A

PROJECT REPORT

On

# POWER FACTOR CORRECTION AND POWER QUALITY IMPROVEMENT IN BLDC MOTOR DRIVE USING SEPIC COVERTER

***Submitted by***


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***in partial fulfillment for the award of the degree of***

**BACHELOR OF TECHNOLOGY**

IN

**ELECTRICAL AND ELECTROICS ENGINEERING**

**Under The Guidance of**


**Mr. T. Penchalaiah**

**(M. Tech)**

**ELCTRICAL AND ELECTRONICS ENGINEERING**

**ST. MARTIN'S ENGINEERING COLLEGE**

**(An Autonomous Institute)**

**Dhulapally, Secunderabad – 500 100**


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# BONAFIDE CERTIFICATE

This is to certify that the project entitled **POWER FACTOR CORRECTION AND POWER QUALITY IMPROVEMENT IN BLDC MOTOR DRIVE USING SEPIC CONVERTER,** is being submitted by **1.K.Abhilash 17K81A0222, 2.MD.Afroz 17K81A0231, 3.G.Jelendhar Reddy 18D95A0211, 4.B.Rahul 17K81A0208** in partial fulfillment of the requirement for the award of the degree of **BACHELOR OF TECHNOLOGY IN** Electrical and Electronics Engineering is recorded of bonafide work carried out by them. The result embodied in this report have been verified and found satisfactory.

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**Date:**

# DECLARATION

We, the student of **Bachelor of Technology** in Department of Electrical and Electronics Engineering, session: 2017 – 2021, St. Martin's Engineering College, Dhulapally, Kompally,Secunderabad, hereby declare that work presented in this Project Work entitled **"Power factor correction and Power Quality Improvement in BLDC Motor Drive using SEPIC Converter"** is the outcome of our own bonafide work and is correct to the best of our knowledge and this work has been undertaken taking care of Engineering Ethics. This result embodied in this project report has not been submitted in any university for award of any degree.

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# ABSTRACT

**In this project, a (PF) Power factor correction and Power Quality (PQ) improvement-based BLDC motor drive proposed. Normally the permanent magnet BLDC motor drive connected with the diode bridge rectifier and high value of the capacitor due to which poor power factor and higher THD (Total harmonic distortion) value at the input side to overcome this difficulty SEPIC (Single-ended primary inductance converter) converter use to optimize the PF and THD value. The converter operates in discontinuous conduction mode to get the desired result. This scheme also used for speed control of BLDC motor by controlling the VSI (voltage source inverter) feeding the BLDC drive.**

## LIST OF CONTENTS

# LIST OF FIGURES



# LIST OF PHOTOGRAPHS

# LIST OF GRAPHS

# NOMENCLATURE

| | | |
|---|---|---|
| BLDC | : | Brushless DC motor |
| PF | : | Power Factor |
| SEPIC | : | Single ended primary Inductance Converter |
| IGBT | : | Insulated Gate Bipolar Transistor |
| MOSFET | : | Metal Oxide Semiconductor field effecting transistor |
| BJT | : | Bipolar junction transistor |
| ASD | : | Adjustable Speed Drives |
| UPS | : | United Power Supply |
| FACTS | : | Flexible AC Transmission Systems |
| VSI | : | Voltage Source Inverter |
| CSI | : | Current Source Inverter |
| STATCOM | : | Static Synchronous Compensator |
| PWM | : | Pulse Width Modulation |
| SPWM | : | Sinusoidal Pulse Width modulation |
| THD | : | Total Harmonic Distortion |
| HVDC | : | High Voltage Direct Current |
| API | : | Application Program Interface |
| PID | : | Proportional integral derivative |

# CHAPTER 1
# INTRODUCTION

## 1.1 OVERVIEW OF THE PROJECT:

- **DEFINATION OF POWER QUALITY**

Power quality is a term that means different things to different people. Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE1100 defines power quality as “The concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment.” As appropriate as this description might seem, the limitation of power quality to “sensitive electronic equipment” might be subject to disagreement. Electrical equipment susceptible to power quality or more appropriately to lack of power quality would fall within a seemingly boundless domain. All electrical devices are prone to failure or malfunction when exposed to one or more power quality problems. The electrical device might be an electric motor, a transformer, a generator, a computer, a printer, communication equipment or a household appliance. All of these devices and others react adversely to power quality issues, depending on the severity of problems.

A simpler and perhaps more concise definition might state: “Power quality is a set of electrical boundaries that allows a piece of equipment to function in its intended manner without significant loss of performance or life expectancy embraces two things that we demand from an electrical device: performance and life Expectancy.

- **POWER FACTOR:**

Linear loads with low power factor (such as induction motors) can be corrected with a passive network of capacitors or inductors. Non-linear loads, such as rectifiers, distort the current drawn from the system. In such cases, active or passive power factor correction may be used to counteract the distortion and raise the power factor.

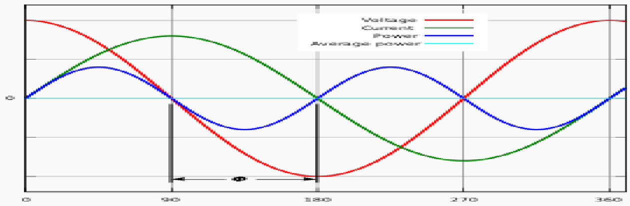



Fig1.1

Instantaneous and average power calculated from AC voltage and current with a zero-power factor ($\varphi = 90^\circ$, $\cos\varphi = 0$).

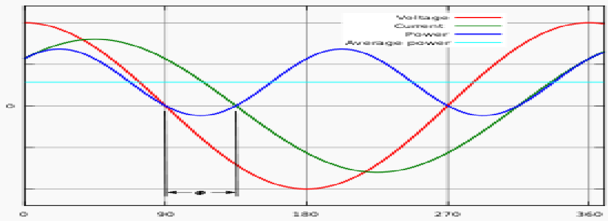



Fig 1.2

Instantaneous and average power calculated from AC voltage and current with a lagging power factor ($\varphi = 45^\circ$, $\cos\varphi \approx 0.71$).

- **DIODE RECTIFIER:**

Diodes are widely used semiconductor devices. A Rectifier diode is a two-lead semiconductor that allows current to pass in only in one direction. Generally, the P-N junction diode is a formed by joining together n-type and p-type semiconductor materials. The P-type side is called the anode and the N-type side is called the cathode.

Many types of diodes are used for a wide range of applications. Rectifier diodes are a vital component in power supplies where they are used to converts AC voltage to DC voltage.

A rectifier diode is a semiconductor diode, used to rectify AC to DC using the rectifier bridge application. The alternative of rectifier diode through the Schottky barrier is mainly valued within digital electronics. This diode is capable to conduct the values of current which changes from mA to a few kA and voltages up to a few kV.

- **SEPIC COVERTER**

The SEPIC is type of DC-DC Converter that allows the electrical potential at its output to be greater than, less than or equal to that its input. The output of the SEPIC is controlled by duty cycle of control switch. A SEPIC is same as traditional Buck-Boost converter, but having advantage of non-inverting output.

- **ADVANTAGES OF SEPIC CONVERTER OTHER THAN VARIOUS CONVERTERS:**

- Switching is easier. Because of the switch is connected to parallel to the voltage source.
- Non-inverting output.
- Isolation is present between input and output.
- In SEPIC there is no any coupling of inductor in their construction. i.e.. is uncoupled inductor.

In general, the SEPIC converter construction will takes place by using following components:

a) Two capacitors (called Input and Output as Cin & Cout).
b) Two inductors (L1 & L2).
c) A Coupling capacitor (Cp).
d) Controlled switch (like MOSFET).

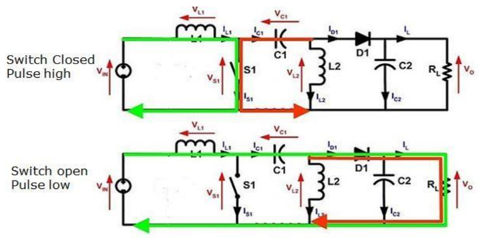



**Fig 1.3 MODES OF SEPIC CONVERTER**

- **VOLTAGE SOURCE INVERTER(VSI):**

Inverter circuit which creates as AC voltage (or current) from a dc voltage source is called as voltage source inverter. VSIs are inverters are used in ac motor drive and uninterruptable supply source. The pulse width modulated inverters, the input dc supply voltage is constant, the controls the magnitude and frequency of the ac output from the inverter. The synthesized output PWM voltage simplifies filtering and obtains a pure sine-wave curve.

## 1.2 OBJECTIVES OF THE STUDY:

In this project, it is clearly emphasizing that Power Factor correction & Power Quality improvement can make the system in to reliable. By taking an example of BLDC drive using SEPIC converter. And here it explains about working of SEPIC converter & its modes other than other types of converters.

In SEPIC converter which operates on Discontinuous conduction mode (DCM) toget desired response.

This scheme also used for speed control of BLDC motor by controlling the VSI feeding the BLDC drive. In electrical engineering, the power factor of an AC electrical power system is defined as the ratio of the real power flowing to the load to the apparent power in the circuit,[1][2] and is a dimensionless number in the closed interval of -1 to 1.

A power factor of less than one means that the voltage and current waveforms are not in phase, reducing the instantaneous product of the two waveforms (V x I). A negative power factor occurs when the device (which is normally the load) generates power, which then flows back towards the source, which is normally considered the generator. In an electric power system, a load with a low power factor draws more current than a load with a high-power factor for the same amount of useful power transferred.

## 1.3 SCOPE OF THE STUDY

The essential scope of the project, Understanding the Power factor, it's improvement & power quality improvement in a single establishment. And more over the role of each and every gadget of project realization. Especially the duty cycle variation using the SEPIC converter with BLDC Motor fed by VSI. Improvement of Power Quality & Power Factor in a system indicates that reliable or a healthy system.

So, Here the BLDC motor drive can able to explain the improvement of electrical parameters. (i.e., Improvement of Power Quality & Power Factor).

There are main components involved to make a final triumph. They are Diode Rectifier, SEPIC Converter and Voltage Source Inverter (VSI) respectively.

## 1.4 MATERIAL REQUIREMENT

### SOFTWARE REQUIREMENT

1. MATLAB Software

2. Simulink library

3. Diode Bridge Rectifier

4. SEPIC Converter

5. Voltage source inverter

6. Permanent Magnet Motor

7. Hall Sensor

8. Pulse Width Modulator Generator

9. Discrete Power gui

## 1.5 PROCUREMENT OF EQUIPMENT

There are several equipment, In order to increase the overall efficiency of the System. And we have various electrical gadgets in our project establishment, they are Diode Rectifier, SEPIC Converter and VSI type converter.

- **SEPIC Converter**: A SEPIC (Single ended primary inductor converter) Converter is a enhanced DC to DC Converter. It is also termed as modified buck boost Converter.

- **Diode rectifier**: A Diode rectifier is a Electrical device that converts AC to DC which flows only in one direction.

- **Voltage source inverter:** A Voltage source inverter is used in AC and uninterruptible supply systems.

- **BLDC Motor:** A BRUSH LESS DC (BLDC) Motor is an electronically commuted DC motor which does not have brushes. The controller provides pulses of current to the motor windings which control the speed and torque of the synchronous motor.

- **PWM Generator:** A Pulse Width Modulation (PWM) signal generator works by varying the duty cycle of a square wave while keeping the period fixed.

- **PI Controller:** A proportional–integral controller (PI controller) is a generic control loop feedback mechanism (controller) widely used in industrial control systems.

The important aspect of this each and every procurement of the equipment can elucidate the characteristics and function s of their individual identity. From above finally we conclude that the procurement of each equipment is indicates in perspective Economical operations. And procurement can essentially have an vital role to justify the Power Quality Improvement.

## 1.6. ORGANIZATION OF CHAPTERS

### 1.6.0. INTRODUCTION

Normally for drive application induction motor were used because it has own advantages like rugged construction, low maintenance, low cost, available in different ratings. But sometimes induction motor not use because of its difficulty in speed control and also not useful for low voltage application. All the above problems overcome in

BLDC (Brushless DC) motor. It also has rugged construction, high torque per weight ratio, simple in construction and a wide range of speed control

### 1.6.1. LITERATURE SURVEY:

There are more than two kinds of Converters, several switches, motor and other types of electronic devices have keys roles in this project. Diode Rectifier, VSI and SEPIC Converter are the three types of converters will assist to this entire set-up for getting the loss-less and reliability of system.

### 1.6.2. PROJECT DESIGN:

The designing of the project might here possible by using a software called MATLAB (Matrix laboratory). Here, first of all the design can commence from Simulink Library

### 1.6.3. PROJECT IMPLEMENTATION:

The entire establishment should be designed on MATLAB, then the next process is about Implementation. By giving the appropriate specifications to every device and then RUN the circuit by providing the certain Time period.

### 1.6.4. PROJECT TESTING:

At commencement the inherent results were obtained. Now by testing the project as changing values of each equipment. Project testing can make the entire response into accurate.

### 1.6.5. CONCLUSION AND FUTURE ENCHANCEMENT:

THD and PF value without SEPIC converter is found 113.94 % and 0.95 respectively. THD and PF value with SEPIC converter is found 4.94% and unity respectively.

# CHAPTER 2

# LITERATURE SURVEY

Power electronics is the application of solid-state electronics for the control and conversion of electric power. It also refers to a subject of research in electronic and electrical engineering which deals with design, control, computation and integration of nonlinear, time varying energy processing electronic systems with fast dynamics.

The first high power electronic devices were mercury-arc valves. In modern systems the conversion is performed with semiconductor switching devices such as diodes, thyristors and transistors, pioneered by R. D. Middle brook and others beginning in the 1950s. In contrast to electronic systems concerned with transmission and processing of signals and data, in power electronics substantial amounts of electrical energy are processed. An AC/DC converter (rectifier) is the most typical power electronics device found in many consumer electronic devices, e.g. television sets, personal computers, battery chargers, etc. The power range is typically from tens of watts to several hundred watts. In industry a common application is the variable speed drive (VSD) that is used to control an induction motor. The power range of VSDs start from a few hundred watts and end at tens of megawatts.

The power conversion systems can be classified according to the type of the input and output power AC to DC (rectifier), DC to AC (inverter), DC to DC (DC-to-DC converter), AC to AC (AC-to-AC converter)

## 2.1 History

Power electronics started with the development of the mercury arc rectifier. Invented by Peter Cooper Hewitt in 1902, it was used to convert alternating current (AC) into direct current (DC). From the 1920s on, research continued on applying thyratrons and grid-controlled mercury arc valves to power transmission. Uno Lamp developed a valve with grading electrodes making mercury valves usable for high voltage direct current transmission. In 1933 selenium rectifiers were invented.

