Power Quality Improvements in a Zeta Converter Using Brushless DC Motor

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Abstract— Two stage PFC converters are widely in practice in which first stage is used for the power factor correction which is preferably a boost converter and second stage for voltage regulation which can be any converter topology depending upon the requirement . This two stage topology is complex and results in higher cost and more losses. A sensorless approach is used to detect the rotor position for electronic commutation. A blind start up is used for starting the BLDC motor. A high frequency MOSFET of suitable rating is used in the front end converter for its high frequency operation whereas an IGBT's (Insulated Gate Bipolar Transistor) are used in the VSI for low frequency operation.

Index Terms— Data Exchange, Data Slicing, Encryption, Privacy Preserving, X-OR.

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1 INTRODUCTION

1.1 PROPOSED SYSTEM:

A single-phase supply is used to feed a DBR followed by a filter and an isolated zeta converter. The filter is designed to avoid any switching ripple in the DBR and the supply system. An isolated zeta converter is designed to operate in DCM to act as an inherent power factor corrector. This combination of DBR and PFC converter is used to feed a BLDC motor drive via a three-phase VSI as shown in Fig. 1. The dc link voltage of the VSI is controlled by varying the duty ratio of the PWM pulses of PFC converter switch. However, VSI is operated in a low frequency switching to achieve an electronic commutation of BLDC motor for reduced switching losses. A single voltage sensor is used at the front-end converter for the control of dc link voltage for speed control of BLDC motor. The proposed drive is designed and its performance is validated on a developed prototype for improved power quality at ac mains for a wide range of speed control and supply voltage variations.

1.2 NEED FOR THE STUDY:

1.2.1 EXISTING SYSTEM:

Two stage PFC converters are widely in practice in which first stage is used for the power factor correction which is preferably a boost converter and second stage for voltage regulation which can be any converter topology depending upon the requirement . This two stage topology is complex and results in higher cost and more losses.

1.2.2 EXISTING SYSTEM DISADVANTAGES:

This two stage topology is complex and results in higher cost and more losses.

1.3 OBJECTIVE OF THE STUDY:

1.3.1 PROPOSED SYSTEM INTRODUCTION:

The proposed scheme for the Sensorless BLDC motor drive fed by a Zeta based PFC converter operating in DICM mode is shown in Fig. 1. The front end Zeta DC-DC converter maintains the DC link voltage to a set reference value. Switch of the Zeta converter is to be operated at high switching frequency for effective control and small size of components

like inductors. A sensorless approach is used to detect the rotor position for electronic commutation. A blind start up is used for starting the BLDC motor. A high frequency MOSFET of suitable rating is used in the front end converter for its high frequency operation whereas an IGBT's (Insulated Gate Bipolar Transistor) are used in the VSI for low frequency operation.

1.3.2 PROPOSED SYSTEM ADVANTAGES:

Moreover a sensorless control of BLDC motor is used, to eliminate the requirement of Hall Effect position sensors and making the drive more cost effective.

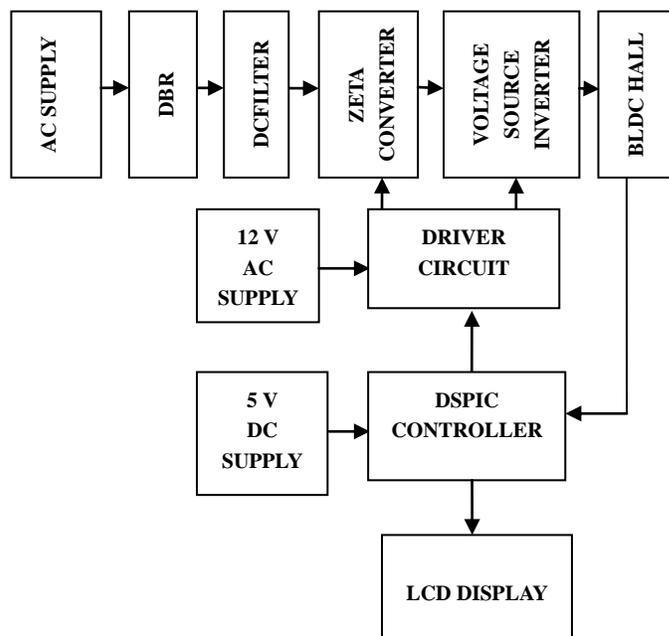### 2. DIAGRAM REVIEW:

