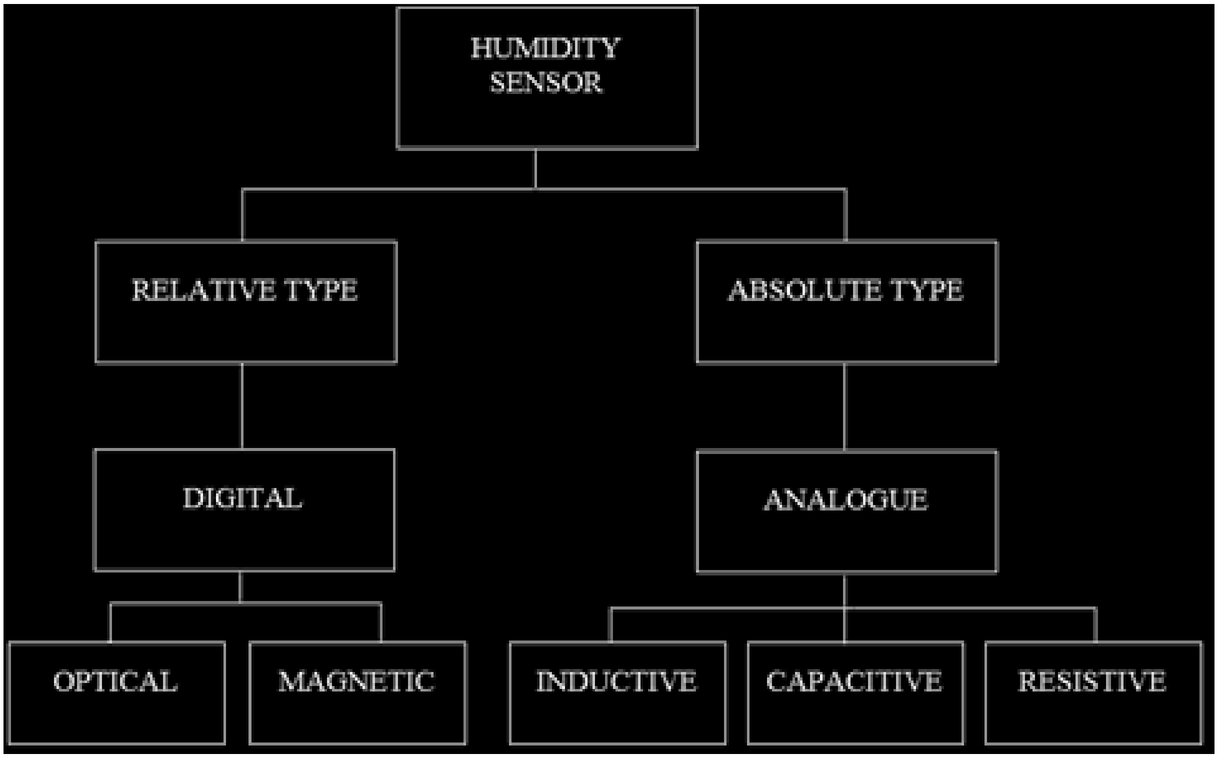


Fig. 2.1. Flowchart of Humidity Sensors

In our dissertation work, we have used capacitive humidity sensor to design the capacitance to voltage converter.

2.3 Capacitive Humidity Sensor

Capacitive humidity sensor mainly detects the changes in its chemical or physical properties occur due to the change in dielectric property of the sensing material. Capacitive humidity sensor generally assembled by using thin film of $\gamma - Al_2O_3$ formed in between two conducting electrodes. Capacitive sensors are extensively used due to its low cost and compact structure, highly sensitive than other type of sensors. These sensors use the capacitive technique to detect the moisture level by absorbing and reabsorbing the water molecules [9].

The concept of capacitance

Capacitance between any two electrodes in its simplest form is defined as charge produced due to the potential difference applied between these two electrodes i.e. when we apply the potential between any two electrodes, a charge will produce on any of the electrode. This is shown in Fig. 2.2. Mathematically, capacitance can be defined as,

$$C = \frac{Q}{V} = \frac{coulumb}{voltage} = farad \qquad (2.1)$$

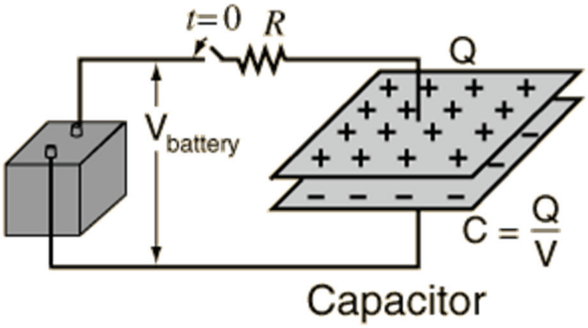


Fig. 2.2. Representation of capacitance between two electrodes plates

Structure of capacitive humidity sensor

The structure of capacitive sensor in its simplest form consists of two parallel plates having equal area ‘A’ and distance between two is ‘d’ as shown below:

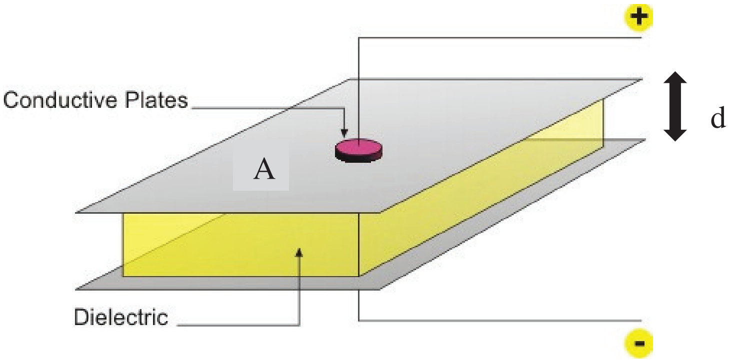


Fig. 2.3.Simple representation of capacitive sensor with dielectric

Now, the value of distance between the plates (d) is smaller than the area of plate then the approximate value of capacitance will be given in [10] as,

$$C = \in_r \in_o \frac{A}{d} \qquad (2.2)$$

Here, ‘$\in_o$’is the permittivity of vacuum and its value is around $8.85*10^{-12}$ F/m.

And '$\in_r$' is the relative permittivity of the dielectric material placed in between two conducting electrodes as shown in fig 1.3.

In capacitive humidity sensor, area of plates or electrodes and the distance between them remains same throughout the process of absorption and reabsorption of water molecules. Here, '$\in_r$' is a fundamental quantity whose value changes according to the water molecules absorb or reabsorb onto the dielectric material i.e. thin film of $\gamma - Al_2O_3$ behaving as dielectric in this sensor. Hence, we can conclude that capacitance value of this sensor will be different for both dry as well as wet surface of thin film. Mathematically, it can be illustrated as:

$$\left(\frac{C_w}{C_d}\right) = \left(\frac{\in_{rw}}{\in_{rd}}\right)^n \tag{2.3}$$

C_w - Capacitance of sensor during wet surface condition.

C_d - Capacitance during dry surface condition.

$\in_{rw}$ - Relative permittivity during wet condition.

$\in_{rd}$ - Relative permittivity during dry condition.

Here, value of 'n' depends upon the dielectric material and its properties.

CHAPTER-3
POWER SEMI-CONDUCTOR DEVICES

3.1 Introduction

There is a tremendous advancement in the field of power semiconductor devices since the first thyristor was invented in 1957 and named as SCR. Further from 1970's these conventional thyristors had been exclusively used for controlling power in industrial applications [15]. Various kinds of power semiconductor devices were developed that time and become commercial available. These devices play a significant role in the distribution and regulation of power and energy in this world. Some of the conspicuous applications of power semiconductor devices are shown below according to their voltage and current ratings.

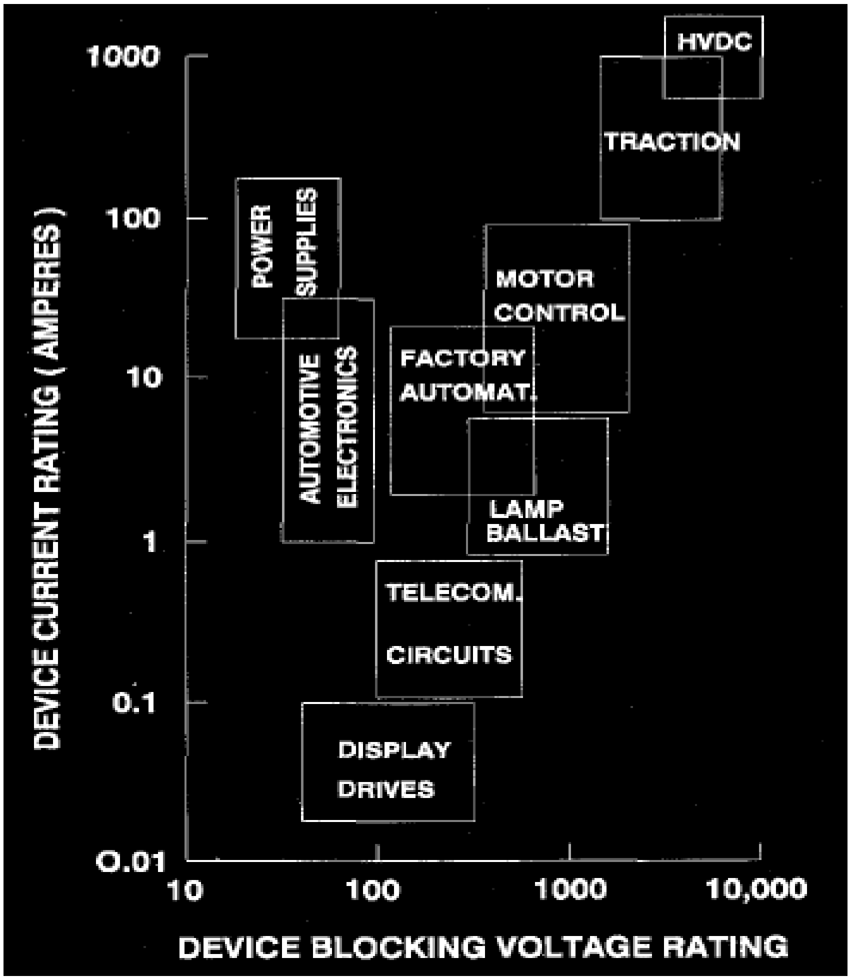


Fig. 3.1. Graphical representation for different applications of power semi-conductor devices [15]

3.2 Types of Power Semi-Conductor Devices

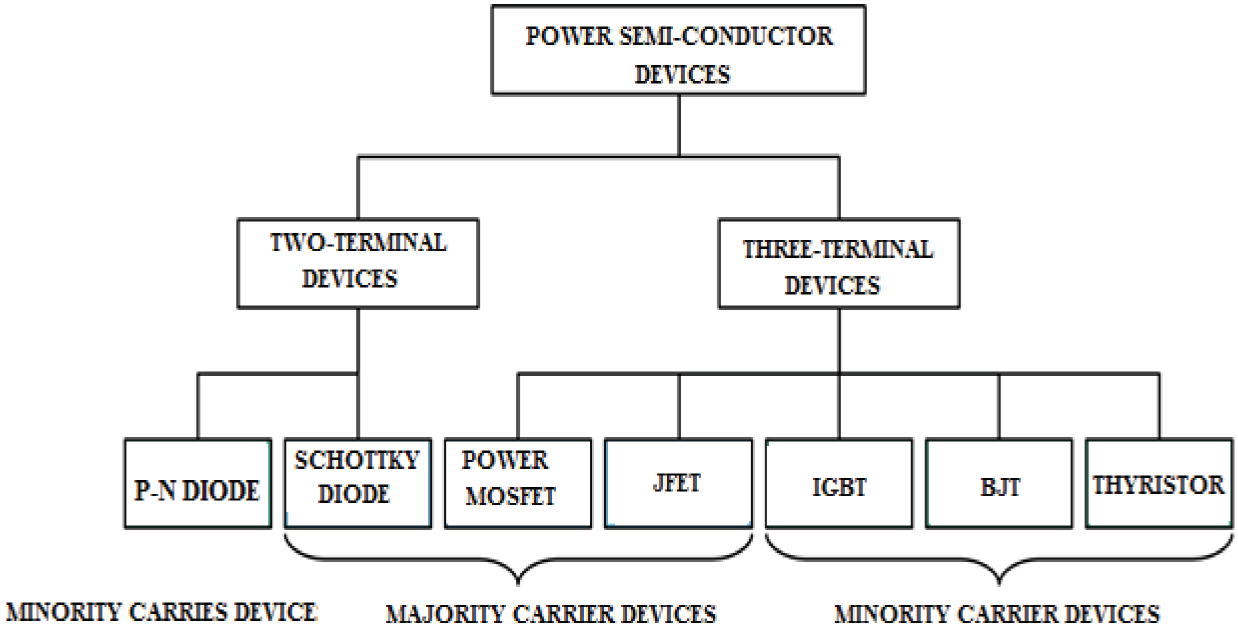


Fig. 3.2.Classification of power semiconductor devices

Majority of devices are made of silicon material, these are broadly classified as (i) Power diodes (ii) Transistors and (iii) Thyristors

These are further divided into 5 categories:

1. Power diodes

2. Thyristors

3. Power bipolar junction transistors(BJT’s)

4. Power metal oxide semiconductor field-effect transistors(MOSFET’s)

5. Insulated gate bipolar transistors(IGBT’s)

3.2.1 Power Diodes

A diode generally has two terminals (i) cathode and (ii) anode. It conducts only when its anode terminal is at higher voltage than the voltage at its cathode terminal, also the forward voltage drop require to be low ranging from 0.5v to 1.2v. When voltage at its cathode terminal is higher than at anode then it is said to be in blocking mode.

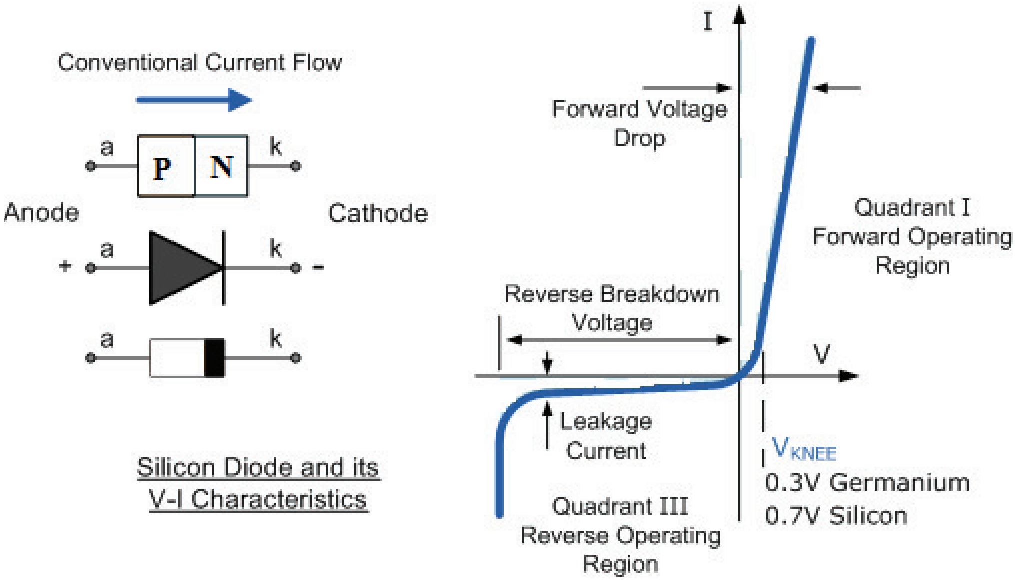


Fig. 3.3. Symbol and V-I characteristics of Si-power diode

Threshold voltage is generally defined as the minimum voltage that is required to start conduction through a diode. Its value for Silicon material diode is 0.7v and for germanium, it is 0.3v.

Power diodes are of three types:-

1. General purpose diodes (up to 6000V, 4500A)
2. Fast-recovery diodes (up to 6000V, 1100A)
3. Schottky diodes (up to 100V, 300A)

Due to the increase of leakage current with their ratings, schottky diodes are limited to the range of 100V and 300A [16].

3.2.2 Thyristors

These are the three terminal devices with an anode, a cathode and a gate. Thyristor conducts only when a low current signal is applied as an input to the gate and cathode terminals, provided than anode terminal must be at higher potential than at cathode terminal.

Thyristors can be sub-divided into 11 types [15]:-

(1) forced-commutated thyristor (2) Line-commutated thyristor (3) gate turn-off thyristor GTO (4) reverse-conducting thyristor RCT (5) static induction thyristor SITH (6) gate assisted turn-off thyristor GATT (7) light activated silicon-controlled rectifier LASCR (8) MOS turn-off MTO thyristor (9) emitter turn-off ETO thyristor (10) integrated gate-commutated thyristor IGCT and (11) MOS controlled thyristor MCT.

3.2.3 Power Transistors

Power transistors are generally of four types:- (i) BJT's (ii) power MOSFET's (iii) IGBT's (iv) SIT's.

A BJT or bipolar transistor has three terminal emitter, base and collector. In common emitter configuration, it is normally operated as a switching device. There are two basic configurations used for designing the transistor are 'npn' and 'pnp' Mostly, 'npn' configured BJT is employed in all applications. As long as the base of npn transistor is at higher potential than the emitter terminal and current at the base terminal is sufficiently large to drive the transistor in saturation region, transistor remains 'ON' provided that collector-emitter junction should be properly biased. High power BJT's are commonly employed for power converters below 10KHz frequency and power ratings up to 1200V and 400A [16]. These devices allow high current density during its ON state with low forward voltage drop but the switching speed for its power applications is intensely reduced due to its bipolar nature [17].

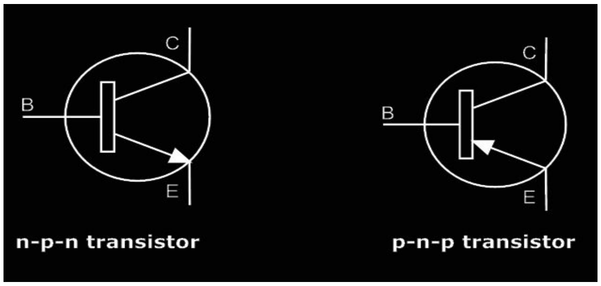


Fig. 3.4. Basic configurations of power transistor

Power MOSFET's require low power driving signals and are generally employed in high speed applications [17] such as power converters and are available in low power ratings than bipolar transistor, available up to 1000V, 100A. These power transistors are used for high frequency operations having a range from several kilohertz to megahertz [16].

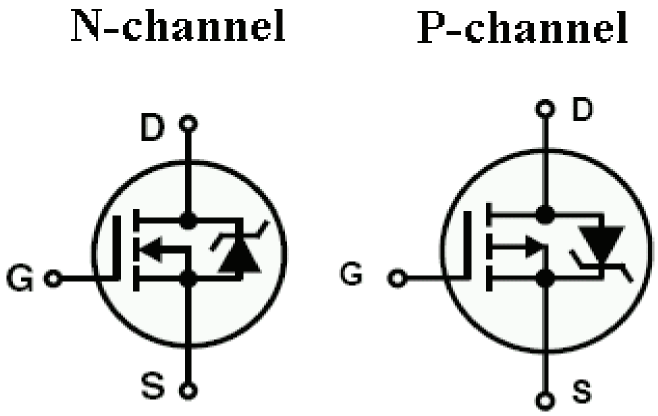


Fig. 3.5. Symbols of n and p channel power mosfet

IGBTs are voltage controlled power transistors and developed by considering the properties of both BJT as well as Power MOSFET [17]. These transistors are not as fast as power MOSFETs but can be used at higher voltage ratings. These devices are available for applications at nearly 20 kilohertz and ratings up to 1700V, 2400A [16].