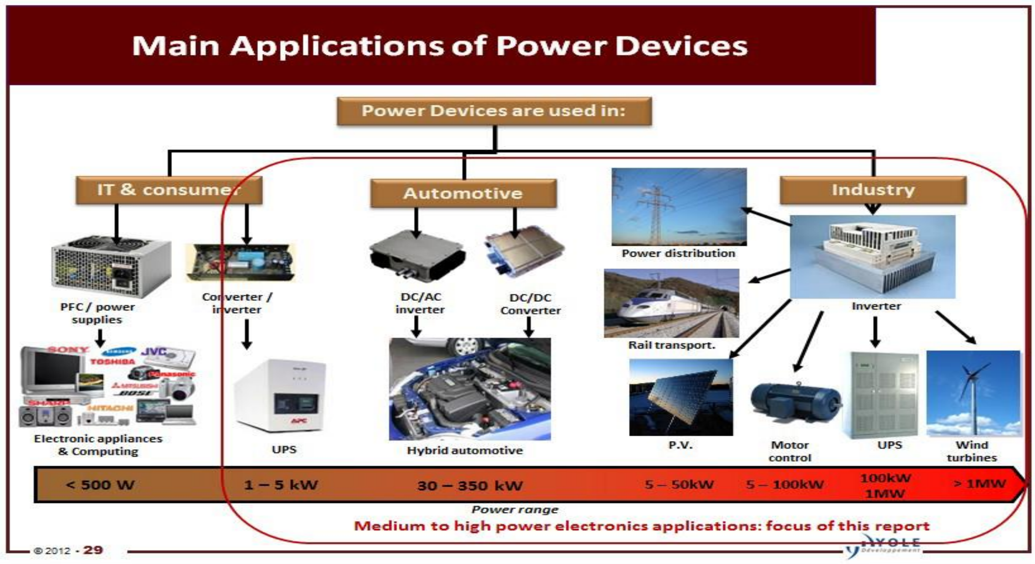



Fig 2.1

In 1957 the bipolar point-contact transistor was invented by Walter H. Brattain and John Bardeen under the direction of William Shockley at Bell Telephone Laboratory. In 1958 Shockley's invention of the bipolar junction transistor improved the stability and performance of transistors, and reduced costs. By the 1950s, semiconductor power diodes became available and started replacing vacuum tubes. In 1956 the Silicon Controlled Rectifier (SCR) was introduced by General Electric, greatly increasing the range of power electronics applications.[2]

In the 1960s the switching speed of bipolar junction transistors allowed for high frequency DC/DC converters. In 1976 power MOSFET became commercially available. In 1982 the Insulated Gate Bipolar Transistor (IGBT) was introduced.

The capabilities and economy of power electronics system are determined by the active devices that are available. Their characteristics and limitations are a key element in the design of power electronics systems. Formerly, the mercury arc valve, the high-vacuum and gas-filled diode thermionic rectifiers, and triggered devices such as the thyratron and ignitron were widely used in power electronics.

As the ratings of solid-state devices improved in both voltage and current-handling capacity, vacuum devices have been nearly entirely replaced by solid-state devices.

Power electronic devices may be used as switches, or as amplifiers.[3] An ideal switch is either open or closed and so dissipates no power; it withstands an applied voltage and passes no current, or passes any amount of current with no voltage drop. Semiconductor devices used as switches can approximate this ideal property and so most power electronic applications rely on switching devices on and off, which makes systems very efficient as very little power is wasted in the switch. By contrast, in the case of the amplifier, the current through the device varies continuously according to a controlled input. The voltage and current at the device terminals follow a load line, and the power dissipation inside the device is large compared with the power delivered to the load.

Several attributes dictate how devices are used. Devices such as diodes conduct when a forward voltage is applied and have no external control of the start of conduction. Power devices such as silicon controlled rectifiers and thyristors (as well as the mercury valve and thyratron) allow control of the start of conduction, but rely on periodic reversal of current flow to turn them off. Devices such as gate turn-off thyristors, BJT and MOSFET transistors provide full switching control and can be turned on or off without regard to the current flow through them. Transistor devices also allow proportional amplification, but this is rarely used for systems rated more than a few hundred watts. The control input characteristics of a device also greatly affect design; sometimes the control input is at a very high voltage with respect to ground and must be driven by an isolated source.

As efficiency is at a premium in a power electronic converter, the losses that a power electronic device generates should be as low as possible. Devices vary in switching speed. Some diodes and thyristors are suited for relatively slow speed and are useful for power frequency switching and control; certain thyristors are useful at a few kilohertz. Devices such as MOSFETS and BJTs can switch at tens of kilohertz up to a few megahertz in power applications, but with decreasing power levels. Vacuum tube devices dominate high power (hundreds of kilowatts) at very high frequency (hundreds or thousands of Mega Hertz of) applications. Faster switching devices minimize energy lost in the transitions from on to off and back, but may create problems with radiated electromagnetic interference.

Gate drive (or equivalent) circuits must be designed to supply sufficient drive current to achieve the full switching speed possible with a device.

A device without sufficient drive to switch rapidly may be destroyed by excess heating. Practical devices have non-zero voltage drop and dissipate power when on, and take some time to pass through an active region until they reach the "on" or "off" state. These losses are a significant part of the total lost power in a converter.

Power handling and dissipation of devices is also a critical factor in design. Power electronic devices may have to dissipate tens or hundreds of watts of waste heat, even switching as efficiently as possible between conducting and non-conducting states. In the switching mode, the power controlled is much larger than the power dissipated in the switch. The forward voltage drop in the conducting state translates into heat that must be dissipated. High power semiconductors require specialized heat sinks or active cooling systems to manage their junction temperature; exotic semiconductors such as silicon carbide have an advantage over straight silicon in this respect, and germanium, once the main-stay of solid-state electronics is now little used due to its unfavorable high temperature properties.

Semiconductor devices exist with ratings up to a few kilovolts in a single device. Where very high voltage must be controlled, multiple devices must be used in series, with networks to equalize voltage across all devices. Again, switching speed is a critical factor since the slowest-switching device will have to withstand a disproportionate share of the overall voltage. Mercury valves were once available with ratings to 100 kV in a single unit, simplifying their application in HVDC systems.

The current rating of a semiconductor device is limited by the heat generated within the dies and the heat developed in the resistance of the interconnecting leads. Semiconductor devices must be designed so that current is evenly distributed within the device across its internal junctions (or channels); once a "hot spot" develops, breakdown effects can rapidly destroy the device. Certain SCRs are available with current ratings to 3000 amperes in a single unit. DC to AC converters produce an AC output waveform from a DC source. Applications include adjustable speed drives (ASD), uninterruptable power supplies (UPS), active filters, Flexible AC transmission systems (FACTS), voltage compensators, and photovoltaic generators.

Topologies for these converters can be separated into two distinct categories: voltage source inverters and current source inverters.

Voltage source inverters (VSIs) are named so because the independently controlled output is a voltage waveform. Similarly, current source inverters (CSIs) are distinct in that the controlled AC output is a current waveform.

Being static power converters, the DC to AC power conversion is the result of power switching devices, which are commonly fully controllable semiconductor power switches. The output waveforms are therefore made up of discrete values, producing fast transitions rather than smooth ones. The ability to produce near sinusoidal waveforms around the fundamental frequency is dictated by the modulation technique controlling when, and for how long, the power valves are on and off. Common modulation techniques include the carrier-based technique, or pulse width modulation, space-vector technique, and the selective-harmonic technique.

Voltage source inverters have practical uses in both single-phase and three-phase applications. Single-phase VSIs utilize half-bridge and full-bridge configurations, and are widely used for power supplies, single-phase UPSs, and elaborate high-power topologies when used in multicell configurations. Three-phase VSIs are used in applications that require sinusoidal voltage waveforms, such as ASDs, UPSs, and some types of FACTS devices such as the STATCOM. They are also used in applications where arbitrary voltages are required as in the case of active filters and voltage compensators.

Current source inverters are used to produce an AC output current from a DC current supply. This type of inverter is practical for three-phase applications in which high-quality voltage waveforms are required.

A relatively new class of inverters, called multilevel inverters, has gained widespread interest. Normal operation of CSIs and VSIs can be classified as two-level inverters, due to the fact that power switches connect to either the positive or to the negative DC bus. If more than two voltage levels were available to the inverter output terminals, the AC output could better approximate a sine wave. It is for this reason that multilevel inverters, although more complex and costly, offer higher performance.

Each inverter type differs in the DC links used, and in whether or not they require freewheeling diodes. Either can be made to operate in square-wave or pulse-width modulation (PWM) mode, depending on its intended usage.

Square-wave mode offers simplicity, while PWM can be implemented several different ways and produces higher quality waveforms.

Voltage Source Inverters (VSI) feed the output inverter section from an approximately constant-voltage source.

The desired quality of the current output waveform determines which modulation technique needs to be selected for a given application. The output of a VSI is composed of discrete values. In order to obtain a smooth current waveform, the loads need to be inductive at the select harmonic frequencies. Without some sort of inductive filtering between the source and load, a capacitive load will cause the load to receive a choppy current waveform, with large and frequent current spikes.

The single-phase voltage source half-bridge inverters, are meant for lower voltage applications and are commonly used in power supplies. Figure 2 shows the circuit schematic of this inverter.

Low-order current harmonics get injected back to the source voltage by the operation of the inverter. This means that two large capacitors are needed for filtering purposes in this design. As Figure 2 illustrates, only one switch can be on at time in each leg of the inverter. If both switches in a leg were on at the same time, the DC source will be shorted out.

Inverters can use several modulation techniques to control their switching schemes. The carrier-based PWM technique compares the AC output waveform, $v_c$, to a carrier voltage signal, $v_\Delta$. When $v_c$ is greater than $v_\Delta$, S+ is on, and when $v_c$ is less than $v_\Delta$, S- is on. When the AC output is at frequency fc with its amplitude at $v_c$, and the triangular carrier signal is at frequency $f_\Delta$ with its amplitude at $v_\Delta$, the PWM becomes a special sinusoidal case of the carrier based PWM.[8] This case is dubbed sinusoidal pulse-width modulation (SPWM).For this, the modulation index, or amplitude-modulation ratio, is defined as $\mathbf{m_a = v_c / v_\Delta}$ .

The normalized carrier frequency, or frequency-modulation ratio, is calculated using the equation $\mathbf{m_f = f_\Delta / f_c}$.

If the over-modulation region, ma, exceeds one, a higher fundamental AC output voltage will be observed, but at the cost of saturation.

For SPWM, the harmonics of the output waveform are at well-defined frequencies and amplitudes. This simplifies the design of the filtering components needed for the low-order current harmonic injection from the operation of the inverter. The maximum output amplitude in this mode of operation is half of the source voltage. If the maximum output amplitude, $m_a$, exceeds 3.25, the output waveform of the inverter becomes a square wave.

As was true for PWM, both switches in a leg for square wave modulation cannot be turned on at the same time, as this would cause a short across the voltage source. The switching scheme requires that both S+ and S- be on for a half cycle of the AC output period. The fundamental AC output amplitude is equal to $\mathbf{v_{o1} = v_{aN}}$.

Therefore, the AC output voltage is not controlled by the inverter, but rather by the magnitude of the DC input voltage of the inverter.

Using selective harmonic elimination (SHE) as a modulation technique allows the switching of the inverter to selectively eliminate intrinsic harmonics. The fundamental component of the AC output voltage can also be adjusted within a desirable range. Since the AC output voltage obtained from this modulation technique has odd half and odd quarter wave symmetry, even harmonics do not exist. Any undesirable odd (N-1) intrinsic harmonics from the output waveform can be eliminated.

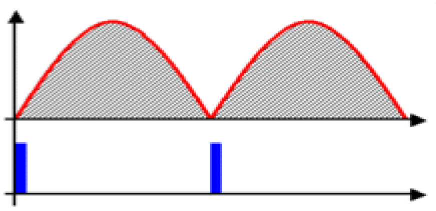
DC Link Converters, also referred to as AC/DC/AC converters, convert an AC input to an AC output with the use of a DC link in the middle. Meaning that the power in the converter is converted to DC from AC with the use of a rectifier, and then it is converted back to AC from DC with the use of an inverter. The end result is an output with a lower voltage and variable (higher or lower) frequency. Due to their wide area of application, the AC/DC/AC converters are the most common contemporary solution. Other advantages to AC/DC/AC converters are that they are stable in overload and no-load conditions, as well as they can be disengaged from a load without damage. Hybrid matrix converters are relatively new for AC/AC converters.

These converters combine the AC/DC/AC design with the matrix converter design. Multiple types of hybrid converters have been developed in this new category, an example being a converter that uses Uni-directional switches and two converter stages without the dc-link; without the capacitors or inductors needed for a dc-link, the weight and size of the converter is reduced. Two sub-categories exist from the hybrid converters, named hybrid direct matrix converter (HDMC) and hybrid indirect matrix converter (HIMC). HDMC convert the voltage and current in one stage, while the HIMC utilizes separate stages, like the AC/DC/AC converter, but without the use of an intermediate storage element.

## 2.2 SALIENT COMPONENTS

- **AC Voltage Controller:** Lighting Control; Domestic and Industrial Heating; Speed Control of Fan, Pump or Hoist Drives, Soft Starting of Induction Motors, Static AC Switches (Temperature Control, Transformer Tap Changing, etc.)
- **Cycloconverter:** High-Power Low-Speed Reversible AC Motor Drives; Constant Frequency Power Supply with Variable Input Frequency; Controllable VAR Generators for Power Factor Correction; AC System Interties Linking Two Independent Power Systems.
- **Matrix Converter**: Currently the application of matrix converters is limited due to non-availability of bilateral monolithic switches capable of operating at high frequency, complex control law implementation, commutation and other reasons.
- **DC Link:** Can be used for individual or multiple load applications of machine building and construction.

## 2.3 Simulations of power electronic systems



Output voltage of a full-wave rectifier with controlled thyristors.

Fig 2.2

Power electronic circuits are simulated using computer simulation programs such as PSIM and MATLAB/ Simu link. Circuits are simulated before they are produced to test how the circuits respond under certain conditions. Also, creating a simulation is both cheaper and faster than creating a prototype to use for testing.

Applications of power electronics range in size from a switched mode power supply in an AC adapter, battery chargers, fluorescent lamp ballasts, through variable frequency drives and DC motor drives used to operate pumps, fans, and manufacturing machinery, up to gigawatt-scale high voltage direct current power transmission systems used to interconnect electrical grids. Power electronic systems are found in virtually every electronic device. For example:

DC/DC converters are used in most mobile devices (mobile phones, PDA etc.) to maintain the voltage at a fixed value whatever the voltage level of the battery is. These converters are also used for electronic isolation and power factor correction.