2.1 BLOCK DIAGRAM:

FIGURE:1

2.1.1 BLOCK DIAGRAM EXPLANATION:

- Input supply:- AC
- Rectifier: It is Converted into AC TO DC Supply.
- Driver circuit: -It can be used to amplify the 5V pulses to 12V for using transistor technology and provided isolations for using optocoupler. It has two functions,
  - Amplification
  - Isolation
- Pulse generator: - Here we have used PIC microcontroller (PIC 16F877A) to make a switching signal.
- Converter: It is converted into DC to DC Supply.
- Load:- Home appliances

2.1.1.1 RECTIFIER:

Here in our project for full wave rectification we use bridge rectifier. From the basic bridge configuration we see that Two diodes(say D2 & D3) are conducting while the other two diodes (D1 & D4) are in off state during the period t = 0 to T/2.Accordingly for the negative cycle of the input the conducting diodes are D1 & D4 .Thus the polarity across the load is the same.

2.1.1.2 FILTER:

In order to obtain a dc voltage of 0 Hz, we have to use a low pass filter. So that a capacitive filter circuit is used where a capacitor is connected at the rectifier output& a dc is obtained across the filtered waveform is essentially a dc voltage with negligible ripples &it is ultimately fed to the load.

2.1.1.3 INVERTERS:

DC to AC converters are known as inverters. The function of an inverter is to change a dc input voltage to a symmetrical ac output voltage of desired magnitude and frequency. The output voltage could be fixed or variable at a fixed or variable frequency. A variable output voltage can be obtained by varying the input dc voltage and maintaining the gain of the inverter constant.

2.1.1.4 CONTROLLER-PIC:

PIC stands for Peripheral Interfacing Controller. We are using PIC 16F877A for producing switching pulses to multilevel inverter. The Pic microcontroller are driven via the driver circuit so as to boost the voltage triggering signal to 9V.To avoid any damage to micro controller due to direct passing of 230V supply to it we provide an isolator in the form of optocoupler in the same driver.

2.1.1.5 DRIVER CIRCUIT:

The driver circuit forms the most important part of the hardware unit because it acts as the backbone of the inverter AS it gives the triggering pulse to the switches in the proper sequence. The driver unit contains the following important units.

- Optocoupler
- Totem pole
- Capacitor
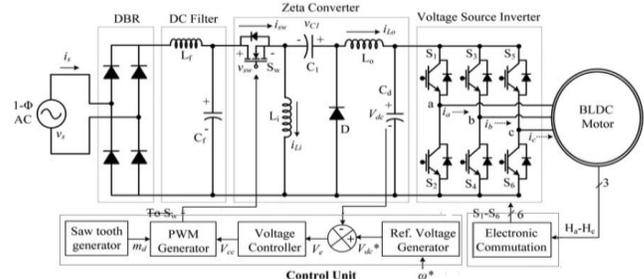- Supply
- Diode
- Resistor