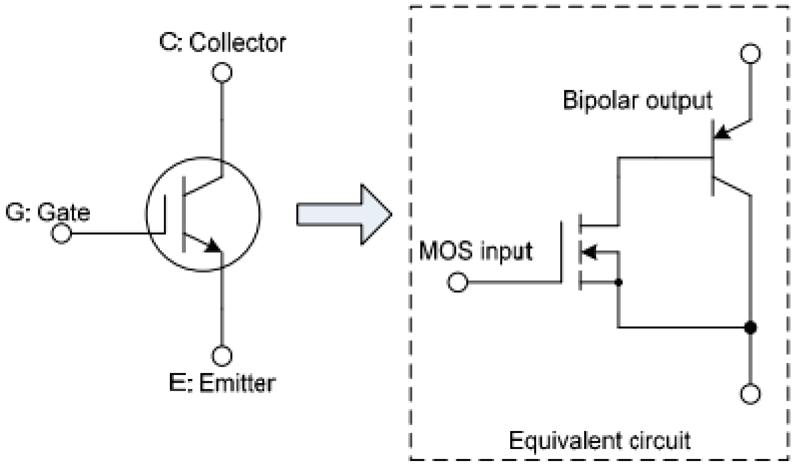


Fig. 3.6. IGBT symbol and its equivalent

3.3 Power MOSFET

A power MOSFET is a voltage controlled device and requires a small input driving current. These devices are used for high frequency operations and having switching time of around the order of nanoseconds. These have an emerging trend toward low power and high frequency power converters. These devices don't have problems related to second breakdown phenomenon as in case of BJT. These devices require special care for the condition of short-circuit or during high current applications [18].

3.3.1 Fundamentals of Power MOSFET

From the operating principle point of view, MOSFET is a voltage controlled device whose working depends upon the majority charge carriers. A metal oxide semiconductor field-effect transistor (MOSFET) depends up on the modulation of concentration of charge by the MOS capacitance present between an electrode and a gate electrode located above the body which are insulated by using an oxide layer from all other regions of a device. Basic structure of n-channel power MOSFET is shown below in Fig. 3.7.

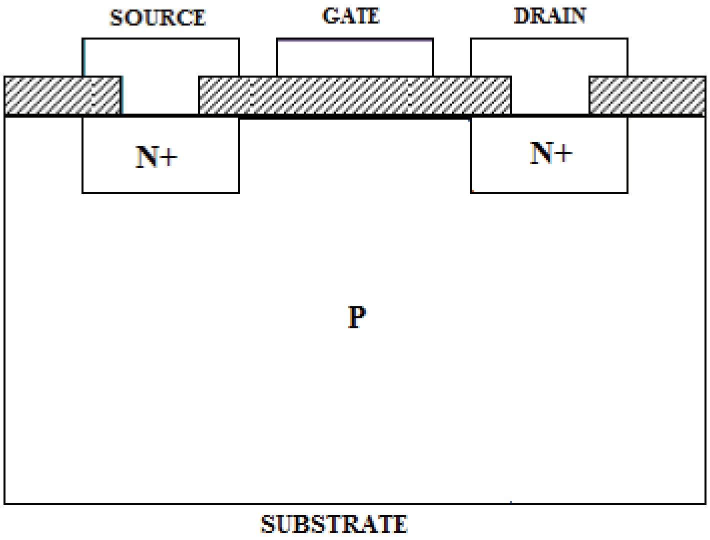


Fig. 3.7. Cross-section of basic MOSFET

The MOSFET consist of two other terminals – drain and source, each connected individually highly doped regions separated by the body region. When the applied gate voltage is higher than threshold voltage, electrons starts entering from the source into the inversion layer or n-channel at the crossing point between the p region and the oxide. This conducting channel starts expanding between the drain and source, and conduction starts through it when a voltage is applied between drain and source.

3.3.2 Operating Principle of Power MOSFET

The gate region of a MOSFET comprises of gate metallization, the p-body silicon and the gate oxide layer (SiO_2) and forms a high quality capacitor. When we apply small voltage to this capacitor structure with gate terminal positive with respect to the source provided that body and source are shorted, depletion region forms at the interface between the oxide layer and the body silicon as shown in Fig. 3.8.

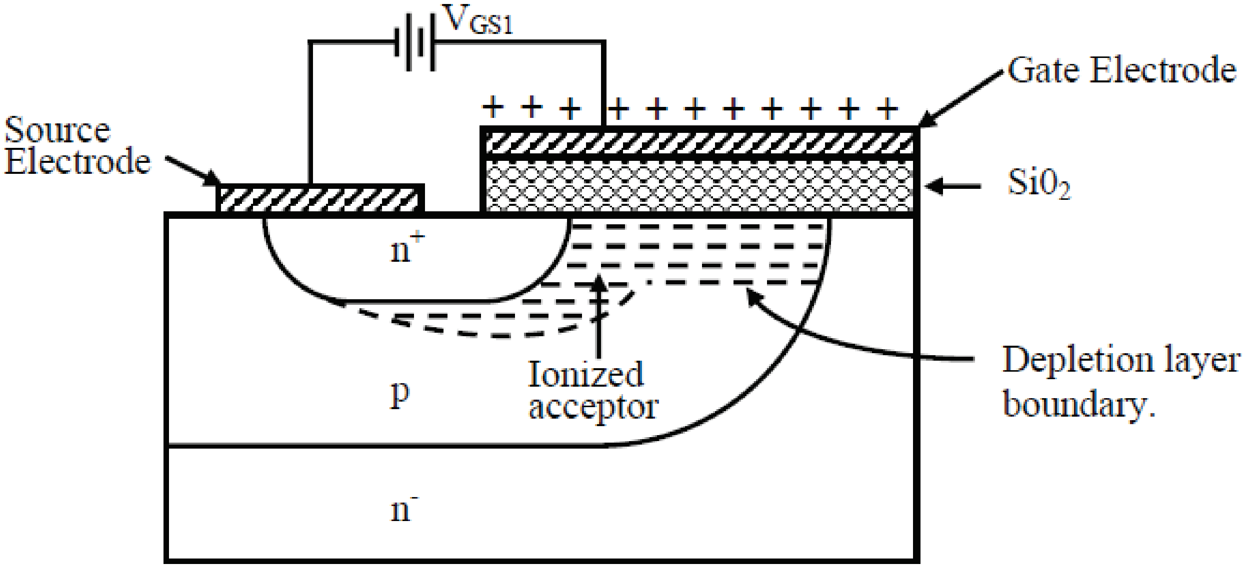


Fig. 3.8. Formation of depletion layer

The positive (+ve) charge induced on the gate metal contact repels the majority hole carriers from the interface region shown between the gate oxide and the p-type body. This results in the induction of negatively (-ve) charged acceptors and a depletion region. The thickness layer of depletion layer will expand with the further increase of gate source voltage (V_{GS}). On the other hand, the electric field at the oxide-silicon interface gets larger and start attracting free electrons as shown in Fig. 3.9

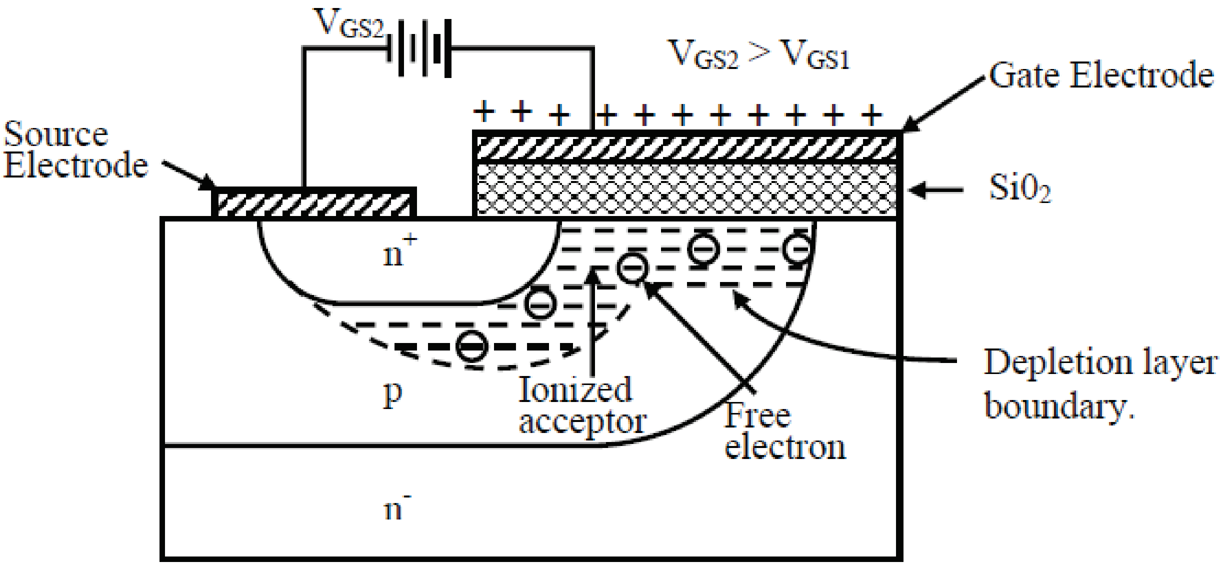


Fig. 3.9. Free electron accumulation in MOSFET

Thermal ionization is a process of generating electron-hole which is the immediate source of electrons. The holes are repelled into the semiconductor layer near the depletion region. Electrons from the source will neutralize the extra holes. Further increase in V_{GS} will result into an increase the density of free electrons at the interfacing region becomes equivalent to free hole density in body region beyond the depletion layer. This layer of free electrons at the interfacing region is known as the inversion layer and is shown in Fig. 3.10.

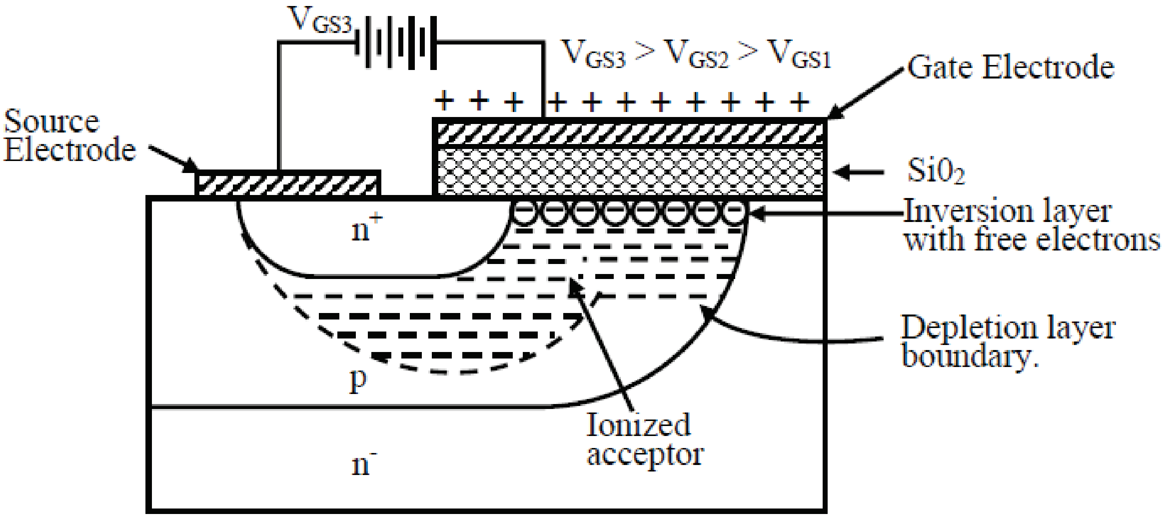


Fig. 3.10. Formation of inversion layer

The inversion layer exhibit all the properties similar to an n-type semiconductor and is a conductive channel between the source and drain which permits the flow of current between them. As the current conduction in this device is possible only through an n- type channel created by the electric field due to the applied gate source voltage, it is known as Enhancement type n-channel MOSFET.

The value of V_{GS} at which the inversion layer is considered to have formed is called the Gate–Source threshold voltage V_{GS} is that minimum voltage at which the formation of inversion layer takes place. As the density of free electrons increases further with the increase in applied V_{GS} will result into the expansion of inversion layer and hence, more will be the conduction.

In the basic MOSFET structure, voltage and current ratings both depends upon the channel dimensions, i.e., its length and width, resulting in unproductive use of the "silicon estate" for their applications in power electronics [19].

3.4 Different Types of Power MOSFET

Based on nature of operation, MOSFET devices are of two types:

1. Depletion type

2. Enhancement type

Depletion type MOSFETs are normally employed as “ON” type switches i.e. when the gate terminal is opened, a non-zero drain current can flow in these type of devices. These types of devices are inconvenient in many power electronic applications. Therefore, the enhancement type MOSFETs (specifically n-channel devices) are mostly employed in power electronics applications. This is the type of MOSFET will be discussed later in this lesson.

Now based on above two types they are divided into four categories:

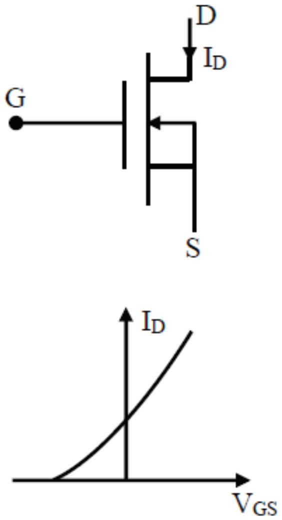
1. n-depletion type power MOSFET

2. n-enhancement type power MOSFET

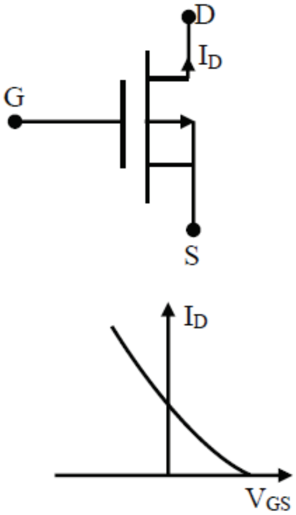
3. p-depletion type power MOSFET

4. p-enhancement type power MOSFET

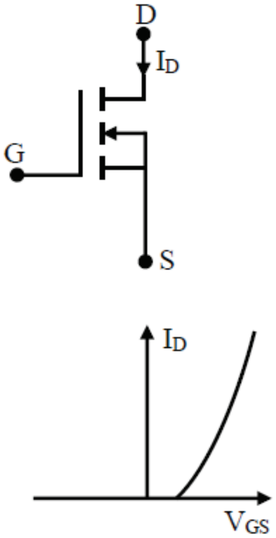
Basic circuit symbols & transfer characteristics of different types of power MOSFET:



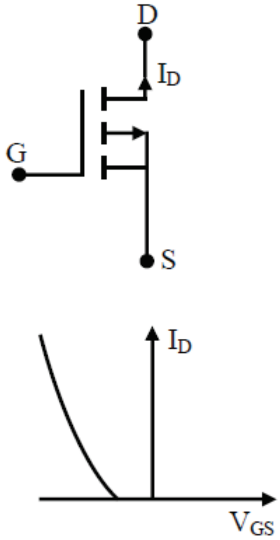
N-channel depletion
type MOSFET



P-channel depletion
type MOSFET



N-channel enhancement
type MOSFET



P-channel enhancement
type MOSFET

N-channel depletion type:

This type of power MOSFET is formed on p-type silicon substrate, having two heavily doped n^+ regions in order to have low resistance connections. A thin oxide layer is used to have isolation between gate and channel as shown in Fig. 3.11. Gate, drain and source are the three terminals having substrate normally connected to the source. V_{gs} is the gate to source voltage and could be either +ve or –ve. When V_{gs} is negative, there is repulsion of electrons in n-channel region which forms the depletion region below the oxide layer, resulting in narrow effective channel and high resistance from drain to source. No current will flow through the drain to source if this V_{gs} is made –ve enough and the channel becomes fully depleted i.e. at high R_{ds}, I_{ds} will be zero. This much –ve value of V_{gs} is used to called as pinch-off voltage V_P [20].

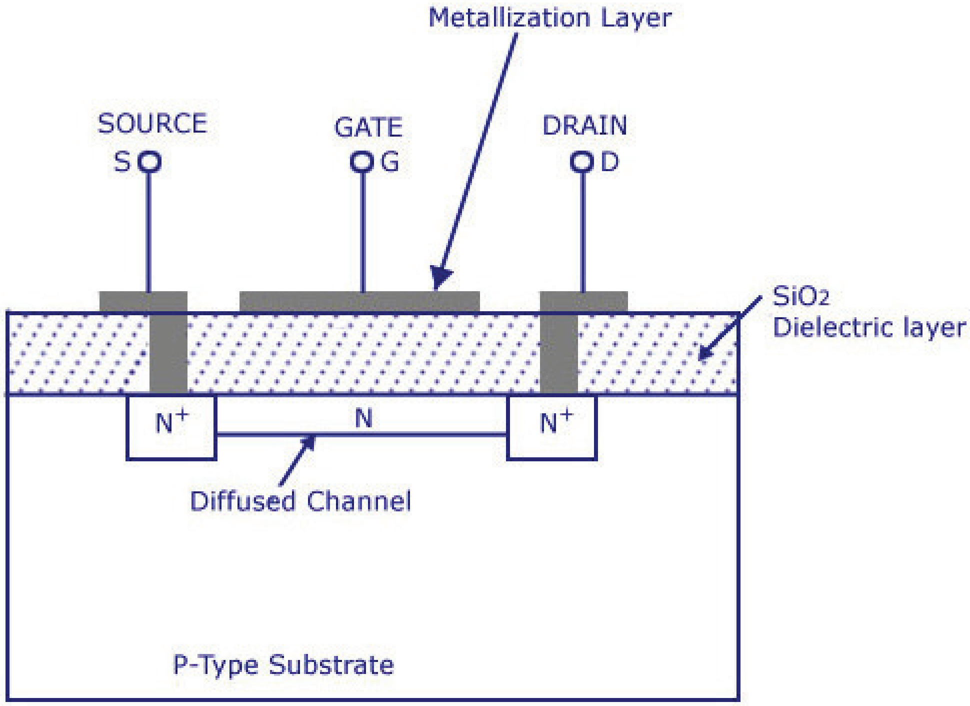


Fig. 3.11. n-channel depletion type mosfet

On the other hand, if V_{gs} is made positive (+ve) then the channel becomes wider and drain to source current (I_{ds}) will increase as a result of reduction in drain to source (R_{ds}) resistance.