AC/DC converters (rectifiers) are used every time an electronic device is connected to the mains (computer, television etc.). These may simply change AC to DC or can also change the voltage level as part of their operation.

AC/AC converters are used to change either the voltage level or the frequency (international power adapters, light dimmer). In power distribution networks AC/AC converters may be used to exchange power between utility frequency 50 Hz and 60 Hz power grids.

DC/AC converters (inverters) are used primarily in UPS or renewable energy systems or emergency. Mains power charges the DC battery. If the mains fail, an inverter produces AC electricity at mains voltage from the DC battery.

Motor drives are found in pumps, blowers, and mill drives for textile, paper, cement and other such facilities. Drives may be used for power conversion and for motion control. For AC motors, applications include variable-frequency drives, motor soft starters and excitation systems.

In hybrid electric vehicles (HEVs), power electronics are used in two formats: series hybrid and parallel hybrid. The difference between a series hybrid and a parallel hybrid is the relationship of the electric motor to the internal combustion engine (ICE).

Devices used in electric vehicles consist mostly of dc/dc converters for battery charging and dc/ac converters to power the propulsion motor. Electric trains use power electronic devices to obtain power, as well as for vector control using pulse width modulation (PWM) rectifiers.

The trains obtain their power from power lines. Another new usage for power electronics is in elevator systems.Hense systems may use thyristors, inverters, permanent magnet motors, or various hybrid systems that incorporate PWM systems and standard motors.

In general, inverters are utilized in applications requiring direct conversion of electrical energy from DC to AC or indirect conversion from AC to AC. Dc to AC conversion is useful for many fields, including power conditioning, harmonic compensation, motor drives, and renewable energy grid-integration.

In power systems it is often desired to eliminate harmonic content found in line currents. VSIs can be used as active power filters to provide this compensation. Based on measured line currents and voltages, a control system determines reference current signals for each phase. This is fed back through an outer loop and subtracted from actual current signals to create current signals for an inner loop to the inverter. These signals then cause the inverter to generate output currents that compensate for the harmonic content. This configuration requires no real power consumption, as it is fully fed by the line; the DC link is simply a capacitor that is kept at a constant voltage by the control system. In this configuration, output currents are in phase with line voltages to produce a unity power factor. Conversely, VAR compensation is possible in a similar configuration where output currents lead line voltages to improve the overall power factor.

In facilities that require energy at all times, such as hospitals and airports, UPS systems are utilized. In a standby system, an inverter is brought online when the normally supplying grid is interrupted.

Power is instantaneously drawn from onsite batteries and converted into usable AC voltage by the VSI, until grid power is restored, or until backup generators are brought online. In an online UPS system, a rectifier-DC-link-inverter is used to protect the load from transients and harmonic content.

A battery in parallel with the DC-link is kept fully charged by the output in case the grid power is interrupted, while the output of the inverter is fed through a low pass filter to the load. High power quality and independence from disturbances is achieved.

Various AC motor drives have been developed for speed, torque, and position control of AC motors. These drives can be categorized as low-performance or as high-performance, based on whether they are scalar-controlled or vector-controlled, respectively. In scalar-controlled drives, fundamental stator current, or voltage frequency and amplitude, are the only controllable quantities. Therefore, these drives are employed in applications where high-quality control is not required, such as fans and compressors. On the other hand, vector-controlled drives allow for instantaneous current and voltage values to be controlled continuously. This high performance is necessary for applications such as elevators and electric cars.

Inverters are also vital to many renewable energy applications. In photovoltaic purposes, the inverter, which is usually a PWM VSI, gets fed by the DC electrical energy output of a photovoltaic module or array. The inverter then converts this into an AC voltage to be interfaced with either a load or the utility grid. Inverters may also be employed in other renewable systems, such as wind turbines. In these applications, the turbine speed usually varies causing changes in voltage frequency and sometimes in the magnitude. In this case, the generated voltage can be rectified and then inverted to stabilize frequency and magnitude.

A smart grid is a modernized electrical grid that uses information and communications technology to gather and act on information, such as information about the behaviors of suppliers and consumers, in an automated fashion to improve the efficiency, reliability, economics, and sustainability of the production and distribution of electricity. Electric power generated by wind turbines and hydroelectric turbines by using induction generators can cause variances in the frequency at which power is generated.

Power electronic devices are utilized in these systems to convert the generated ac voltages into high-voltage direct current (HVDC). The HVDC power can be more easily converted into three phase power that is coherent with the power associated to the existing power grid.

Through these devices, the power delivered by these systems is cleaner and has a higher associated power factor. Wind power systems optimum torque is obtained either through a gearbox or direct drive technologies that can reduce the size of the power electronics device.

Electric power can be generated through photovoltaic cells by using power electronic devices. The produced power is usually then transformed by inverters. Inverters are divided into three different types: central, module-integrated and string. Central converters can be connected either in parallel or in series on the DC side of the system.

For photovoltaic "farms", a single central converter is used for the entire system. Module-integrated converters are connected in series on either the DC or AC side. Normally several modules are used within a photovoltaic system, since the system requires these converters on both DC and AC terminals.

A string converter is used in a system that utilizes photovoltaic cells that are facing different directions. It is used to convert the power generated to each string, or line, in which the photovoltaic cells are interacting.

Power electronics can be used to help utilities adapt to the rapid increase in distributed residential/commercial solar power generation. Germany and parts of Hawaii, California and New Jersey require costly studies to be conducted before approving new solar installations.

Relatively small-scale ground- or pole-mounted devices create the potential for a distributed control infrastructure to monitor and manage the flow of power. Traditional electromechanical systems, such as capacitor banks or voltage regulators at substations, can take minutes to adjust voltage and can be distant from the solar installations where the problems originate.

If voltage on a neighborhood circuit goes too high, it can endanger utility crews and cause damage to both utility and customer equipment.

Further, a grid fault causes photovoltaic generators to shut down immediately, spiking demand for grid power. Smart grid-based regulators are more controllable than far more numerous consumer devices.

# CHAPTER 3

# PROJECT DESIGN

## 3.1 WHY PULSE WIDTH MODULATION

1. Cheap to make.
2. Little heat whilst working.
3. Low power consumption.
3. Can utilize very high frequencies (30-100 KHz is not uncommon.)
5. Very energy-efficient when used to convert voltages or to dim light bulbs.
6. High power handling capability
7. Efficiency up to 90%

A modulation technique used to encode a message into a pulsing signal. Although this modulation technique can be used to encode information for transmission, its main use is to allow the control of the power supplied to electrical devices, especially to inertial loads such as motors. In addition, PWM is one of the two principal algorithms used in photovoltaic solar battery chargers,[1] the other being MPPT.

The average value of voltage (and current) fed to the load is controlled by turning the switch between supply and load on and off at a fast rate. The longer the switch is on compared to the off periods, the higher the total power supplied to the load.

The PWM switching frequency has to be much higher than what would affect the load (the device that uses the power), which is to say that the resultant waveform perceived by the load must be as smooth as possible. Typically switching has to be done several times a minute in an electric stove, 120 Hz in a lamp dimmer, from few kilohertz (kHz) to tens of kHz for a motor drive and well into the tens or hundreds of kHz in audio amplifiers and computer power supplies.

The term duty cycle describes the proportion of 'on' time to the regular interval or 'period' of time; a low duty cycle corresponds to low power, because the power is off for most of the time. Duty cycle is expressed in percent, 100% being fully on.

The main advantage of PWM is that power loss in the switching devices is very low.

When a switch is off there is practically no current, and when it is on and power is being transferred to the load, there is almost no voltage drop across the switch. Power loss, being the product of voltage and current, is thus in both cases close to zero. PWM also works well with digital controls, which, because of their on/off nature, can easily set the needed duty cycle.

PWM has also been used in certain communication systems where its duty cycle has been used to convey information over a communications channel.

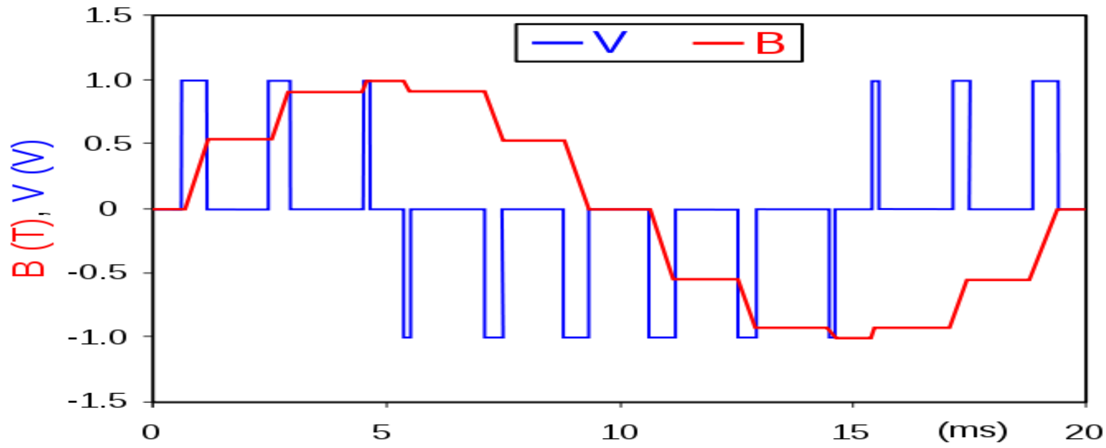



Fig 3.1 wave for combined positive and negative pulse

An example of PWM in an idealized inductor driven by a voltage source: the voltage source (blue) is modulated as a series of pulses that results in a sine-like current/flux (red) in the inductor. The blue rectangular pulses nonetheless result in a smoother and smoother red sine wave as the switching frequency increases. Note that the red waveform is the (definite) integral of the blue waveform.

**Principle:**

Pulse-width modulation uses a rectangular pulse waves whose pulse width is modulated resulting in the variation of the average value of the waveform. If we consider a pulse waveform $f(t)$, with period $T$, low value $y_{min}$, a high value $y_{max}$ and a duty cycle D (see figure 1), the average value of the waveform is given by:

$$\bar{y} = \frac{1}{T}\int_0^T f(t)\,dt.$$

As $f(t)$ is a pulse wave, its value is $y_{max}$ for $0 < t < D \cdot T$ and $y_{min}$ for $D \cdot T < t < T$. The above expression then becomes:

$$\bar{y} = \frac{1}{T}\left(\int_0^{DT} y_{max}\, dt + \int_{DT}^{T} y_{min}\, dt\right)$$
$$= \frac{D \cdot T \cdot y_{max} + T\,(1-D)\, y_{min}}{T}$$
$$= D \cdot y_{max} + (1-D)\, y_{min}.$$

This latter expression can be fairly simplified in many cases whereas $\bar{y} = D \cdot y_{max}$. From this, it is obvious that the average value of the signal ($\bar{y}$) is directly dependent on the duty cycle D.

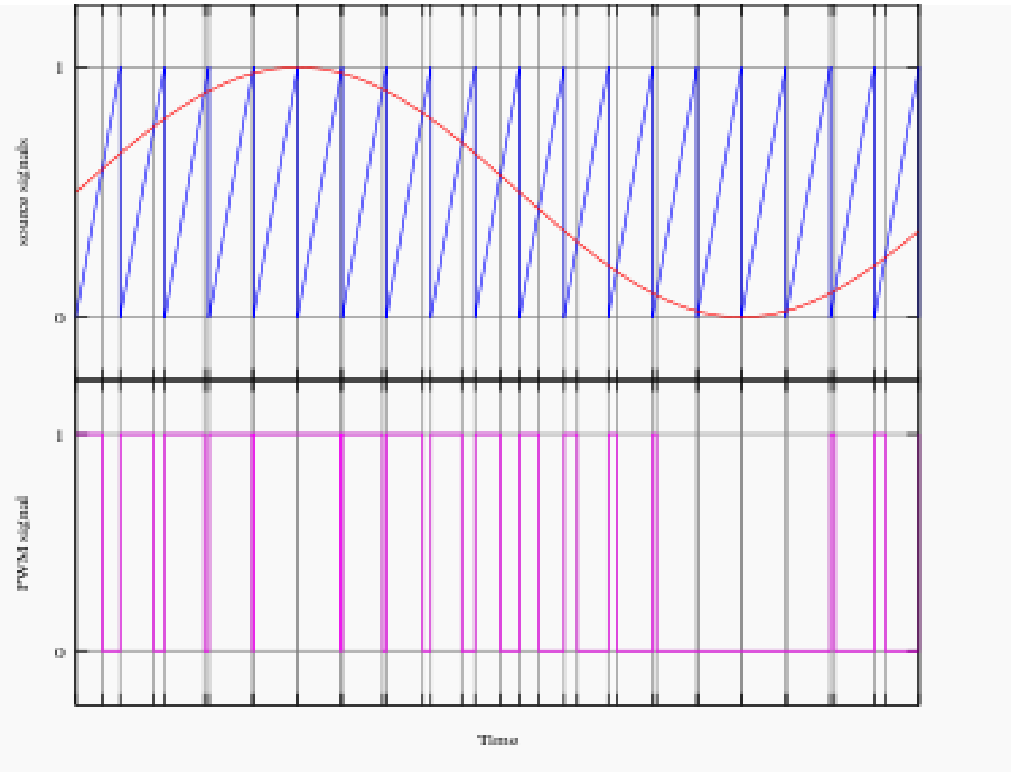



Fig. 3.2: A simple method to generate the PWM pulse train corresponding to a given signal is the intersective PWM: the signal (here the red sinewave) is compared with a sawtooth waveform (blue).

When the latter is less than the former, the PWM signal (magenta) is in high state (1).

Otherwise it is in the low state (0).The simplest way to generate a PWM signal is the intersective method, which requires only a sawtooth or a triangle waveform (easily generated using a simple oscillator) and a comparator.

When the value of the reference signal (the red sine wave in figure 2) is more than the modulation waveform (blue), the PWM signal (magenta) is in the high state, otherwise it is in the low state.

The **PWM** is a technique which is used to drive the inertial loads since a very long time. The simple example of an inertial load is a motor. Apply the power to a motor for a very short period of time and then turn off the power: it can be observed that the motor is still running even after the power has been cut off from it.

This is due to the inertia of the motor and the significance of this factor is that the continuous power is not required for that kind of devices to operate. A burst power can save the total power supplied to the load while achieving the same performance from the device as it runs on continuous power.

The **PWM technique** is use in devices like DC motors, Loudspeakers, Class - D Amplifiers, SMPS etc. They are also used in communication field as-well. The modulation techniques like AM, FM are widely used RF communication whereas the PWM is modulation technique is mostly used in Optical Fiber Communication (OFC).