2.2 CIRCUIT DIAGRAM:

FIGURE:2

2.2.1 EXPLANATION:

- This AC supply is converted to a DC voltage by using a diode bridge rectifier.
- Initially 230 V AC supply is reduced to 50V with the help of a step down transformer having a capacity of 1A.
- Output from the rectifier unit having harmonic contents , so we provided the filter circuit, filter circuit is used to reduce the harmonics.
- Here we can use the electrolytic capacitor
- This eliminates the harmonics from both voltage and current signals.
- The power inverter has 6 switches that are controlled in order to generate an AC output from the DC input.
- PWM signals generated from the microcontroller control these 6 switches. The phase voltage is determined by the duty cycle of the PWM signals.
- In time, a maximum of three switches will be on, either one upper and two lower switches, or two upper and one lower switch.
- When the switches are on, current flows from the DC bus to the motor winding. Because the motor windings are highly inductive in nature, they hold electric energy in the form of current.
- This current needs to be dissipated while switches are off. Diodes connected across the switches give a path for the current to dissipate when the switches are off. These diodes are also called freewheeling diodes.
- Upper and lower switches of the same limb should not be switched on at the same time. This will prevent the DC bus supply from being shorted.
- A dead time is given between switching off the upper switch and switching on the lower switch and vice versa. This ensures that both switches are not conductive when they change states from on to off, or vice versa.
- The motor is connected to the inverter.

3. TECHNICAL DESCRIPTION:

3.1 BLDC MOTOR:

The BLDC motor is an AC synchronous motor with permanent magnets on the rotor (moving part) and windings on the stator (fixed part). Permanent magnets create the rotor flux and the energized stator windings create electromagnet poles. The rotor (equivalent to a bar magnet) is attracted by the energized stator

phase. By using the appropriate sequence to supply the stator phases, a rotating field on the stator is created and maintained. This action of the rotor, chasing after the electromagnet poles on the stator, is the fundamental action used in synchronous permanent magnet motors. The lead between the rotor and the rotating field must be controlled to produce torque and this synchronization implies knowledge of the rotor position.

3.1.1 REFERENCE VOLTAGE GENERATOR:

The speed of BLDC motor is proportional to the DC link voltage of the VSI, hence a reference voltage generator is required to produces an equivalent voltage corresponding to the particular reference speed of the BLDC motor. The reference voltage generator produces a voltage by multiplying the speed with a constant value known as the voltage constant (Kb) of the BLDC motor.

3.1.2 SPEED CONTROLLER:

An error of the Vdc* and Vdc is given to a PI (Proportional Integral) speed controller which generates a controlled output corresponding to the error signal. The error voltage Veat any instant of time k is as;

Ve(k) = Vdc*(k) – Vdc(k)

and the output Vc(k) of the PI controller is given by,

Vc(k) = Vc(k-1) + Kp.(Ve(k) – Ve(k-1)) + Ki.Ve(k)

Where Kp is the proportional gain and Ki is the integral gain constant.

3.1.3 PWM GENERATOR:

The output of the PI controller Vcis given to the PWM generator which produces a PWM signal of fixed frequency and varying duty ratio. A saw tooth waveform is compared

with the output of PI controller as shown in Fig. 3 and PWM is generated as;

If md(t)<Vc(t) then S=1 else S=0 (10) where S denotes the switching signals as 1 and 0 for MOSFET to switch on and off respectively.

4. MODES OF OPERATIONS:

The modelling of a BLDC motor drive consists of a modelling of a BLDC motor, a VSI and an electronic commutation using sensor less approach.

4.1 BLDC MOTOR:

The dynamic modelling of the BLDC motor is governed by the following equations given as [8],

Van = Raia + p☐a + ean

Vbn = Rbib + p☐b + ebn

Vcn = Rcic + p☐c + ecn

where p represents the differential operator, Van, Vbn and Vcnare the per phase voltages, Ra, Rb and Rcare resistances perphase, ia, ib and ic are currents, ean, ebn and ecn represents back

emf and ☐a, ☐b, and ☐c represents flux linkages. Van, Vbn and Vcnis also given as,

Van = Vao – Vno, Vbn = Vbo – Vno and Vcn = Vco - Vno

Where Vao, Vbo, Vco are the three phase voltages and Vno is the neutral voltage referred to the zero reference potential as showing Fig. 4.

