

PPU DESIGN FOR LOW POWER AND LOW COST AC DRIVE

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

MASTER OF ENGINEERING *in* **Electronic Instrumentation & Control Engineering**

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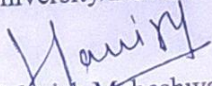
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Declaration

I hereby declare that the work which is presented in this dissertation entitled as, '**PPU Design For Low Power and Low Cost AC drive**' in partial fulfillment of the requirements for the award of degree of Masters of Engineering in Electronic Instrumentation and Control Engineering, Thapar University, Patiala is an authentic record of my own work carried out under the supervision and guidance of **Mr. Ramakant Mahajan, Sr. Manager- Technology, Electronic Design Centre, Global R&D, Crompton Greaves Ltd.** and **Dr. Jainy Sachdeva, Assistant Professor, Thapar University, Patiala** and refer to the other researcher's work which are duly listed in the reference section.

The matter embodied in this thesis has not been submitted to any other University/Institute for the award of any Degree or Discipline.

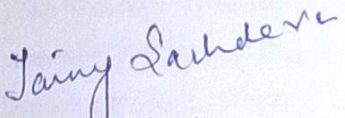
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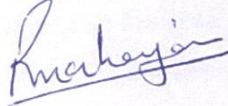
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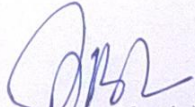
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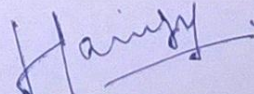

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NOMENCLATURE

ACIM	Alternate Current Induction Motor
ARM	Advanced RISC Machine
DMA	Direct Memory Access
DT	Dead Time
EMC	Electro Magnetic Compatibility
EMI	Electro Magnetic Interference
FOC	Field Oriented Control
HVAC	Heating, Ventilation and Air Conditioning
IGBT	Insulated Gate Bipolar Transistor
IPM	Intelligent Power Module
NTC	Negative Temperature Coefficient
NVIC	Nested Vector Interrupt Controller
Param	Parameters
PCB	Printed Circuit Board
PM	Permanent Magnet
PSRAM	Pseudo- Static RAM
PWM	Pulse Width Modulation
RISC	Reduced Instruction Set Computing
SDIP	Shrink Dual Inline Package
SRAM	Static Ram
UVLO	Under Voltage Lock Out

ABSTRACT

Of all the electrical motors, Induction motors are the most widely used because of their reliability, robustness and low cost. However, induction motors do not have their own capability of variable speed operation and due to this reason dc motors were used earlier in most of the electrical drives. In the recent developments of speed control methods have led to the large scale use of induction motor in almost all electrical drives.

There are several methods used for speed control of an induction motor such as frequency variation, variable rotor resistance, pole changing, constant V/f control, variable stator voltage, slip recovery method etc., the most widely used method is the constant V/f speed control. In this method, the constant V/f ratio is maintained which in turn provides the steady magnetizing flux so that the maximum torque remains unchanged. Thus, the motor is fully utilized in this method.

This dissertation describes the designing and development of motor control card for low power up to 2kW 3-phase motor featuring the IGBT intelligent power module. The developed motor control board is an AC-DC inverter that produces a 3-phase waveform for driving the 3-phase motors either an induction motors or permanent magnet synchronous motors (PMSM) up to maximal 2000 W with or without sensors.

The main device presented in this motor control board is a universal, fully evaluated and populated design consisting of a 3-phase inverter bridge based on the 600 V IGBT power module mounted on a heat sink. The power module integrates the power IGBT switches with high voltage gate drivers together with the freewheeling diodes. The board also features the STM32F103 microcontroller which comes with the set of peripherals that makes them suitable for performing both with PM and AC induction motor scalar control. With this the motor control board the system has been designed to achieve power inversion in a compact and reliable way. Such integration saves the PCB space occupation and assembly costs, together with high reliability due to the design simplicity that will lead to the low power and low cost AC drive. The designed board is used for the applications in industrial drives, power tools, high power industry pumps, power fans for HVAC application.

CHAPTER 1

INTRODUCTION TO AC DRIVE

1 Introduction

In today's scenario, the world is moving towards the automated system. The need for improved productivity along with product quality has copulated with a rising concern for energy efficiency. The domestic and industry products referred as appliances include washing machines, fans, pumps etc. The systems that are employed for purpose of driving these appliances are called drives. Such a system which makes use of electric motor (AC or DC) and motion control card for controlling the speed of AC and DC is known as an electrical drive. AC drive consists of rectifier unit, dc network, inverter section and gate drive. The block diagram of an electric drive is shown in figure 1.1.

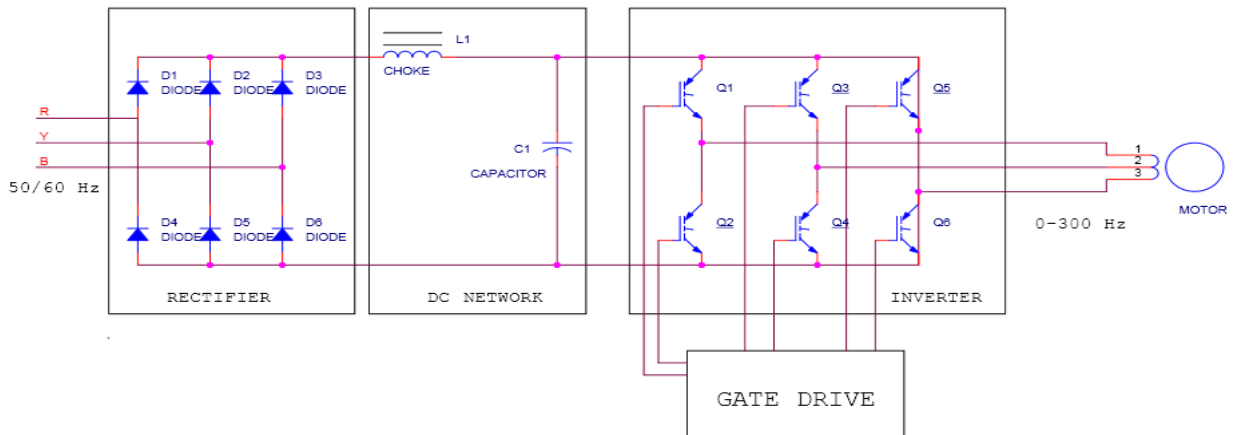


Figure 1.1: Block Diagram of an AC drive

AC drive is supplied by an electrical network via rectifier. The rectifier converts the 3-phase AC supply into the pulsating DC which is then fed to the DC network. The DC network consists of a LC filter and converts the pulsating DC into pure DC. The DC network stores electrical energy from rectifier to be used by an inverter. The inverter section consists of six IGBT's. It uses modulation technique to generate 3-phase AC supply to drive the motor.

Both AC and DC drives are manufactured to deal with the energy efficiency requirements. Earlier due to simple speed control methods, DC drives were used. However, DC drives have less efficiency and high cost. Hence, technology is on one side of the AC drive and they are projected to overhaul DC drives in virtually all industrial applications with further enhancement

in technology. The 70 percent of the cost of an AC drive is restricted to the power electronics portion and thus only about 30 percent remains for the DC drive. Therefore, production has spurred the advancement of solid-state AC drives. At present, AC drives are in the succession of replacing DC drives in many industrialized applications which include paper mills, machine tool drives, air conditioning and waste water treatment.

AC drive unit consists of motor control card and 3-phase AC induction motor in which the control card provides the AC signal to drive (run) the motor. AC drives are of three types viz. low power (up to 2 kW), medium power (up to 375 kW) and high power (375 kW-10000 kW). These drives form an integral part in domestic as well as industrial appliances such as fans, centrifugal pumps, washing machines air conditioners etc. Generally, low power AC drives are used in these appliances. In AC drives, use of various sensors and control algorithms is done to control the speed of the motor using suitable speed control methods. However, the conventional methods used for speed control of an AC induction motor were either too inefficient or costly thus restricting their use to only fixed speed drives.

In this thesis, motor control card development is proposed which controls the speed of AC induction motor of an AC drive. The main objective of proposing this drive system is that it offers both low power and cost as compared to the drives of different companies such as VACON, ABB etc. The details of these drives are briefly described in the following sections. The objectives of this dissertation are:

1. To design and develop power processing unit for low power AC drives up to 2kW, 3-phase induction motor by using V/F method.
2. To develop a low cost AC drive by using IGBT intelligent power module that will easily drive through STM32 microcontroller.
3. To develop a unique featured system that will have a smart shut down function with advanced current sensing network, over current protection, over voltage protection against short circuits.
4. To evaluate the performance of the low power AC drive for lower failure rate, high quality and reliability with reduced total system cost.

1.1 Brief History of the Previous Developed Products

The products which were initially used for control of AC induction motors and developed by companies such as Vacon, ABB and Siemens and are still in market. These products are VACON-10, ABB-ACS-310 and Siemens Micromaster-430. The brief detail of these products is in the following sections.

1.2 VACON-10

VACON-10 is a compact drive intended for applications where ease and effectiveness are key necessities. All the functionality is built into its own compact unit. The unit consists of alternative DIN-rail mounting which provides fast and simple installation and offers less handling time. A forced cooled heat sink is a main feature of this drive [1].

1.2.1 VACON-10 Drive Features

The features of the VACON-10 are as follows:

1. Easy-to-use push button interface.
2. Wide standard I/O.
3. Temperature controlled cooling fan.
4. Side-by-side mounting.
5. Built-in EMC filter.
6. Built-in PI controller DIN-rail mounting available.
7. Short installation time.
8. Fast commissioning.
9. Space-saving design.



Figure 1.1: Vacon-10 AC Drive [1]

1.3 ABB ACS-310 – General Purpose Drive

A drive is generally used to optimize the variable torque applications such as booster pumps and centrifugal fans. It has distinctive set of features which are powerful enough to change with the performance of the drive with respect to the change in pressure, flow or all other external data. It helps to reduce operating cost, increases energy efficiency and reduces CO₂ emissions [2].



Figure 1.2: ABB ACS-310 General Purpose Drive [2]

1.3.1 ACS-310 Drive Features

The features of ACS-310 are given below [2].

1. Increased system reliability as a result of reduced voltage fluctuations and lower harmonic stress.
2. Longer service life of equipping reducing switching over-voltages and inrush currents.
3. Possible replacement of costly, complex mechanical auxiliary equipping, such as closing resistors.

1.4 Siemens MicroMaster-430

Every task performed by a drive requires its general specifications and the requirement for inverter solutions shall be easy enough for installation. The flexibility of the system drive characterizes the siemen's modular MICROMASTER-430. It has high power efficiency with an optimized panel to switch between the two modes of operation i.e. automatic and manual and is used for general applications such as in pumps and fans. [3].



Figure 1.3: Siemens Micromaster-430 [3]

1.4.1 Micromaster-430 Drive Features

The major strengths of the micromaster-430 drive are:





1. Compact housing.
2. Easy to install.

3. Numerous communications options.
4. Ability to cope with high starting torques.
5. Flux current control for high drive quality, even when load changes occur.
6. Integrated activation of up to three extra drives for low-cost power.
7. Compound braking for controlled rapid braking.
8. Energy-saving function with motor shut-off.
9. Dry-running detection for pump drives.
10. It is particularly suitable for pumps and fans [3].

1.5 Benchmarking

The benchmarking is used to show the comparison of different above products that are of similar range. Table 1 compares the various specifications of the products developed by different companies as listed below:

Table 1: Benchmarking

Specifications	Vacon	ABB	Siemens	CG
Look				
Name	VACON-10	ACS-310	MICROMASTER 430	EMOTRON FDU
Voltage and power ranges	3-phase, 208 to 240V, 0.25 to 2.2 Kw	3-phase, 200 to 240V, 0.37 to 11 kW	200 to 240V, 0.12-11kW	400-460V, up to 0.75-7.5kW
Protection classes	IP21	IP20	IP20	IP20,IP21
Mounting Arrangements	Optional for cabinet mounting, wall mounting	Optimal for cabinet mounting, wall mounting	Cabinet mounting	Optional for cabinet mounting, wall mounting
Human machine interface	Basic control panel	Basic control panel	Basic control panel	Basic/Assistant control panel
Ambient	Up to 70°C	-10° to 50°C, no	Up to 20°C	-20° to -60°C

Temperature		frost allowed		
Digital inputs /outputs	6/6	5/1	3/1	8/2
Relay outputs	2	1	1	3
Analogue inputs/outputs	½	2/1	1/1	4/2
Speed feedback	√	X	X	√
Supported field bus protocols	√	√	√	√
EMC compliance	C2	C3, industrial use	C3	C3
Chokes	X	√	√	√
Brake chopper	√	X	X	√
Switching frequency	1.5kHz to 16kHz	Upto 16kHz	Upto 16kHz	Adjustable (1.5kHz- 6kHz)
Output frequency	0 to 320Hz	0 to 599Hz	0 to 350Hz	0 to 400Hz

1.6 Organization of the Dissertation

The structure of the dissertation is as follows:

Chapter 2 includes literature survey about the different electrical machines and their control techniques.