As in the case of the inertial loads mentioned previously, the PWM in a communication link greatly saves the transmitter power. The immunity of the PWM transmission against the inter-symbol interference is another advantage. This article discusses the technique of generating a PWM wave corresponding to a modulating sine wave.

### 3.2 DESCRIPTION:

The **Pulse Width Modulation** is a technique in which the ON time or OFF time of a pulse is varied according to the amplitude of the modulating signal, keeping t the (ON time + OFF time) time of the pulse as constant.

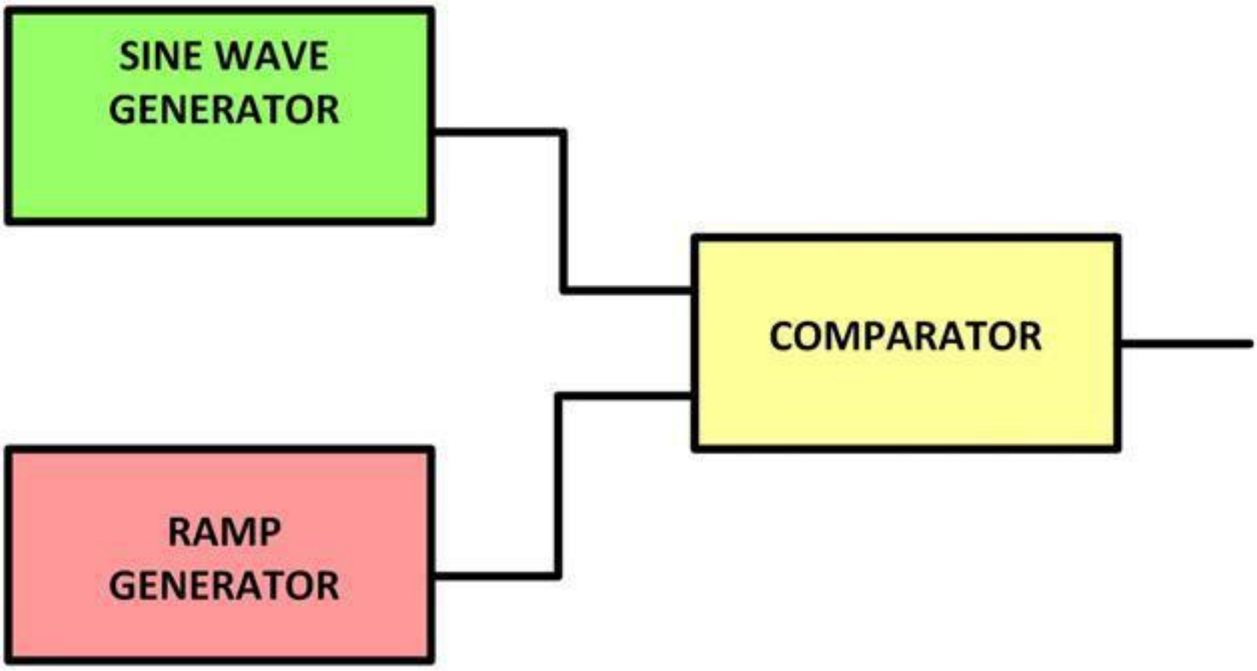



Fig 3.3 SPWM block diagram

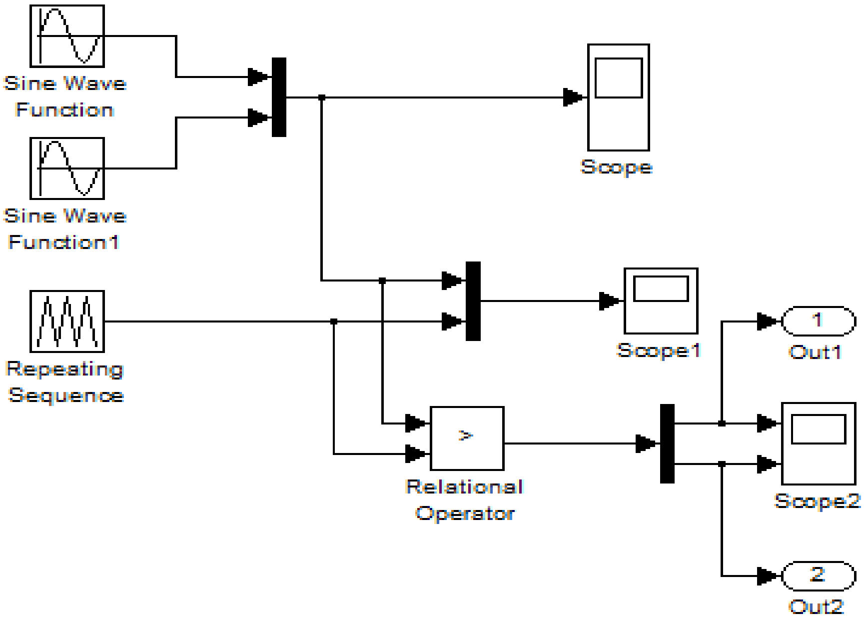



Fig 3.4

### 3.3 SPWM SIMULATION DIAGRAM

The conventional method of generating a PWM modulated wave is to compare the message signal with a ramp waveform using a comparator. The block diagram required for the generation of a simple PWM is shown.

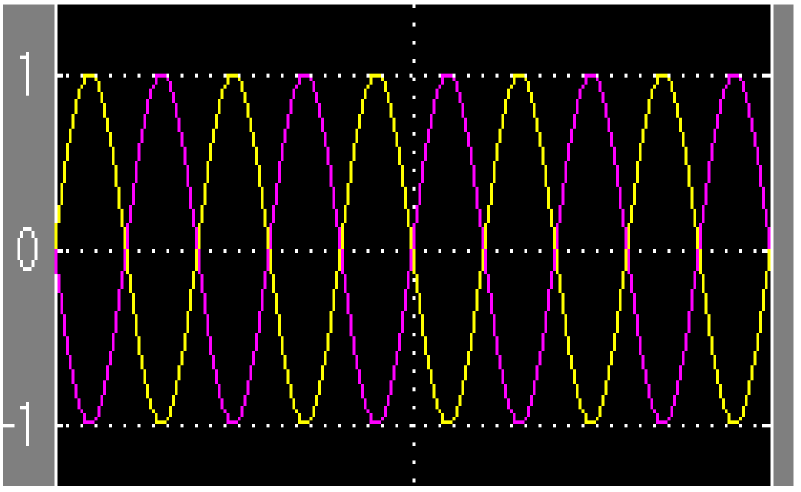



Fig 3.5 SCOPE view

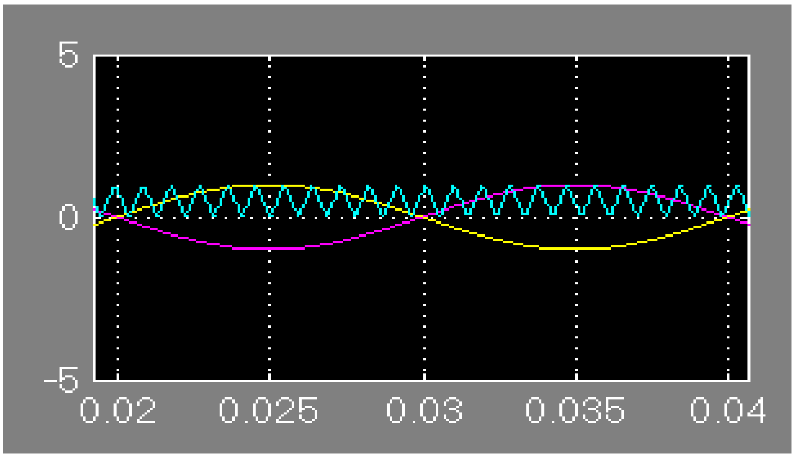



Fig 3.6 SCOPE 1 view

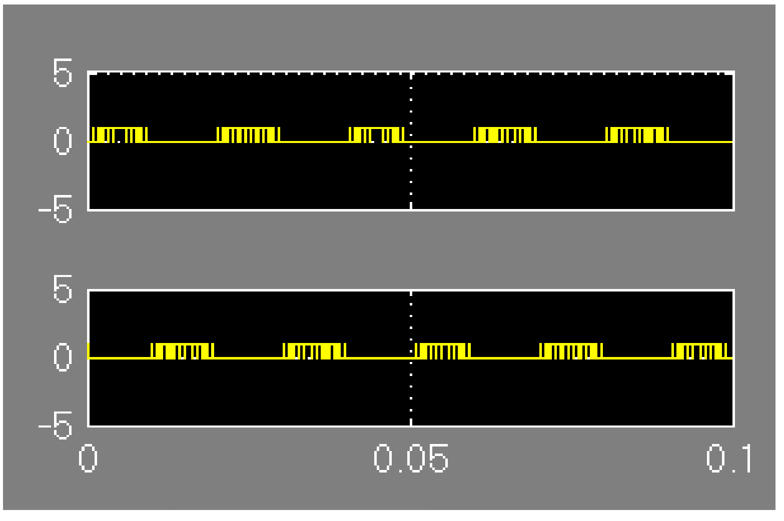



Fig 3.7 SCOPE 2 view

The (ON time + OFF time) of a pulse is called 'Period' of the pulse, and the ratio of the ON time or OFF time with the Period is called the 'Duty Cycle'.

# CHAPTER 4

# PROJECT IMPLEMENTATION

**Brushless DC motors (BLDC)** have been a much-focused area for numerous motor manufacturers as these motors are increasingly the preferred choice in many applications, especially in the field of motor control technology.

BLDC motors are superior to brushed DC motors in many ways, such as ability to operate at high speeds, high efficiency, and better heat dissipation. They are an indispensable part of modern drive technology, most commonly employed for actuating drives, machine tools, electric propulsion, robotics, computer peripherals and also for electrical power generation.

With the development of sensor less technology besides digital control, these motors become so effective in terms of total system cost, size and reliability.

A brushless DC motor (known as BLDC) is a permanent magnet synchronous electric motor which is driven by direct current (DC) electricity and it accomplishes electronically controlled commutation system (commutation is the process of producing rotational torque in the motor by changing phase currents through it at appropriate times) instead of a mechanically commutation system.

BLDC motors are also referred as trapezoidal permanent magnet motors.

Unlike conventional brushed type DC motor, wherein the brushes make the mechanical contact with commutator on the rotor so as to form an electric path between a DC electric source and rotor armature windings, BLDC motor employs electrical commutation with permanent magnet rotor and a stator with a sequence of coils.

In this motor, permanent magnet (or field poles) rotates and current carrying conductors are fixed. The armature coils are switched electronically by transistors or silicon-controlled rectifiers at the correct rotor position in such a way that armature field is in space quadrature with the rotor field poles.

Hence the force acting on the rotor causes it to rotate. **Hall sensors** or rotary encoders are most commonly used to sense the position of the rotor and are positioned around the stator.

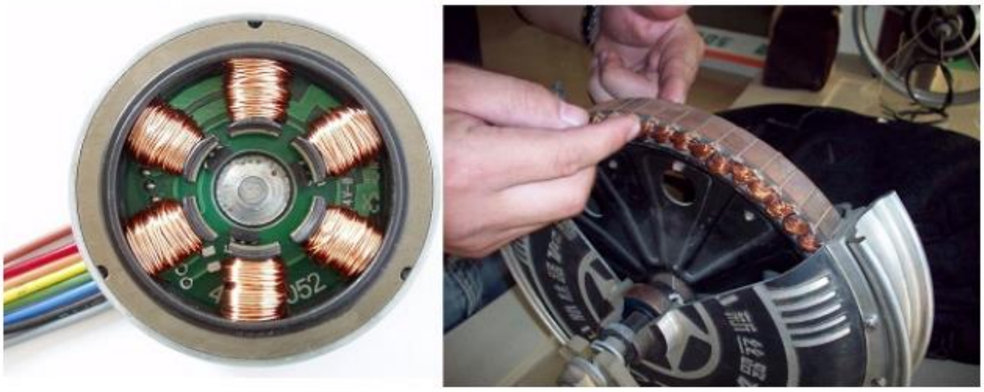



Fig4.1

The rotor position feedback from the sensor helps to determine when to switch the armature current. This electronic commutation arrangement eliminates the commutator arrangement and brushes in a DC motor and hence more reliable and less noisy operation is achieved.

Due to the absence of brushes BLDC motors are capable to run at high speeds. The efficiency of BLDC motors is typically 85 to 90 percent, whereas as brushed type DC motors are 75 to 80 percent efficient. There are wide varieties of BLDC motors available ranging from small power range to fractional horsepower, integral horsepower and large power ranges.

Construction of BLDC Motor

BLDC motors can be constructed in different physical configurations. Depending on the stator windings, these can be configured as single-phase, two-phase, or three-phase motors. However, three-phase BLDC motors with permanent magnet rotor are most commonly used.

The construction of this motor has many similarities of three phase induction motor as well as conventional DC motor. This motor has stator and rotor parts as like all other motors. Stator of a BLDC motor made up of stacked steel laminations to carry the windings.

These windings are placed in slots which are axially cut along the inner periphery of the stator. These windings can be arranged in either star or delta. However, most BLDC motors have three phase star connected stator. Each winding is constructed with numerous interconnected coils, where one or more coils are placed in each slot. In order to form an even number of poles, each of these windings is distributed over the stator periphery.

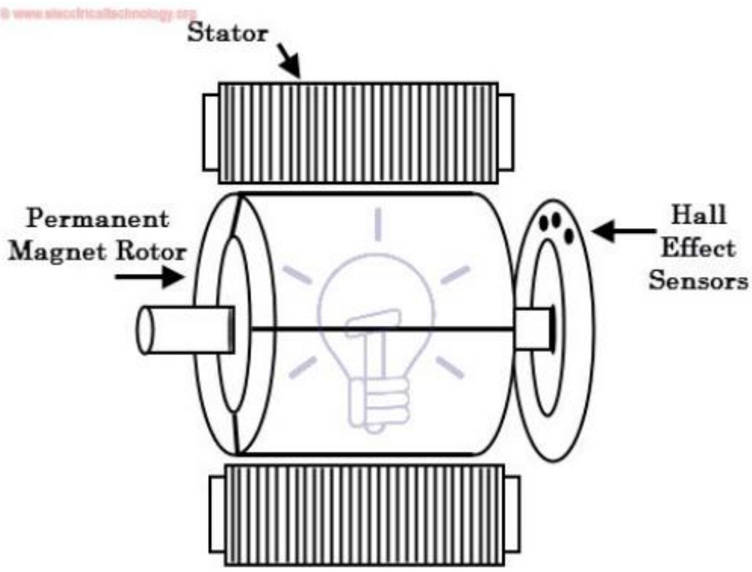



Fig 4.2

The stator must be chosen with the correct rating of the voltage depending on the power supply capability. For robotics, automotive and small actuating applications, 48 V or less voltage BLDC motors are preferred. For industrial applications and automation systems, 100 V or higher rating motors are used.