P-channel depletion type:

Mosfet having p-channel depletion type, the polarities of drain to source voltage (V_{ds}), drain to source current (I_{ds}) and applied gate to source voltage (V_{gs}) are reversed as shown below:

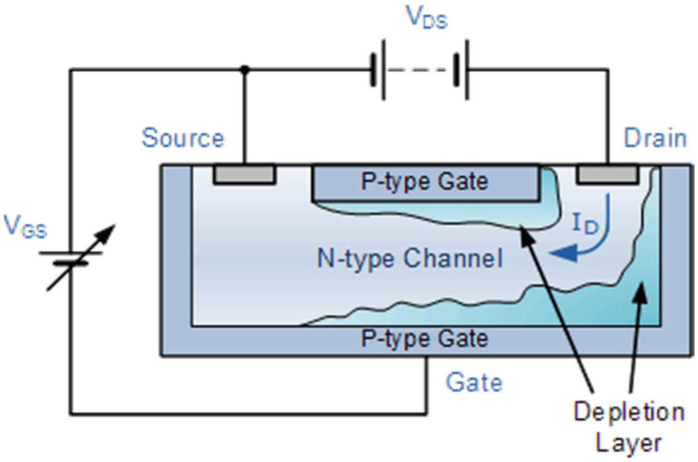


Fig. 3.12. p-channel depletion type mosfet

N-channel enhancement type:

In this, if gate to source voltage (V_{gs}) is positive then an induced voltage will attract the electrons from p-substrate towards the surface beneath the oxide layer. To form a virtual n-channel, V_{gs} should be equal to or greater than the threshold voltage (V_T). This voltage is the minimum voltage require to start the flow of current from drain to source. This value generally depends upon the type of material used to develop the mosfet [21]. In the n-channel enhancement type power MOSFET, the voltage and current ratings are functions of the channel dimensions i.e. its length and width are the rating deciding factors and measurement were taken at different dimensions of channel in [22]. Basic structure of n-channel enhancement type power MOSFET is shown below:

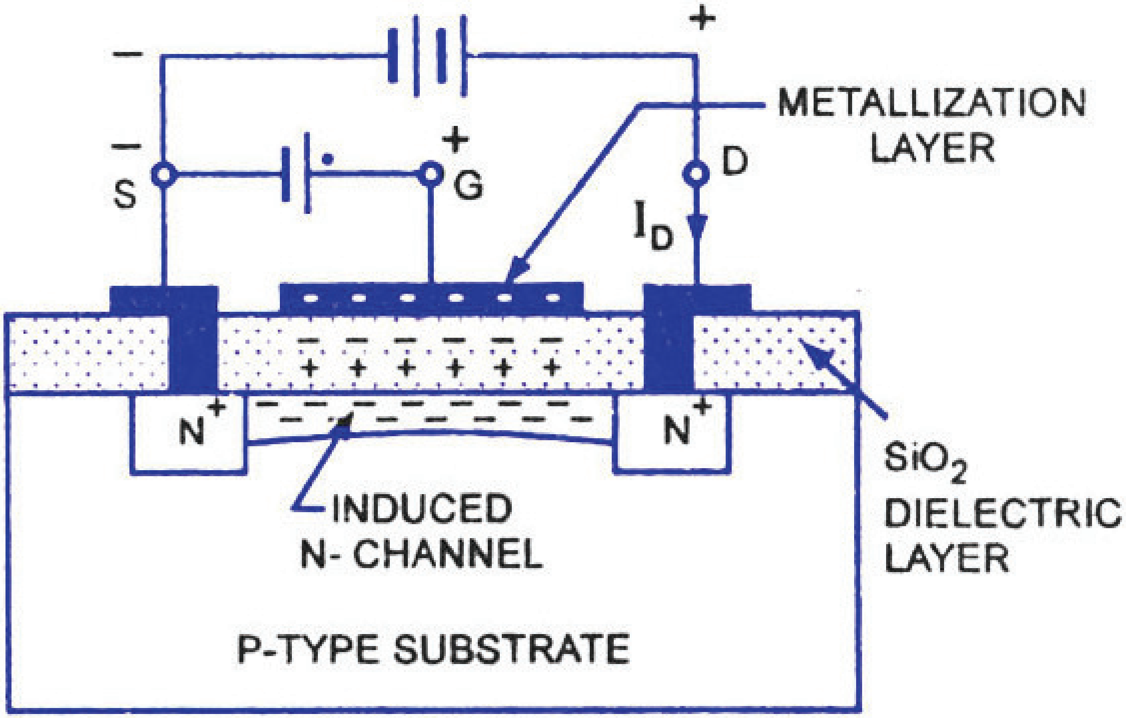


Fig. 3.13. Basic structure of n-channel E-type power MOSFET

2.5 Steady State Output (I-V) Characteristics of Power MOSFET

Power MOSFET, like the BJT is a three terminal device in which the voltage across the gate terminal determine the flow of current at the output terminals that are drain and source. The source terminal is usually common between the input (I/P) and the output (O/P) terminals of the MOSFET. The output (O/P) characteristics of a power MOSFET is a plot drawn of drain current

(I_D) as a function of the drain source voltage (V_{DS}) with gate source voltage (V_{GS}) as a variable parameter. Fig. 3.14 shows such characteristics:

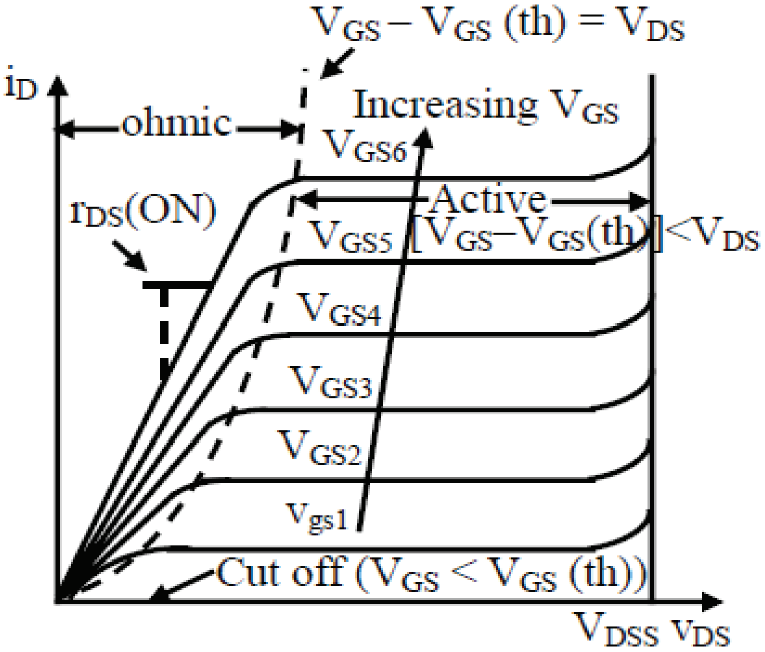


Fig. 3.14. O/P I-V characteristics

When the gate to source voltage (V_{GS}) is below the threshold voltage (V_{TH}), at this time the power MOSFET operates in the cut-off region. Therefore, no drain current will flow in this mode and the applied voltage between drain and source terminals (V_{DS}) is supported by the p-n junction formed between body and collector. To avoid destruction of the device, maximum applied voltage should be less than the breakdown voltage for this junction i.e. (V_{DSS}). When the input V_{GS} is increased beyond the threshold voltage of the device, drain current starts flowing. As we see in the plot for small values of V_{DS} i.e. ($V_{DS} < V_{GS} - V_{TH}$), drain current I_D is linearly proportional to V_{DS} [23]. This mode of operation is known as “Ohmic mode” of operation. Power MOSFET in most of power electronic applications is operated either in the cut off region or in the ohmic mode. The slope of the ($V_{DS} - I_D$) characteristics in this mode determines the ON state resistance of the power MOSFET (R_{DS} (ON)). Note that R_{DS} (ON) is decreasing with the increase in V_{GS} due to reduction in the channel resistance at large values of V_{GS} [23]. Hence, this will expand the field of their applications in power electronics where higher values of V_{GS} is mostly used. Further at higher values of V_{DS}, these characteristics deviates from the linear relationship towards the saturation region. The exact mechanism behind this is quite complex. It will be enough to state that, at higher drain current values the voltage drop across the channel resistance will tends to reduce the channel width formed at the drain drift layer end. In this saturation condition, there will be no increment in drain current with any further increase in drain source voltage (V_{DS}).

3.6 Power MOSFET Gate Drive

Power MOSFET is a voltage controlled device which does not have need of a continuous gate current to retain it in the ON state. However, it is required to charge and discharge the capacitors present between both gate-source and the gate-drain terminals in each switching operation. The switching times mainly depends upon the charging and discharging speed of these capacitors. Therefore, the gate drive power requirement is essential for the fast switching operations of the capacitors i.e. these gate drive arrangements are significant at high frequency operations [24]. A typical gate drive circuit of a power MOSFET is shown below in Fig. 3.15.

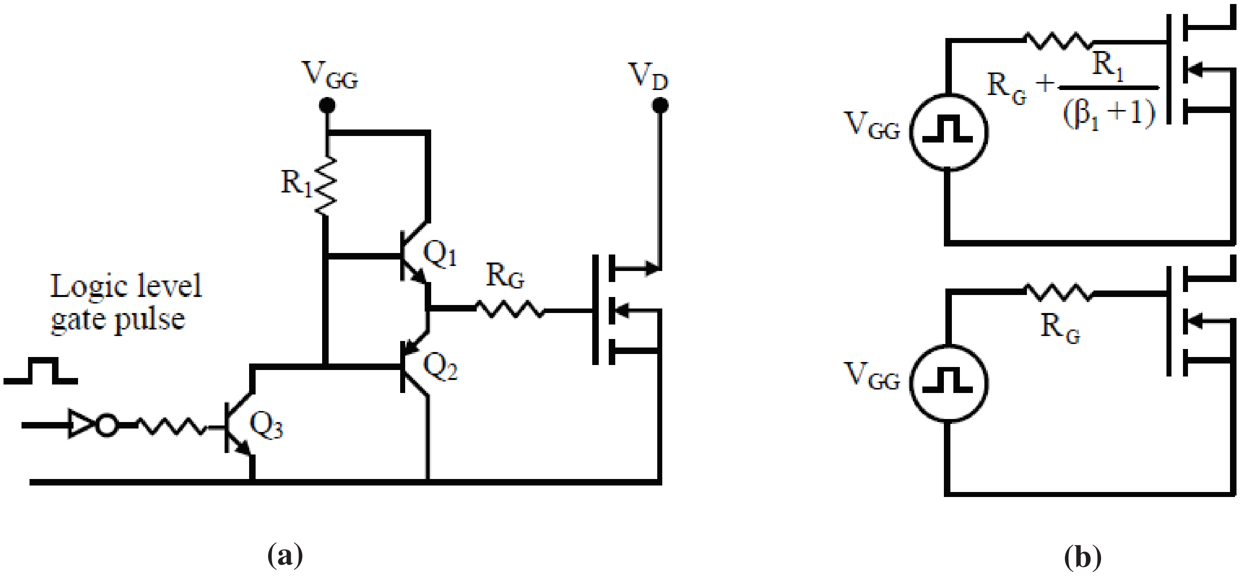


Fig. 3.15. Power MOSFET Gate Drive circuit

(a) Basic gate drive circuit

(b) Equivalent circuit during turn-on and turn-off

The logic level which is input to the inverting buffer should be in high state to turn-on the power MOSFET so that transistor Q3 turns-off and transistor Q1 turns-on. The circuit of Fig. 3.15 (b) describes the equivalent circuit during turn on condition. Note that, Q1 remains in the active region during the device remain in turn-on condition. The effective gate resistance is $R_G + \frac{R_1}{(\beta_1 + 1)}$ where, β1 is the dc current gain of transistor Q1.

Now if you want to turn-off the power MOSFET, the logic level input should be at low state. Here, transistor Q_3 and Q_2 turns-on while transistor Q_1 turns off. The corresponding equivalent circuit is shown at the bottom circuit in Fig. 3.15 (b). The switching time or switching speed of the power MOSFET can be adjusted by selecting a proper value of R_G. Reducing the value of R_G will result into an increase the switching speed of the power MOSFET [25].

3.6.1 PWM Direct Drive

In power supply applications, the easiest way of driving the gate terminal of the main switching device is to utilize the output of the PWM controller as shown in Fig. 3.16.

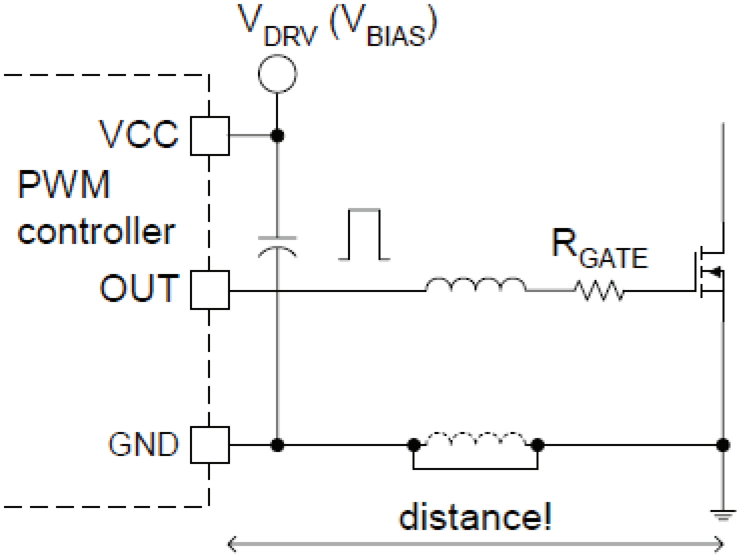


Fig. 3.16. Direct gate drive circuit

The most difficult task in direct gate drive circuits is the optimization of the circuit layout. As indicated above in Fig. 3.16., there might be any considerable distance between the PWM controller and the power MOSFET. This distance will produce a parasitic inductance due to the formation of loop in between the gate drive circuit and ground return which can results in slowing down the switching speed and can cause distraction in the gate drive waveform [26]. To reduce the inductance effect linked to the gate drive circuit, a wider distance between driver and the switching device is preferable. Another problem in these gate drives is the limited current capability of the PWM controllers. The direct connections can be used only when the control circuit is having the same ground reference as in the power circuit, and power levels are comparatively low. To protect these gate drives from any reverse current, bipolar transistors and schottky diodes are used as shown below in Fig. 3.17.

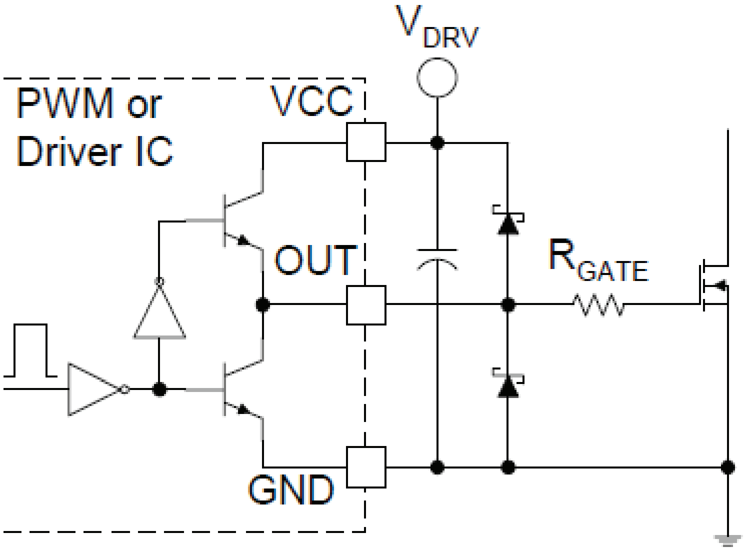


Fig. 3.17. Direct gate drive using bipolar transistor

The NPN transistor can handle the current in one direction only. The high side of this transistor is used as a current source but cannot sink the current while its low side operation is exactly opposite to its high side. In order to provide a path for reverse currents, low voltage schottky diodes must be placed in between the capacitor and gate drive circuit to protect the output [26].

3.6.2 Bipolar Totem-Pole Driver

One of the most prevalent and cost effective driver circuit for driving the power MOSFET is a bipolar, non-inverting totem-pole arrangement as shown below in Fig. 3.18. A totem pole arrangement consists of a pnp and npn transistor connected emitter to emitter with their bases coupled together. Transistors are used to supply large current to the load. This circuit can handle the current spikes and also minimize the power losses by making the operating conditions more favorable for the PWM controller.

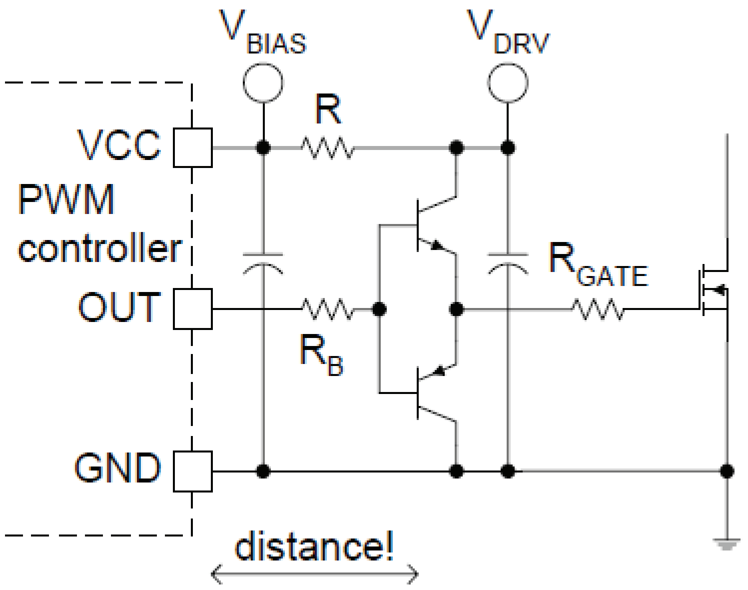


Fig. 3.18. Bipolar totem-pole arrangement

To increase the noise immunity, there should be a smoothing resistor or inductor placed in between the bypass capacitor of the driver and the capacitor of the PWM controller [26] as shown above. Another benefit of this arrangement that its working is based upon the same clamp mechanism that the npn-pnp transistor based totem-pole driver circuit does not require schottky diode for the reverse current protection.

CHAPTER-4
ELECTRONIC SIGNAL CONDITIONING

4.1 Introduction

Signal conditioning in its simplest form can defined as the manipulation of any signal from one useful form to another useful form to meet the requirements of next stage application for further processing. Therefore, electronic signal conditioning system can be defined as the circuit used as an interfacing circuit for converting one form of signal to another by utilizing some electronic circuits. Now, the designing of these electronic circuits depends upon the type of application for it is used. There are number of ways of designing these electronic circuits such as oscillator based, CMOS based, integrated system etc. [11]. Presently our work in this dissertation is about the designing of interfacing circuit to manipulate the differential capacitance change into the differential voltage [12]. Signal conditioning circuits used to convert the capacitance into the voltage are known as capacitive interfacing circuit. This circuit utilize an electronic technique to convert the change in capacitance due to the change in dielectric constant in case of capacitive humidity sensors into the change in voltage. These circuits are essential to detect the moisture of air or atmosphere and respond back electrically to meet the requirement of automated industries. This work generally includes the design of circuit having ability to sense the capacitive change and respond back electrically.

4.2 Types of Signal Conditioning System

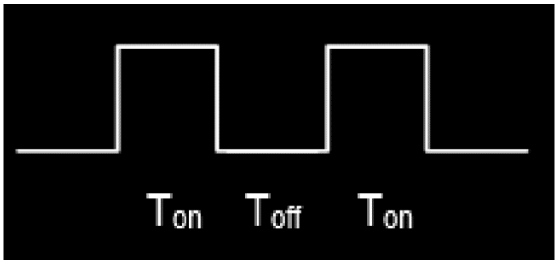
Based on capacitive sensing system, these interfacing circuits are sub-categorized into following way**:**

1. Capacitance to Pulse-Width converter
2. Capacitance to Voltage converter
3. Capacitance to Current converter
4. Capacitance to Frequency converter
5. Capacitance to Digital converter

The selection of any particular converter from all of these depends upon the type of application for which they are used. Our work deals with two capacitive sensing system that are (i) capacitance to Pulse-Width converter and (ii) capacitance to voltage converter.

4.2.1 Capacitance to Pulse-Width Converter

It is well known that change in dielectric constant will result into the change in capacitance of humidity sensor [13]. The designed circuit uses 555 timer circuit to generate pulse width modulated (PWM) signal whose duty cycle changes with respect to the capacitance of the sensor. Duty Cycle of PWM signal is defined as the proportion of one period for which it remains in active mode. One period is generally defined as the time period to complete both ON and OFF cycles.



Duty Ratio of any PWM signal is given by the following expression,

$$D.R = \frac{T_{on}}{\left(T_{on} + T_{off}\right)} \tag{4.1}$$

The circuit we have designed to convert capacitance change of humidity sensor to get the varying pulse width modulated signal. Astable mode of 555 timer is generally used to get the PWM signal. Here, C1 variable capacitor is denoting as a capacitive humidity sensor with its capacitance increases or decreases according to the increase or decrease in moisture level respectively. C2 is acting as a fixed capacitor in this circuit and described as a humidity sensor in dry conditions i.e. why we are getting fixed pulse width signal from the lower timer circuit. Initially, when there is no moisture present in the atmosphere it means capacitance of C1 and C2 is same. Hence, there is no output PWM signal from EX-OR logic gate. Output from this logic gate is possible only when there is any difference between its input terminals. This means whenever moisture ingress onto the C1humidity sensor, there will be the corresponding change in width of PWM signal output of upper timer circuit. The designed capacitance to PWM converter is shown below in Fig. 4.1.