Chapter 3 deals with the target motor theory and the hardware implementation in which different modules of the system has been discussed in detail with the help of block diagram.

Chapter 4 develops theory algorithms to compute the pulse width modulation by using the IGBT intelligent power module and V/F control library functions. It also described the state machine operations.

Chapter 5 this section gives the testing procedure and test results.

Chapter 6 gives the conclusion and future scope.

CHAPTER 2

LITERATURE REVIEW

2 Literature Review

Electrical motors are expected to make use of half of the full amount of electrical power formed in a distinctive industrialized economy. The AC electrical machines are classified as: Synchronous Machine and Asynchronous or Induction Machine [4,5].

The main types of electrical machines used in industrial and traction drives are the dc commutator, induction machines, synchronous machines, and the switched reluctance machines discussed by Jahns and Blasko [6], and Ehsaniet al. [7].

Even for over 100 years, the principles of these machine type is well known and exploited with immense initiative in AC drives, as Jahns and Owen [8] describe, the substantial progress is being achieved because of the advances in electronics, materials and also by the ingenuity of engineers. These drives play a vital role as electromechanical energy converters in the field of transportation, material handling and most production processes. The use of controlling an electrical drive is an important aspect for meeting the increasing demands by the user with respect to flexibility and precision, caused by the technological advances in industry as well as the need for energy conservation [9].

At the same time, the control of electrical drives has provided strong incentives to control engineering which leading to the development of new control structures and their introduction to the other areas of control. Due to the rigorous operating conditions and extensively varying specifications, a drive may alternately require control of torque, acceleration, speed or position and the fact that most electric drives have in contrast to chemical or thermal processes, well

defined structures and consistent dynamic characteristics. As with the introduction of the solid-state devices, the constant V/Hz control technique became the most popular [10]–[12], and today the majority of the adjustable speed drives in operation are of this type [13]. These drives consist of several other parts, the electrical machine, the power converter, the control equipment and the mechanical load, all of which are dealt with in varying depths.

The majority of the drives are based on induction machine that are being used in the industrial sector [14]

Induction machine domination is challenged by the advances in permanent magnet machines particularly for high performance applications. Zhu and Howe [15], in general illustrated very well review of machines and drives mainly for electric vehicles, explained configurations of machines.

The operation of an induction machine in the alleged constant volts per hertz mode has been well known for many decades, and its principle is well understood [16]. Since the beginning of the vector control theory by Blaschke [17], almost all the research has been concerted in this area, and a few has been published about constant V/f operation. The practical application at a low frequency is still very challenging, because of the control of the required rotor slip and stator resistance to derive the useful torque. In additionally, the non linear behavior of the present pulse width modulated voltage-source inverter (PWMVSI) in the low voltage limit makes it hard to use constant V/f drives at the frequencies which are below 3 Hertz [18]. The very simplest stator resistance compensation technique consists of the boosting stator voltage by which the magnitude of current–resistance (IR) drops [19]. New techniques have also been proposed by using the components of in-phase stator current and the compensation directs upon a slip signal [16]. The next vector compensation was introduced but it required both the current and the voltage sensors with an accurate knowledge of the machine inductances. The other scalar control technique was proposed and in this technique, the flux magnitude is resulting from the current estimation. By using the dc-link voltage and current, both the torque and flux loops are originated. Also limit the use of this at low frequency by the flux estimation. The compensation for slip was derived from a linear torque–speed assumption that leads to larger steady-state errors for a high load torques in speed [20].

The other new frequency compensation and stator resistance technique requires less knowledge of the motor parameters in which the measureable quantity is only the stator current.

The voltage drop of the stator resistance is compensated by adding vectorially to the directed voltage using the quadrature and the both in-phase stator current components. The compensation for frequency is based upon an approximation a nonlinear relationship between slip frequency and air gap also power of the air gap. This is used to predict the accurate slip frequency at any frequency for any load. The planned control technique requires only the name plate data, the stator resistance value, and a reasonable estimation of the breakdown torque. The proposed method is evaluated by obtaining the simulation and experimental results [16].

In addition to this control techniques reduction of hardware implementation costs and elimination of any mechanical equipment for speed or angle detection represents a practical manufacturing advantage in terms of cost and size reduction of electric drives. A sensor less vector control evaluated on a low cost hardware can replace the conventional scalar control in all the low-cost application, where adjustable speed drives are used. Many such schemes have been proposed in to perform the sensor less estimation of the machine quantities from the current and voltage measurements [21,22]. Ranges from the simplest which uses only the model of the machine to a more complex that adds some feedbacks to the model of the machine. The adaptation of these schemes to the discrete domain evaluated by using low-cost hardware and by comparing the simple and more complex estimation schemes that too by using a STM32 (core CORTEX-M3) microcontroller [23].

3 Introduction

The description of AC induction motor and control process for control card is given in detail in this chapter. Basically, the design concept i.e. hardware implementation of control card is discussed in the section 3.4.

The hardware part involves the description of the 3 phase motor control board used to drive up to 2 kW AC induction motor with Insulated Gate Bipolar Transistor (IGBT) intelligent power module. The control board consists of STM32F103 controller (marked with red arrow in figure 3.1) which generates Pulse Width Modulation (PWM) waveform fed to the IGBT's in the inverter. The inverter will convert the AC into DC power and generates a 3-phase waveform to drive the 3 phase induction motors or the permanent magnet synchronous motors with or without sensors. The AC induction motor and the concept of motor card are described below.

3.1 AC Induction Motor

The most commonly used type AC induction motor is 3-phase squirrel cage induction motor and is quite appropriate with adjustable speed drive systems as it is cheap, efficient and less noisy. In this type of motor the stator is provided with a 3 phase AC power supply and the synchronous speed n_s of the motor is calculated given equation 3.1

$$n_s = \frac{120 \times f_s}{p} \quad (\text{eqn. 3.1})$$

where, stator synchronous frequency f_s is in Hz and p is the number of poles. The slip frequency produces the load torque. The speed of motor is characterized by a slip gap S_r as given in equation 3.2.

$$S_r = \frac{(n_s - n_r)}{n_s} = \frac{n_{sl}}{n_s} \quad (\text{eqn. 3.2})$$

where, the rotor mechanical speed is given by n_r (in rpm) and slip speed is n_{sl} (in rpm). The torque characteristics and relative slip are demonstrated in figure 3.1. As from the equation 3.1

and equation 3.2, the speed of the motor is controlled by any changes in a stator frequency with the influence of the load torque.

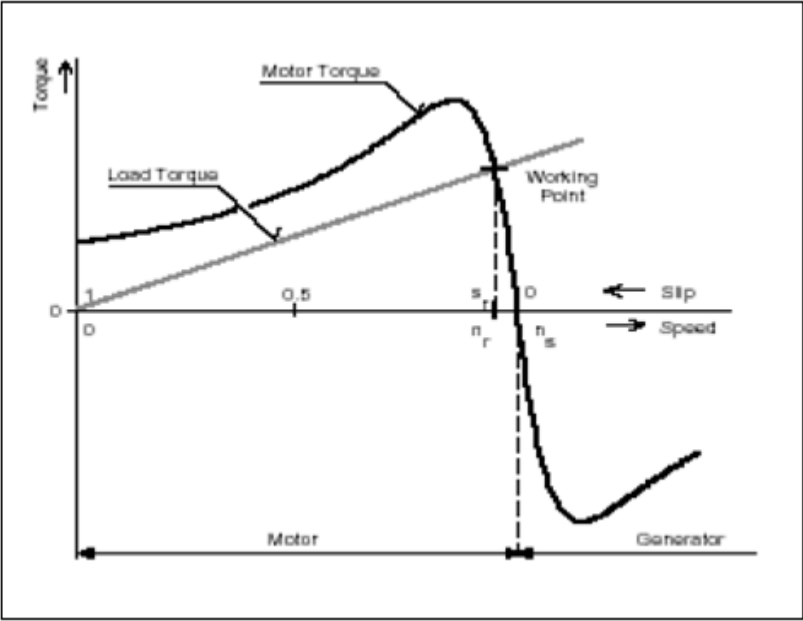


Figure 3.1: Characteristic of Torque-Speed at a Fixed Frequency and Voltage [24]

In the adjustable speed drives, inverters are used to convert the DC into AC at a requisite frequency and amplitude. The 3 phase inverter is illustrated in figure 3.2.

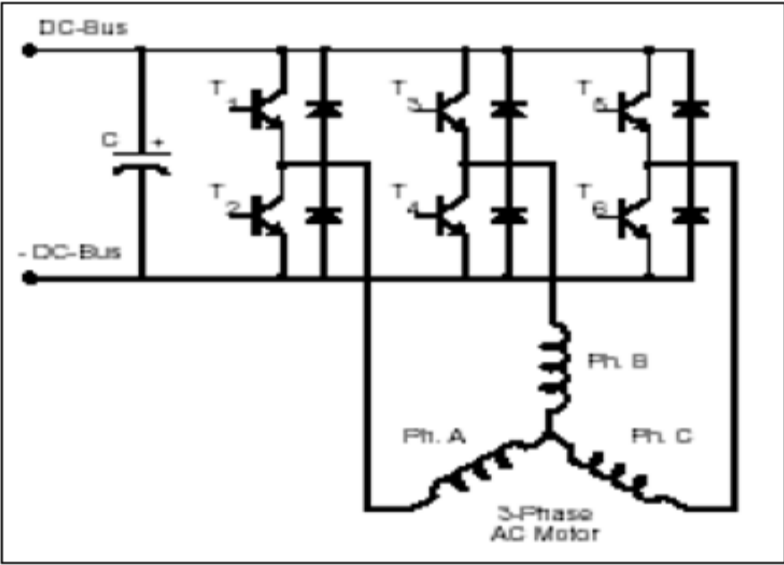


Figure 3.2: 3-Phase Inverter Section [24]

The inverter section mainly consists of three bridge units: the upper switch and the lower switch are controlled complementarily which means only one switch is working at the time. As the off time of the power device is longer than on time, so some amount of dead time is also be

inserted among the two transistors of the half bridge. The output is normally produced by using a PWM modulation technique as shown in figure 3.3. There is a phase shift of 120° to each of the 3 phase voltage and thus supplied to a 3-phase motor [24].

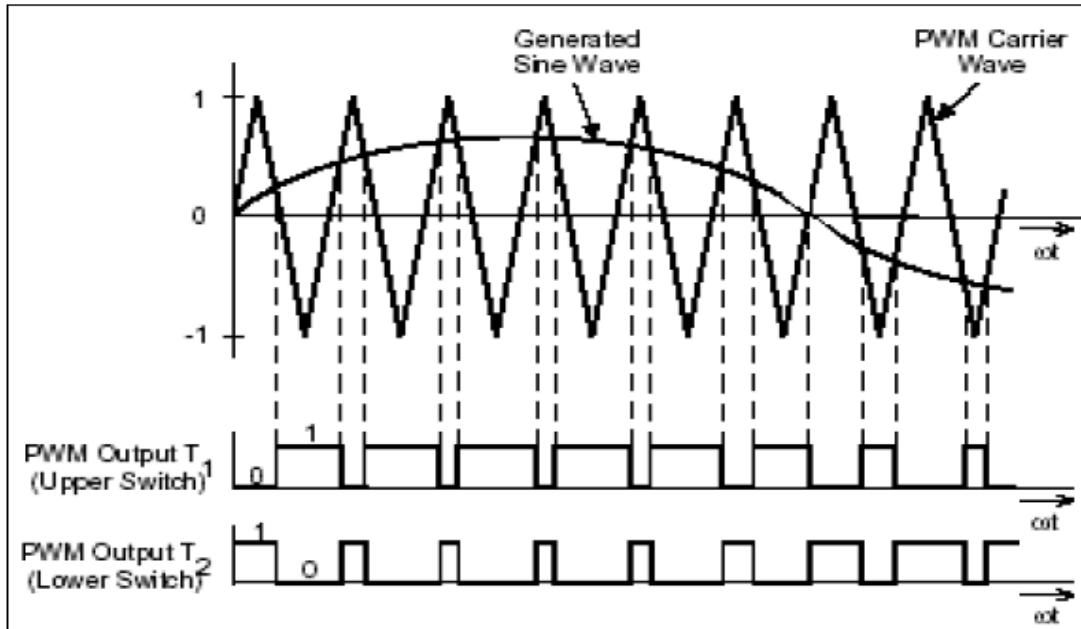


Figure 3.3: Pulse Width Modulation Technique [24]

The two commonly used power devices for the control of motor applications:

1. IGBTs
2. Power MOSFETs.

Firstly, an Insulated Gate Bipolar Transistor is a bipolar transistor combines the simplicity of drive and a fast switching capability. The IGBT needs a low drive current with MOSFET at its base ability to handle a low value current. The only drawback is the voltage drop of the bipolar transistor which is high and that falls out at the higher conduction losses.

Where as a Power MOSFET is a voltage controlled transistor device. It is used for the high frequency operation. Its main advantage is a low power loss because of less voltage drop. However it restricts its usage at high power because of saturation in temperature sensitivity [24].