The flux linkages are given as,

Van = Vao – Vno, Vbn = Vbo – Vno and Vcn = Vco - Vno (14)

Where Vao, Vbo, Vco are the three phase voltages and Vno is the

neutral voltage referred to the zero reference potential,

The flux linkages are given as,

☐a = Lsia – M(ib+ic) (15)

☐b = Lsib – M(ia+ic) (16)

☐c = Lsic – M(ia+ib) (17)

Where Ls is the self inductance per phase and M is the mutual inductance of the windings. Moreover for star connected three phase windings of the stator,

Ia + Ib+ Ic = 0 (18)

The flux linkages can be expressed as,

☐x = (Ls + M).ix (19)

where x denotes a, b or c (i.e. phase terminals). The generalized equation by using equations (11)-(13) and (18),

pix = (Vxn – ixRx – exn)/(Ls+M) (20)

The developed electromagnetic torque is expressed as,

Te = (eania + ebnib + ecnic)/☐r (21)

where ☐r is the rotor speed in electrical rad/sec. This expression for the torque faces computational difficulty at zero speed as induced emf's are zero. Hence, it is reformulated by expressing back-emf as a function of position which can be written as,

ean = kbfa(☐)☐r (22)

ebn = kbfb(☐)☐r (23)

ecn = kbfc(☐)☐r (24)

Substituting equations (22)-(24) into equation (21), the torque expression becomes,

Te = kb{fa(☐) ia + fb(☐) ib + fc(☐) ic} (25)

where kb is the back emf constant and fa(☐), fb(☐) and fc(☐)are rotor position function having a maximum magnitude of plus or minus 1 and is given as,

fa(☐) = 1; for 0<☐<120° (26)

fa(☐) = {(6/☐)(☐-☐)}-1; for 120°<☐<180° (27)

fa(☐) = -1; for 180°<☐<300° (28)

fa(☐) = {(6/☐)(☐-2☐)}+1; for 300°<☐<360° (29)

The functions for b and c phase can be calculated by using a 120° and 240° phase difference respectively. The torque balance equation is given as,

Te = TL + B☐r + J. (2/P).d☐r/dt (30)

where Te is developed electromagnetic torque, TL is load Torque, B represents the frictional coefficient in Nms/rad, P is the number of poles and J represents the moment of inertia inkg-m2.The potential of neutral terminal with respect to zero potential (Vno) is required to be considered in order to avoid unbalance in applied voltage. Substituting equation (14) in equation (11) to (13) and adding them together gives,

Vao + Vbo + Vco – 3Vno = R(ia + ib + ic) + (Ls+M)(pia + pib + pic) + (ean + ebn + ecn) (31)

Substituting equation (18) in equation (31) one gets,

Vao + Vbo + Vco – 3Vno = (ean + ebn + ecn) (32)

Thus,

Vno = {Vao + Vbo + Vco - (ean + ebn + ecn)}/3 (33)

A dynamic model of a BLDC motor is represented inequations (11)-(33).

4.2 VOLTAGE SOURCE INVERTER:

The d.c to a.c power converters are known as inverters. In other words, an inverter is a circuit which converts a D.C. power into an AC power at desired output

voltage and frequency. The AC output voltage could be fixed at a fixed or variable frequency. This conversion can be achieved either by controlled turn-on and turn-off devices. For low and medium power outputs, the power devices are suitable but for high power outputs, thyristors should be used. The output voltage waveforms of an ideal inverter should be sinusoidal.

The voltage waveforms of practical inverters are, however, non-sinusoidal and contain certain harmonics. Square wave or quasi -square wave voltages may be acceptable for low and medium power applications, and for high power applications low, distorted, sinusoidal waveforms are required. The output frequency of an inverter is determined by the rate at which the semiconductor devices are switched on and off by the inverter control circuitry. The harmonic contents of output voltage can be minimized or reduced significantly by switching techniques of available high speed power semiconductor devices.

The D.C. power input to the inverter may be battery, fuel cell, solar cells or other D.C. source. But in most industrial applications, it is fed by a rectifier. This configuration of A.C. to D.C. converter and D.C to A.C inverter is called a D.C link converter because it is a two-stage static frequency converter in which AC power at network frequency is rectified and then filtered in the D.C link before being inverted to AC at an adjustable frequency.