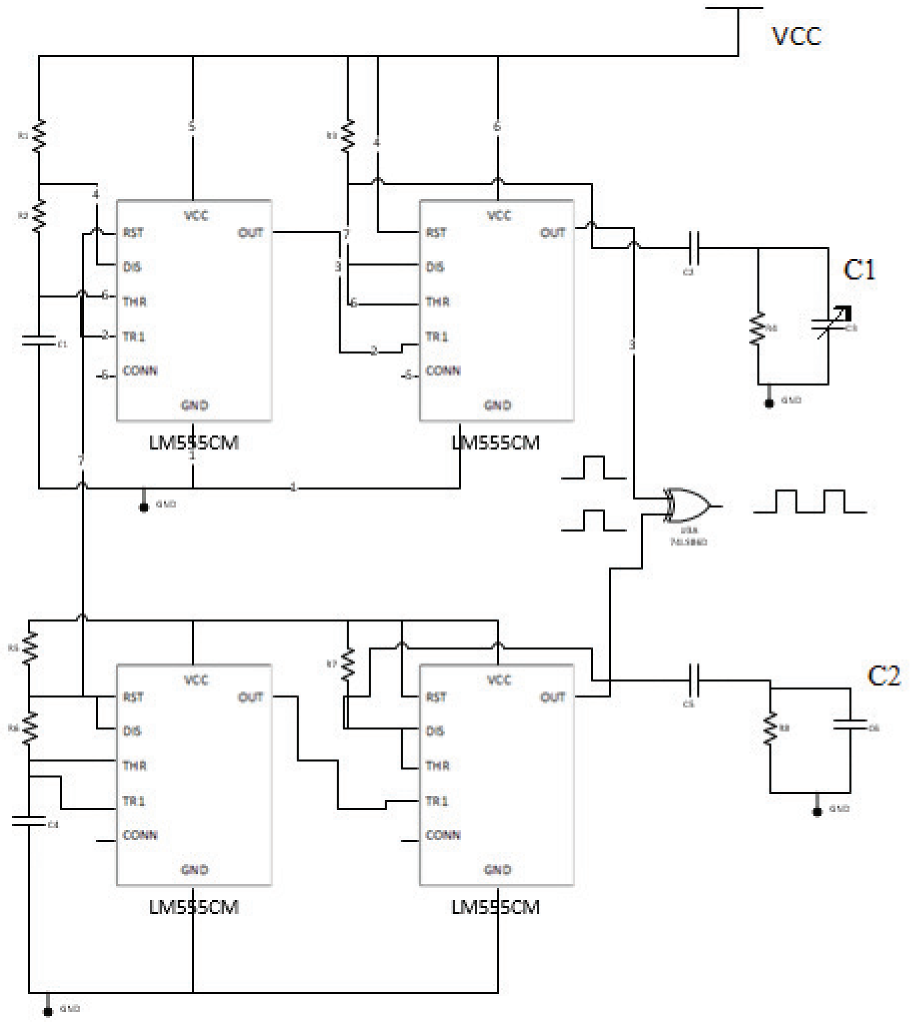


Fig. 4.1. Circuit diagram for capacitance to PWM converter

This time EX-OR logic gate have inputs of different pulse width, therefore we will get the resulted PWM signal at its output. Pulse width of this output signal will increase or decrease with the increase or decrease of capacitance of variable capacitor C1. Hence, in this way we have achieved our goal to manipulate the capacitive signal into the PWM signal.

4.2.2 Capacitance to Voltage Converter (CVC)

Now to convert the capacitive controlled PWM signal into the average output voltage, we have to pass the PWM signal we got from capacitance to PWM converter through a RC low pass passive filter. Therefore, this converter manipulates the capacitive signal into the voltage signal.

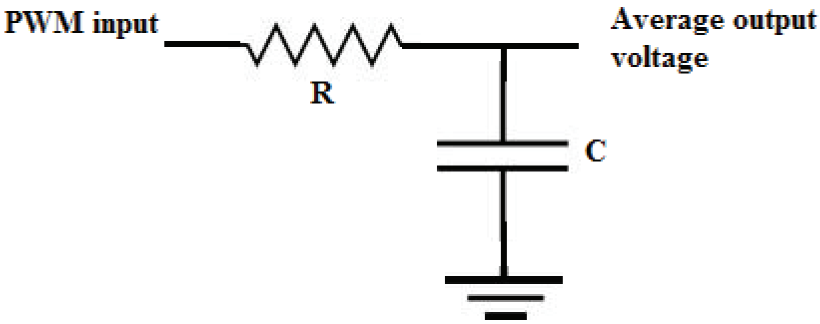


Fig. 4.2. RC low pass filter

Output voltage (V_{out}) and cutoff frequency of this filter is given by,

$$|V_{out}| = |V_{in}| \frac{1}{\sqrt{1+\omega^2 R^2 C^2}} \tag{4.2}$$

$$f_{cutoff} = \frac{1}{2\Pi RC} \tag{4.3}$$

4.3 CMOS 555 Timer:

Multivibrators and CMOS Oscillators can be easily designed from discrete components to produce relaxation oscillators for generating output of square waveforms. Some IC's are especially designed to accurately produce the required output waveform accurately with the addition of few extra timing components. One such device that is well-known since the invention of IC's that has itself become standard of an industry is the **555 Timer Oscillator,** most commonly known as the **"555 Timer" [14]**. The 555 timer utilize three 5 kΩ resistors to generate the reference voltage for two comparators, i.e. why it is known as 555 timer. Though it is a very cheap, popular and useful precise timing device that can be used to generate single pulse or long time delays, as a relaxation oscillator generating stabilized waveforms of varying duty cycles from 10 to 100%. The 555 timer chip is a stable and extremely robust 8-pin device that can be operated in different modes such as Monostable, Bistable or Astable Multivibrator for various applications such as one-shot or delay timers, LED, pulse generation, lamp flashers, tone generation, logic clocks, alarms, frequency division, converters, power supplies etc., and other time controlling applications. The single 555 Timer chip is a bipolar 8-pin mini Dual-in-line Package (DIP) device. It consists of around 25 transistors, 16 resistors and nearly 2 diodes that are arranged to construct two comparators, a flip-flop and a high current output stage. NE556 Timer Oscillator combines two individual 555 timers within a single 14-pin DIP package and low power CMOS versions of the single 555 timer which use MOSFET transistors instead such as the 7555 and LMC555.

The Fig. 4.3 below shows a functional block diagram of the 555 timer IC.

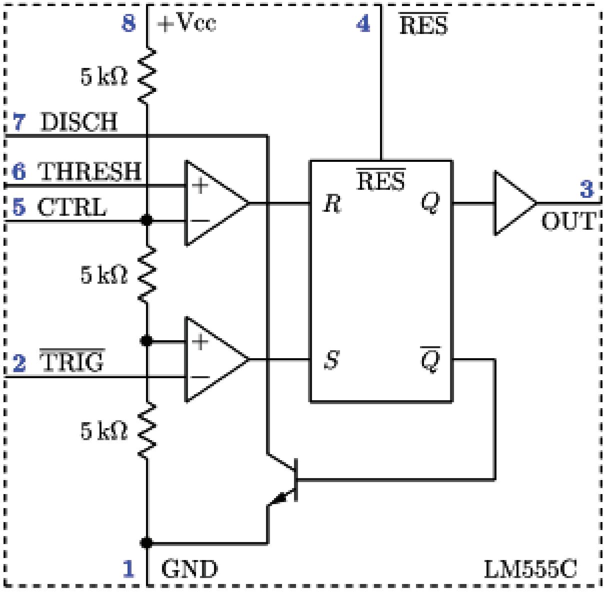


Fig. 4.3. Block diagram of 555 timer IC

Brief pin description of 555 timer IC is illustrated below:

Ground-This pin connects the timer to the -ve (0v) supply.

Trigger-This pin is –ve I/P for lower comparator. When the voltage goes below 1/3 Vcc, a -ve pulse on this pin “sets” the Flip-flop and causing the output to shift from a low state to high state.

Output- O/P pin can be the input for any TTL and CMOS circuit and is capable of sourcing or sinking of current at an O/P voltage equal to or nearly equal to Vcc – 1.5V so small motors, LED’s can be connected directly to the output.

Reset- Used to reset the Flip-flop by controlling the state of the output pin. It is an active-low input and is connected to logic 1 level when not in use to avoid any unwanted resetting.

Control Voltage- Controls the timing by overruling the 2/3Vcc level of the voltage dividing network. Width of the output signal can be varied by applying input to this pin independently of the RC timing network. It is connected to ground when not in use.

Threshold- +ve pin for upper comparator and used to reset the Flip-flop when the applied voltage to it go beyond 2/3Vcc causing the output to change the state from high to low state. This is connected directly to the RC timing network.

Discharge- Connected directly to the Collector of an npn-transistor and when the output at pin 3 switches low then it will discharge the timing circuit capacitor to ground.

Supply +Vcc- Input power supply and for general purpose CMOS and TTL 555 timers is between 5V and 15V.

4.4 Modes of Operation

Depending upon the application for which the timer is used, its mode of operation can be divided into two basic categories (i) Astable and (ii) Monostable

4.4.1 Astable Operation

If the 555 timer circuit is connected with THRESH and TRIG connected to each other at the upper terminal of the timing capacitor C as shown below, then it will work as a multivibrator. In this mode, we must require three external R_A, R_B and C components [14]. Design of this mode should have 10 nF capacitor connected between pin 5 i.e. CTRL to GND and a 100 nF capacitor between +Vcc to GND. These two capacitors are used to suppress the noise and support to deliver energy through the transition time of the output, which is not shown below for clarity. In the mode of operation, whenever the voltage across C goes lower than $V_{CC}/3$ then 555 timer circuit triggers itself, therefore setting the OUT pin high and cause the turning OFF of the discharge transistor. Then capacitor C is charged through $(R_A + R_B)$ till the threshold level reaches to $2V_{CC}/3$. In that condition the upper comparator resets the flip-flop and the OUT pin goes low and thus turning ON the transistor. Now capacitor C is discharged through resistor R_B until the trigger level reaches to $V_{CC}/3$. Astable mode of operation in 555 timer is shown in Fig. 4.4. including the input and output waveforms.

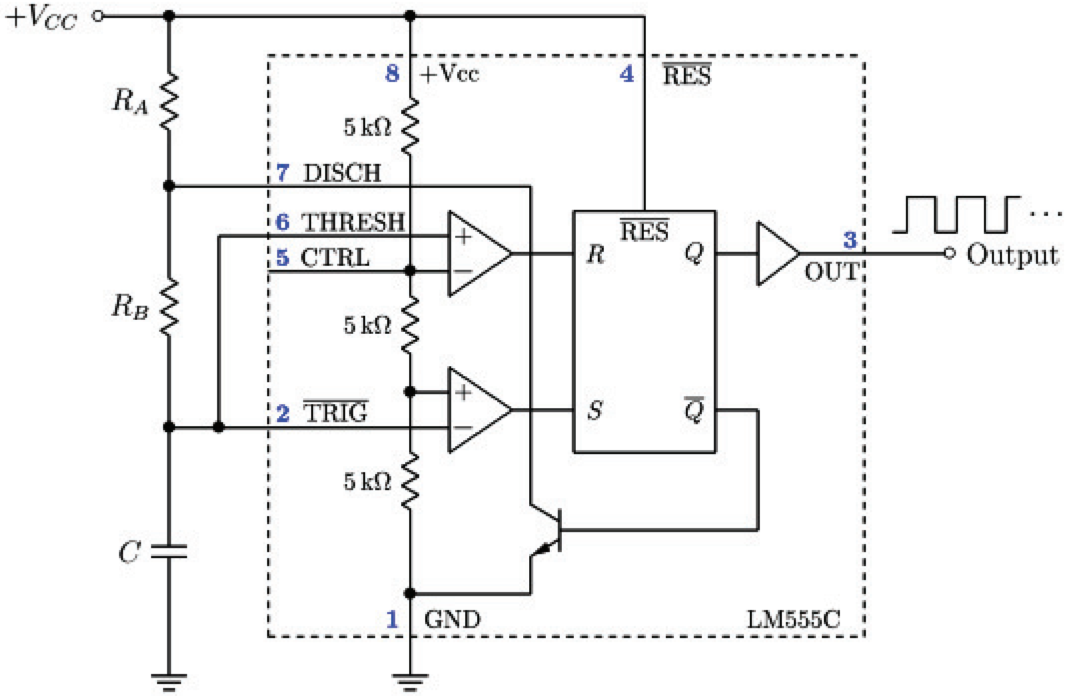


Fig. 4.4. Astable mode of 555 timer circuit

4.4.2 Monostable Operation

When a –ve or 0V pulse is applied to the trigger pin of the monostable operating 555 Timer circuit, the internal comparator i.e. lower one identifies this input and "sets" the state of the flip-flop that will change the output from a "low" to "high" state. This will turn "OFF" the discharge transistor connected to DISCH pin (7) by removing the short circuit across the timing capacitor C1 (external). It will start charging the timing capacitor through resistor (R1) till the voltage across the capacitor reaches the THRESH pin (6) of 2/3Vcc setup by the internal voltage divider arrangement. Now the comparator output goes high and resets the flip-flop to its original state which will turn ON the transistor and discharges the capacitor to ground through DISCH (7) pin. It will change the output back to the original stable low state value till another trigger pulse to start the timing process. As before, the monostable multivibrator has only one stable state. In this mode, 555 Timer circuit triggers when negative pulse is applied to pin 2 (TRIG) and this trigger pulse need be much shorter than the O/P pulse width which allows the time for the timing capacitor to charge or discharge fully.

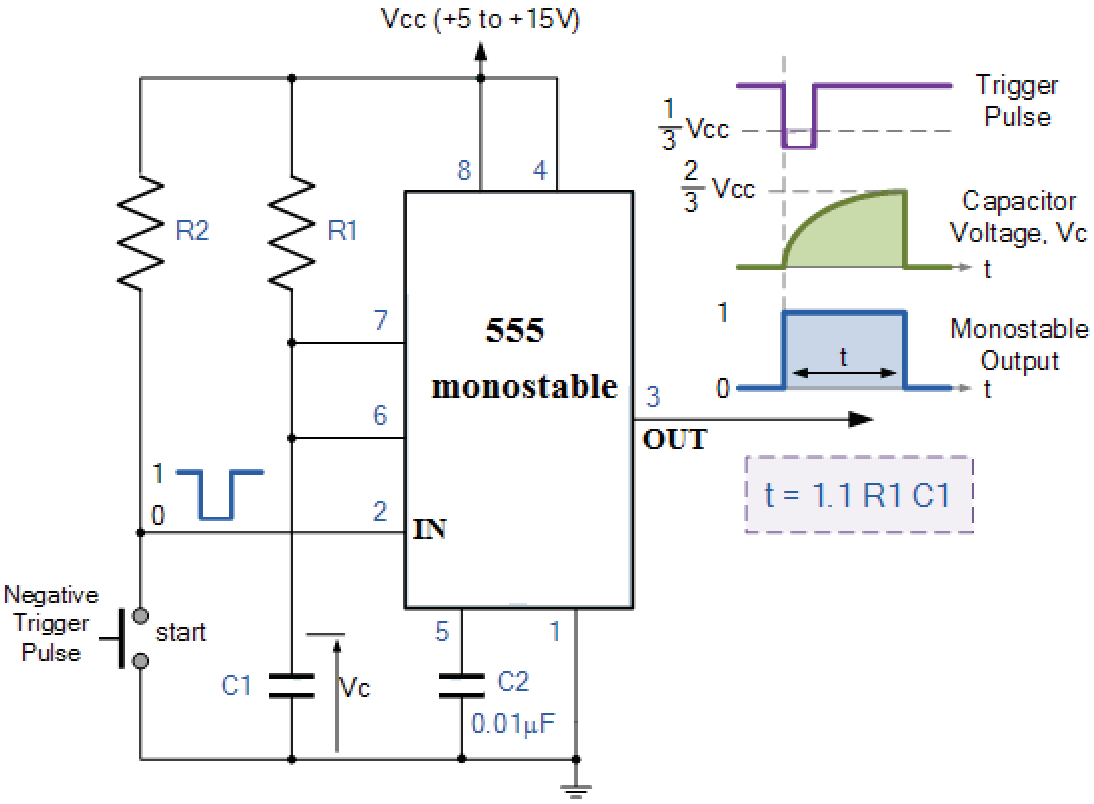


Fig. 4.5. Monostable mode of 555 timer

Once triggered, it will remain in this high unstable output state till the time period which is being set up by the R1, C1 network has elapsed. The amount of time for which the output voltage remains high or at a logic 1 level, is given by the following equation [14].

$$t = 1.1 R_1 C_1 \tag{4.4}$$

CHAPTER-5
VOLTAGE CONTROLLER

5.1 Introduction

In order to control the power for any type of load, we have to design a voltage or current regulating circuit. A voltage regulator is a controlling circuit designed to automatically maintain the constant level of voltage. It may be a simple "feed-forward" design or may use the principle of negative feedback control loops. It may use electromechanical mechanism, or electronic components in their designing. Depending upon their applications, these regulating devices can be used to regulate one or more AC or DC voltages.

Electronic voltage regulators are mostly used in devices such as computer power supplies where they help in maintaining the DC voltages used by its processor & other elements. Voltage regulators control the output of the plant in the field of automobile industry, alternators and generating plants. In the field of electrical power distribution system, these regulators may be installed along distribution lines or at substations to provide steady voltage to the consumers which is independent of the amount of power drawn from the line. Therefore, we can conclude that voltage regulators have their wide range of applications such as used for controlling the speed of a motor, a toy train, a pump, brightness of lamp or LED etc.

In this dissertation, I have used the voltage regulator to control the speed of permanent magnet dc motor (PMDC) by using pulse width modulated (PWM) technique.

5.2 DC Motors

Direct current (dc) motors are used extensively in applications where variable speed is essential. These motors have wide range of speed control and also used in high torque applications. These motors play a significant role in the field of modern industrial drives. DC motors are distinguished according to their ability to operate from direct current. There are different types of D.C. motors available to us, but they all work on the similar principles. We will study the basic principle of operation of dc motor and their characteristics in this chapter. It is quite necessary to understand the motor characteristics so we can choose the right one for our application according to the requirement.

5.2.1 Electro-Mechanical Energy Conversion

An electromechanical energy conversion is a process or a medium of transfer between an input and an output. Three electrical machines that are DC, induction and synchronous machines are used extensively for this electromechanical energy conversion process. This conversion occurs only where there is a change in magnetic flux linking with a current carrying coil, associated with mechanical motion.