3.2 Volts/Hz Control Technique

The Volts/Hz control technique is the mostly used scalar control method in which the magnitude is controlled for such variables like frequency, current and voltage. The feedback signals are the DC quantities and are proportional to that of the particular variables. The main

reason of using this technique is to keep the air gap flux of AC induction motor stable with higher run time efficiency. The Volts/Hz control system is described in figure 2.4. The base point of the curve defined the characteristic of the motor. Above this point the motor is excited due to the DC Bus voltage limit. Below this point, the motor runs at optimum excitation because of the constant V_s/f_s ratio.

A simple closed loop Volts/Hz speed control technique for an induction motor is set for the low performance drives. This basic technique is unacceptable for more challenging applications, where speed accuracy is necessary.

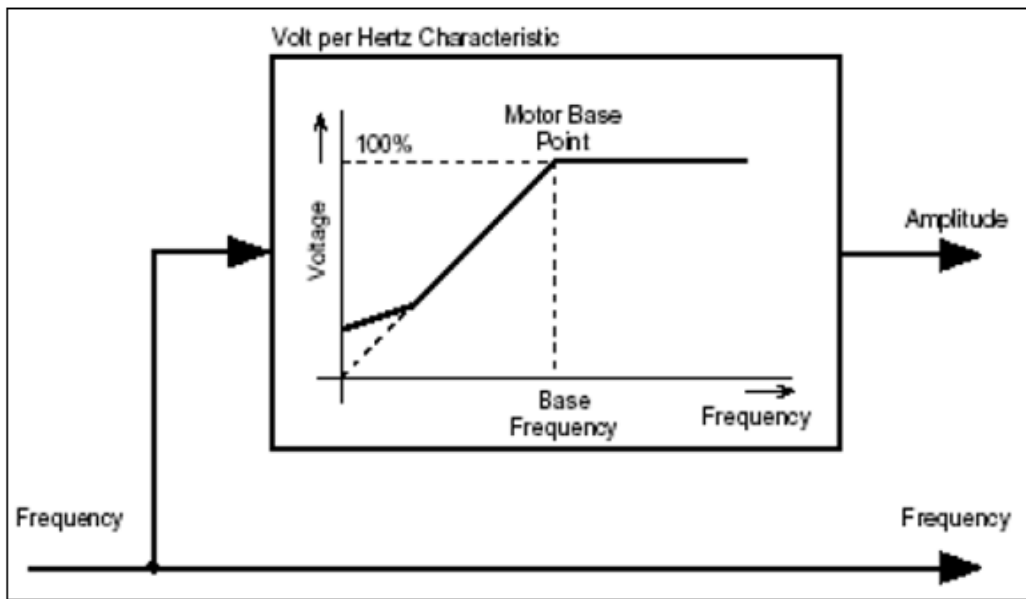


Figure 3.4: V/Hz Control Method [24]

3.3 The Control Process

As the start or stop switch is pressed, the command is generated with the blinking of the LED light and the state of the inputs is time to time monitored. The speed command is deliberated using the push button for speed up and down. In contrast with the actual speed and the measured speed error E is generated, which is then brought to the controller. The controller thus generates a new required motor stator frequency. The V/Hz ramp gives the corresponding measured voltage and the DC bus ripple cancellation function diminish the affect of the DC Bus voltage ripples to the generated phase voltage amplitude. The PWM generation method measures a 3-

phase voltage system at the requisite frequency and amplitude, including the dead time. Finally, the 3-phase PWM motor control signals are produced.

The power stage temperature and DC bus voltage are measured continuously. This is also a smart feature for the drive to protect it from the overvoltage and overheating. Both the overheating and the under voltage protection are performed by analog to digital converter and software, while the DC Bus over current and over voltage fault signals are connected to the PWM fault inputs. If any of the faults occurs, the system will shut down the drive.

3.4 Hardware Implementation of Motor Control Card

A general motor control system can be characterized mainly as the arrangement of the four main blocks:

1. Control block –the main task of the control block is to accept the commands and execute the signals to drive the motor in an appropriate manner. The STM32F103 microcontroller is used as a control block and the board is equipped by the motor control connector.
2. Power block –the power block consists of a three phase inverter. At the heart of this power block is the IPM module (STGIPS20C60), which contains all the required solid state power devices.
3. Motor –the motor control board is able to drive properly any 3 phase asynchronous motor or AC induction motor.
4. Power supply block –it is used to supply power to all the components on the board. The VIPer26 controller is used and is based on a buck converter.

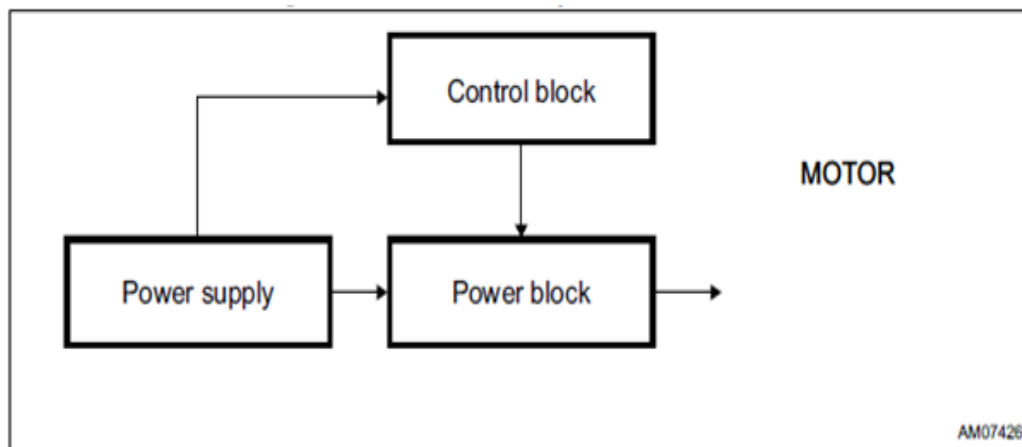


Figure 3.5: Motor Control System Architecture

Of the mentioned motor control system architecture, the control board also includes the start up power supply.

At the heart of the motor control card, the device design consists of a 3 phase inverter bridge based on the 600V IGBT power module. The power module consists of six IGBT power switches, freewheeling diodes in conjunction with high voltage gate drivers. Due to the presence of integrated power module, the system has been configured to obtain the reliable power inversion. This helps in reducing the space as well as assembly cost. The motor control board is shown in figure 3.1.

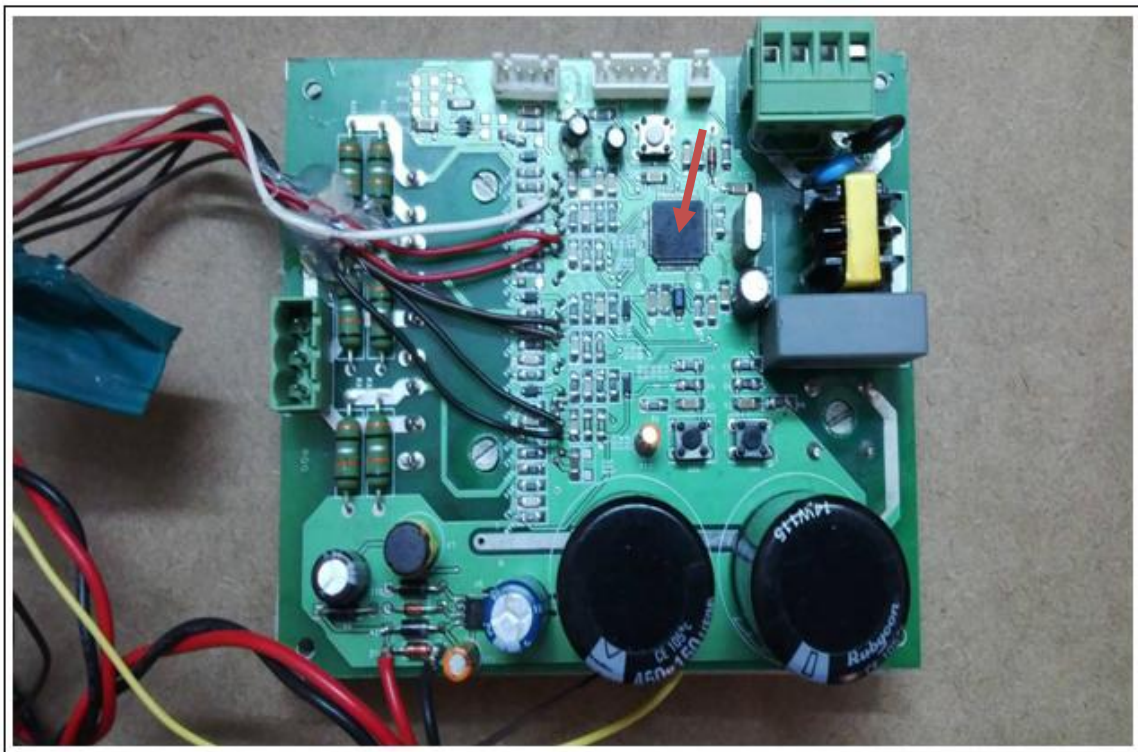


Figure 3.6: Motor Control Board for 3-phase AC Induction Motor

3.5 Concept for System Design

The designed system is used to drive a 3 phase AC induction motor for the following performance characteristics:

1. To drive a 3 phase AC Induction Motor control development platform at a variable AC line voltage.
2. Volts/Hz speed close loop control technique.
3. Manually interface for start or stop switch.

4. Push buttons for speed control, LED indication.
5. Software interface for motor start or stop, speed set up.
6. Smart features like overvoltage, over current and overheating fault protection.

3.6 Circuit Description

The circuit description involves the study of different blocks that are described as below:

3.6.1 Power Supply

The power supply for the control board has a very extensive range of power converters. The converters convert the range of the AC voltage from 90 V_{AC} to 285 V_{AC} or DC Voltage from 125 V_{DC} to 400 V_{DC}. This range allows the control board to be used directly with the various single phase motors as well as the power factor control input stage.

If the applied AC voltage fail to pass the input voltage of 145 V_{AC} than it is also feasible to relate with input voltage doubler. This will almost increases to double till it meets the required standard level. The VIPer26L is used as a power converter based on a buck converter supplied by a fixed frequency of 60Hz. The auxiliary power supply for every active board components is implemented through the buck converter. The output of the converter is +15 V_{DC}. This is used as a supply voltage for the intelligent power module (IPM), as well as into the linear regulators. The supplies to the linear regulators are +3.3 V_{DC} and +5 V_{DC} which is also be used as a supplying voltage for operational amplifiers and further related parts placed on the control board. It is possible to supply the connected microcontroller with related supply voltage. The presence of +15 V_{DC} on the board is indicated with green LED.

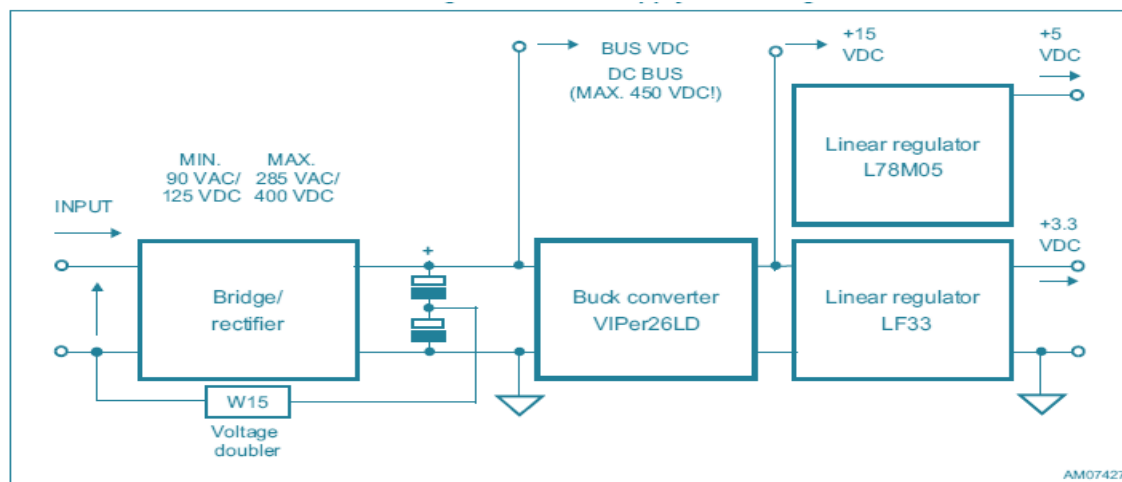


Figure 3.7: Power Supply Block Diagram [25]

3.6.2 Inrush Current Limitation

At the input stage NTC resistor is implemented which is used to eliminate any sudden input current peak through the charging of the large valued capacitors. In order to get the higher efficiency the NTC should be bypass after the start up phase. The bypass signal for NTC is provided from the microcontroller.

A basic EMI filter was applied on the board to absorb all the electromagnetic interference. This EMI filter is unable to absorb all EMI distortion coming from the inverter for all ranges of the applications. The final EMI filter must be designed in accordance with the motor specifications.