A voltage source inverter is one in which the D.C. source has small or negligible impedance. In other words, a voltage source inverter has stiff D.C Voltage source at its input terminals. Because of low internal impedance, the terminal voltage of a voltage source inverter remains substantially constant with variations in load. It is therefore, equally suitable to single motor and multi-motor drives.

The output of the VSI for phase 'a' is expressed as,
Van = Vdc / 2 for S1=1; (34)
Van = -Vdc / 2 for S2=1; (35)
Van = 0 for S1=0, S2=0; (36)

Where Vdc is the DC link voltage and the values for S1 and S2as 1 and 0 represent the on and off condition of the IGBT's S1and S2. When switch S1 and S4 are on then phase 'a' and 'b' are connected and the current ia (ia = ib) flows through the motor windings and the third phase 'c' remains in floating condition as shown in Fig. 4. The equation for line voltage Vab is givenas,

Vab = Vdc = Ra + La dia/dt + ean + Rb + Lb dib/dt + ebn (37)
If La = Lb = L, Ra = Rb = R, ia =ib and eab = ea + eb then,
Vdc = 2.R.ia + 2 L.dia/dt + eab (38)
Where ia is the line current (or the phase current) of the motor. Similarly the other combin C.

5. CONTROLLING TECHNIQUE EXPLANATION:
5.1 PI CONTROLLER:
A proportional integral-derivative is control loop feedback mechanism used in industrial control system. In industrial process a

PI controller attempts to correct the error between a measured process variable and desired set point by calculating and then giving corrective action that can adjust the process accordingly. The PI controller calculation involves two separate modes the proportional mode and integral mode. The proportional mode determine the reaction to the current error, integral mode determines the reaction based recent error. The weighted sum of the two modes output as corrective action to the control element. PI controller is widely used in industry due to its ease in design and simple structure. PI controller algorithm can be implemented as

$$output(t) = K_p e(t) + K_I \int_0^t e(\tau)d\tau$$

Where e(t) = set reference value – actual calculated

The drive consists of speed controller, reference current generator, PWM current controller, position Sensor, the motor and MOSFETs based current controlled voltage source inverter (CC-VSI). The speed of the motor is compared with its reference value and the speed error is processed in proportional- integral (PI) speed controller.
e(t) = ωref-ωm(t)

ωm(t) is compared with the reference speed ωref and the resulting error is estimated at the nth sampling instant as.

Tref(t) = Tref(t-1) + Kp[e(t) - e(t-1)] + K1 e(t)

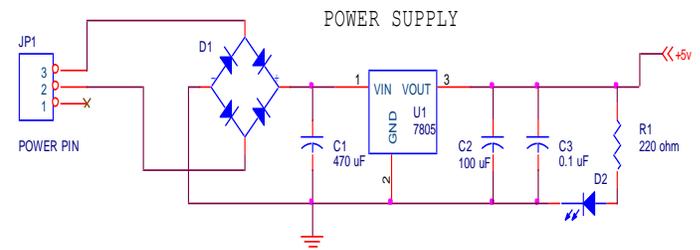### 5.2 POWER SUPPLY DIAGRAM:

FIGURE:3

5.3 DRIVER CIRCUIT:

It is used to provide 9 to 20 volts to switch the MOSFET Switches of   the inverter. Driver amplifies the voltage from microcontroller which is 5volts. Also it has an optocoupler for isolating purpose. So damage to   MOSFET is prevented.
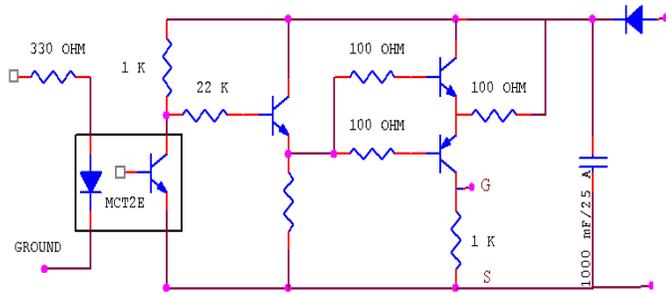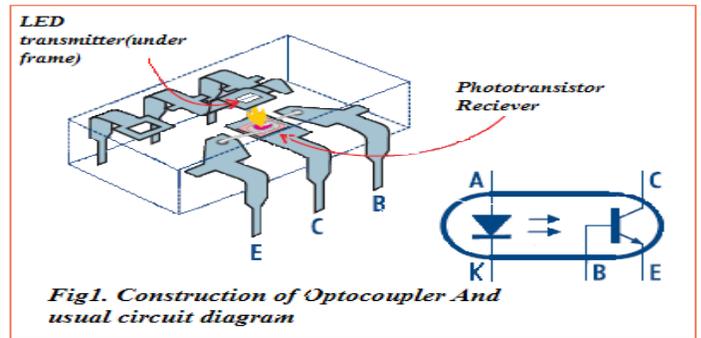
FIGURE:4

FIGURE:5

5.3.1 COMPONENTS:
1.IRF840
2.Diode IN4007
3.Capacitors

    1000uF/63V
    1000uF/25V
    1000uF/250V

4.Optocoupler MCT2E
5.Transistors

    2N2222
    CK100

6.Resistors

    1k
    100ohm

6. DRIVER CIRCUIT OPERATION:

The driver circuit forms the most important part of the hardware unit because it acts as the backbone of the inverter because it gives the triggering pulse to the switches in the proper sequence. The diagram given above gives the circuit operation of the driver unit. The driver unit contains the following important units.

- Optocoupler
- Totem pole
- Capacitor
- Supply
- Diode
- Resistor

6.1 OPTOCOUPLER:

Optocoupler is also termed as optoisolator. Optoisolator a device which contains a optical emitter, such as an LED, neon bulb, or incandescent bulb, and an optical receiving element, such as a resistor that changes resistance with variations in light intensity, or a transistor, diode, or other device that conducts differently when in the presence of light. These devices are used to isolate the control voltage from the controlled circuit.

6.1.1 USES OF OPTOCOUPLER:

Basically the simplest way to visualize an optocoupler is in terms of its two main components: the input LED and the output transistor or diac. As the two are electrically isolated, this gives a fair amount of flexibility when it comes to connecting them into circuit. All we really have to do is work out a convenient way of turning the input LED on and off, and using the resulting switching of the phototransistor/ diac to generate an output waveform or logic signal that is compatible with our output circuitry.
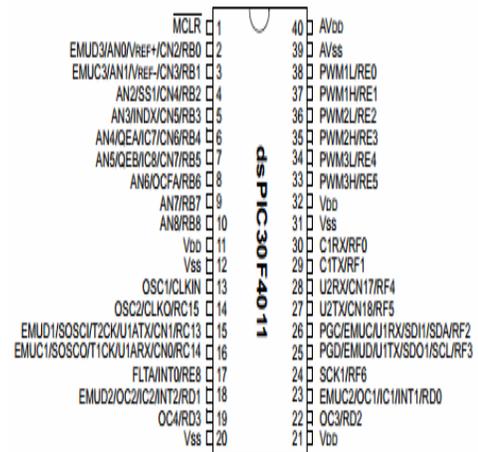
7. PIC 16F877A MICROCONTROLLER:

FIGURE:6

We are using PIC 16F877A for producing switching pulses to multilevel inverter. so as to use those vectors which do not generate any common mode voltage at the inverter poles. .This eliminates common mode voltage Also it is used to eliminate capacitor voltage unbalancing. The microcontroller are driven via the driver circuit so as to boost the voltage triggering signal to 9V.To avoid any damage to micro controller due to direct passing of 230V supply to it we provide an isolator in the form of optocoupler in the same driver circuit.

7.1 FEATURES OF PIC MICROCONTROLLER :
The microcontroller has the following features:

7.1.1 HIGH PERFORMANCE RISC CPU:
- Only 35 single word instructions to learn.
- All single cycle instructions except for program branches, which are two cycle.
- Operating speed: DC – 20 MHZ clock input DC – 200 ns instruction cycle.