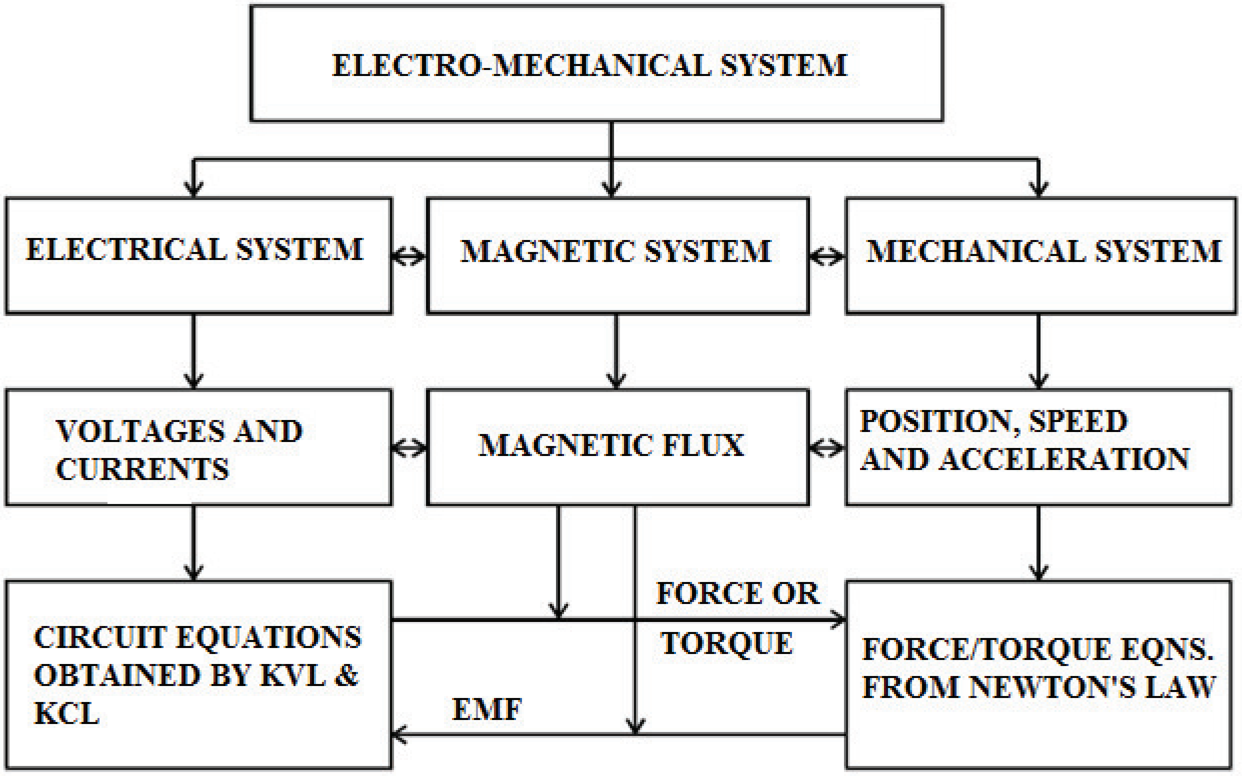
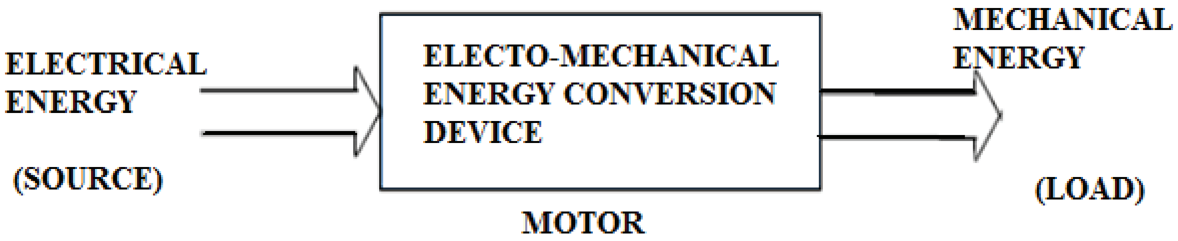
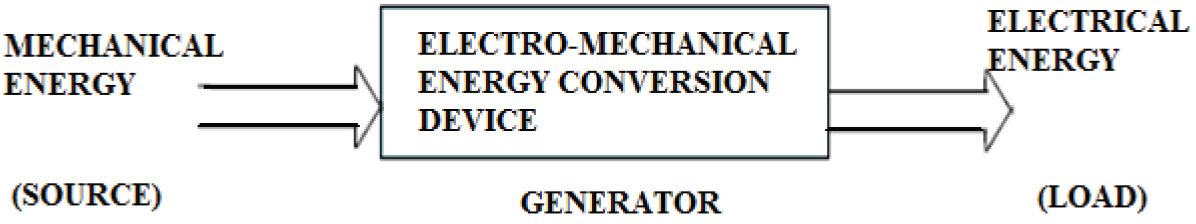


Fig. 5.1. Basic electromechanical conversion system

Electric motor: In this case the input is electrical power and after conversion we get the mechanical power as an output. This is shown below:



Electric generator: Output in case of generator is electrical energy with the conversion of input mechanical power as shown below:



5.2.2 Principle of Operation and Construction of DC Motor

DC motors generally consist of one set of coils, known as armature winding inside another set of coils or permanent magnets, known as the stator. Applying a voltage to the armature coils will produce a torque in the armature resulting into the production of motion.

Stator: - It is a stationary outside part of an electric dc motor in which field flux is produced.

Rotor:- It is a rotating member of machine on which armature winding is placed.

Field flux is produced either from permanent magnet or from exciting the field winding placed on stator. This generated field flux interacts with current carrying conductors placed on armature which results into the production of torque. Commutating circuit on armature will always ensure the maximum torque production regardless the position of rotor.

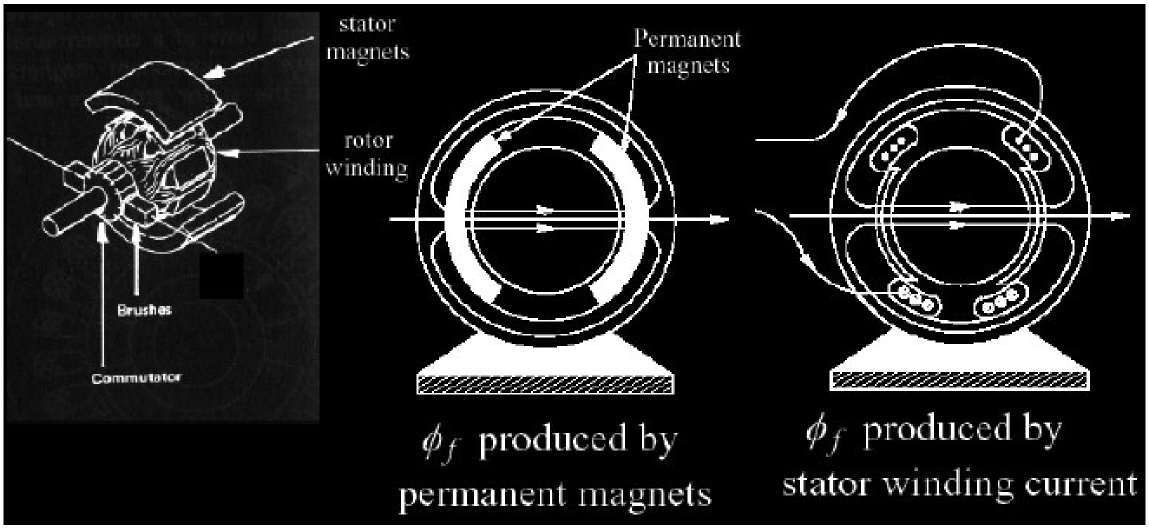


Fig. 5.2. Construction of dc motor

5.2.3 Modelling of DC Motor

As a result of interaction between the current carrying conductors and field flux, torque will be produced which is given by [27],

$$T_e = k_t \phi I_a \tag{5.1}$$

k_t is a constant whose value depends upon the motor windings and its geometry.

ϕ is the flux per pole produced due to the field winding.

For the motor having wound field, flux can be varied according to our requirements or to control the speed but in case of permanent magnet dc motor flux generated is of constant value. In this case modified torque equation will be [27],

$$T_e = kI_a \tag{5.2}$$

Value of 'k' in this depends upon permanent magnet material.

Here we conclude that torque obtained is directly proportional to the armature current. Now, the direction of armature current will determine the direction of torque produced. According to the faraday's law of electromagnetic induction, whenever the flux linking with the moving armature field an EMF (electromotive force) will induce across the winding which varies according to the time. This generated emf is also known as back emf, it's value depends upon the amount of flux generated and speed of rotation [27]. It is given by,

$$EMF = k_t \phi \omega_m \tag{5.3}$$

Similarly for permanent magnet dc motors where flux value remains constant, it can be written as:

$$EMF = k\omega_m \tag{5.4}$$

Therefore, the direction of rotation of motor will determine the polarity of back emf.

5.3 Permanent Magnet DC motor

PM motors also operates with the same principle that a force will be generated whenever the current starts flowing through an inductor which is placed in a region magnetic field. In conventional dc motors, stator field winding is excited through a direct current for the production of magnetic flux in the machine. But in case of permanent magnet dc (PMDC) motors, stationary electromagnets with their linked field windings are replaced by permanent magnets [28]. In other words, we can say that field flux required for the air gap of PMDC motor will be produced by using set of permanent magnets fixed on stator. The rotor of this type of motor also includes armature winding, armature core and the commutator same as in the case of conventional dc (CDC) motors. The circuit or equivalent model for PMDC motor is shown below in Fig. 5.3.

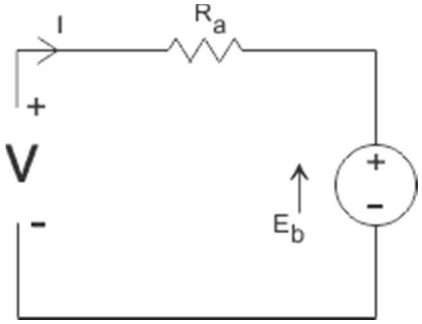


Fig. 5.3. Circuit model of PMDC motor

As we know that the field flux is generated by the help of permanent magnets and is of constant value that is why we didn't show the field winding in this equivalent model.

Torque equation of PMDC motor is given by,

$$T_e = kI_a \tag{5.5}$$

EMF equation of PMDC motor is given by,

$$EMF(E_b) = k\omega_m \tag{5.6}$$

From equivalent circuit of PMDC motor, it can be concluded that,

$$V = E_b + IR_a \tag{5.7}$$

As we know, $E_b = k\omega_m$

Therefore, $V = k\omega_m + IR_a$ or $\omega_m = \dfrac{V - IR_a}{k}$ (5.8)

Equations prevailing the performance of PMDC motors are similar in the case of shunt field having constant field in case of dc shunt motor. Therefore, speed of PMDC motors can be easily varied by varying any of these (i) armature-terminal voltage, V (ii) armature resistance (iii) armature current.

5.4 Speed Control of DC Motor

"Speed control" this term stands generally to have the speed variations intentionally which is carried out manually or automatically. In this control, natural change in speed due to load variations is not included. DC motors have their wide range of applications in variable speed drives [29].

5.4.1 Armature Voltage Control

Speed of PMDC motors can be controlled by varying the armature terminal voltage. In this case, field flux remains constant hence speed is directly proportional to the applied terminal voltage. Armature resistance speed control method involves various losses which is an inefficient method to adopt for controlling the speed of PMDC motor. Variable armature terminal voltage is used to control the speed with the rated value of armature current and constant field flux.

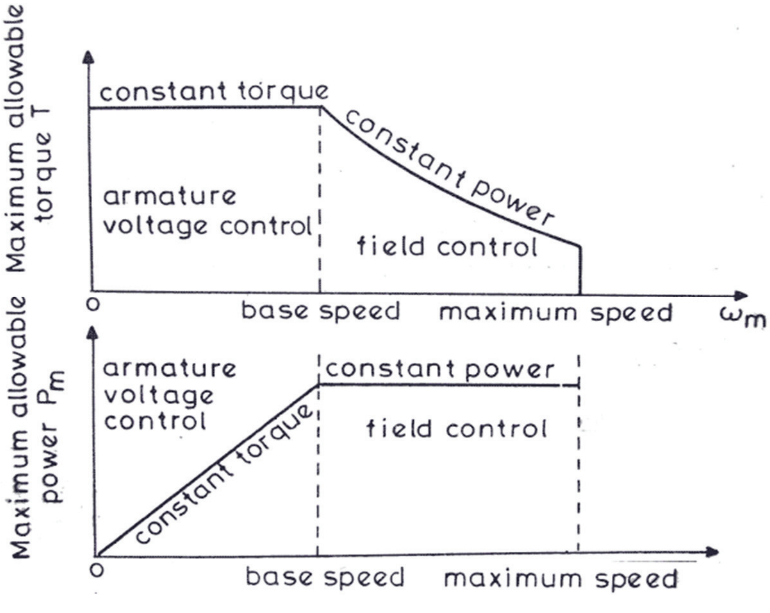


Fig. 5.4. Speed characteristics of armature voltage method

5.4.2 Chopper Control

Control circuit for single quadrant operation for speed control is shown in fig 3.5

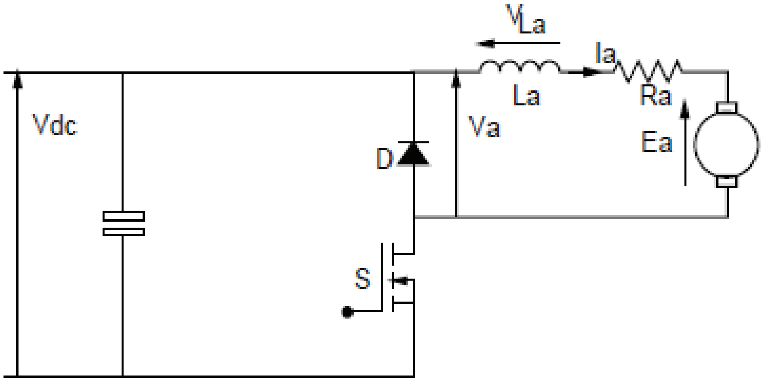


Fig. 5.5. Single quadrant chopper circuit

As we know that the speed of PMDC motor is directly proportional to the applied voltage to its armature terminals. Therefore, we require to control the armature terminal voltage for having speed variations in PMDC motor. Here, power semi-conductor device is used to control the input voltage of the motor. The input to the gate terminal of this semi-conductor device is triggered with the help of pulse width modulated (PWM). The average voltage applied to the armature terminals of the motor connected to its drain terminal is controlled by varying the duty cycle of this PWM signal. Hence, the speed of PMDC motor is controlled through the pulse width or duty cycle of the input PWM signal. Neglecting the armature resistance and input switch resistance, the voltage across the armature inductor will be given by ($V_{dc} - E_a$) and the rate of rise of armature current is given in [30] as,

$$\frac{dI_a}{dt} = \frac{V_{dc} - E_a}{L_a} \tag{5.9}$$

During the power switch turns-off, the energy already stored in the armature inductor must be dissipated. This time the polarity of the voltage across the inductance (L_a) reverses, results in forward biasing of the diode D and the flow of armature current remains continue. The rate of fall of armature current is given in [30] as,

$$\frac{dI_a}{dt} = \frac{-E_a}{L_a} \tag{5.10}$$

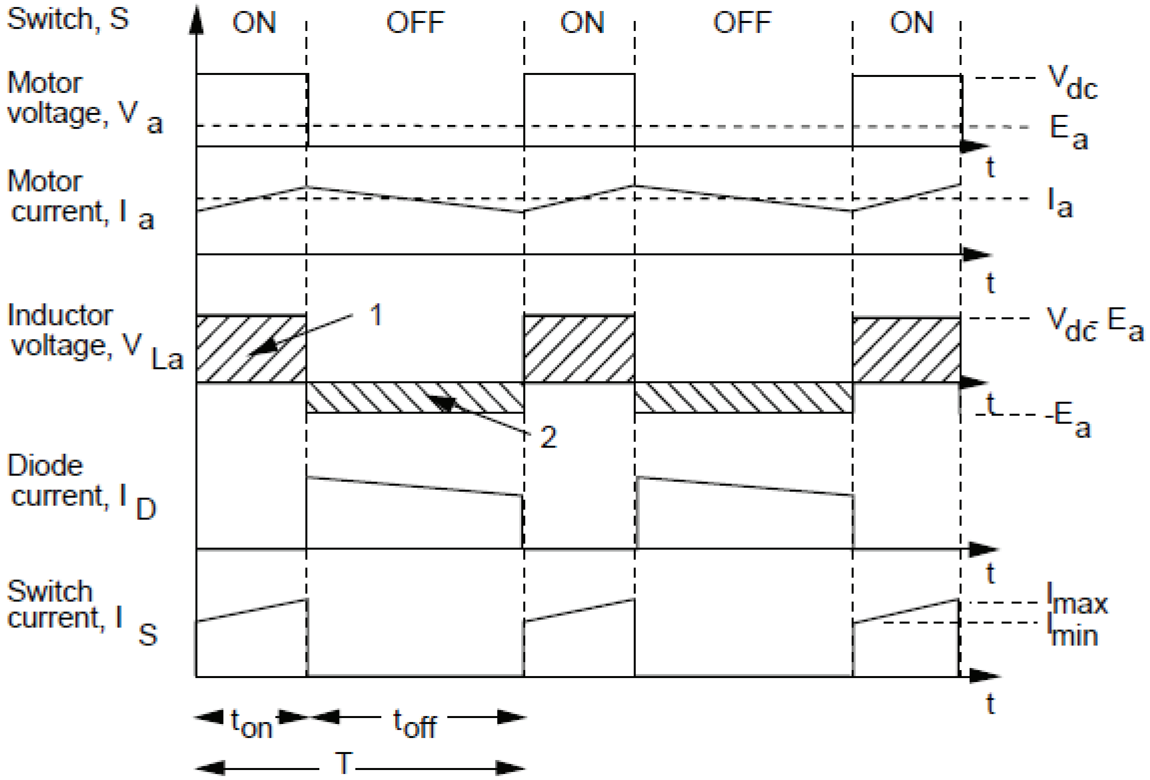


Fig. 5.6. Switching waveforms of single quadrant operation

The average voltage applied to the motor is controlled by controlling the duty cycle of switch is referred to as PWM speed control technique. The average voltage across the inductor over the full period is zero that is given by,

$$\int_0^T v_L.dt = \int_0^{t_{on}} v_L.dt + \int_{t_{on}}^T v_L.dt = 0 \qquad (5.11)$$

The shaded portion 1 shown in the switching waveforms corresponds to the turn on (t_{on}) period of inductor voltage and shaded portion 2 is equivalent to the turn off (t_{off}) period. Both the areas are equal and the transfer equation of the controller by using equations 1 and 3 will be given by,

$$V_a = \frac{t_{on}}{T}.V_{dc} \qquad (5.12)$$

5.5 Advantages and Applications of PMDC Motors

The advantage of using PMDC motor instead of conventional ones is that there is a saving of energy required to produce the field flux due to the absence of field current. They are less expensive and comparatively smaller in size than the conventional dc (CDC) motors.