3.6.3 Power Block based on IGBT Module

The intelligent power module (STGIPS20C60) based IGBT consists of a high, rugged IGBT power switches and three smart drivers. The IPM is provided with the advanced integrated gate smart drivers. The details about power block based on IGBT module is mentioned in the later section.

3.6.4 Brake Function

A brake feature is implemented on the control board to eliminate the over voltage produced when the motor behaves as a generator. This feature connects the external resistive load to the applied main supply bus. The load connected to the motor has to dissipate all the generated energy. Any high power resistor used as a dissipative load also has a relative high parasitic inductance. Due to the relative high inductance the dissipative load has to be taken care as it will damage the power module. The voltage on the bus is sensed through a divider resistor. The brake load is activated when the DC bus voltage reaches nearly to $435 V_{DC}$ and is deactivated when the voltage falls below $415 V_{DC}$. The brake function can also be activated by the microcontroller through (PWM_Brakesignal).

3.6.5 Over Current Protection

The over current protection feature takes advantage of the IPM where an internal comparator is implemented. With the use of internal connection of the comparator and the

power module shut down the block of the IPM, the intervention time for over current protection is extremely low i.e. 200 ns.

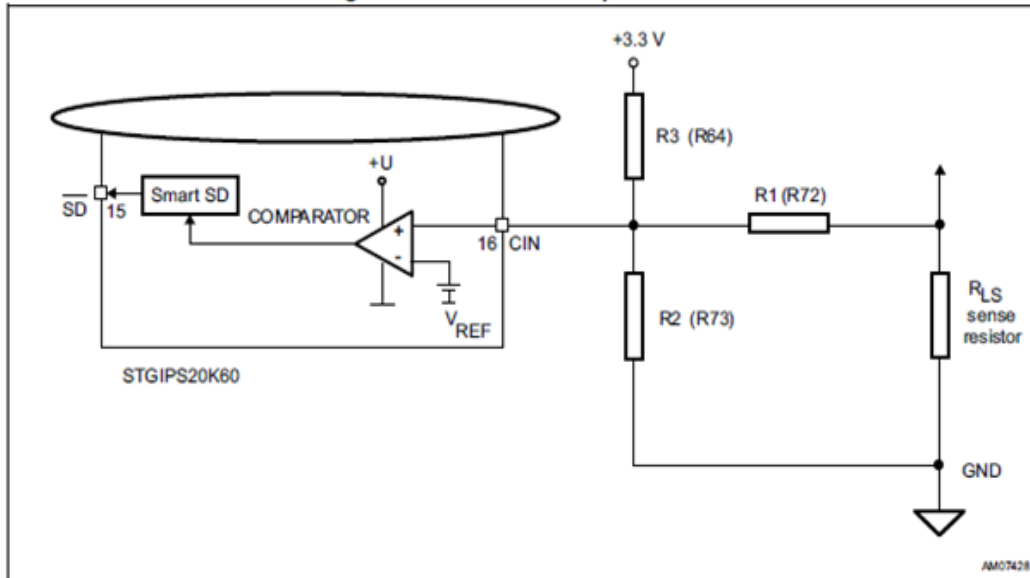


Figure 3.8: Over Current Protection [25]

Over current protection is activated as the voltage on the CIN pin is increased above the internal voltage reference. Allowing for the default value of the over current protection shunt resistor, the maximum allowed current is given in equation 3.3

$$I_{shunt_MAX} = \frac{0.53 \times (R1 \times R2 + R2 \times R3 + R1 \times R3) - 3.3 \times R1 \times R2}{R_{LS} \times R2 \times R3} \quad (\text{eqn. 3.3})$$

Given: $I_{shunt_MAX} = 20 \text{ A}$.

3.6.6 Current Sensing Amplifying Network

The control board can be configured in various current reading configuration modes:

1. Three-shunt configuration: it is appropriate for the field oriented control (FOC)
2. Single-shunt configuration: it is appropriate for FOC in a single-shunt configuration
3. Single-shunt - six-step configuration: it is used for the scalar control.

3.6.7 Configuration for Three shunt FOC or Single Shunt FOC Current Reading

The alternating signal with negative and positive value on the shunt resistor must be converted to be matched with the single positive input of the microcontroller and ADC is used to read the current value.

The operational amplifier used in symmetrical follower mode and its gain is set by resistors r and R given by the equation no. 3.4 and equation no. 3.5.

$$r = \frac{(r1+R_{LS})X r2}{r1+R_{LS} + r2} \quad (\text{eqn. 3.4})$$

$$G = \frac{R+r}{r} \quad (\text{eqn. 3.5})$$

It is possible to calculate the voltage on the output of the op amp OP OUT - V_{OUT} as a sum of a bias V_{BIAS} and a signal V_{SIGN} component given by the equation 3.6

$$V_{OUT} = V_{SIGN} + V_{BIAS} \quad (\text{eqn. 3.6})$$

$$V_{BIAS} = \frac{3.3}{\left(\frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3}\right) X R3} X G \quad (\text{eqn. 3.7})$$

$$V_{SIGN} = \frac{I X R_{HS}}{\left(\frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3}\right) X R1} X G \quad (\text{eqn. 3.8})$$

Total gain of the circuit including the resistor divider is given by equation 3.9

$$G_{TOT} = \frac{V_{SIGN}}{V_{IN}} = \frac{V_{SIGN}}{R_{HS} X I} \quad (\text{eqn. 3.9})$$

With the set values this gives:

1. $V_{BIAS} = 1.58 \text{ V}$
2. Maximal voltage $V_{SIGN} = 1.57 \text{ V}$
3. $G = 5.39$
4. $G_{TOT} = 3.92$
5. Maximum current amplifiable without distortion is 16 A.

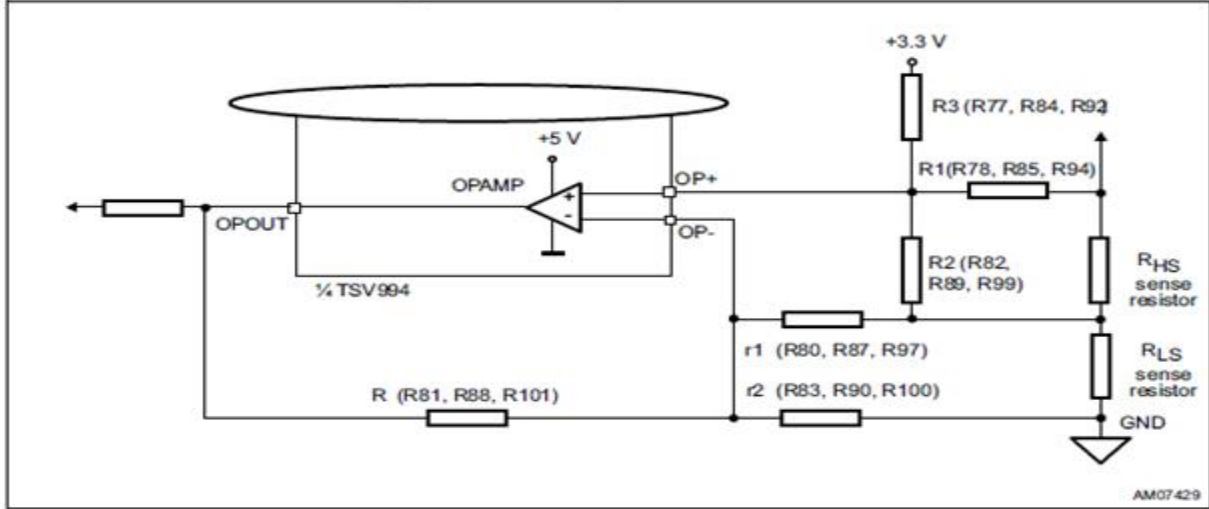


Figure 3.9: FOC Configuration [25]

3.6.8 Six Step Current Reading Configuration

The six step current reading configuration is also called as block commutation. In this configuration only two of the motor phases carry current at the same time. Thus it is possible to use only one shunt resistor placed on the DC link to calculate the motor phase current. In this configuration, the current sampling is done only when the value on the shunt resistor is positive. Only the positive value read on the shunt resistor allows the setting of a higher gain for the op amp than the one set in three-shunt reading mode.

The op amp is used in follower mode with gain of the op amp set by resistors given by the equation no. 3.10 and gain is given by equation no. 3.11.

$$r = \frac{(r1 + R_{LS}) \times r2}{r1 + R_{LS} + r2} \quad (\text{eqn. 3.10})$$

$$G = \frac{R+r}{r} \quad (\text{eqn. 3.11})$$

It is possible to calculate the voltage on the op amp output OP OUT - V_{OUT} as the sum of a bias V_{BIAS} and a signal V_{SIGN} component given by equation 3.12

$$V_{OUT} = V_{SIGN} + V_{BIAS} \quad (\text{eqn. 3.12})$$

$$V_{BIAS} = \frac{3.3}{\left(\frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3}\right) \times R3} \times G \quad (\text{eqn. 3.13})$$

3.7 Main Characteristics of the Control Card

The control board specification data and the main parameters set are:

1. Minimum input voltage 90 V_{AC} or 125 V_{DC}.
2. Maximum input voltage 285 V_{AC} or 400 V_{DC}.
3. With the input voltage doubler the voltage varies from 65 V_{AC} to 145 V_{AC}.
4. Output power for the applied motor up to 2kW.
5. Feature of regenerative brake control.
6. Bypassing relay for an Input inrush limitation.
7. +15 V auxiliary power supply based on a buck converter.
8. Using STGIPS20C60 IPM in SDIP 25L molded package.
9. With inbuilt test point features and fully populated board conception.
10. Tachometer input.
11. Hall or encoder inputs.
12. Overheating protection and Overvoltage protection.
13. Possibility to connect for a sensorless six step control.

3.8 Various Useful Applications

The system is designed for various applications such as:

1. Power fans for air conditioning systems.
2. Industrial drives.
3. Industry pumps.

3.9 IGBT Intelligent Power Module (STGIPS20C60)

The IGBT intelligent power module gives the simple and compact solution for AC motor drive up to 2 kW [44].

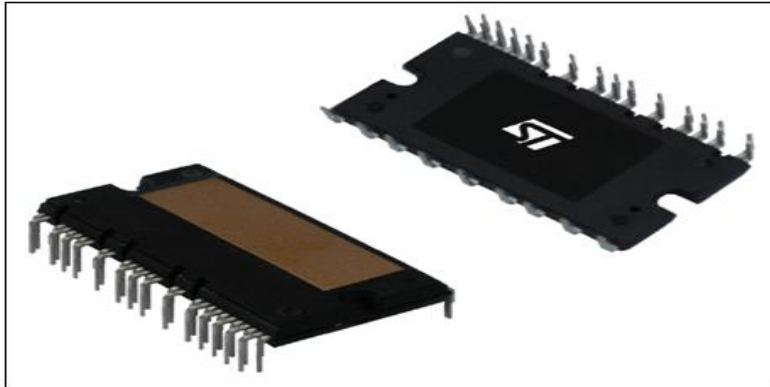


Figure 3.11: STGIPS20C60 Intelligent Power Module [26]

3.9.1 Module Approach

1. Greater than 30 discrete devices in a package.
2. Easy layout and design.
3. Reduced the total system cost.
4. Reduced Electro Magnetic Interference (EMI).
5. High reliability and quality.
6. Improved efficiency.
7. Advanced protection functions [26].

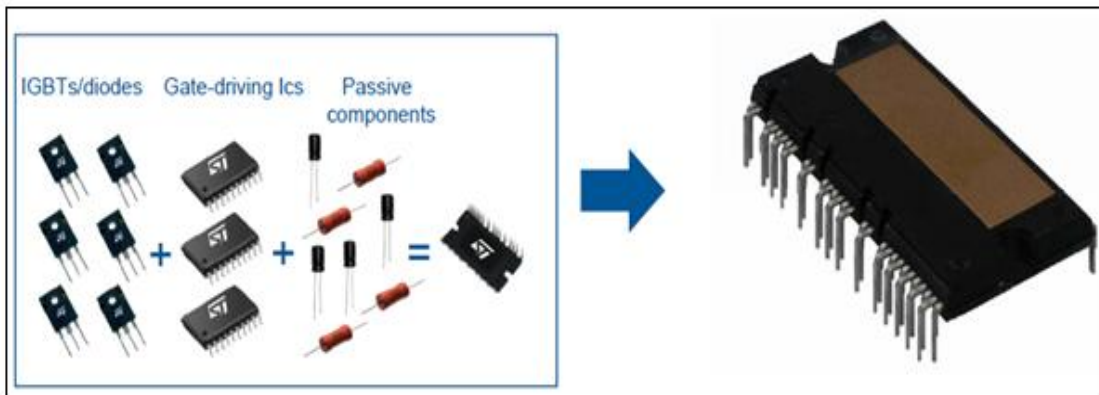


Figure 3.12: Basic Module Component [26]

It combines the application specific IGBTs and diodes, proprietary control functions, smart protections and extra optional features as shown in figure 4.11.