Fig 4.3

**4.1 ROTOR**

BLDC motor incorporates a permanent magnet in the rotor. The number of poles in the rotor can vary from 2 to 8 pole pairs with alternate south and north poles depending on the application requirement. In order to achieve maximum torque in the motor, the flux density of the material should be high. A proper magnetic material for the rotor is needed to produce required magnetic field density.

Fig 4.4

Ferrite magnets are inexpensive; however, they have a low flux density for a given volume. Rare earth alloy magnets are commonly used for new designs. Some of these alloys are Samarium Cobalt (SmCo), Neodymium (Nd), and Ferrite and Boron (NdFeB). The rotor can be constructed with different core configurations such as the circular core with permanent magnet on the periphery, circular core with rectangular magnets, etc.

### 4.2 Hall Sensors

Hall sensor provides the information to synchronize stator armature excitation with rotor position. Since the commutation of BLDC motor is controlled electronically, the stator windings should be energized in sequence in order to rotate the motor. Before energizing a particular stator winding, acknowledgment of rotor position is necessary. So the Hall Effect sensor embedded in stator senses the rotor position. Most BLDC motors incorporate three Hall sensors which are embedded into the stator. Each sensor generates Low and High signals whenever the rotor poles pass near to it. The exact commutation sequence to the stator winding can be determined based on the combination of these three sensor's responses.

### 4.3 Working Principle and Operation of BLDC Motor

BLDC motor works on the principle similar to that of a conventional DC motor, i.e., the Lorentz force law which states that whenever a current carrying conductor placed in a magnetic field it experiences a force. As a consequence of reaction force, the magnet will experience an equal and opposite force. In case BLDC motor, the current carrying conductor is stationary while the permanent magnet moves.

When the stator coils are electrically switched by a supply source, it becomes electromagnet and starts producing the uniform field in the air gap.

Though the source of supply is DC, switching makes to generate an AC voltage waveform with trapezoidal shape. Due to the force of interaction between electromagnet stator and permanent magnet rotor, the rotor continues to rotate. Consider the figure below in which motor stator is excited based on different switching states. With the switching of windings as High and Low signals, corresponding winding energized as North and South poles. The permanent magnet rotor with North and South poles aligns with stator poles causing motor to rotate. Observe that motor produces torque because of the development of attraction forces (when North-South or South-North alignment) and repulsion forces (when North-North or South-South alignment). By this way motor moves in a clockwise direction.

Here, one might get a question that how we know which stator coil should be energized and when to do. This is because; the motor continuous rotation depends on the switching sequence around the coils. As discussed above that Hall sensors give shaft position feedback to the electronic controller unit. Based on this signal from sensor, the controller decides particular coils to energize. Hall-effect sensors generate Low- and High-level signals whenever rotor poles pass near to it. These signals determine the position of the shaft.

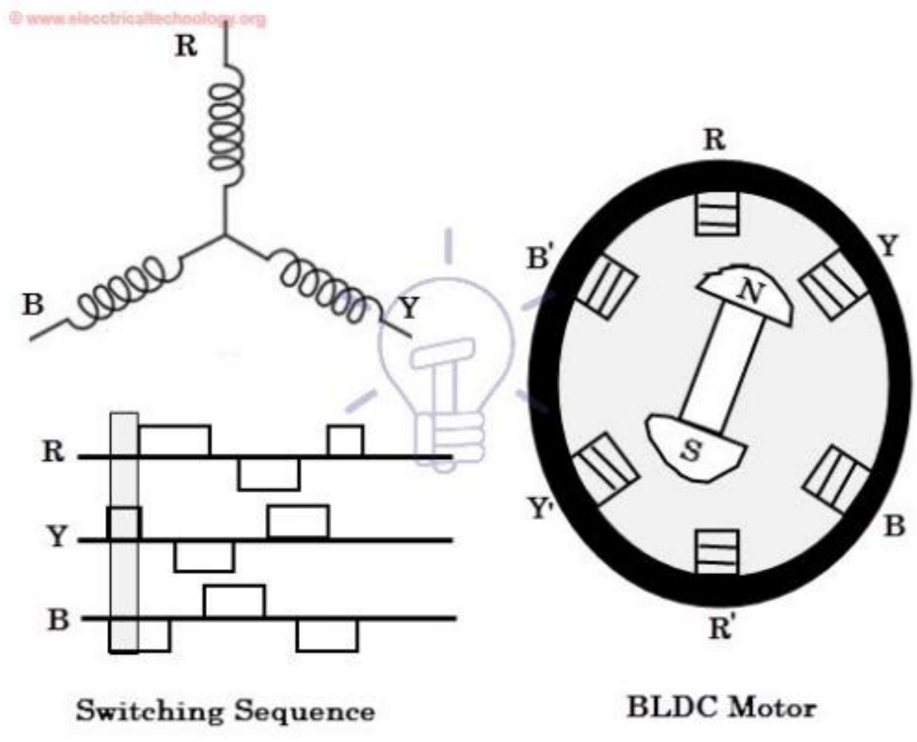



Fig 4.5

### 4.4 Brushless DC Motor Drive

As described above that the electronic controller circuit energizes appropriate motor winding by turning transistor or other solid-state switches to rotate the motor continuously. The figure below shows the **simple BLDC motor drive circuit** which consists of MOSFET bridge (also called as inverter bridge), electronic controller, hall effect sensor and BLDC motor.

Here, Hall-effect sensors are used for position and speed feedback. The electronic controller can be a microcontroller unit or microprocessor or DSP processor or FPGA unit or any other controller. This controller receives these signals, processes them and sends the control signals to the MOSFET driver circuit.

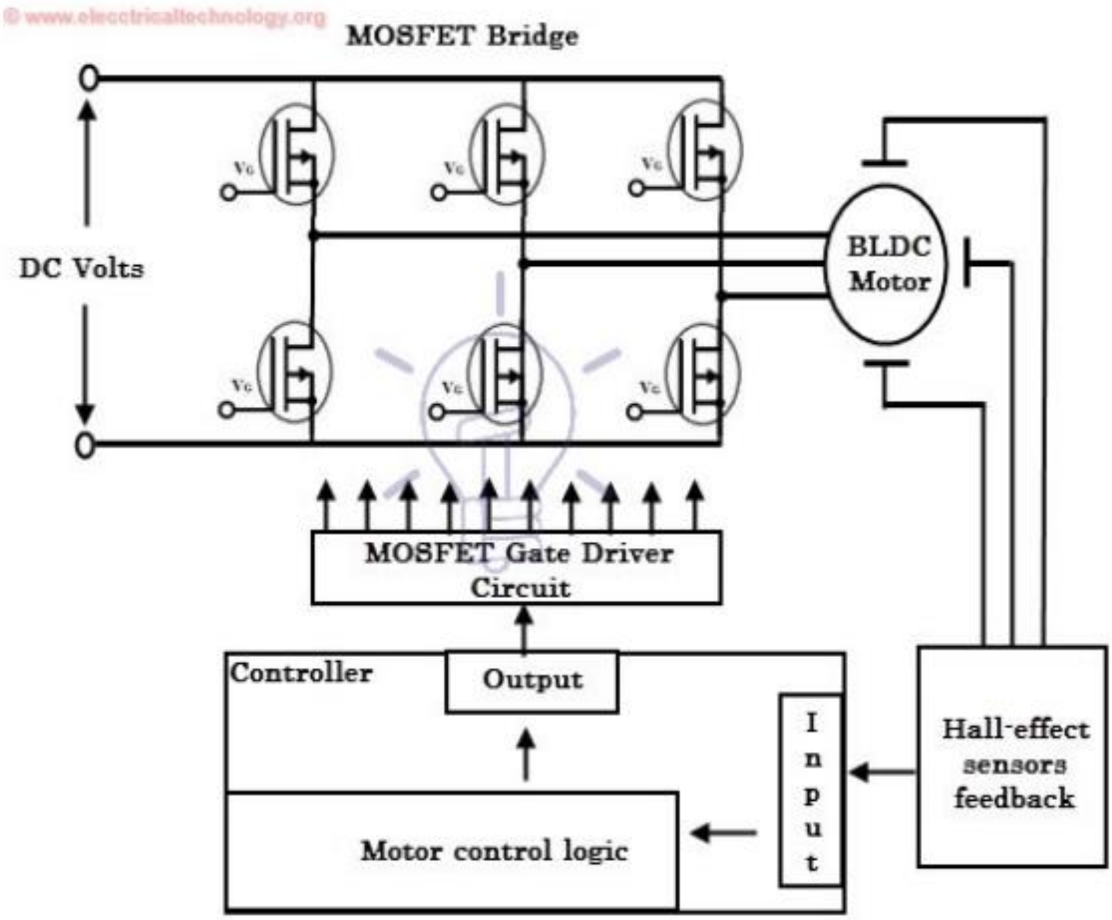



Fig4.6

In addition to the switching for a rated speed of the motor, additional electronic circuitry changes the motor speed based on required application. These speed control units are generally implemented with PID controllers to have precise control.

It is also possible to produce four-quadrant operation from the motor whilst maintaining good efficiency throughout the speed variations using modern drives.

### 4.5 Advantages of BLDC Motor

BLDC motor has several advantages over conventional DC motors and some of these are

- It has no mechanical commutator and associated problems
- High efficiency due to the use of permanent magnet rotor
- High speed of operation even in loaded and unloaded conditions due to the absence of brushes that limits the speed
- Smaller motor geometry and lighter in weight than both brushed type DC and induction AC motors
- Long life as no inspection and maintenance is required for commutator system
- Higher dynamic response due to low inertia and carrying windings in the stator
- Less electromagnetic interference
- Quite operation (or low noise) due to absence of brushes

### 4.6 Disadvantages of Brushless Motor

- These motors are costly
- Electronic controller required control this motor is expensive
- Not much availability of many integrated electronic control solutions, especially for tiny BLDC motors
- Requires complex drive circuitry
- Need of additional sensors

### 4.7 Applications of Brushless DC Motors (BLDC)

**Brushless DC Motors (BLDC) are used** for a wide variety of application requirements such as varying loads, constant loads and positioning applications in the fields of industrial control, automotive, aviation, automation systems, health care equipment, etc. Some specific applications of BLDC motors are

- Computer hard drives and DVD/CD players
- Electric vehicles, hybrid vehicles, and electric bicycles
- Industrial robots, CNC machine tools, and simple belt driven systems
- Washing machines, compressors and dryers
- Fans, pumps and blowers

# CHAPTER 5
# PROJECT TESTING

## 5.1 INTRODUCTION

Simulink is a software package for modeling, simulating, and analyzing dynamical systems. It supports linear and nonlinear systems, modeled in continuous time, sampled time, or a hybrid of the two. For modeling, Simulink provides a graphical user interface (GUI) for building models as block diagrams, using click-and-drag mouse operations.

Models are hierarchical, so we can build models using both top-down and bottom-up approaches. We can view the system at a high level, then double-click on blocks to go down through the levels to see increasing levels of model detail. This approach provides insight into how a model is organized and how its parts interact. After we define a model, we can simulate it, using a choice of integration methods, either from the Simulink menus or by entering commands in MATLAB's command window.

Using scopes and other display blocks, we can see the simulation results while the simulation is running. In addition, we can change parameters and immediately see what happens, for "what if" exploration.

The simulation results can be put in the MATLAB workspace for post processing and visualization. Simulink can be used to explore the behavior of a wide range of real-world dynamic systems, including electrical circuits, shock absorbers, braking systems, and many other electrical, mechanical, and thermodynamic systems. Simulating a dynamic system is a two-step process with Simulink.

First, we create a graphical model of the system to be simulated, using Simulink's model editor.

The model depicts the time-dependent mathematical relationships among the system’s inputs, states, and outputs. Then, we use Simulink to simulate the behavior of the system over a specified time span. Simulink uses information that you entered into the model to perform the simulation.

## 5.2 BLOCK DIAGRAM

A Simulink block diagram is a pictorial model of a dynamic system. It consists of a set of symbols, called blocks, interconnected by lines. Each block represents an elementary dynamic system that produces an output either continuously (a continuous block) or at specific points in time (a discrete block). The lines represent connections of block inputs to block outputs. Every block in a block diagram is an instance of a specific type of block. The type of the block determines the relationship between a block's outputs and its inputs, states, and time. A block diagram can contain any number of instances of any type of block needed to model a system. Blocks represent elementary dynamic systems that Simulink knows how to simulate. A block comprises one or more of the following:

1) A set of inputs,
2) A set of states, and
3) A set of outputs.
4) A block's output is a function of time and the block's inputs and states (if any). The specific function that relates a block's output to its inputs, states, and time depends on the type of block of which the block is an instance. Continuous Versus discrete Blocks Simulink's standard block set includes continuous blocks and discrete blocks. Continuous blocks respond continuously to continuously changing input. Discrete blocks, by contrast, respond to changes in input only at integral multiples of a fixed interval called the block's sample time.
5) Discrete blocks hold their output constant between successive sample time hits. Each discrete block includes a sample time parameter that allows you to specify its sample rate. The Simulink blocks can be either continuous or discrete, depending on whether they are driven by continuous or discrete blocks. A block that can be either discrete or continuous is said to have an implicit sample rate. The implicit sample time is continuous if any of the block's inputs are continuous.

The implicit sample time is equal to the shortest input sample time if all the input sample times are integral multiples of the shortest time. The Simulink blocks can be either continuous or discrete, depending on whether they are driven by continuous or discrete blocks.

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. Typical uses include:

- Math and computation
- Algorithm development
- Modelling, simulation, and prototyping
- Data analysis, exploration, and visualization
- Scientific and engineering graphics
- Application development, including Graphical User Interface building

MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. This allows you to solve many technical computing problems, especially those with matrix and vector formulations, in a fraction of the time it would take to write a program in a scalar noninteractive language such as C or Fortran.

MATLAB was originally written to provide easy access to matrix software developed by the LINPACK and EISPACK projects, which together represent the state-of-the-art in software for matrix computation.

MATLAB has evolved over a period of years with input from many users. In university environments, it is the standard instructional tool for introductory and advanced courses in mathematics, engineering, and science.

In industry, MATLAB is the tool of choice for high-productivity research, development, and analysis. MATLAB features a family of application-specific solutions called toolboxes.

Very important to most users of MATLAB, toolboxes allow you to learn and apply specialized technology.

Toolboxes are comprehensive collections of MATLAB functions (M-files) that extend the MATLAB environment to solve particular classes of problems.