Permanent magnet dc (PMDC) motors are extensively used as windshield wipers and washers in automobile industries. These are also used as blower motors in case of heaters as well as air-conditioners, in disk drives of personal computer, electric tooth brushes etc. [31]. These motors have widen their range of applications where speed or torque control is required such as in the field of power electronics with the development of power semi-conductor device

CHAPTER-6
SIMULATION MODEL AND RESULTS

6.1 Capacitance to Voltage Converter

In the designed capacitance to voltage (C2V) converter circuit, 5v is utilized as input to this circuit. The designed signal conditioning circuit comprises of LMC555CM dual CMOS timer, 74LS86D EX-OR logic gate, variable capacitor, RC filter and other electrical components etc. In this circuit, I have used two dual timers (i) consists of two interconnected timers U1 and U2 (ii) and second is U4 and U5. Here, U1 and U4 are acting as fixed pulse generator to trigger U2 and U5 respectively. There are two variable capacitors C3 and C6 connected separately to U2 and U5 timers as shown below:

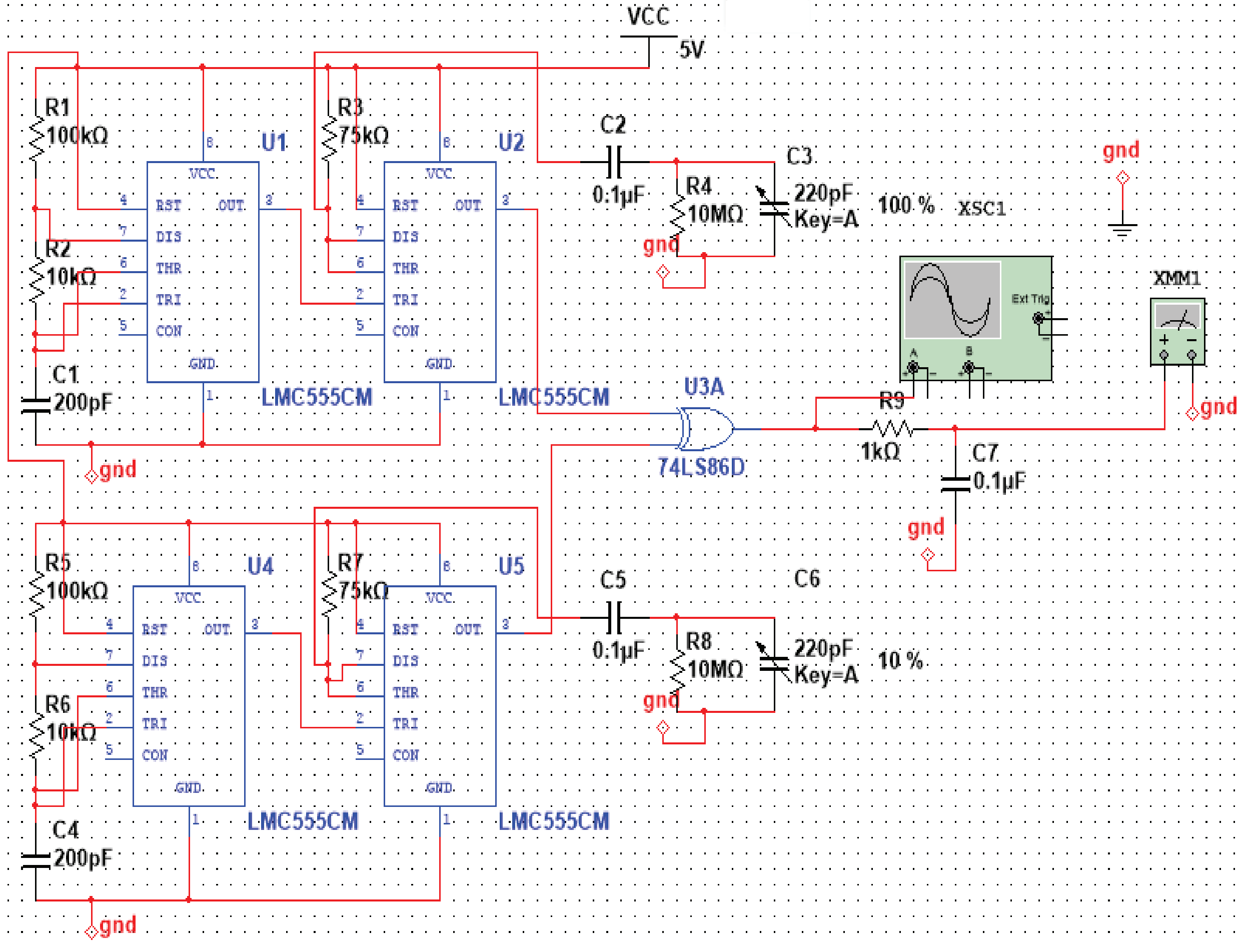
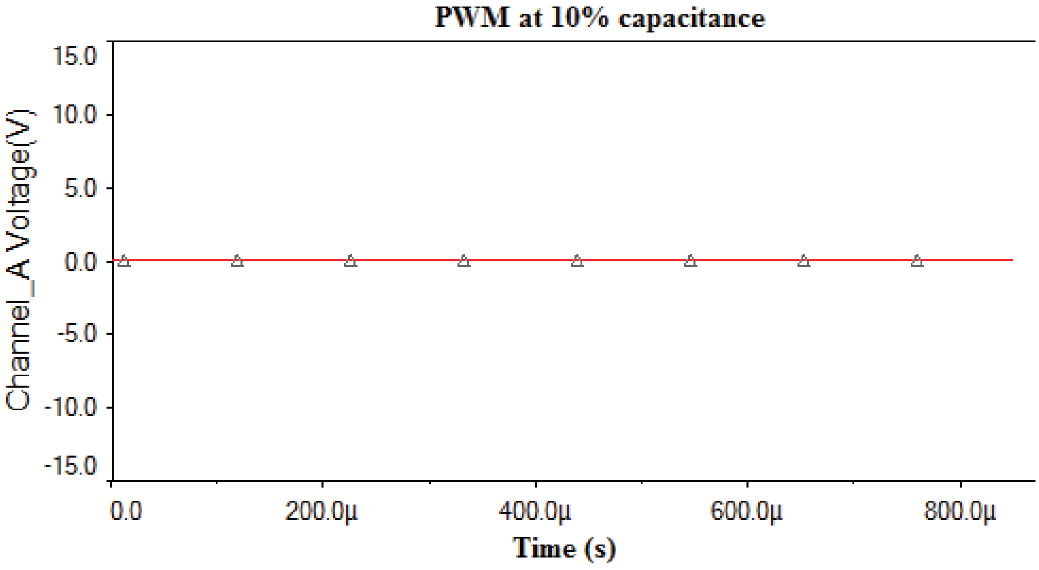


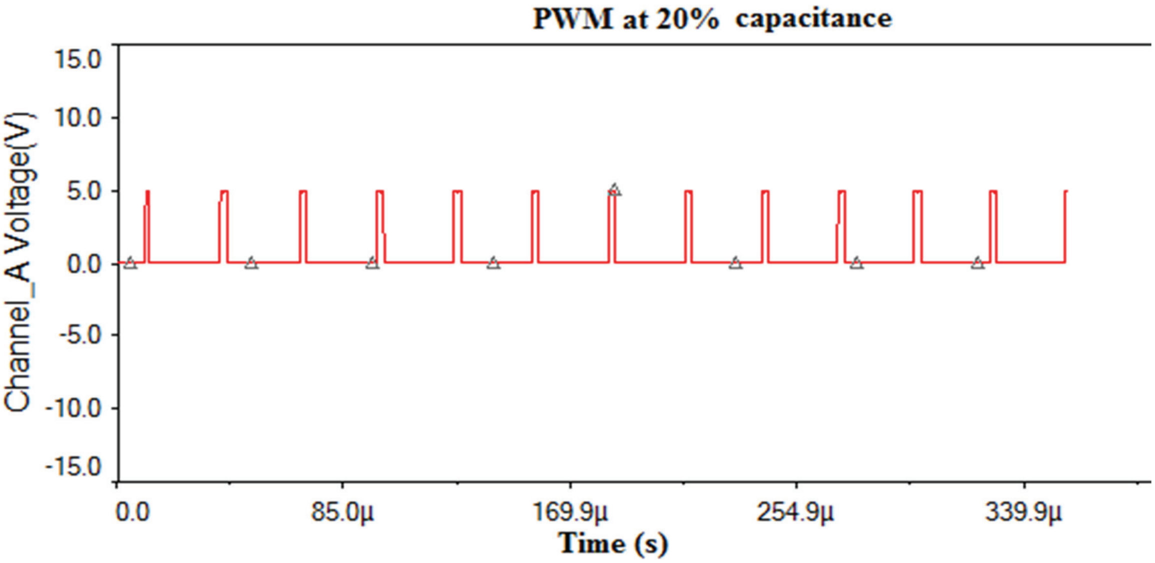
Fig. 6.1. Simulink model of capacitance to voltage

Here, C3 variable capacitor is allowed to change to represent the change in dielectric due to the ingress of moisture content onto the capacitive sensor. It means C3 is behaving as capacitive sensor at wet conditions and C6 variable capacitor is acting as fixed reference capacitive sensor at dry conditions. Now, PWM output from both the timers U2 and U5 are compared by using EX-OR logic gate and then we will get the capacitive controlled PWM at the gate output whose pulse width varies according to the C3 capacitance value. As the value of C3 goes beyond the 10% of 220pf, PWM signal will continue to reach at the output terminal of logic gate. At the time when both the sensors having same capacitance, output of EX-OR will be 0 volts. RC low pass passive filter is used to convert the PWM signal into the average output voltage. The designed circuit shown above is simulated by using NI-Multisim software and the value of variable capacitor C3 is varied and accordingly the PWM output of EX-OR gate changes as shown below:

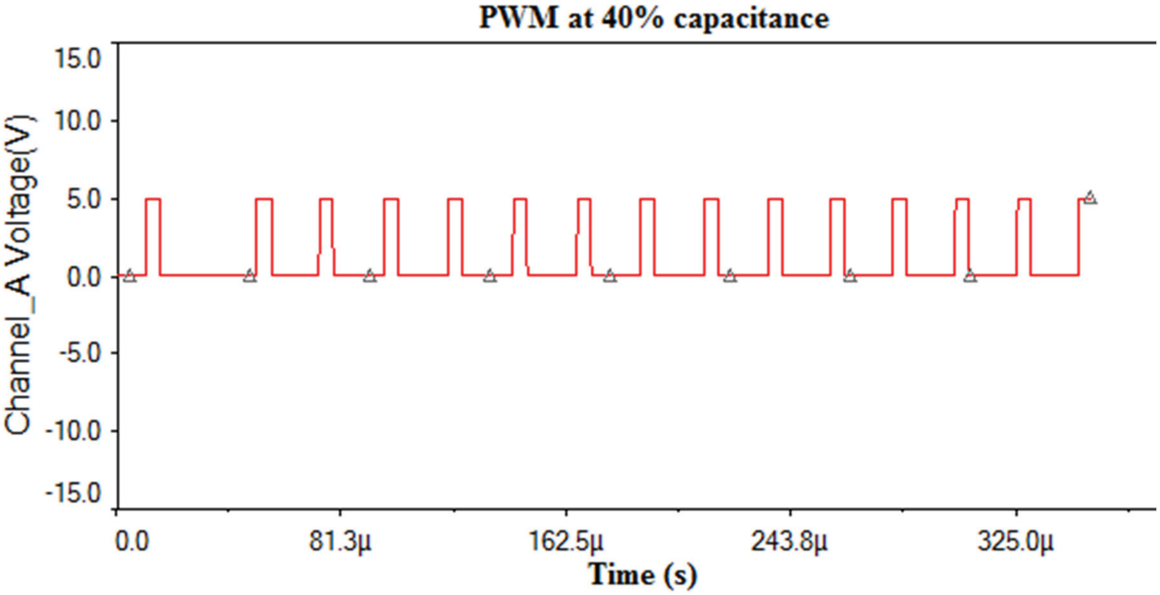
(i) Initially, when the value of both variable capacitors (C3 and C6) is fixed at 10% of 220pf then the EX-OR gate output will be,



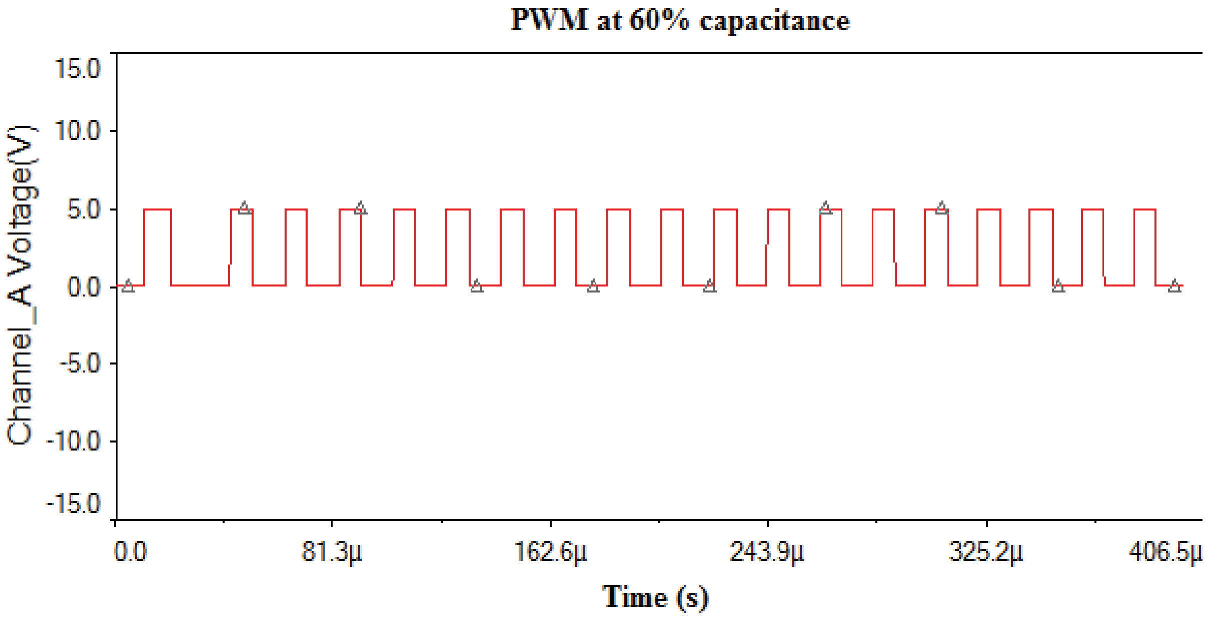
(ii) Increasing the value of C3 variable capacitor to 20% keeping the value of C6 unchanged then the result will be as shown below:



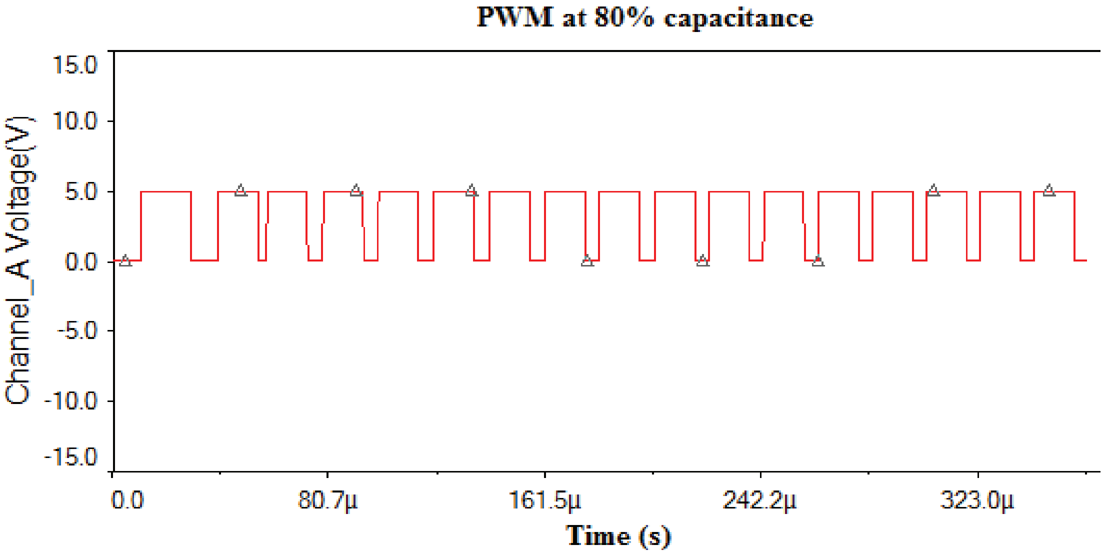
(iii) Increasing the value of C3 up to 40% keeping C6 untouched, then result will be



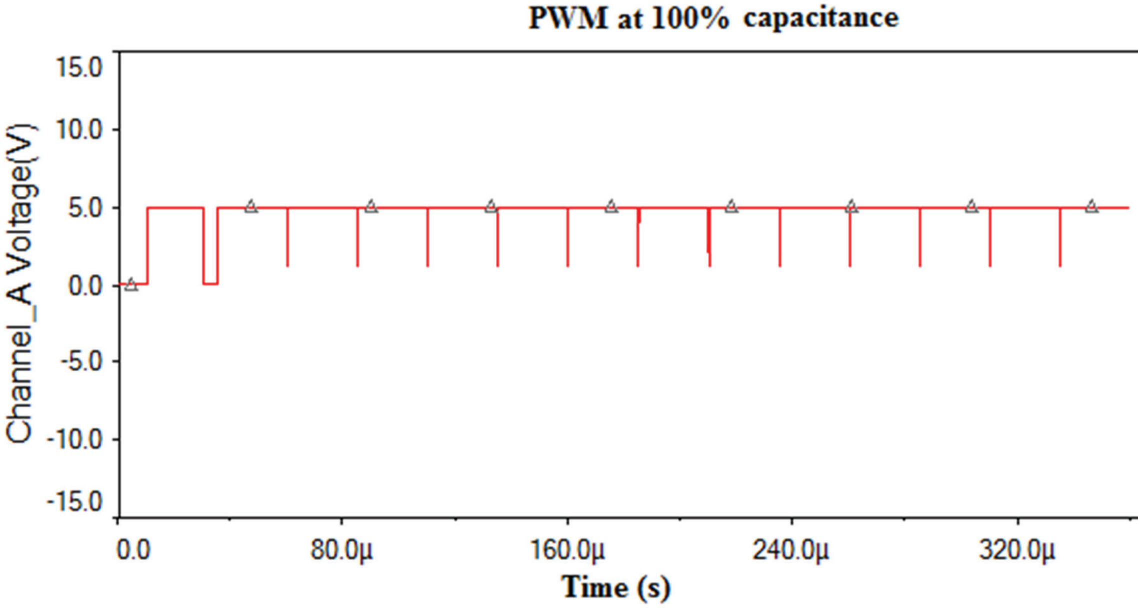
(iv) Increasing the value of C3 up to 60% and keeping C6 unchanged then results will be



(v) Increasing the value of C3 up to 80% then result will be,



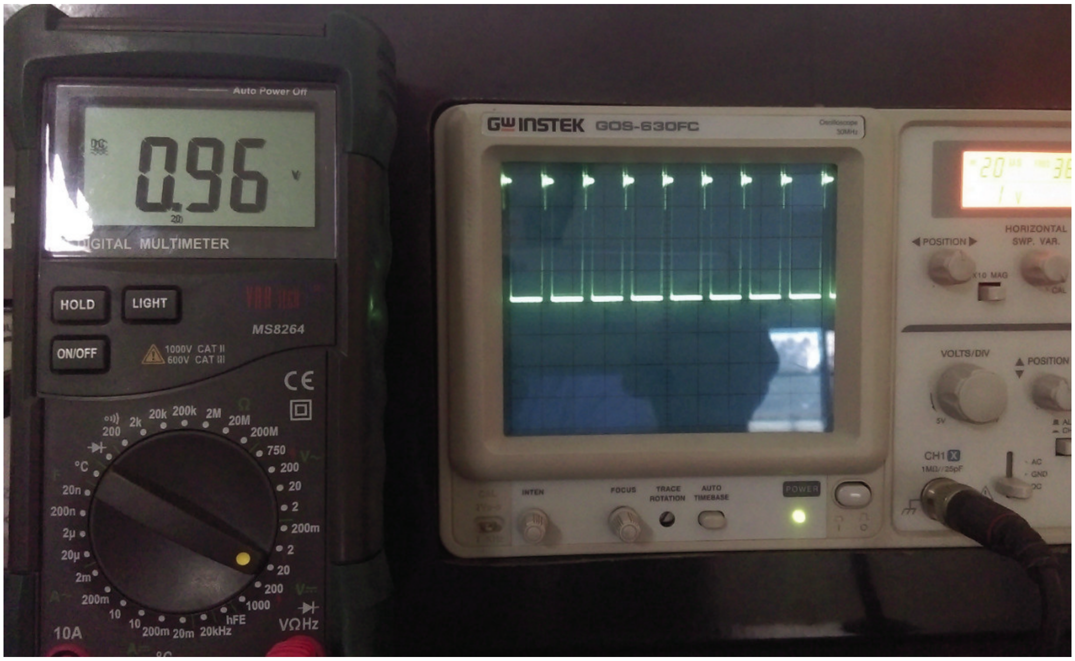
(vi) Increasing the value of C3 up to 100% i.e. 220pf then result will be,



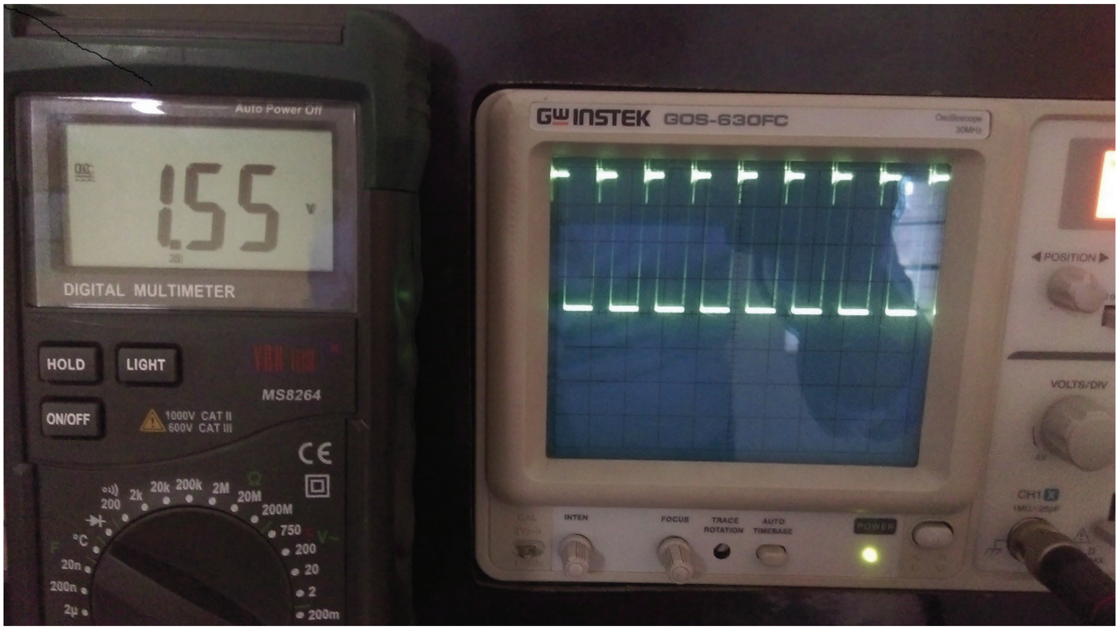
The designed simulink model of capacitance to voltage converter is deliberately implemented in real time. Complete hardware design and its outputs are shown below:

Here, the duty cycle changes according to the change in variable capacitor and hence average output voltage changes after passing PWM through low pass filter (RC filter).