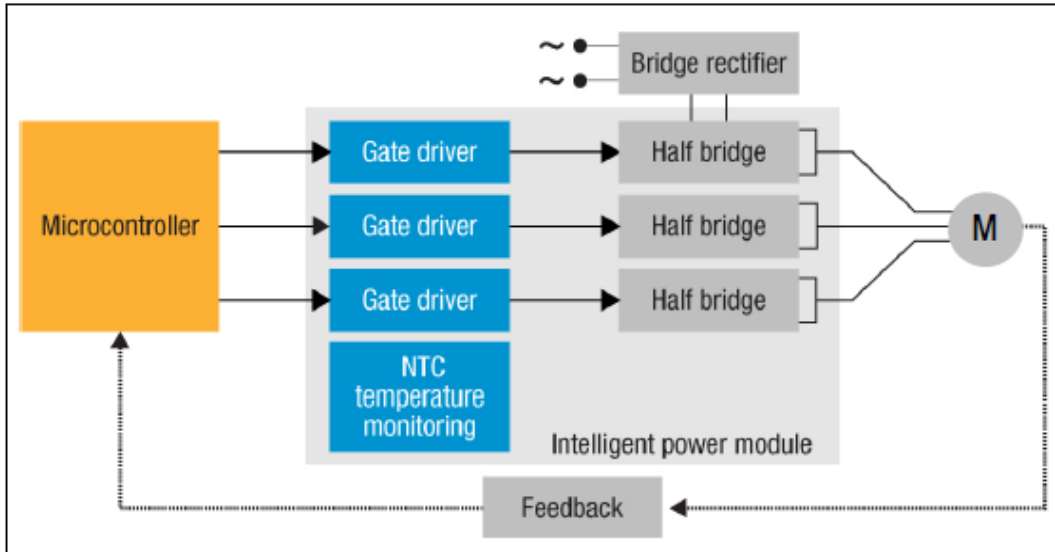


Figure 3.13: Control Card Architecture with IPM Module [26]

3.9.2 Benefits of using IPM (STGIPS20C60)

The benefits using IPM module are:

1. Easy to drive through microcontroller.
2. High efficiency and reliability.
3. Very low R_{th} with reduced component count.
4. PCB space reduction (compact design).
5. Lower failure rate.
6. Easy sensor less field-oriented control (FOC).

3.9.3 Integrated Boot Strap Diode

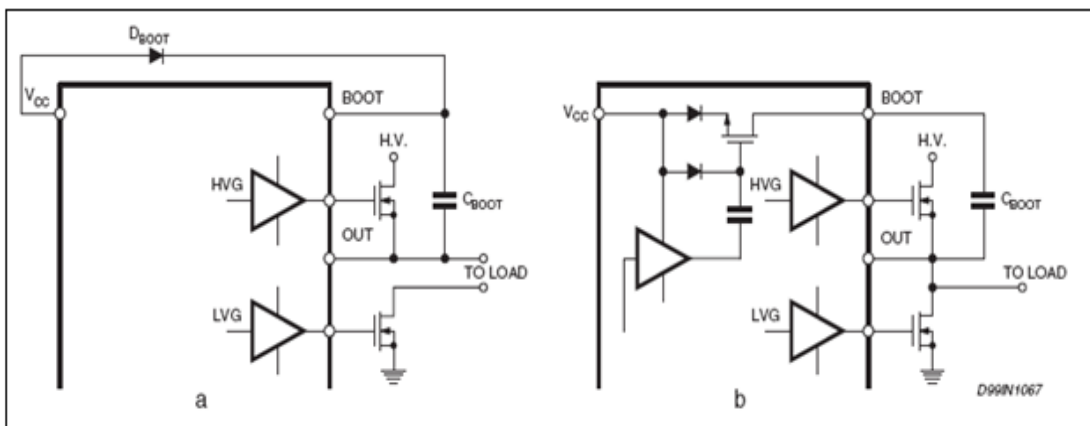


Figure 3.14: Internal Circuit for Bootstrap Diode [26]

- i. External bootstrap diode.
- ii. Patented integrated bootstrap structure.

A bootstrap circuitry is used for high voltage. This is generally done by an external high voltage fast recovery diode. This result in component cost saving and easier layout.

The shutdown/open drain is an input/output pin. It can be used both as input with microcontroller for a rapid shutdown. Shutdown truth table:

Table 2: Shut Down Truth Table

Condition	Logic Input (V_i)			Output	
	$\overline{SD/OD}$	\overline{LIN}	HIN	LVG	HVG
Shutdown enable half-bridge tri-state	L	X	X	L	L
Interlocking half bridge tri-state	H	L	H	L	L
0 “logic state” half bridge tri-state	H	H	L	L	L
1 “logic state” Low side direct driving	H	L	L	H	L
1 “logic state” High side direct driving	H	H	H	L	H

If the voltage on SD pin drops down the lower threshold voltage, the output of the IPM module is set to the low level. The maximum delay time from SD to the IGBT gates once the fault condition is detected is 200ns. The internal comparator can be used to implement different protection functions such as over current or over-temperature protection.

3.9.4 Integrated Op-Amps

The integrated op-amps are completely in different, so a large number of amplifier configurations can be used by an application designer.

Many motor control types required to calculate the phase currents to execute their algorithms. With the IPM, these can be implemented with no external components and avoiding very complex layouts.

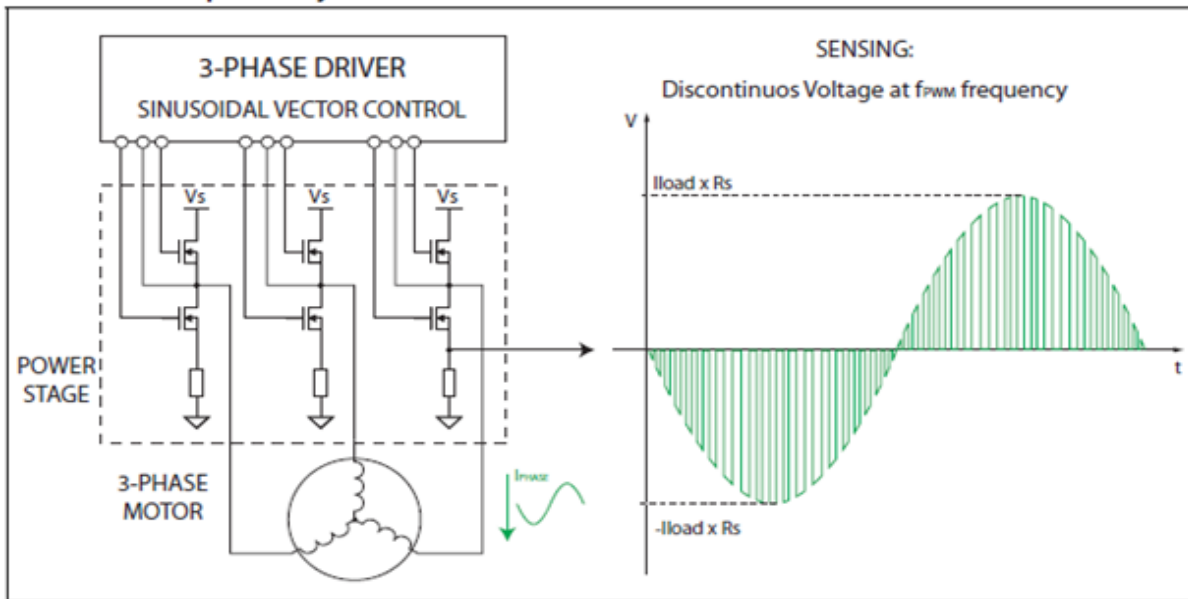


Figure 3.15: 3-Phase System [26]

3.9.5 Interlocking Function

The interlock function is an inbuilt protection feature that avoids the cross-conduction occurring due to overlapped input signals.

Dead time (DT) is the minimum time between turn-off of one IGBT and turn-on of the other one in the same leg but it can also be adjusted with user via software.

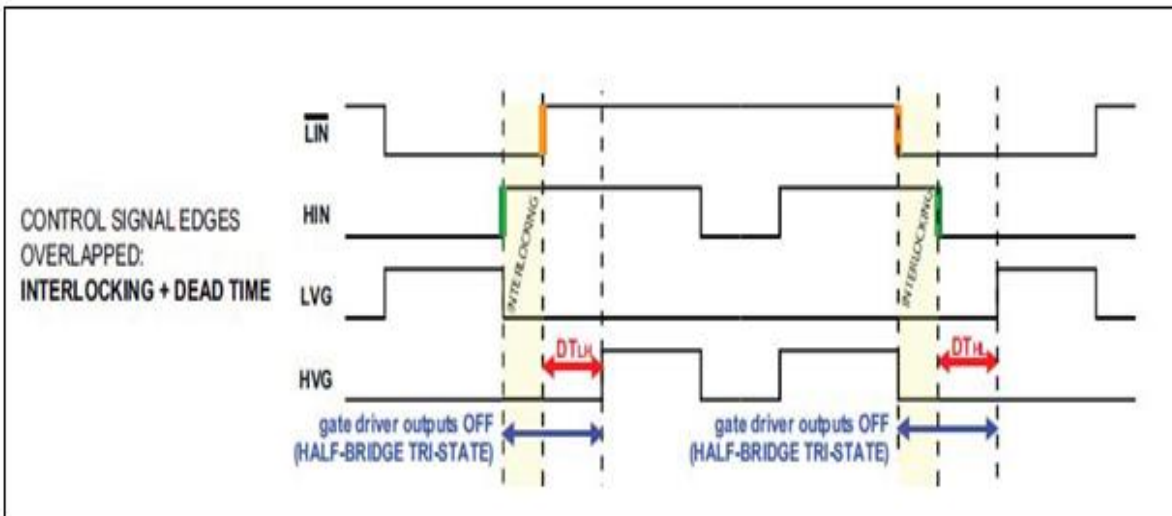


Figure 3.16: Interlocking function with dead time [26]

3.9.6 Under Voltage Lockout Function (UVLO)

If V_{CC} or V_{BOOT} drop below the UVLO low threshold, the driver itself shuts down to evade any high power dissipation condition for the IGBT.

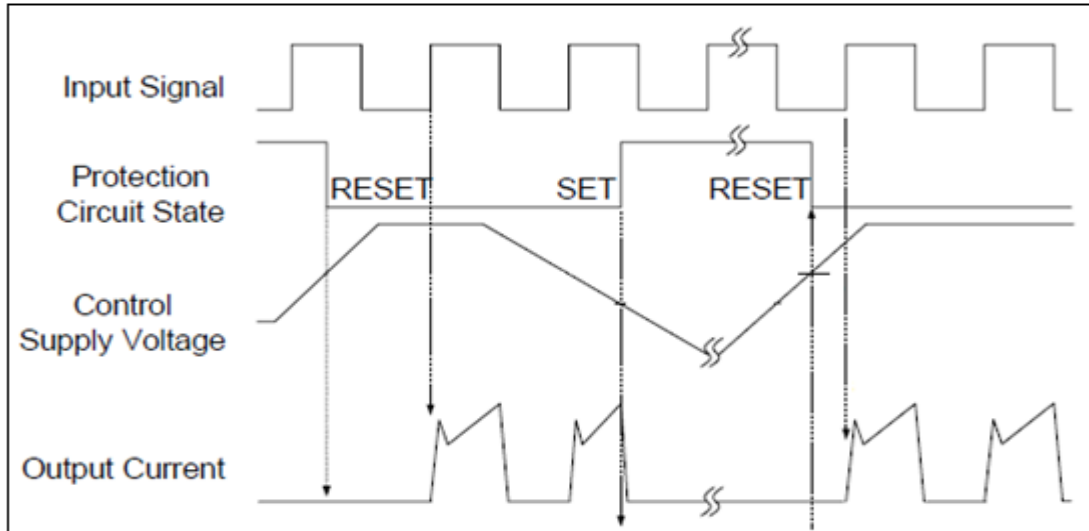


Figure 3.17: Under Voltage Look Out Function [26]

Under voltage lockout also works at start-up, then V_{CC} and V_{BOOT} must be higher than the UVLO high threshold in order to correctly switch the IPM on.

4.1 Introduction

The ACIM motor software library is particularly designed for the STM32 microcontrollers. These are 32-bit microcontrollers inbuilt with a set of peripherals that are used to drive both PM and AC induction motor. The library comprised of several C modules and is created in ‘IAR Embedded Workbench for ARM’. The designed library is smartly used with the microcontroller unit with the available tools. It also reduces the time for development of low power drive and provides the speed regulation algorithms ready to use with functions that allows to mainly focusing on the application layer.