Areas in which toolboxes are available include signal processing, control systems, neural networks, fuzzy logic, wavelets, simulation, and many others.

## 5.3 The MATLAB system consists of five main parts:

**The MATLAB language.**

This is a high-level matrix/array language with control flow statements, functions, data structures, input/output, and object-oriented programming features. It allows both "programming in the small" to rapidly create quick and dirty throw-away programs, and "programming in the large" to create complete large and complex application programs.

**The MATLAB working environment.**

This is the set of tools and facilities that you work with as the MATLAB user or programmer. It includes facilities for managing the variables in your workspace and importing and exporting data. It also includes tools for developing, managing, debugging, and profiling M-files, MATLAB's applications.

**Handle Graphics.**

This is the MATLAB graphics system. It includes high-level commands for two-dimensional and three-dimensional data visualization, image processing, animation, and presentation graphics. It also includes low-level commands that allow you to fully customize the appearance of graphics as well as to build complete Graphical User Interfaces on your MATLAB applications.

**The MATLAB mathematical function library.**

This is a vast collection of computational algorithms ranging from elementary functions like sum, sine, cosine, and complex arithmetic, to more sophisticated functions like matrix inverse, matrix eigenvalues, Bessel functions, and fast Fourier transforms.

**The MATLAB Application Program Interface (API).**

This is a library that allows you to write C and Fortran programs that interact with MATLAB.

It includes facilities for calling routines from MATLAB (dynamic linking), calling MATLAB as a computational engine, and for reading and writing MAT-files.

The mathematical basis for the first version of MATLAB was a series of research papers by J. H. Wilkinson and 18 of his colleagues, published between 1965 and 1970 and later collected in Handbook for Automatic Computation, Volume II, Linear Algebra, edited by Wilkinson and C. Reinsch.

These papers present algorithms, implemented in Algol 60, for solving matrix linear equation and eigenvalue problems.

In 1970, a group of researchers at Argonne National Laboratory proposed to the U.S. National Science Foundation (NSF) to “explore the methodology, costs, and resources required to produce, test, and disseminate high-quality mathematical software and to test, certify, disseminate, and support packages of mathematical software in certain problem areas.”

The group developed EISPACK (Matrix Eigensystem Package) by translating the Algol procedures for eigenvalue problems in the handbook into Fortran and working extensively on testing and portability. The first version of EISPACK was released in 1971 and the second in 1976.

A block that can be either discrete or continuous is said to have an implicit sample rate. The implicit sample time is continuous if any of the block's inputs are continuous.

The implicit sample time is equal to the shortest input sample time if all the input sample times are integral multiples of the shortest time.

Otherwise, the input sample time is equal to the fundamental sample time of the inputs, where the fundamental sample time of a set of sample times is defined as the greatest integer divisor of the set of sample times.

Simulink can optionally color code a block diagram to indicate the sample times of the blocks it contains, e.g., black (continuous), magenta (constant), yellow (hybrid), red (fastest discrete), and so on.

The block contains block name, icon, and block library that contain the block, the purpose of the block.

## 5.4 SIMULINK BLOCK LIBRARIES

Simulink organizes its blocks into block libraries according to their behavior.

1) The Sources library contains blocks that generate signals.
2) The Sinks library contains blocks that display or write block output.
3) The Discrete library contains blocks that describe discrete-time components.
4) The Continuous library contains blocks that describe linear functions.
5) The Math library contains blocks that describe general mathematics functions.
6) The Functions & Tables library contains blocks that describe general functions and table look-up operations.
7) The Nonlinear library contains blocks that describe nonlinear functions.
8) The Signal & Systems library contains blocks that allow multiplexing and demultiplexing, implement external input/output, pass data to other parts of the model, and perform other functions.
9) The Subsystems library contains blocks for creating various types of subsystems.
10) The Block sets and Toolboxes library contains the Extras block library of specialized blocks.

### 5.4.1 SUB SYSTEMS

Simulink allows to model a complex system as a set of interconnected subsystems each of which is represented by a block diagram. We create a subsystem using Simulink's Subsystem block and the Simulink model editor.

We can embed subsystems with subsystems to any depth to create hierarchical models. We can create conditionally executed subsystems that are executed only when a transition occurs on a triggering or enabling input.

### 5.4.2 SOLVERS

Simulink simulates a dynamic system by computing its states at successive time step solver a specified time span, using information provided by the model. The process of computing the successive states of a system from its model is known as solving the model. No single method of solving a model suffices for all systems. Accordingly, Simulink provides a set of programs, known as solvers, that each embody a particular approach to solving a model.

The Simulation Parameters dialog box allows us to choose the solver most suitable for our model.

### 5.4.3 Fixed-Step and Variable-Step Solvers

Fixed-step solvers solve the model at regular time intervals from the beginning to the end of the simulation. The size of the interval is known as the step-size. We can specify the step size or let the solver choose the step size. Generally decreasing the step size increases the accuracy of the results while increasing the time required to simulate the system.

Variable-step solvers vary the step size during the simulation, reducing the step size to increase accuracy when a model's states are changing rapidly and increasing the step size to avoid taking unnecessary steps when the model's states are changing slowly. Computing the step size adds to the computational overhead at each step but can reduce the total number of steps, and hence simulation time, required to maintain a specified level of accuracy for models with rapidly changing or piecewise continuous states.

### 5.4.4 Continuous and Discrete Solvers

Continuous solvers use numerical integration to compute a model's continuous states at the current time step from the states at previous time steps and the state derivatives. Continuous solvers rely on the model's blocks to compute the values of the model's discrete states at each time step.

Mathematicians have developed a wide variety of numerical integration techniques for solving the ordinary differential equations (ODEs) that represent the continuous states of dynamic systems. Simulink provides an extensive set of fixed-step and variable-step continuous solvers, each implementing a specific ODE solution method.

Some continuous solvers subdivide the simulation time span into major and minor steps, where a minor time step represents a subdivision of the major time step. The solver produces a result at each major time step. It uses results at the minor time steps to improve the accuracy of the result at the major time step.

Discrete solvers exist primarily to solve purely discrete models. They compute the next simulation time-step for a model and nothing else.

They do not compute continuous states and they rely on the model's blocks to update the model's discrete states. We can use a continuous solver, but not a discrete solver, to solve a model that contains both continuous and discrete states. This is because a discrete solver does not handle continuous states. If you select a discrete solver for a continuous model, Simulink disregards your selection and uses a continuous solver instead when solving the model.

Simulink provides two discrete solvers, a fixed-step discrete solver and a variable-step discrete solver. The fixed-step solver by default chooses a step size and hence simulation rate fast enough to track state changes in the fastest block in our model. The variable-step solver adjusts the simulation step size to keep pace with the actual rate of discrete state changes in our model. This can avoid unnecessary steps and hence shorten simulation time for multi date models.

## 5.5 MODEL EXECUTION PHASE

In the simulation model execution phase, Simulink successively computes the states and outputs of the system at intervals from the simulation start time to the finish time, using information provided by the model. The successive time points at which the states and outputs are computed are called time steps. The length of time between steps is called the step size.

The step size depends on the type of solver used to compute the system's continuous states, the system's fundamental sample time, and whether the system's continuous states have discontinuities (Zero Crossing Detection).

At the start of the simulation, the model specifies the initial states and outputs of the system to be simulated. At each step, Simulink computes new values for the system's inputs, states, and outputs and updates the model to reflect the computed values. At the end of the simulation, the model reflects the final values of the system's inputs, states, and outputs.

At each time step:

1) Simulink Updates the outputs of the models' blocks in sorted order. Simulink computes a block's outputs by invoking the block's output function. Simulink passes the current time and the block's inputs and states to the output function as it may require these arguments to compute the block's output. Simulink

updates the output of a discrete block only if the current step is an integral multiple of the block's sample time.

2) Updates the states of the model's blocks in sorted order. Simulink computes a block's discrete states by invoking its discrete state update function. Simulink computes a block's continuous states by numerically integrating the time derivatives of the continuous states. It computes the time derivatives of the states by invoking the block's continuous derivatives function.
3) Optionally checks for discontinuities in the continuous states of blocks. Simulink uses a technique called zero crossing detection to detect discontinuities in continuous states.
4) Computes the time for the next time step.

Simulink repeats steps 1 through 4 until the simulation stop time is reached.

## 5.6 Block Sorting Rules

Simulink uses the following basic update rules to sort the blocks:

1) Each block must be updated before any of the direct-feed through blocks that it drives. This rule ensures that the inputs to direct-feed through blocks will be valid when they are updated.
2) Non-direct-feed through blocks can be updated in any order as long as they are updated before any direct-feed through blocks that they drive.
3) This rule can be met by putting all non-direct-feed through blocks at the head of the update list in any order.
4) It thus allows Simulink to ignore non direct-feed through blocks during the sorting process.

The result of applying these rules is an update list in which non-direct-feed through blocks appear at the head of the list in no particular order followed by direct-feed through blocks in the order required to supply valid inputs to the blocks they drive.

During the sorting process, Simulink checks for and flags the occurrence of algebraic loops, that is, signal loops in which an output of a direct-feed through block is connected directly or indirectly to one of the block's inputs.

Such loops seemingly create a deadlock condition since Simulink needs the input of a direct-feed through block in order to compute its output.

.

However, an algebraic loop can represent a set of Simultaneous algebraic equations (hence the name) where the block's input and output are the unknowns.

Further, these equations can have valid solutions at each time step. Accordingly, Simulink assumes that loops involving direct-feed through blocks do, in fact, represent a solvable set of algebraic equations and attempts to solve them each time the block is updated during a simulation.

## 5.7 DETERMINING BLOCK UPDATE ORDER

During a simulation, Simulink updates the states and outputs of a model's blocks once per time step. The order in which the blocks are updated is therefore critical to the validity of the results. In particular, if a block's outputs are a function of its inputs at the current time step, the block must be updated after the blocks that drive its inputs. Otherwise, the block's outputs will be invalid.

The order in which blocks are stored in a model file is not necessarily the order in which they need to be updated during a simulation. Consequently, Simulink sorts the blocks into the correct order during the model initialization phase.

In order to create a valid update ordering, Simulink categorizes blocks according to the relationship of outputs to inputs. Blocks whose current outputs depend on their current inputs are called direct feed through blocks.

All other blocks are called non direct-feed through blocks. Examples of direct-feed through blocks include the Gain, Product, and Sum blocks.

Examples of non-direct-feed through blocks include the Integrator block (its output is a function purely of its state), the Constant block (it does not have an input), and the Memory block (its output is dependent on its input in the previous time step).

Simulink allows you to assign update priorities to blocks. Simulink updates higher priority blocks before lower priority blocks. Simulink honors the priorities only if they are consistent with its block sorting rules.

Some of SIMULINK blocks, which are used in this thesis, are given below.

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. Typical uses include-

- Math and computation
- Algorithm development

- Data acquisition
- Modeling, simulation, and prototyping
- Data analysis, exploration, and visualization
- Scientific and engineering graphics

MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. This allows solving many technical computing problems, especially those with matrix and vector formulations, in a fraction of the time it would take to write a program in a scalar non-interactive language such as C or FORTRAN.

The MATLAB system consists of six main parts:

**(a) Development Environment**

This is the set of tools and facilities that help to use MATLAB functions and files. Many of these tools are graphical user interfaces. It includes the MATLAB desktop and Command Window, a command history, an editor and debugger, and browsers for viewing help, the workspace, files and the search path.

**(b) The MATLAB Mathematical Function Library**

This is a vast collection of computational algorithms ranging from elementary functions, like sum, sine, cosine, and complex arithmetic, to more sophisticated functions like matrix inverse, matrix Eigen values, Bessel functions, and fast Fourier transforms.

**(c) The MATLAB Language**

This is a high-level matrix/array language with control flow statements.

Functions, data structures, input/output, and object-oriented programming features. This is a high-level matrix/array language with control flow statements, functions, data structures, input/output, and object-oriented programming features.

This is a high-level matrix/array language with control flow statements, functions, data structures, input/output, and object-oriented programming features.

It allows both "programming in the small" to rapidly create quick and dirty throw-away programs, and "programming in the large" to create large and complex application programs.

**(d) Graphics**

MATLAB has extensive facilities for displaying vectors and matrices as graphs, as well as annotating and printing these graphs. It includes high-level functions for two-dimensional and three-dimensional data visualization, image processing, animation, and presentation graphics. It also includes low-level functions that allow to fully customize the appearance of graphics as well as to build complete graphical user interfaces on MATLAB applications.

**(e) The MATLAB Application Program Interface (API)**

This is a library that allows writing in C and FORTRAN programs that interact with MATLAB. It includes facilities for calling routines from MATLAB (dynamic linking), calling MATLAB as a computational engine, and for reading and writing MAT-files.

**(f) MATLAB Documentation**

MATLAB provides extensive documentation, in both printed and online format, to help to learn about and use all of its features. It covers all the primary MATLAB features at a high level, including many examples. The MATLAB online help provides task-oriented and reference information about MATLAB features. MATLAB documentation is also available in printed form and in PDF format.

**(1) Three phase source blocks**

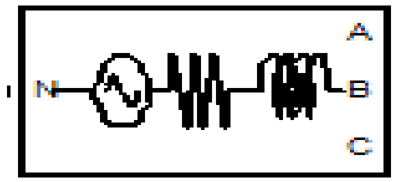



Fig 5.1 Three Phase Source Block

The three voltage sources are connected in Y with neutral connection that can be internally ground.

**(2) VI measurement block**

The Three-Phase V-I Measurement block is used to measure three-phase voltages and currents in a circuit. When connected in series with three-phase elements, it returns the three phase-to-ground or phase-to-phase voltages and the three line currents

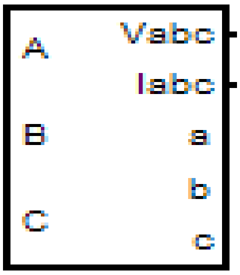



Fig 5.2 Three Phase V-I Measurement

**(3) Scope**

Display signals generated during a simulation. The Scope block displays its input with respect to simulation time. The Scope block can have multiple axes (one per port); all axes have a common time range with independent y-axes. The Scope allows you to adjust the amount of time and the range of input values displayed.

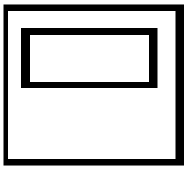


Fig 5.3 Scope

**(4) Three-Phase Series RLC Load**

The Three-Phase Series RLC Load block implements a three-phase balanced load as a series combination of RLC elements. At the specified frequency, the load exhibits constant impedance.