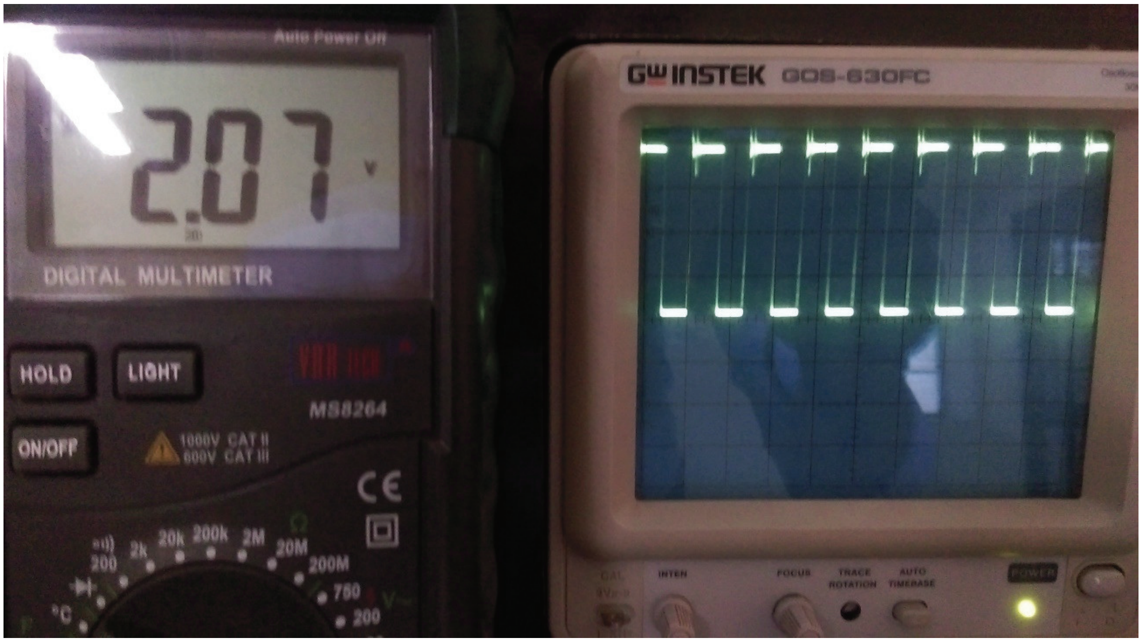
(i) Output when C3 is at 20% and the corresponding average output voltage of RC filter.



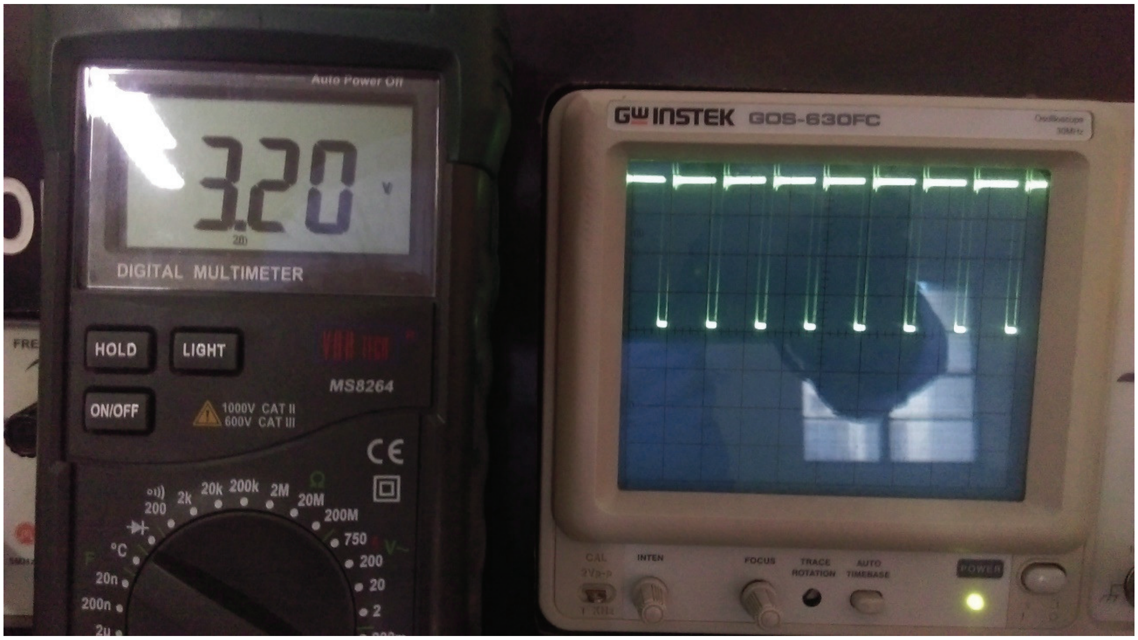
(ii) Output when C3 is at 40% and the corresponding voltage of RC filter.



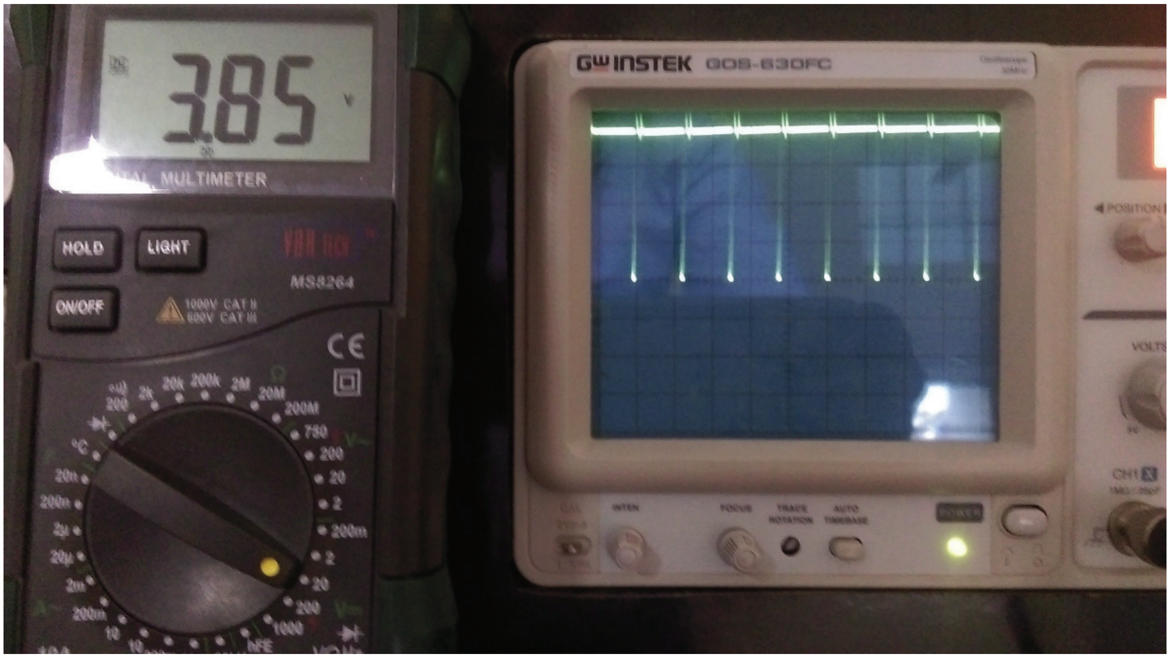
(iii) Output when C3 is at 60% and the corresponding voltage of RC filter



(iv) Output when C3 is at 80% and the corresponding output voltage of RC filter circuit.



(v) Output when C3 is at 100% i.e. 220pf and the corresponding output voltage of RC filter



6.2 Simulink Model for Speed Control PMDC Motor

Now to control the triggering of n-channel enhancement type power MOSFET for variable speed drive, we have to use the designed converter circuit which is shown above. The capacitive controlled PWM output signal from the EX-OR logic gate is acting as firing signal for the power MOSFET shown below:

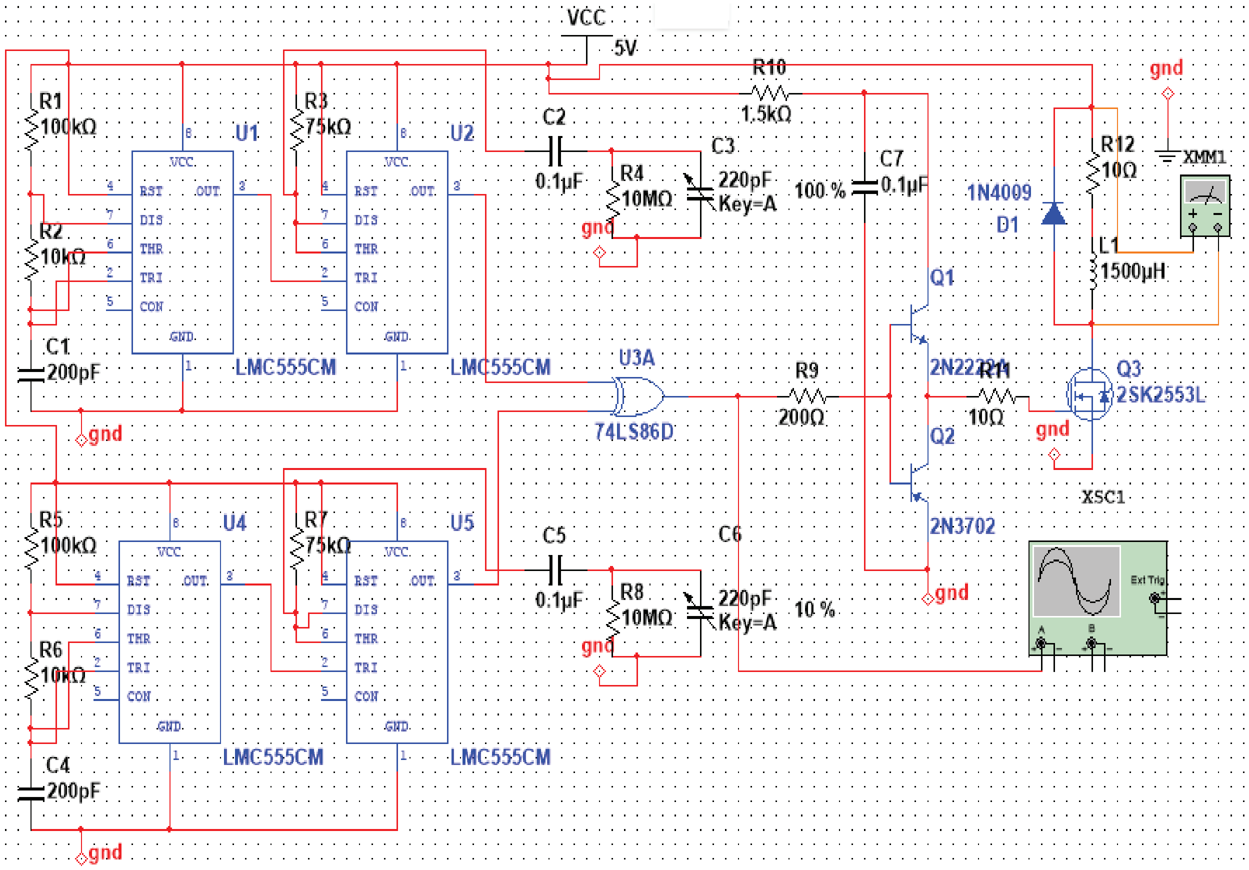
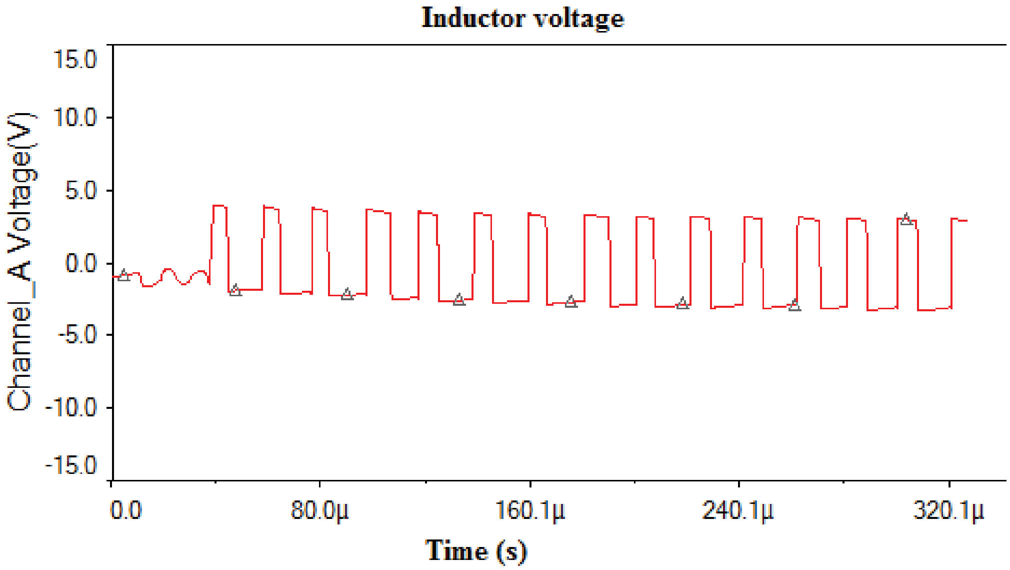


Fig. 6.2. Simulink model for speed control of PMDC motor

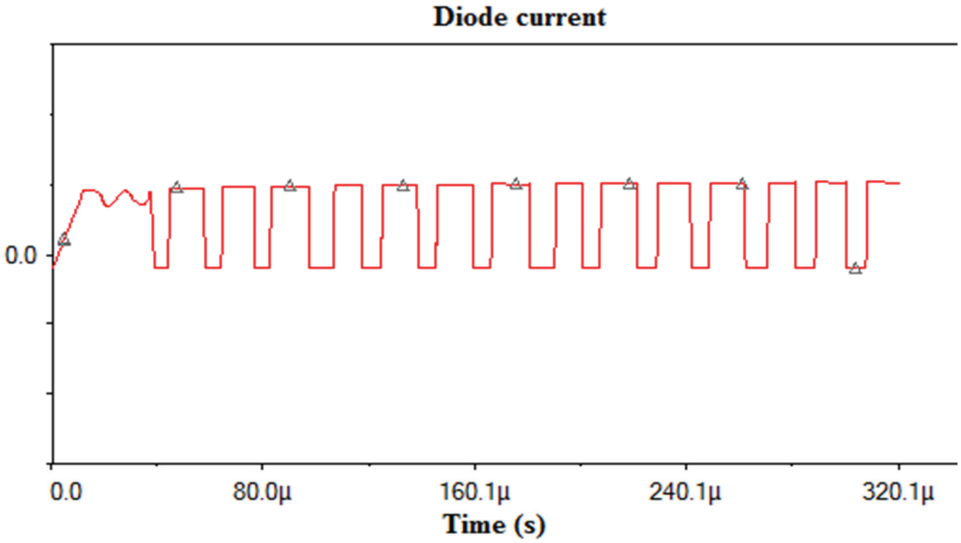
Totem-pole arrangement is used as a driver circuit to reduce the switching losses at high frequency operations thus increasing the overall efficiency of the circuit. Here, L1 inductor and R12 resistor are connected to drain terminal of n-channel enhancement type power MOSFET representing the armature inductance and armature resistance respectively of 5V PMDC motor. PWM technique is used to control the speed of the motor by controlling the applied voltage to its armature. More the duty cycle of the PWM signal, more will be the speed of PMDC motor. The diode is connected parallel to the armature circuit to flow the stored energy to dissipate across the resistive component in the form of current. In this way, capacitive controlled PWM is acting as gate controlled firing signal to control the applied voltage to the load connected to the drain terminal of power MOSFET.