The requirement for ACIM library is the familiarity of C programming, AC drives and power inverter. The block diagram of STM32controller with its applications is shown in figure 5.1

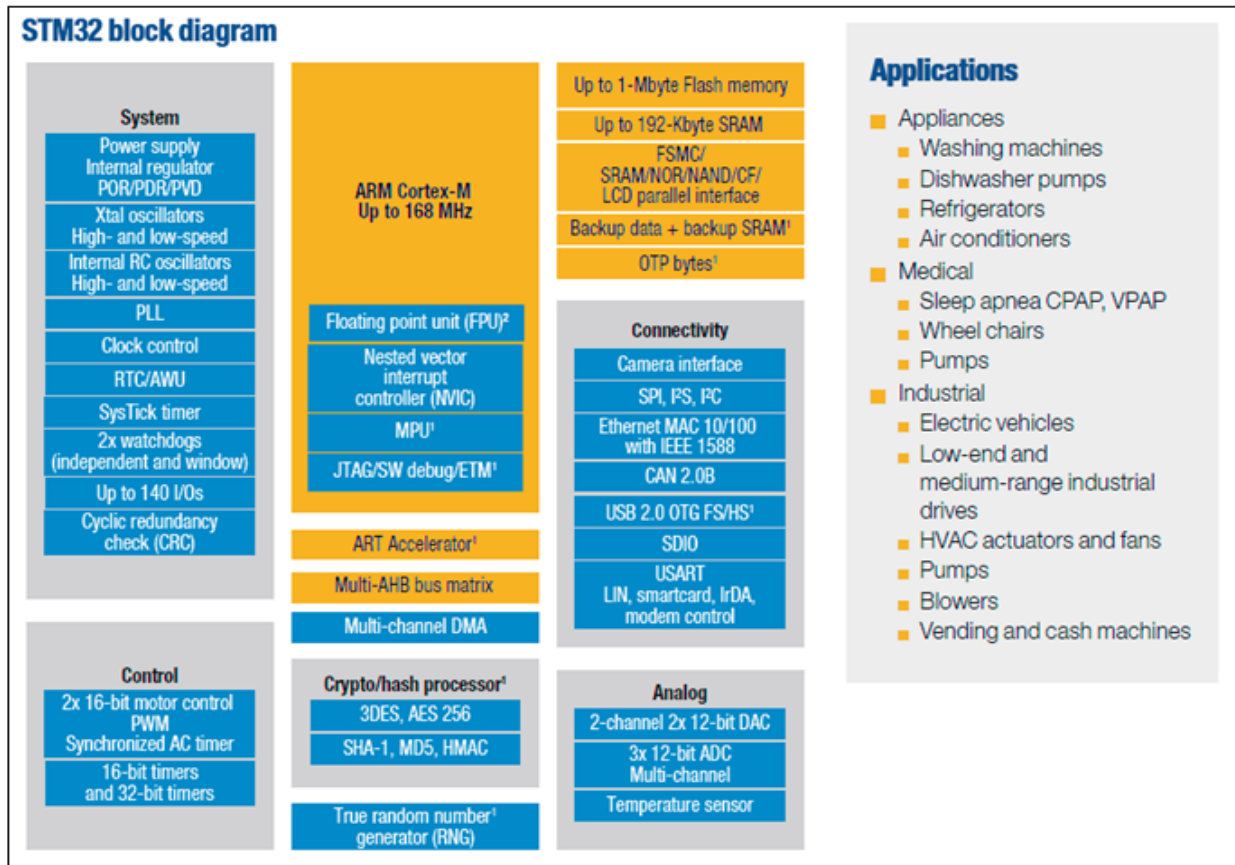


Figure 4.1: STM32 Block Diagram [27]

4.2 Open Loop Speed Control and Slip Regulation

The drive is applied with a constant V/f ratio to supply the essential magnetizing current and a fixed slip frequency.

The speed variation in motor is by changing the stator frequency as a function of slip frequency and target speed given by equation 4.1

$$\omega_e = \omega_{target} + \omega_{se} \quad (\text{eqn. 4.1})$$

4.3 Startup Strategy

A fixed or steady slip frequency which is equal to that in the define statement 'STARTUP_SLIP' is applied to the motor. The primary boost voltage is also equal to that in the define statement 'STARTUP_BOOST_VOLTAGE' to compensate the drop across the motor windings.

The maximum voltage (stator voltage V_s) linearly increases as a function of time as long as the below equation 4.2 is true.

$$V_s/\omega_s < \text{STARTUP_V_F_RATIO} \quad (\text{eqn. 4.2})$$

Where, V_s is stator voltage, ω_s is stator frequency including slip frequency. STARTUP_V_F_RATIO is the V/f ratio during motor startup. The above algorithm is applied during the value of time in milliseconds stated in the define statement 'STARTUP_DURATION'. The slope of the ramp rather the factor with which we would change the max voltage linearly would be calculated with the values of define statements 'STARTUP_DURATION' and 'STARTUP_TARGET_SPEED'

4.4 Three phase PWM Sine Wave and Generation of Third Harmonic

Induction motor voltage requires the pure sine wave as a reference PWM modulating signal. Though, with this type of modulation provides very less usage of the DC bus voltage. If V_{bus} is the bus voltage after rectification, the utmost voltage available using a standard three-phase power inverter is nearly 86% of the V_{bus} . This is given by equation 4.3, equation 4.4 and equation 4.5.

$$V_{phase - neutral} = V_{bus} / 2 \quad (\text{eqn. 4.3})$$

$$V_{neutral} = V_{bus} / 2 \quad (\text{eqn. 4.4})$$

$$V_{phase - phase} = \sqrt{3} * V_{pk} = \sqrt{3} * 2 * V_{bus} \quad (\text{eqn. 4.5})$$

Adding third harmonic, decreases the overall amplitude of the PWM modulation. The PWM duty cycle will neither be 0% nor 100%.

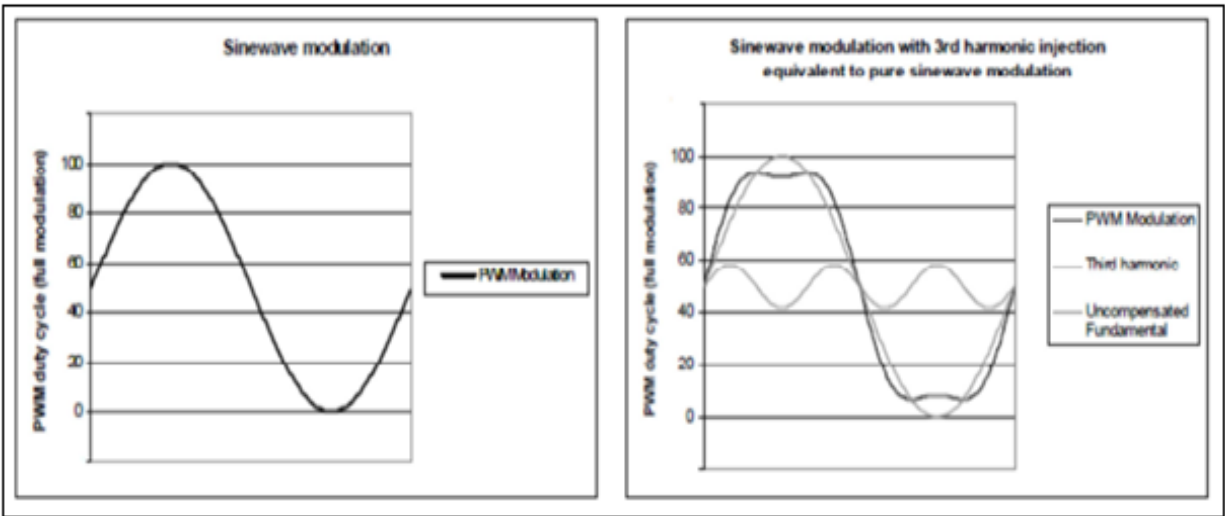


Figure 4.2: Sine Wave Modulation with Equivalent Third Harmonic Added [26]

As a result the resulting amplitude of the third harmonic signal is increased up to 100% PWM modulation with a suitable coefficient to the third harmonic component, the fundamental amplitude may be increased to 15 %.

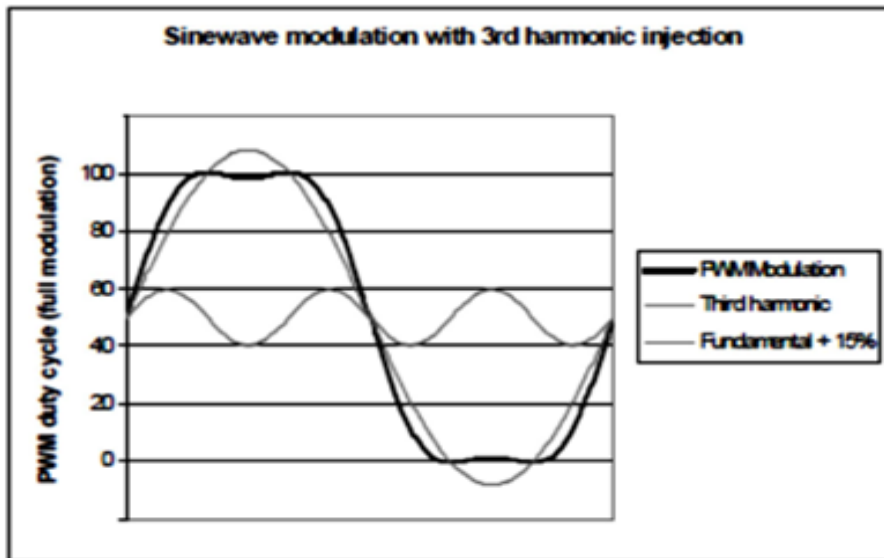


Figure 4.3: 3-Harmonic with Amplified Fundamental Amplitude [26]

When allowing for phase to phase voltage, the third harmonic components are equally neglected and therefore no further iron losses mainly of current harmonics. Also the phase to phase voltage is 15% more than the sine wave PWM modulation.

4.5 The STM32 ACIM firmware

The AC induction motor firmware comprises of different sub modules as described below

4.5.1 State Machine Application

In order to provide ample space/options for initialization and implementation of user defined application algorithms, there are nine different states in the state machine application. The user or the application states are mentioned and explained in below sub section.

4.5.2 Description of the States

RESET

The system comes in reset state as after the main is reset. This RESET state is used for the main initializations.

IDLE

The motor is stopped during the idle state.

START INIT

This state is executed whenever motor restart. This state is mainly for specific initializations.

START

The motor starts up with this state.

RUN

After startup phase, motor is said to be in a normal run state. The user can change parameters, interacts with the system or may give a stop request.

STOP

The motor is stopped in the stop state.

WAIT

The system will wait as the motor is stopped and it will remain in this state as until a new restart is present.

FAULT

There is a fault state during an error condition happens and it will remain in this state till the fault condition is present.

FAULT OVER

The system will enter into the fault over state, when there is no fault or no error on the system.

4.5.2.1 Operations of State Machine

Each state is related to the execution of the state machine function. Any change of state is performed with the value returned by that particular state machine function. The returned value can be anyone of the following:

1. **State remain:** The state remains unchanged as required by the state machine function
2. **Next state:** The usual flow of the state machine is followed. This is marked with the green lines in figure 4.4.
3. **Error condition:** When an error condition has occurred. This is marked by red lines. Every state machine function calls to the allied drive functions, to error check functions and to user interaction functions. Therefore executes the action with respect to these function outputs.

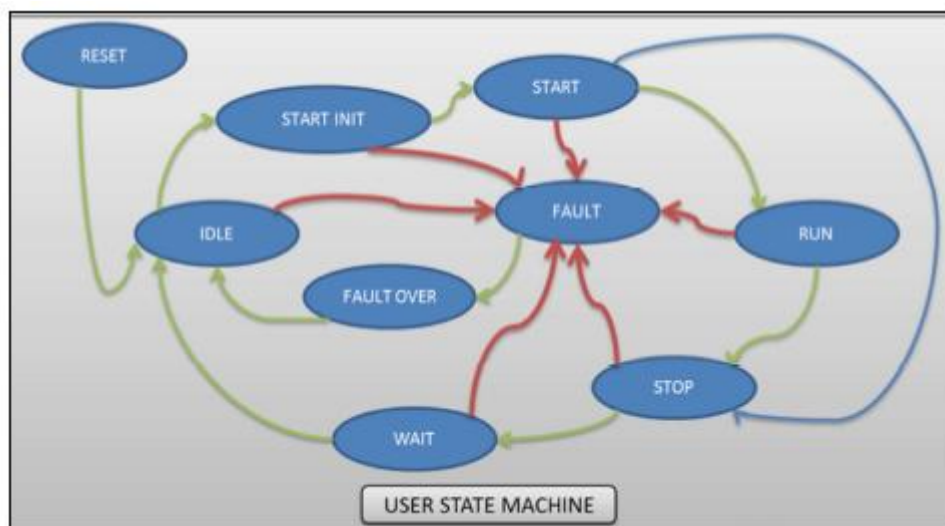


Figure 4.4: User State Machine

4.5.3 Lower Layer State Machine

The user state machine runs in synchronization with the lower layer state machine. Three states **DRIVE_IDLE**, **DRIVE_STARTUP** and **DRIVE_RUN**. The possible transitions across states are shown in the figure 5.5 below.