7.1.2 PERIPHERAL FEATURES:
- It is used for synchronisation.
- Timer 1: it can be incremented during sleep.
- Timer 2: it is a 8-bit period register, prescaler and postscaler.
- PWM maximum resolution that is 10 bit.

7.1.3 ANALOG FEATURES:
- It has a analog module.
- Two analog comparators.
- Programmable onchip voltage reference module.
- Programmable input multiplexing from device input and internal voltage reference.

7.1.4 CMOS TECHNOLOGY:
- Low-power, high-speed Flash/EEPROM technology.
- Fully static design.
- Wide operating voltage range (2.0V to 5.5V).
- Commercial and Industrial temperature ranges.

8. MAT LAB INTRODUCTION:
MATLAB (matrix laboratory) is a multi-paradigm numerical computing environment. A proprietary programming language developed by MathWorks, MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, C#, Java, Fortran and Python.

MATLAB is a software package for computation in engineering, science, and applied mathematics. It offers a powerful programming language, excellent graphics, and a wide range of expert knowledge. MATLAB is published by and a trademark of The MathWorks,Inc.

Simulink, developed by MathWorks, is a graphical programming environment for modeling, simulating and analyzing multidomain dynamical systems. Its primary interface is a graphical block diagramming tool and a customizable set of block libraries.

It offers tight integration with the rest of the MATLAB environment and can either drive MATLAB or be scripted from it. Simulink is widely used in automatic control and digital signal processing for multidomain simulation and Model-Based Design.

The focus in MATLAB is on computation, not mathematics: Symbolic expressions and manipulations are not possible (except through the optional Symbolic Toolbox, a clever interface to maple). All results are not only numerical but inexact, thanks to the rounding errors inherent in computer arithmetic. The limitation to numerical computation can be seen as a drawback, but it's a source of strength too:

MATLAB is much preferred to Maple, Mathematical, and the like when it comes to numeric's. On the other hand, compared to other numerically oriented languages like C++ and FORTRAN.

MATLAB is much easier to use and comes with a huge standard library.1 the unfavourable comparison here is a gap in execution speed. This gap is not always as dramatic as popular lore has it, and it can often be narrowed or closed with good MATLAB programming (see section 6). Moreover, one can link other codes into MATLAB, or vice versa, and MATLAB now optionally supports parallel computing. Still, MATLAB is usually not the tool of choice for maximum-performance Computing.

The MATLAB niche is numerical computation on workstations for non-experts in computation. This is a huge niche—one way to tell is to look at the number of MATLAB-related books on mathworks.com. Even for supercomputer users, MATLAB can be a valuable environment in which to explore and fine-tune algorithms before more laborious coding in another language Most successful computing languages and environments acquire a distinctive character or culture in MATLAB, that culture contains several elements: an experimental and graphical bias, resulting from the interactive environment and compression of the write-compile-link-execute analyze cycle; an emphasis on syntax that is compact and friendly to the interactive mode, rather than tightly constrained and verbose; a kitchen-sink mentality for providing functionality; and a high degree of openness and transparency (though not to the extent of being open source software).

The component that is the heart of MATLAB is called the Command Window, located on the 1Here and elsewhere I am thinking of the "old FORTRAN," FORTRAN 77. This is not a commentary on the usefulness of FORTRAN 90 but on my ignorance of it.

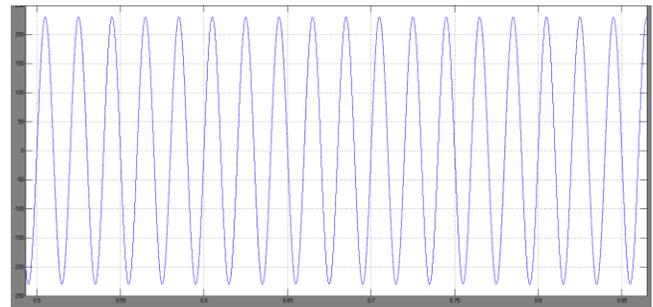## 9 SIMULATION:

9.1 AC INPUT SIGNAL:

FIGURE:7

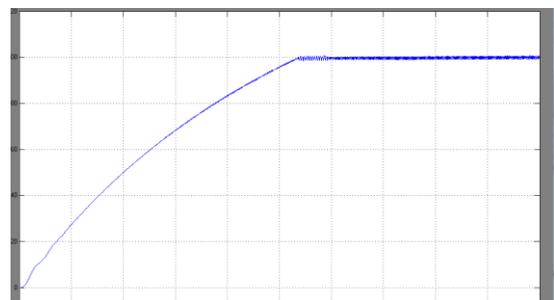### 9.2 DC SIGNAL:

FIGURE:8

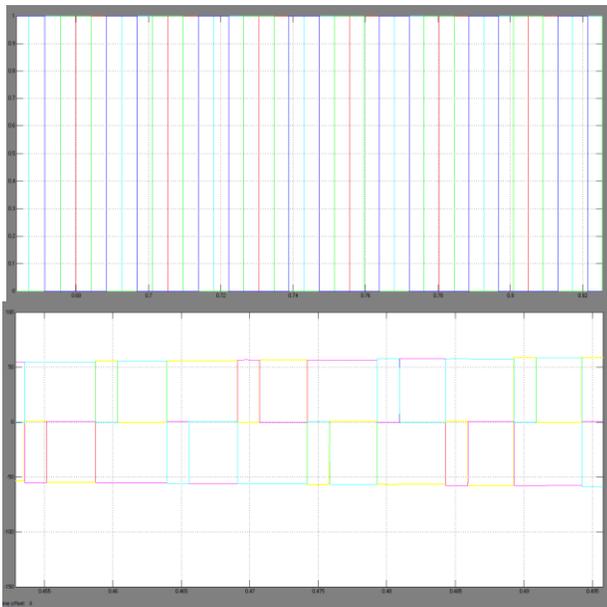**9.3 GATE PULSES:**

FIGURE:9
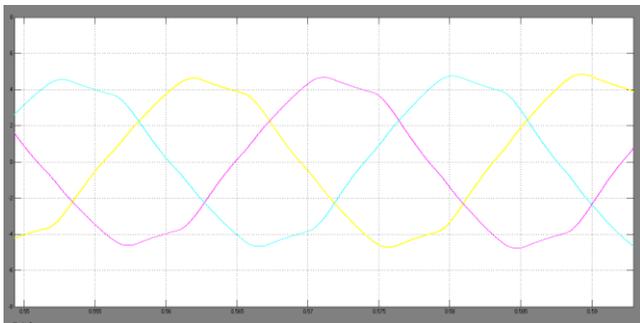
9.4 INVERTER OUTPUT:

FIGURE:10
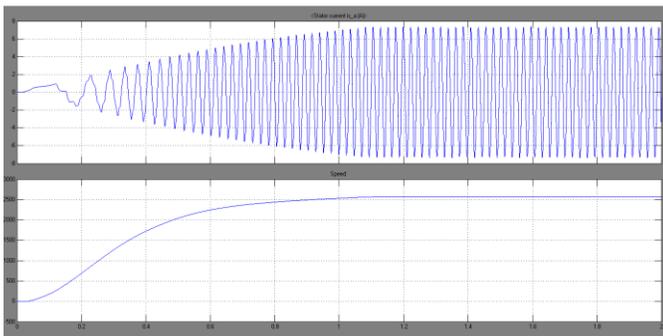
9.5 STATOR CURRENT AND SPEED OUTPUT:

FIGURE:11

10. ADVANTAGES:
- Voltage Control.
- Power Factor Correction.

11. APPLICATION:
- Home Applications.
- DC Motor Drive.
-

12. FUTURE ENHANCEMENT:
- DC-DC Converter has to operate over a wide range of output DC voltage for the speed control of BLDC motor, unlike many applications which require a constant DC link voltage.

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