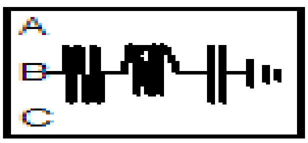



Fig 5.4 Three-Phase Series RLC Load

**(5) Three-Phase Breaker block**

The Three-Phase Breaker block implements a three-phase circuit breaker where the opening and closing times can be controlled either from an external Simulink signal or from an internal control signal.

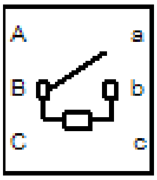



Fig 5.5 Three-Phase Breaker Block

**(6) Integrator**

**Library:** Continuous

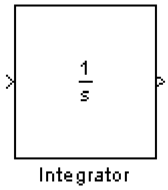



Fig 5.6

The integrator block outputs the integral of its input at the current time step. The following equation represents the output of the block y as a function of its input u and an initial condition $y_0$, where y and u are vector functions of the current simulation time t.

**(7) Breaker**

Implement circuit breaker opening at current zero crossing.

**Library**: Elements

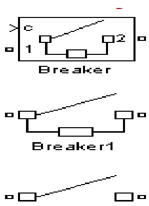



Fig 5.7 Circuit Breaker

**Purpose**: The Breaker block implements a circuit breaker where the opening and closing times can be controlled either from an external SIMULINK signal (external control mode), or from an internal control timer (internal control mode).

A series $R_s$-$C_s$ snubber circuit is included in the model. It can be connected to the circuit breaker. If the Breaker block happens to be in series with an inductive circuit, an open circuit or a current source, you must use a snubber.

When the breaker block is set in external control mode, a SIMULINK input appears on the block icon. The control signal connected to the SIMULINK input must be either 0 or 1 (0 to open the breaker, 1 to close it).

When the Breaker block is set in internal control mode, the switching times are specified in the dialog box of the block.

When the breaker is closed, it is represented by a resistance $R_{on}$. The Ron value can be set as small as necessary in order to be negligible compared with external components (a typical value is 10 m ohms). When the breaker is open, it has an infinite resistance.

## (8) Three-Phase Programmable Voltage Source

Implement three-phase voltage source with programmable time variation of amplitude, phase, frequency, and harmonics.

**Library:** Electrical Sources

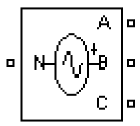



Fig 5.8 Three Phase Voltage Sources

**Purpose:** This block is used to generate a three-phase sinusoidal voltage with time-varying parameters. It can be programmed with the time variation for the amplitude, phase or frequency of the fundamental component of the source.

**(9) Trigonometric Function**

Specified trigonometric function on input

**Library**: Math Operations

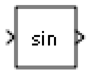


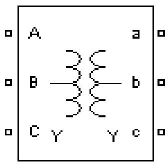

Fig 5.9 Trigonometric Function

**Purpose:** The Trigonometric Function block performs common trigonometric functions

## (10) Three-Phase Transformer (Two Windings)

Implement three-phase transformer with configurable winding connections

**Library:** Elements




5.10 Three Phase Transformer

**Purpose:**

The Three-Phase Transformer (Two Windings) block implements a three-phase transformer using three single-phase transformers. The saturation characteristic, when activated, is the same as the one described for the saturable Transformer block, and the icon of the block is automatically updated. If the fluxes are not specified, the initial values are automatically adjusted so that the simulation starts in steady state.

### (11) Three-Phase Transformer 12 Terminals

Implement three single-phase, two-winding transformers where all terminals are accessible

**Library:** Elements

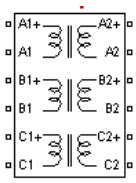



Fig 5.11 Two winding Transformer

**Purpose:** The Three-Phase Transformer 12 Terminals block implements three single-phase, two-winding linear transformers where all the twelve winding connectors are accessible. The block can be used in place of the Three-Phase Transformer (Two Windings) block to implement a three-phase transformer when primary and secondary are not necessarily connected in Star or Delta.

### (12) IGBT/Diode

Implements ideal IGBT, GTO, or MOSFET and antiparallel diode

Library: **Power Electronics**

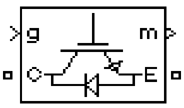



Fig 5.12 IGBT

**Purpose**: The IGBT/Diode block is a simplified mode of an IGBT (or GTO or MOSFET)/Diode pair where the forward voltages of the forced-commutated device and diode are ignored.

# CHAPTER 6

# CONCLUSION AND FUTURE ENHANCEMENT

## 6.1 ADVANTAGES:

There are several advantages mentioned below: -

1. From this establishment, the concept of the Power Quality can be described by using various components as Diode rectifier, SEPIC converter and VSI.

2. Not only the Power Quality improvement but also speed control of BLDC motor estimated.

3. Analyzed the characteristics of a sophisticated gadget called SEPIC converter.

4. Power factor correction and total harmonic distortion (THD) also verified.

## 6.2 APPLICATIONS:

1. It is portable and reliable.

2. Improvement of Power Factor & Power Quality.

3. Due to cheap cost of SEPIC Converter it is very economical

4. SEPIC Converter has more advantages than other converter

5. THD and PF value without SEPIC converter is found 113.94 % and 0.95 respectively. THD and PF value with SEPIC converter is found 4.94% and unity respectively.

## 6.3 BLOCK DIAGRAM REPRESENTAION IN MATLAB:

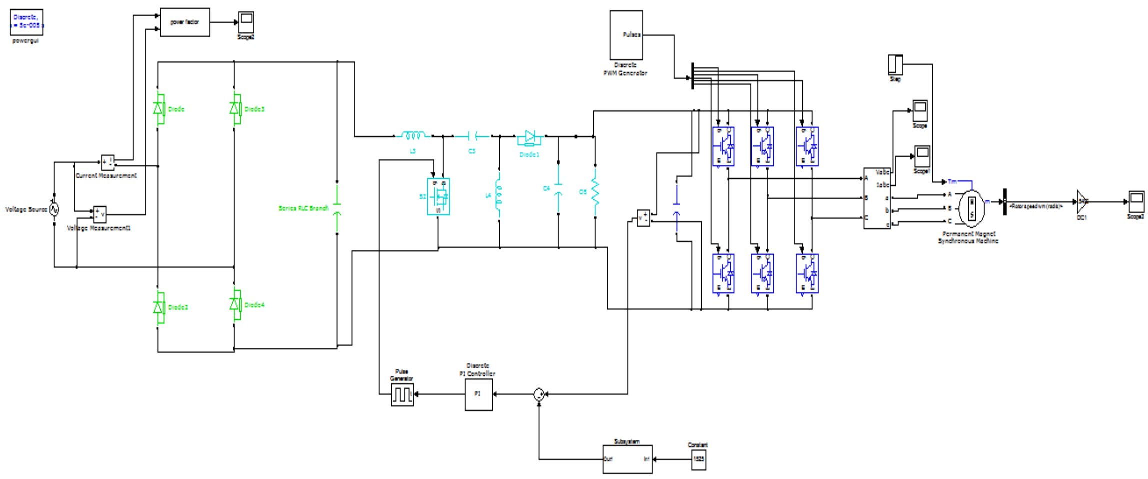


**Fig 6.1 Proposed circuit configuration**

## 6.2 RESULTS:

THD and PF value without SEPIC converter is found 113.94 % and 0.95 respectively and PF value with SEPIC converter is found 4.94% and unity respectively. As shown in following:

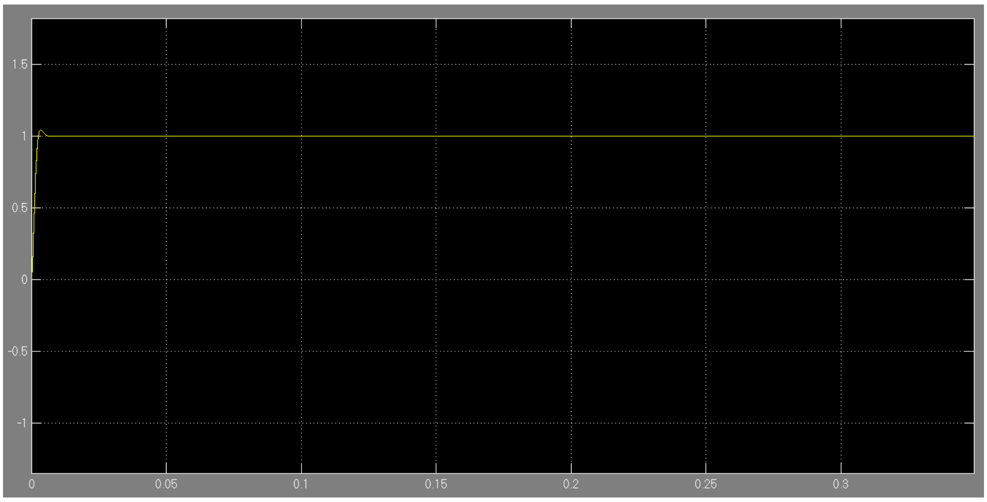



**Fig 6.2 Power factor with SEPIC converter**

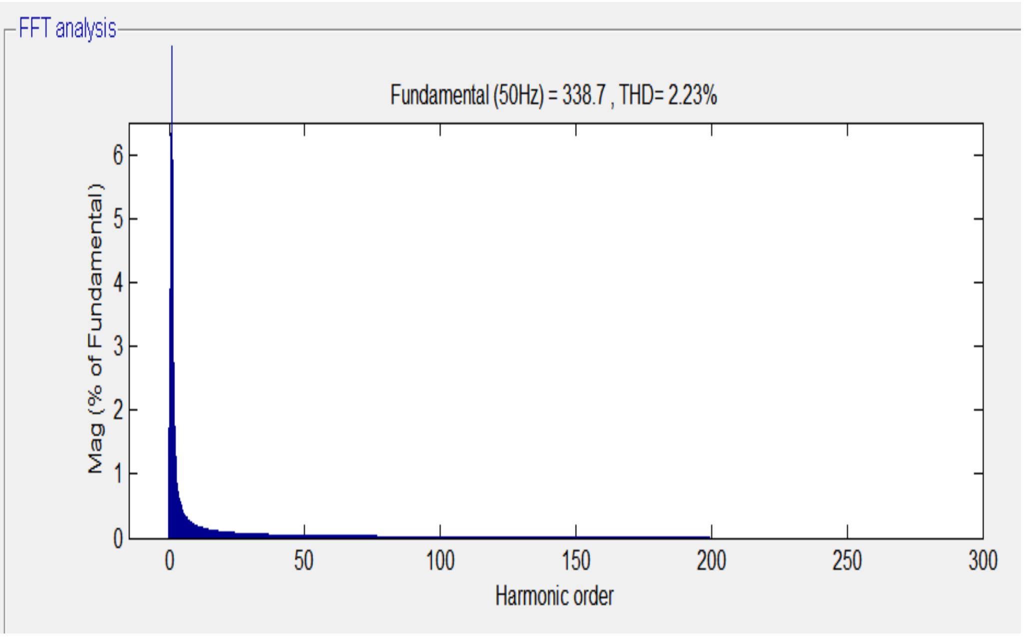



**Fig 6.3 THD for the system**

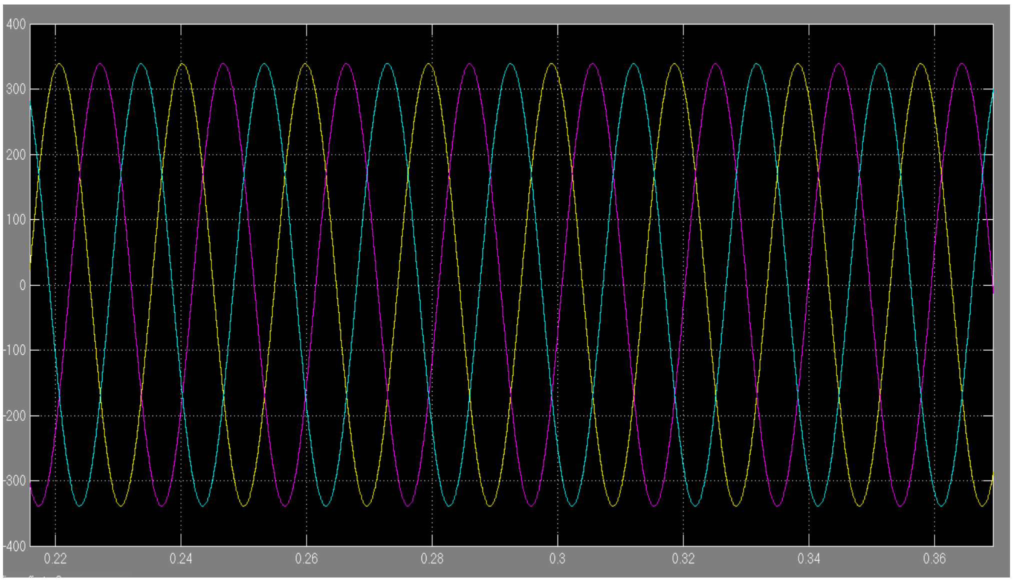


**Fig 6.4 Inverter Voltage**

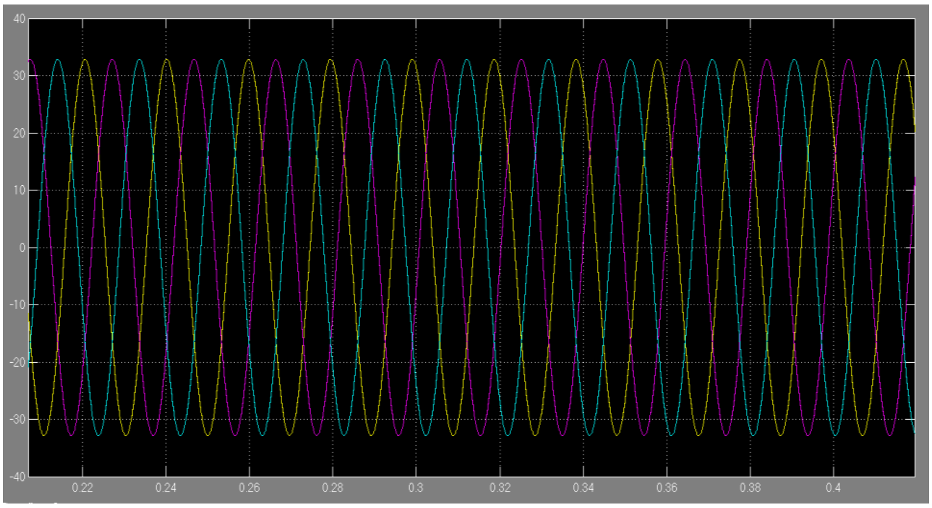



**Fig 6.5 Inverter current**

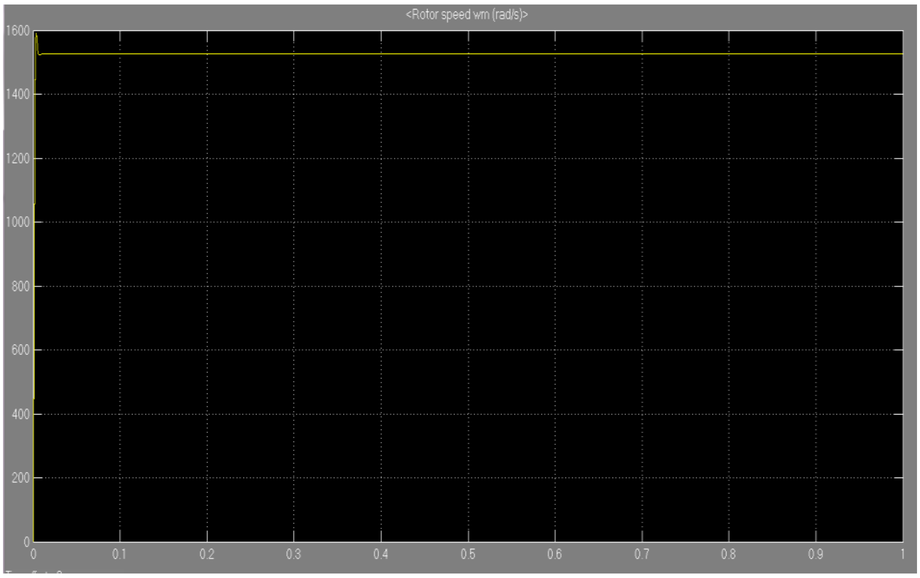



**Fig 6.6 Motor output speed**

## 6.3 FUTURE SCOPE:

- The essential scope of the project, Understanding the Power factor, it's improvement & power quality improvement in a single establishment.
- Moreover, the role of each and every gadget of project realization.
- Especially the duty cycle variation using the SEPIC Converter with BLDC Motor fed by VSI.