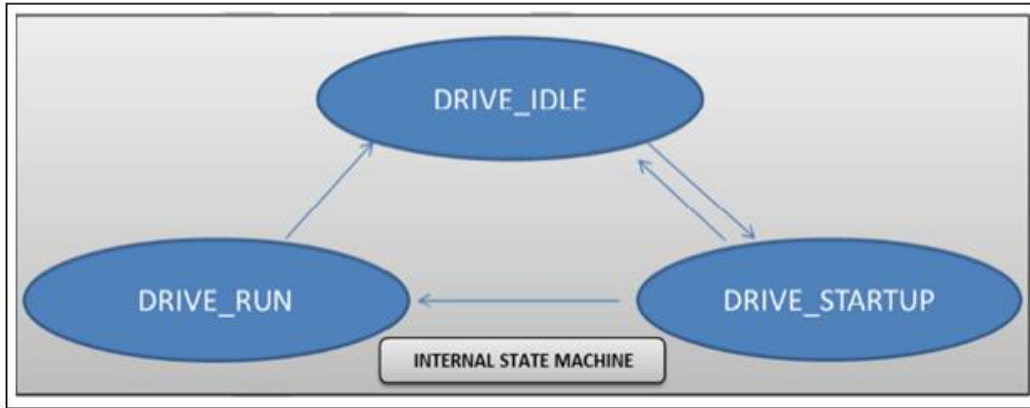


Figure 4.5: Internal State Machine

4.5.4 ACIM System Library Architecture

The STM32 ACIM system library is broadly divided into two different parts as shown in figure 4.6

1. Application Layer called as User State Machine
2. MC_FRAMEWORK as Lower Layer State Machine

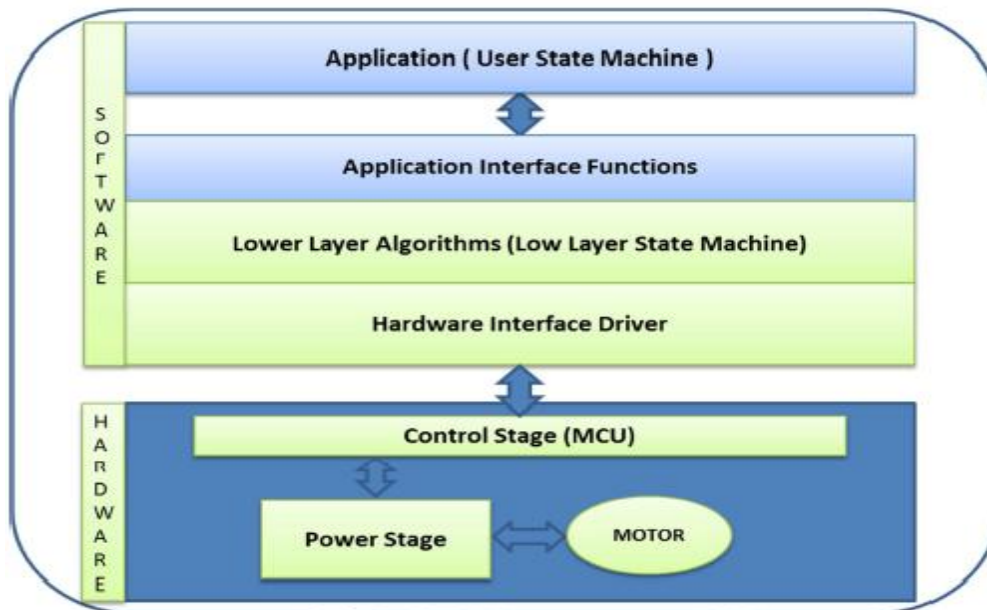


Figure 4.6: ACIM Control Architecture

The application or the user state machine is implemented in function `StateMachineExec()`.

This function is called in every iteration of while (1) loop in the main function and implements all the States.

The `MC_FRAMEWORK` is further divided into three sub levels:

1. **inc** : contains library header files (.h files)
2. **src**: contains files having the source code (.h files)
3. **param**: contains the header files which have the library configuration (.h files). These header files have **MACRO** definitions to configure the library. Four header files and their parameters are explained.

The direct access to the lower layer algorithms is not recommended from the code written in application layer. The User must access the features of library via application interface functions.

The library organization in the IAR workbench environment is shown in figure 4.7. The file `MC_StateMachine.c` contains the user state machine function `StateMachineExec()`. The user state machine is implemented in this function and for each state (switch-case) there are functions defined, which may possibly return values (`STATE_REMAIN / NEXT_STATE` or `OPTIONAL_JUMP`). As the name suggests, `STATE_REMAIN` means no change in state; `NEXT_STATE` means that in the next iteration, the state machine has to transit to the next state. `OPTIONAL_JUMP` would indicate that the state machine has to jump from `SM_START` to `SM_STOP`.

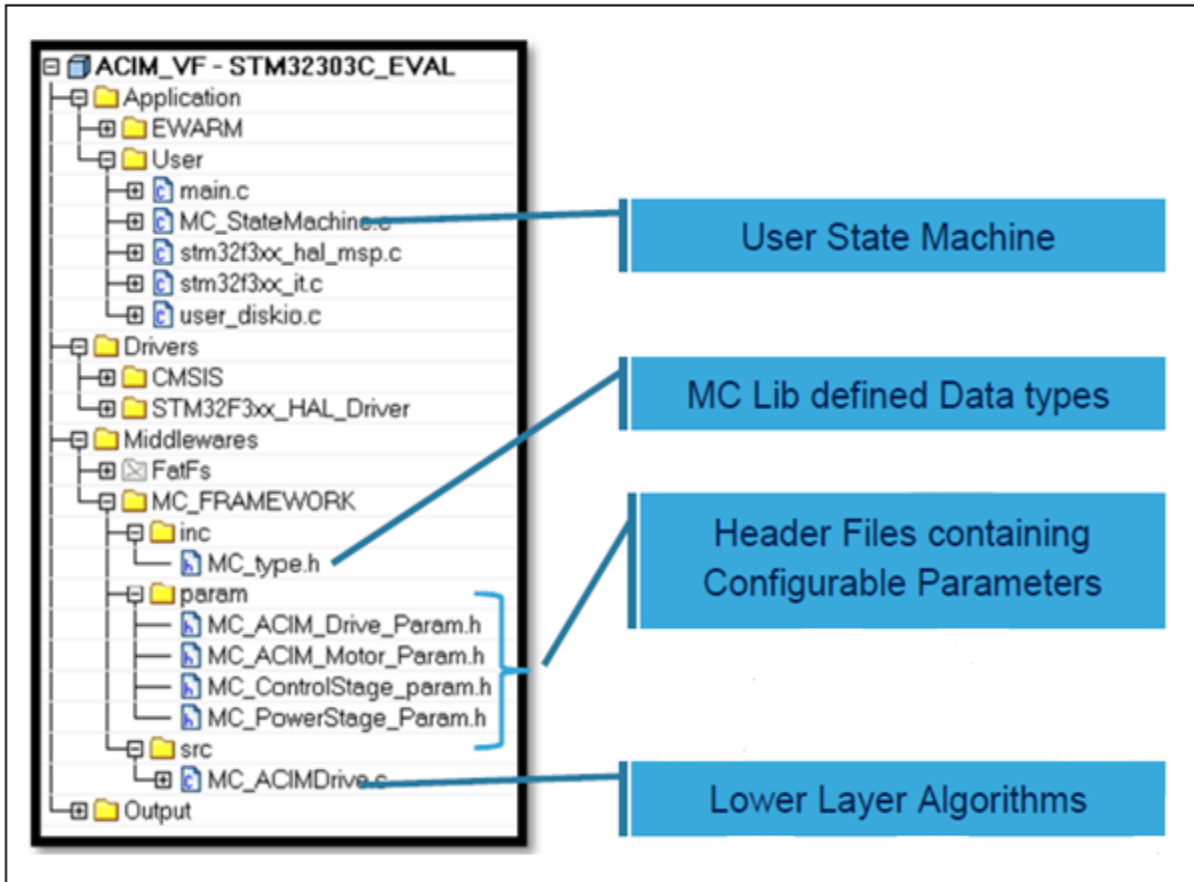


Figure 4.7: STM32 ACIM Library Organization

The file MC_ACIMDrive.c has all the lower layer (core) algorithm implementations. The header files under the project folder 'param' contain the user configurable parameters which are used by the ACIM control library for running the drive. The MC_type.h header file contains all the user defined data types which have been defined for internal use of the library. The variables/structures defined with these types must not be written by the application.

4.6 Application Designing using ACIM Software Library

The ACIM library is designed for considering the complete motor control system as a combination of four different logical blocks:

- i. the motor, power stage
- ii. control stage (MCU)
- iii. drive management.

For using the library for a new platform the user must follow below steps:

Configure the library parameters in the four header files.

1. MC_ACIM_Motor_Param.h
2. MC_ControlStage_Param.h
3. MC_PowerStage_Param.h
4. MC_ACIM_Drive_Param.h

Functions are written and call from the user state machine from appropriate states. Can also be customized the library by configuring different parameters for the above four logical blocks and then conforming to the User Sate Machine.

4.7 Customizing the ACIM Software Library Parameter Files

The parameters which have to be configured for a fore mentioned four stages are present infour different header files. Below tables mention the parameters and their effect on the drives performance.

4.7.1 Motor Parameters

Table 3 gives the different motor parameters

Table 3: MC_ACIM_Motor_Param.h

MOTOR_POLE_PAIRS	Number of Pole Pairs in the AC Induction Motor
MAX_SPEED_RPM	Maximum Rated Speed in rpm of the Motor. This information shall be provided by motor manufacturer
V_F_RATIO	V/f ratio while running in open loop after Start-up. Please note that the V/f ratio for Start-up is defined in separate parameter in the Drive Management parameters.
OPENLOOP_SLIP	Defines one hundredth of the Slip consideration during open loop run. Please note that the Slip consideration during Start-up is defined in separate parameter in the Drive Management configuration.

4.7.2 Control Stage Parameters

Table 4 gives the different control stage parameters.

Table 4: MC_ControlStage_Param.h

PHASE_UH_GPIO_PORT PHASE_UH_GPIO_PIN PHASE_UH_GPIO_AF	State the Port, Pin and Alternate functionality(the value for selection of peripheral on this pin) which is connected to the phase U High side switch
PHASE_VH_GPIO_PORT PHASE_VH_GPIO_PIN PHASE_VH_GPIO_AF	State the Port, Pin and Alternate functionality(the value for selection of peripheral on this pin) which is connected to the phase V High side switch
PHASE_WH_GPIO_PORT PHASE_WH_GPIO_PIN PHASE_WH_GPIO_AF	State the Port, Pin and Alternate functionality(the value for selection of peripheral on this pin) which is connected to the phase W High side switch
PHASE_UL_GPIO_PORT PHASE_UL_GPIO_PIN PHASE_UL_GPIO_AF	State the Port, Pin and Alternate functionality(the value for selection of peripheral on this pin) which is connected to the phase U Low side switch
PHASE_VL_GPIO_PORT PHASE_VL_GPIO_PIN PHASE_VL_GPIO_AF	State the Port, Pin and Alternate functionality(the value for selection of peripheral on this pin) which is connected to the phase V Low side switch
PHASE_WL_GPIO_PORT PHASE_WL_GPIO_PIN PHASE_WL_GPIO_AF	State the Port, Pin and Alternate functionality(the value for selection of peripheral on this pin) which is connected to the phase W Low side switch
EMERGENCY_STOP_GPIO_PORT EMERGENCY_STOP_GPIO_PIN	State Port and Pin for the Emergency Stop signal(Break Input) for Timer1
R_BRAKE_GPIO_PORT R_BRAKE_GPIO_PIN	State the Port and Pin for the Resistive Brake. This port has been configured as an output port. Functions ACIM_BrakeEnable() and ACIM_BrakeDisable() to be called to enable or disable brakes
V_BUS_SENSE_GPIO_PORT V_BUS_SENSE_GPIO_PIN	State the Port and Pin for sensing the Bus Voltage. This pin would be configured as ADC input.

CURRENT_SENSE_U_GPIO_PORT CURRENT_SENSE_U_GPIO_PIN	State the Port and Pin for current sensing in phase U. This pin would be configured as ADC input. To be configured in case of single shunt or three shunt sensing
CURRENT_SENSE_V_GPIO_PORT CURRENT_SENSE_V_GPIO_PIN	State the Port and Pin for current sensing in phase V. This pin would be configured as ADC input. To be configured in case of three shunt sensing
CURRENT_SENSE_W_GPIO_PORT CURRENT_SENSE_W_GPIO_PIN	State the Port and Pin for current sensing in phase V. This pin would be configured as ADC input. To be configured in case of three shunt sensing

4.7.3 Power Stage Parameters

Table 5 gives the different power stage parameters.