Simulink Output Waveforms:

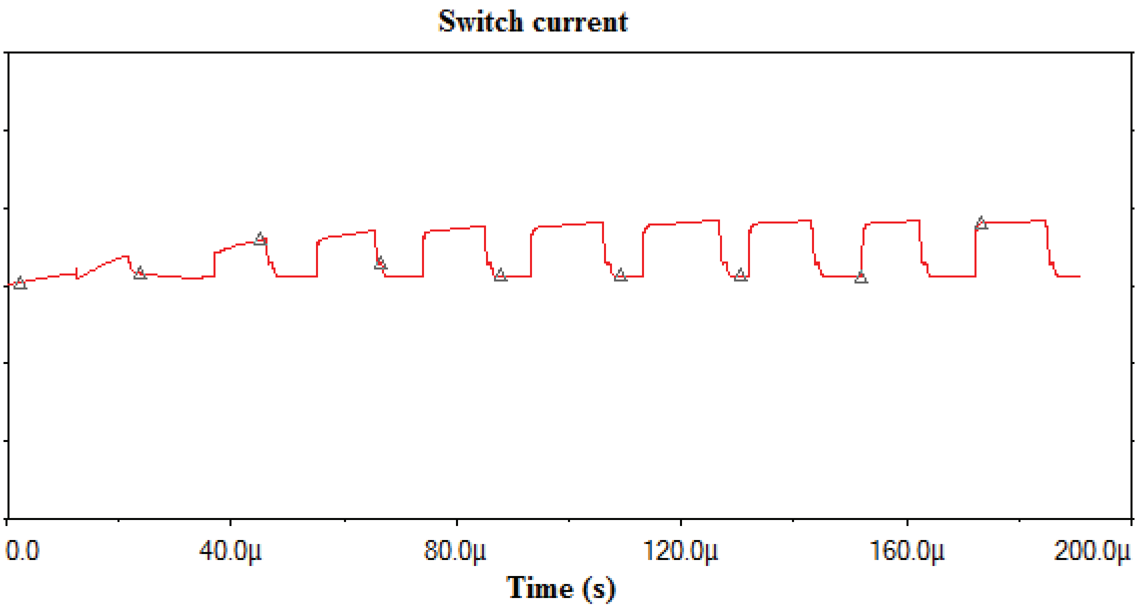
(i) Inductor voltage



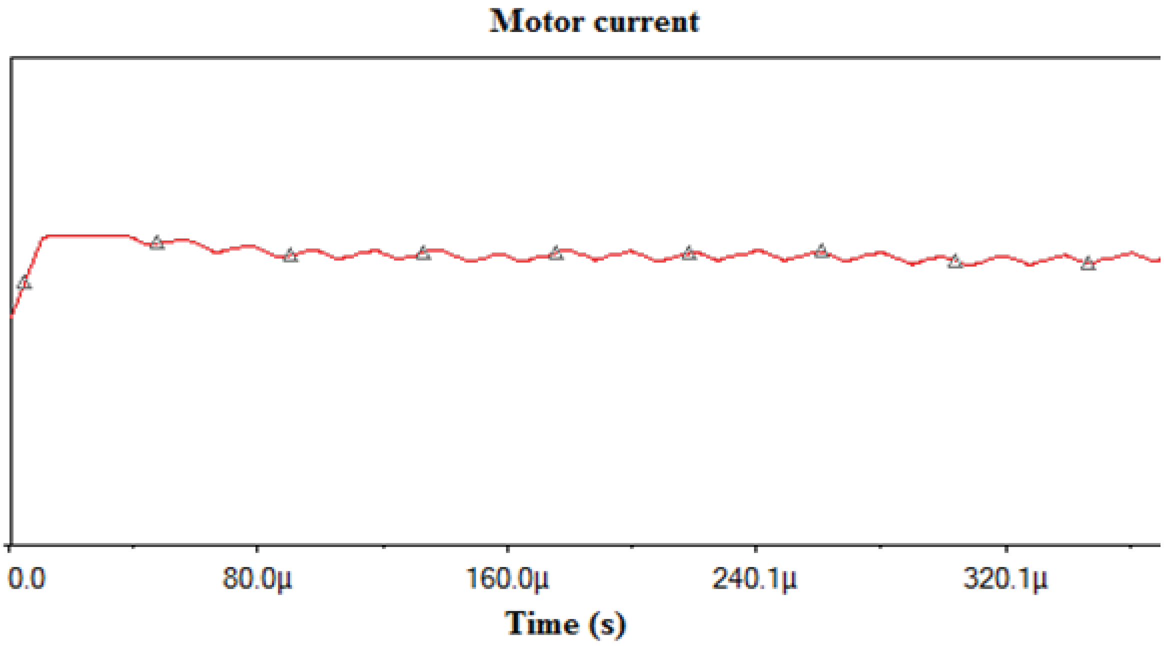
(ii) Diode current



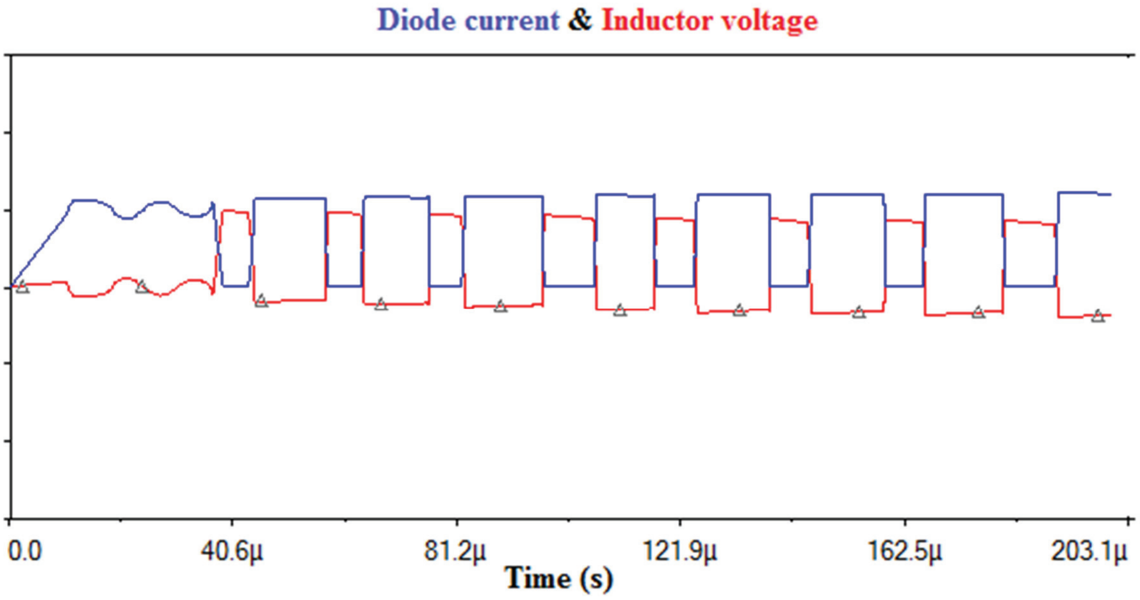
(iii) Switch current



(iv) Motor current:

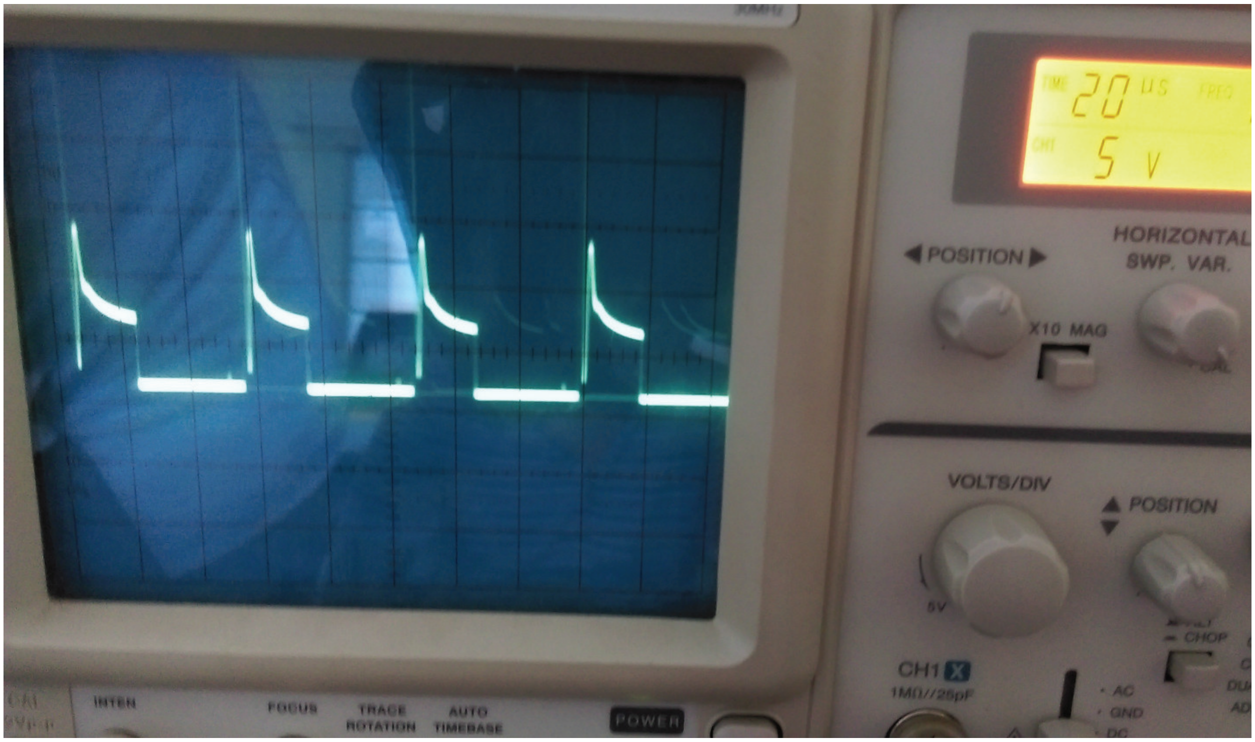


(v) Diode current and inductor voltage

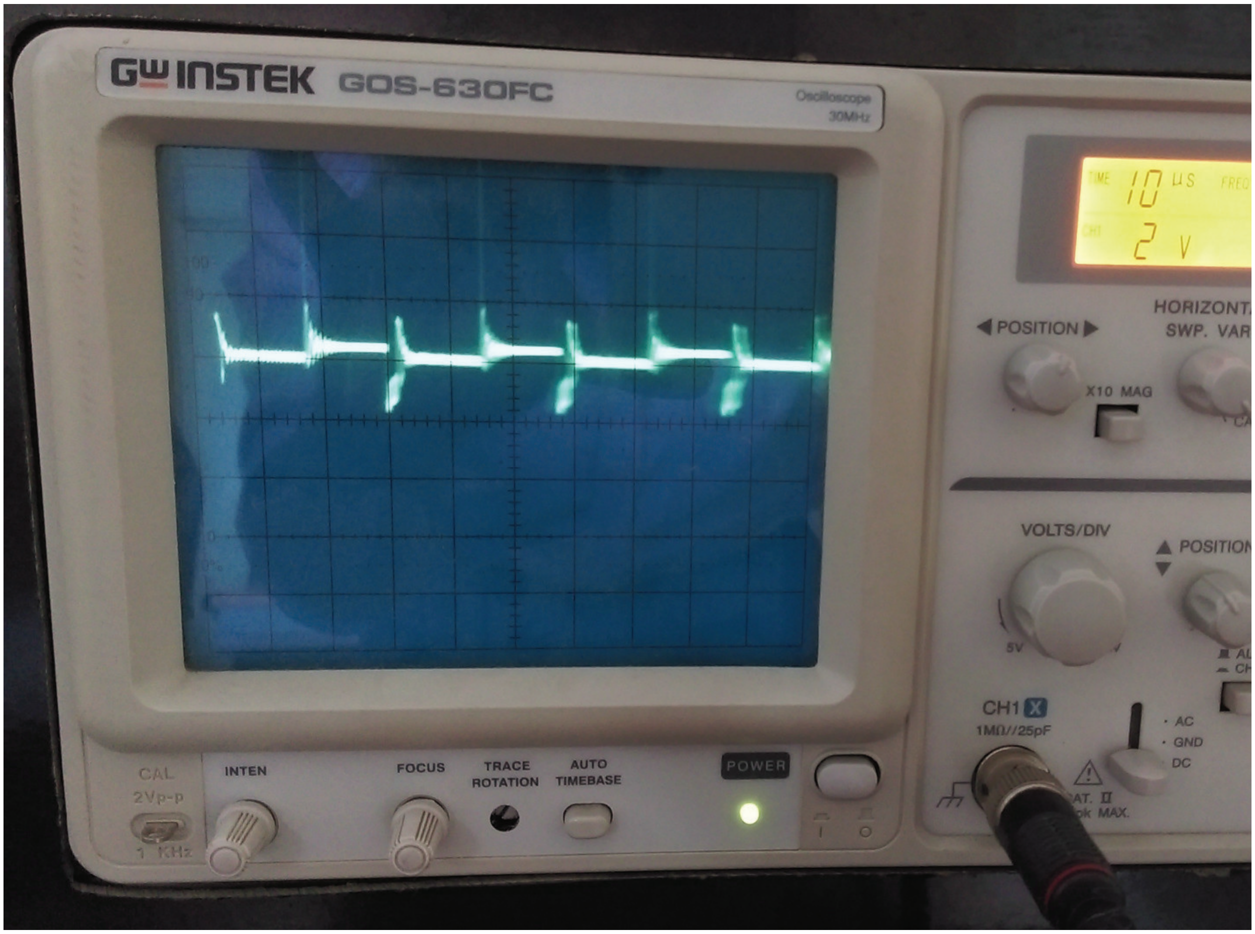


Hardware output waveforms:

(i) Inductor voltage

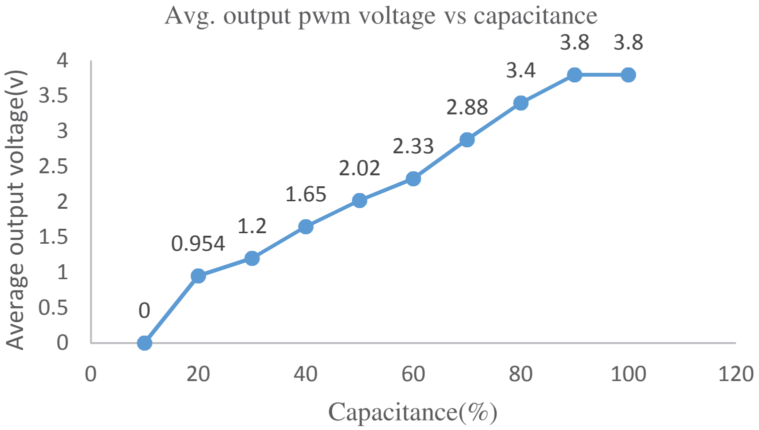


(ii) Diode current

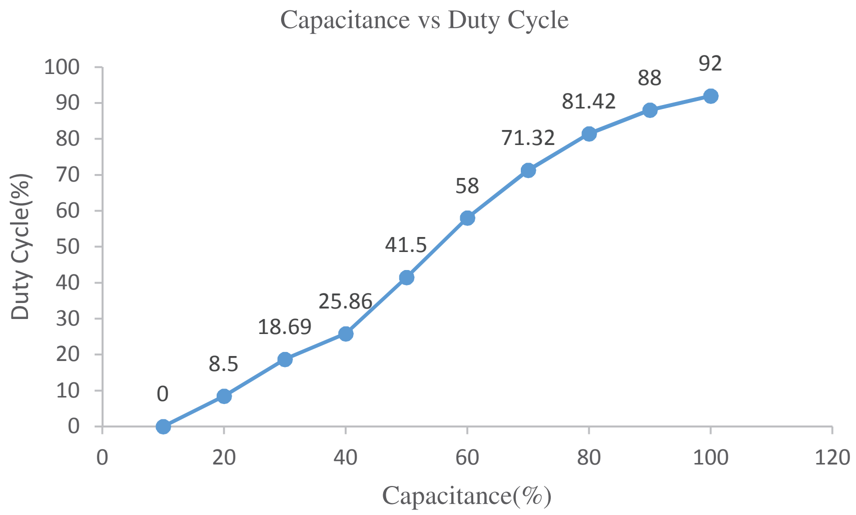


Graphical results:

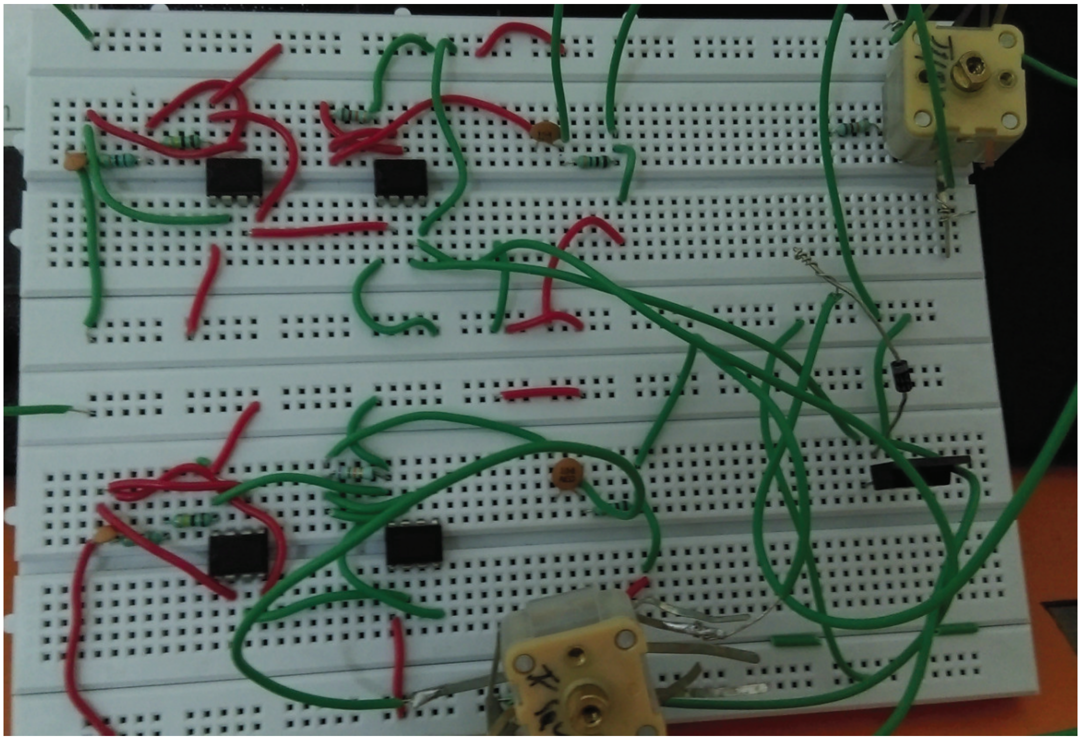
(i) Capacitance (C3) vs. RC filter output voltage

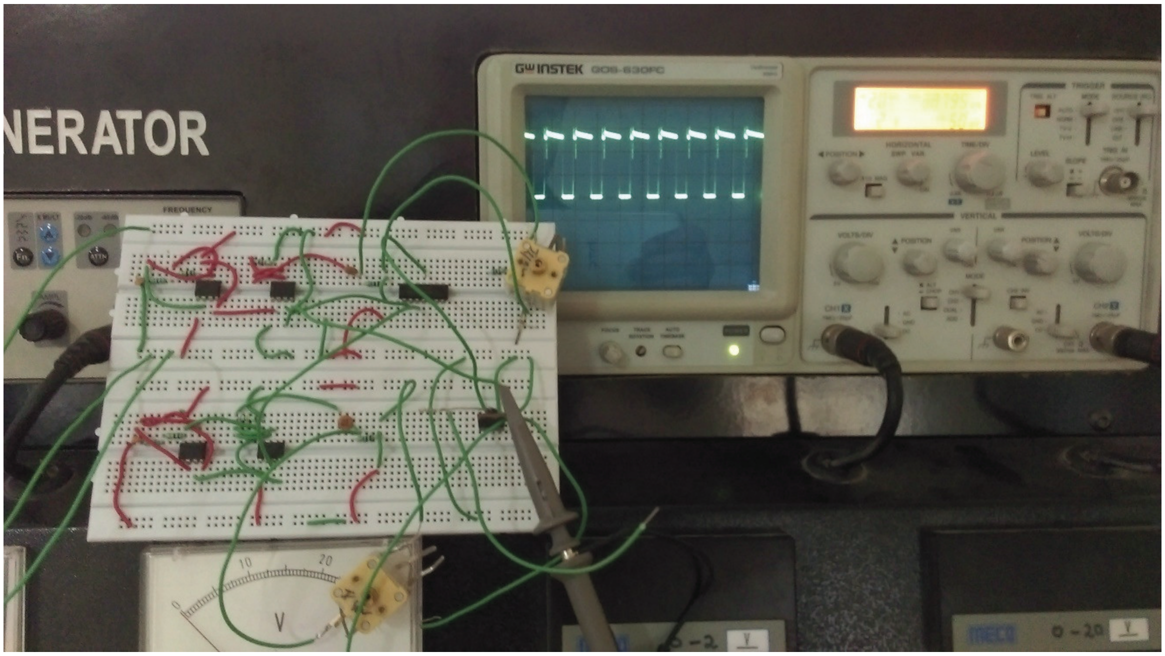


(ii) Capacitance (C3) vs. duty cycle of PWM output of EX-OR gate



Real-time implementation of the designed circuit on breadboard:




NERATOR
GW INSTEK GOS-630FC
MECO
0-20 V

CHAPTER-7
CONCLUSION AND FUTURE SCOPE

7.1 Conclusion

Efforts have been made for the designing of humidity based firing circuit to regulate the load voltage at different humidity levels. Our proposed work deals with the designing of capacitance to voltage converter of low installation cost, high reliability and compactness, less complexity. The PWM output which is obtained from the EX-OR gate is changing its pulse width according to the moisture content ingress onto the surface of the sensor. The designed signal conditioning circuit not only monitors the humidity level but can be employed for controlling the humidity level (i.e. dehumidification). Power semi-conductor device like Power-MOSFET is used here for controlling the voltage applied to the PMDC motor. Totem-pole arrangement is used for reducing switching losses at high frequency operation. Low pass passive filter or RC filter is used to obtain the smooth average output from the capacitive controlled PWM signal. We have used this designed circuit for controlling the speed of permanent magnet dc motor used in dryers, blowers in air-conditioners for dehumidification applications. The designed electronic signal conditioning circuit is successfully simulated using NI-Multisim 12.0 software and also implemented in real-time on breadboard to compare the results of simulation and practical results.

7.2 Future Scope

The future scope of present research work is identified as:

1. To implement the designed circuit in automatic detection and control of humidity level in industrial and domestic dehumidifiers.

2. To design an oscillator based intelligent conditioning circuit to get the variable frequencies from the capacitance variations for controlling the speed of AC machines.

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