## 6.4 CONCLUSION:

THD and PF value without SEPIC converter is found 113.94 % and 0.95 respectively. THD and PF value with SEPIC converter is found 4.94% and unity respectively. BLDC motor drive circuit work properly with SEPIC converter compare to a normal Method, which is without a converter. The output of the SEPIC converter controls the output of the BLDC motor.

VSI use for only electronic commutation hence switching losses reduces and also PWM technique used for the converter. Cost of the project also reduces because of only one voltage sensor required. For future scope, this drive can use for renewable applications also.

# PUBLICATIONS

**Proposed Title: POWER FACTOR CORRECTION AND POWER QUALITY IMPROVEMENT IN BLDC MOTOR DRIVE USING SEPIC CONVERTER**

Conference Name: International conference on "Recent Developments in Power Engineering (ICRDPE-21)", organized by Department of Electrical And Electronics, ST.MARTIN'S ENGINEERING COLLEGE, Hyderabad

# REFERENCES

[1] V. Viswanathan and V. Jeevananthan, "Approach for torque ripple reduction for brushless DC motor based on three-level neutral-point-clamped inverter with DC–DC converter", *IET Power Electron*, vol. 8, no. 1, pp. 47-55, 2019.

[2] R. Kumar and B. Singh, "Solar PV array fed water pumping system using SEPIC converter-based BLDC motor drive", *2014 Eighteenth National Power Systems Conference (NPSC)*, pp. 1-5, 2019.

[3] Awaze and K. Sneha, "Four quadrant operation of BLDC motor in MAT-LAB/SIMULINK", *Computational Intelligence and Communication Networks (CICN) 2013 5th International Conference on*, 2019.

[4] B. Das, S. Chakraborty, P. M. Kasari, A. Chakraborti and M. Bhowmik, "Speed control of BLDC Motor using soft computing Technique and its stability analysis," vol. 3, issue 5, ISSN(Online):2249-071X.

[5] S. Kojima, M. Edahiro and T. Azumi, "Remapping Method to Minimize Makespan of Simulink Model for Embedded Multicore Systems", *Proc. of CATA*, 2020.

[6] Permanent magnet brushless dc motor drives and control by Chang –Liang Xia.

[7] Xia C.L.: “Permanent magnet brushless DC motor drive and controls” (Willey press, Beijing, 2020).

[8] B.Singh , V.Bist , A BL-CSC converter fed BLDC motor drive with P.F correction: IEEE transition India Electron.2019.62(1) pp.172-183.

[9] Singh B.N Chandra A, Al-Haddad, K. Pandey, D.P. Kothhari: A review of single phase improve power quality ACDC converters. IEEE transition India Electron 2019: 50(5) pp.962-981.

[10] An efficient solar power conversion system by Vikas Srivastava. Lambert academic publication.

[11] Bist , V. Singh, B.: ‘A reduced sensor configuration of BLDC motor drive using a PFC based modified-zeta converter’, IET Power Electron., 2019, 7, (9), pp. 2322–2335

[12] Behnam Koushki, Alireza Safe, Praveen Jain, Alireza Bakhshai, Review and Comparison of Bi-Directional AC-DC Converters with V2G Capability for On-Board EV and HEV, in Proc. IEEE Transportation Electrification Conf., June 2019, pp.

[13] X. Du, L. Zhou, H. Lu, and H.-M. Tai, “DC link active power filter for three-phase diode rectifier,” IEEE Trans. Ind. Electron., vol. 59, no. 3, pp. 1430–1442, Mar. 2019.

[14] M. Angulo, D. A. Ruiz-Caballero, J. Lago, M. L. Heldwein, and S. A. Mussa, “Active power filter control strategy with implicit closed loop current control and resonant controller,” IEEE Trans. Ind. Electron., vol. 60, no. 7, pp. 2721–2730.

[15] X. Wang, F. Zhuo, J. Li, L. Wang, and S. Ni, “Modeling and control of dual-stage high-power multifunctional PV system in d-q-0 coordinate,” IEEE Trans. Ind. Electron., vol. 60, no. 4, pp. 1556–1570, Apr. 2020

# APPENDIX

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation.

Typical uses include-

- Math and computation
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- Modeling, simulation, and prototyping
- Data analysis, exploration, and visualization
- Scientific and engineering graphics

MATLAB is an interactive system whose basic data element is an array that does not require dimensioning.

This allows solving many technical computing problems, especially those with matrix and vector formulations, in a fraction of the time it would take to write a program in a scalar non-interactive language such as C or FORTRAN.

The MATLAB system consists of six main parts:

**(a) Development Environment**

This is the set of tools and facilities that help to use MATLAB functions and files. Many of these tools are graphical user interfaces. It includes the MATLAB desktop and Command Window, a command history, an editor and debugger, and browsers for viewing help, the workspace, files and the search path.

**(b) The MATLAB Mathematical Function Library**

This is a vast collection of computational algorithms ranging from elementary functions, like sum, sine, cosine, and complex arithmetic, to more sophisticated functions like matrix inverse, matrix Eigen values, Bessel functions, and fast Fourier transforms.

**(c) The MATLAB Language**

This is a high-level matrix/array language with control flow statements, functions, data structures, input/output, and object-oriented programming features. It allows both "programming in the small" to rapidly create quick and dirty throw-away programs, and "programming in the large" to create large and complex application programs.

**(d) Graphics**

MATLAB has extensive facilities for displaying vectors and matrices as graphs, as well as annotating and printing these graphs. It includes high-level functions for two-dimensional and three-dimensional data visualization, image processing, animation, and presentation graphics. It also includes low-level functions that allow to fully customize the appearance of graphics as well as to build complete graphical user interfaces on MATLAB applications.

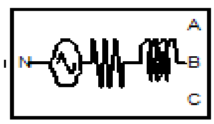
**(e) The MATLAB Application Program Interface (API)**

This is a library that allows writing in C and FORTRAN programs that interact with MATLAB. It includes facilities for calling routines from MATLAB (dynamic linking), calling MATLAB as a computational engine, and for reading and writing MAT-files.

**(f) MATLAB Documentation**

MATLAB provides extensive documentation, in both printed and online format, to help to learn about and use all of its features. It covers all the primary MATLAB features at a high level, including many examples. The MATLAB online help provides task-oriented and reference information about MATLAB features. MATLAB documentation is also available in printed form and in PDF format.

**(1) Three phase source blocks**



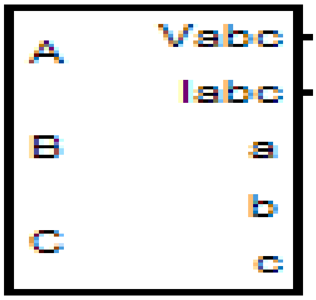

Three Phase Source Block

The Three-Phase Source block implements a balanced three-phase voltage source with internal R-L impedance. The three voltage sources are connected in Y with a neutral connection that can be internally ground.

**(2) VI measurement block**

The Three-Phase V-I Measurement block is used to measure three-phase voltages and currents in a circuit.

When connected in series with three-phase elements, it returns the three phase-to-ground or phase-to-phase voltages and the three-line currents

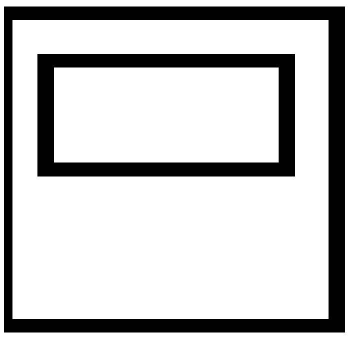



Three Phase V-I Measurement

**(3) Scope**

Display signals generated during a simulation. The Scope block displays its input with respect to simulation time. The Scope block can have multiple axes (one per port); all axes have a common time range with independent y-axes.

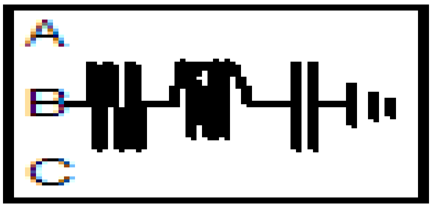
The Scope allows you to adjust the amount of time and the range of input values displayed. You can move and resize the Scope window and you can modify the Scope's parameter values during the simulation



Scope

### (4) Three-Phase Series RLC Load

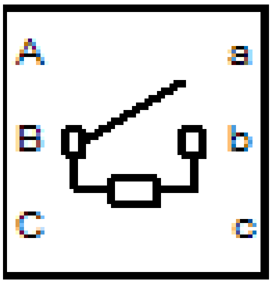
The Three-Phase Series RLC Load block implements a three-phase balanced load as a series combination of RLC elements. At the specified frequency, the load exhibits constant impedance. The active and reactive powers absorbed by the load are proportional to the square of the applied voltage.




Three-Phase Series RLC Load

### (5) Three-Phase Breaker block

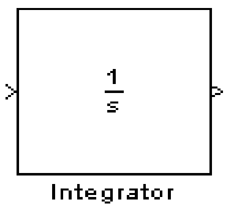
The Three-Phase Breaker block implements a three-phase circuit breaker where the opening and closing times can be controlled either from an external Simulink signal or from an internal control signal.




Three-Phase Breaker Block

### (6) Integrator

**Library:** Continuous



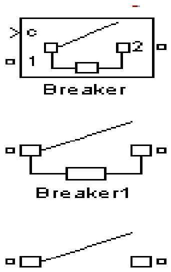

The integrator block outputs the integral of its input at the current time step.

The following equation represents the output of the block y as a function of its input u and an initial condition $y_0$, where y and u are vector functions of the current simulation time t.

**(7) Breaker**

Implement circuit breaker opening at current zero crossing.

**Library**: Elements




Circuit Breaker

**Purpose:** The Breaker block implements a circuit breaker where the opening and closing times can be controlled either from an external SIMULINK signal (external control mode), or from an internal control timer (internal control mode).

A series $R_s$-$C_s$ snubber circuit is included in the model. It can be connected to the circuit breaker. If the Breaker block happens to be in series with an inductive circuit, an open circuit or a current source, you must use a snubber.

When the breaker block is set in external control mode, a SIMULINK input appears on the block icon. The control signal connected to the SIMULINK input must be either 0 or 1 (0 to open the breaker, 1 to close it).

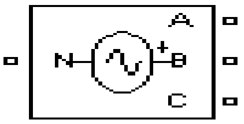
When the Breaker block is set in internal control mode, the switching times are specified in the dialog box of the block.

When the breaker is closed, it is represented by a resistance $R_{on}$. The Ron value can be set as small as necessary in order to be negligible compared with external components (a typical value is 10 m ohms). When the breaker is open, it has an infinite resistance.

### (8) Three-Phase Programmable Voltage Source

Implement three-phase voltage source with programmable time variation of amplitude, phase, frequency, and harmonics

**Library:** Electrical Sources




Three Phase Voltage Sources

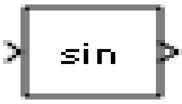
**Purpose:** This block is used to generate a three-phase sinusoidal voltage with time-varying parameters. It can be programmed with the time variation for the amplitude, phase or frequency of the fundamental component of the source.

In addition, two harmonics can be programmed and superimposed on the fundamental signal.

### (9) Trigonometric Function

Specified trigonometric function on input

**Library**: Math Operations



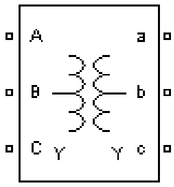

Trigonometric Function

**Purpose:** The Trigonometric Function block performs common trigonometric functions

**(10) Three-Phase Transformer (Two Windings)**

Implement three-phase transformer with configurable winding connections.

Library: **Elements**




Three Phase Transformer

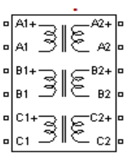
**Purpose:**

The Three-Phase Transformer (Two Windings) block implements a three-phase transformer using three single-phase transformers. The saturation characteristic, when activated, is the same as the one described for the saturable Transformer block, and the icon of the block is automatically updated. If the fluxes are not specified, the initial values are automatically adjusted so that the simulation starts in steady state.

**(11) Three-Phase Transformer 12 Terminals**

Implement three single-phase, two-winding transformers where all terminals are accessible

**Library:** Elements




Two winding Transformer

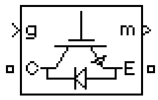
**Purpose:** The Three-Phase Transformer 12 Terminals block implements three single-phase, two-winding linear transformers where all the twelve winding connectors are accessible.

The block can be used in place of the Three-Phase Transformer (Two Windings) block to implement a three-phase transformer when primary and secondary are not necessarily connected in Star or Delta.

**(12) IGBT/Diode**

Implements ideal IGBT, GTO, or MOSFET and antiparallel diode

Library: **Power Electronics**




IGBT

**Purpose**: The IGBT/Diode block is a simplified mode of an IGBT (or GTO or MOSFET)/Diode pair where the forward voltages of the forced-commutated device and diode are ignored.