Table 5: MC_PowerStage_Param.h

PWM_U_HIGH_SIDE_POLARITY PWM_U_LOW_SIDE_POLARITY PWM_U_HIGH_SIDE_IDLE_STATE PWM_U_LOW_SIDE_IDLE_STATE	Polarity = TIM_OCPOLARITY_HIGH or TIM_OCNPOLARITY_LOW Idle State = TIM_OCIDLESTATE_RESET or TIM_OCNIDLESTATE_SET For high & low side switches of U phase
PWM_V_HIGH_SIDE_POLARITY PWM_V_LOW_SIDE_POLARITY PWM_V_HIGH_SIDE_IDLE_STATE PWM_V_LOW_SIDE_IDLE_STATE	Polarity = TIM_OCPOLARITY_HIGH or TIM_OCNPOLARITY_LOW Idle State = TIM_OCIDLESTATE_RESET or TIM_OCNIDLESTATE_SET For high & low side switches of V phase
PWM_W_HIGH_SIDE_POLARITY PWM_W_LOW_SIDE_POLARITY PWM_W_HIGH_SIDE_IDLE_STATE PWM_W_LOW_SIDE_IDLE_STATE	Polarity = TIM_OCPOLARITY_HIGH or TIM_OCNPOLARITY_LOW Idle State = TIM_OCIDLESTATE_RESET or TIM_OCNIDLESTATE_SET For high & low side switches of W phase
BKIN_POLARITY ACTIVE_HIGH or ACTIVE_LOW	polarity for the break Input signal (Emergency Break for TIMER1) to the Advance timer for motor control

4.7.4 Drive Management Parameters

Table 6 gives the different drive management parameters.

Table 6: MC_ACIM_Drive_Param.h

CONTROL_LOOP_PERIOD	Period in milliseconds after which the control method ACIM_Drive () is executed.
PWM_FREQUENCY	It defines PWM switching frequency at the powerstage.
DEAD_TIME_NS	It defines dead time duration to avoid a shoot through.
MIN_RUN_SPEED	Minimum speed at which the Motor would be able to run.
MAX_RUN_SPEED	Maximum rated speed of the Motor (in rpm). This value should come from the motor manufacturer.
DEFAULT_RUN_SPEED	Default Run speed in DRIVE_RUN state.
STARTUP_BOOST_VOLTAGE	Defines in volt, it is required at the startup for voltage boost to any drop for stator voltage drop
STARTUP_V_F_RATIO	Defines the V/f ratio to drive the motor during start up phase.
STARTUP_SLIP	Defines one hundredth of the Slip consideration during start up
STARTUP_DURATION	Defines the duration (in milliseconds) in which the motor should reach STARTUP_TARGET_SPEED from stand still position (i.e. zero speed)
STARTUP_TARGET_SPEED	Defines the target speed (in rpm) during motor start-up. Motor must stabilize at this speed after STARTUP_DURATION milliseconds
RAMP_RESOLUTION_MS	Defines the resolution of speed update events during start-up. This parameter is used to derive the number of times

	and by what increment factor the speed of the motor should be increased while transition from zero speed to STARTUP_TARGET_SPEED
OVER_VOLTAGE_PROTECTION	1 means Over Voltage Protection ENABLED 0 means Over Voltage Protection DISABLED
OVER_CURRENT_PROTECTION	1 means Over Current Protection ENABLED 0 means Over Current Protection DISABLED
OVER_TEMP_PROTECTION	1 means Over Temperature Protection ENABLED 0 means Over Temperature Protection DISABLED

4.8 Application Interface Functions

The library offers a set of application interface functions which the application writer must use to access the features of the library. Table 7 defines the functions.

Table 7: Application Library Interface Functions

void ACIM_ExecSpeedRamp (uint32_tTargetSpeed_rpm,uint32_t RampDuration);	This function to sets new values for the Target speed and duration in which the new speed has to be achieved.
void ACIM_StartMotor (void);	This function starts the motor from zero speed. Internally it changes the state of the lower layer state machine from DRIVE_IDLE to DRIVE_STARTUP. Calling this function in DRIVE_RUN state has no effect. This function must be called after calling the ACIM_ExecSpeedRamp(), otherwise the default values for start-up Target speed and start-up ramp duration will be taken from configuration file.
uint32_t ACIM_GetCurrentSpeed_Rpm (void);	Returns the current rotor speed (in rpm).
void ACIM_ReadBusVoltage (uint16_t	If Bus voltage sensing is enabled. This function would

*VBusValueInVolts);	return the current bus voltage
void ACIM_ReadTemperature (void);	If Temperature sensing is enabled. This function would return the current temperature reading
Void ACIM_FaultAck ();	Once a fault condition has occurred, the application must call this function to acknowledge the fault
void ACIM_StopMotor (void);	This function would stop the Motor. Calling this function has no effect while motor not running.
Void ACIM_BrakeEnable (void);	Calling this function would Enable the Braking through Brake Resistor.
Void ACIM_BrakeDisable (void);	Calling this function would Disable the Braking through Brake Resistor.

CHAPTER 5

TESTING PARAMETERS AND RESULTS

5.1 Overview

The 3-phase induction motor is connected to an intelligent power module (IPM). The module has six IGBT's that need to be controlled appropriately to produce a 3-phase AC output to drive

a motor from the DC bus. The PWM signals generated by the STM32 controller control these IGBT's. As the motor starts, the three IGBT's out of the six will be on at any time. The on-off switching process gives a rectangular output waveform with many harmonics. The stator winding filters this current to produce a 3-phase sine wave. When IGBT's are turned off, the nature of the windings does oppose any abrupt change in the direction of current until all of the energy is dissipated. For this reason freewheeling diodes are used and they are also known as fast recovery diodes.

5.2 Experimental Test Setup

The first experimental setup for testing the motor with the designed motor control card includes the following apparatus:

1. Power supply.
2. Multimeter.
3. Oscilloscope.
4. Tachometer.
5. 3-phase induction motor.
6. Motor control card.



Figure 5.1: General Test Setup for Motor Control Board

Power supply: An external power supply i.e. 16V is given to the micro controller for its programming purpose.

Multimeter: This is used to test the control card like its continuity and for measurement of voltages and currents.

Oscilloscope: It is an instrument used to verify the characteristics and for testing of control card like PWM waveforms, current and voltages characteristics.

Tachometer: tachometer is used to know the actual RPM speed of the motor.

The 3-phase induction motor is used for the testing of designed motor control card.

5.3 Hioki Power Factor Quality Analyzer

The Hioki power quality analyzer includes the following:

1. Hioki analyzer with voltage probes
2. Motor control card
3. 3-phase induction motor



Figure 5.2: Hioki Power Factor Quality Analyzer Test Setup

5.4 Developed Control Board Testing

The test of the designed low power and low cost control board was performed on a two experimental setup.

Test 1 involves:

Characteristics of the motor:

1. No. of pole pairs: 4
2. Nominal power (in kW): 10
3. Nominal speed (in rpm): 3000

Conditions for Test:

1. Supply AC voltage: 330V
2. Frequency (in Hertz): 50
3. Output power (in kW): 1.9
4. Test speed (in rpm): 450-500 varies
5. Temperature (in °C): 22

Test 2 involves:

Characteristics of the motor:

1. No. of pole pairs: 4
2. Nominal power (in kW): 1.6
3. Nominal speed (in rpm): 2000

Test conditions:

1. Supply AC voltage: 330V
2. Frequency (in Hertz): 50
3. Output power (in kW): 1.4
4. Test speed (in rpm): 750 (varies)
5. Temperature (in °C): 22

The STM32 microcontroller was used as the controller which is programmed with STM32 ACIM firmware library. Every associated parameters of the motor were incorporated in the source code file and the output power measured on the load of the motor.

The results have been shown in the following figures:

The generated PWM waveform by a controller is shown in figure 5.3. It is just to verify whether the required waveform is generated by a controller or not using pin no. 3 ($\overline{\text{LIN1}}$) as a test point of an IPM module.

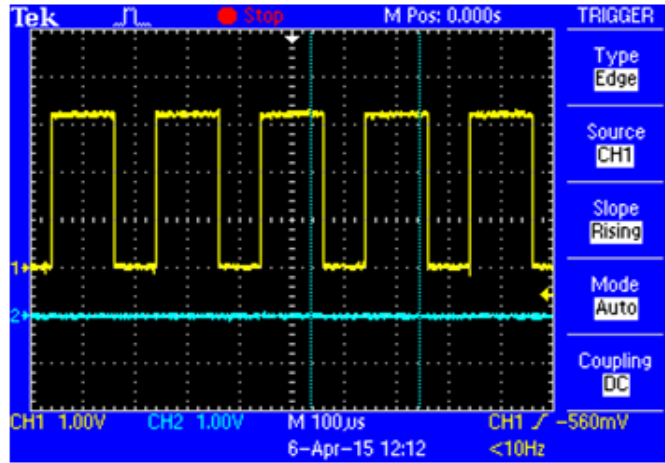


Figure 5.3: PWM Signal Generated by Controller

The pwm waveform generated by a controller required by an IPM module for Phase U at pin no. 3 ($\overline{\text{LIN1}}$) and pin no. 4 (HIN1) of U8 as shown in below figure 5.4.

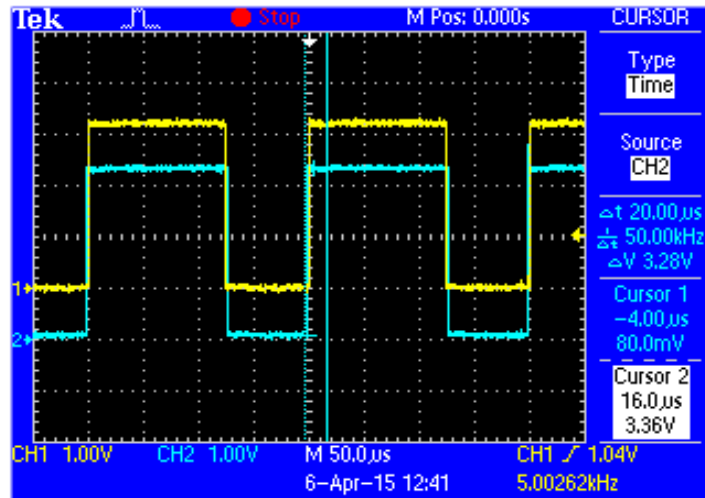


Figure 5.4: PWM Generated at Pin No. 3 and Pin No. 4 of Module

The delay time of approximately 2μ seconds between the two IGBT's of the IPM module (U8) is used to ensure that both the switches are not conductive at the same time as each one changes state as shown in below figure 5.5.

The pin no. 3 ($\overline{\text{LIN1}}$) and pin no. 4 (HIN1) has been used for the readings and as a test point of U8.

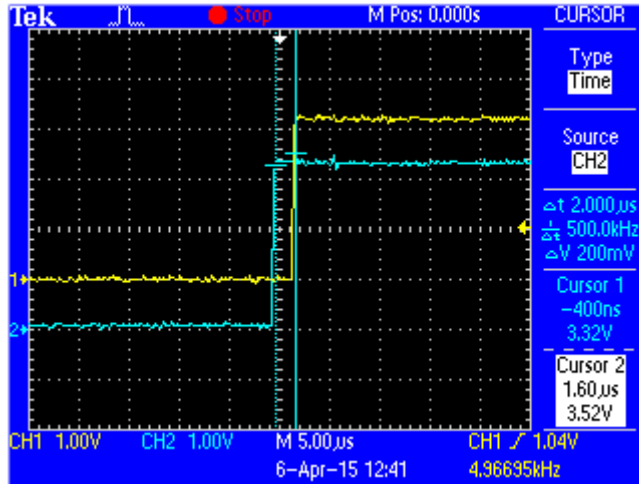


Figure 5.5: Time Delay of 2μ Seconds between the Two IGBT's

The pwm waveform generated by a controller required by an IPM module for phase V at pin no.11 ($\overline{\text{LIN2}}$) and pin no. 12 (HIN2) of U8 as shown in below figure 5.6.

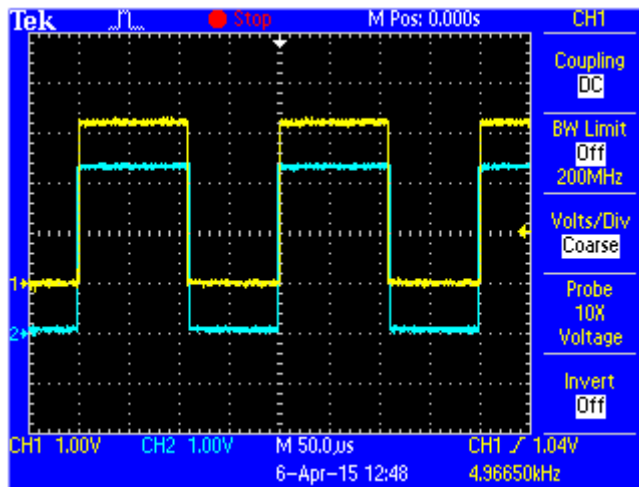


Figure 5.6: PWM Generated at Pin No. 11 and Pin No. 12 of Module

The delay time of approximately 2μ seconds between the two IGBT's of the IPM module (U8) is used to ensure that both the IGBT's are non-conductive at the same time as a result each one changes its state as shown in below figure 5.7.

The pin no. 11 ($\overline{\text{LIN2}}$) and pin no. 12 (HIN2) has been used for the readings and as a test point of U8.

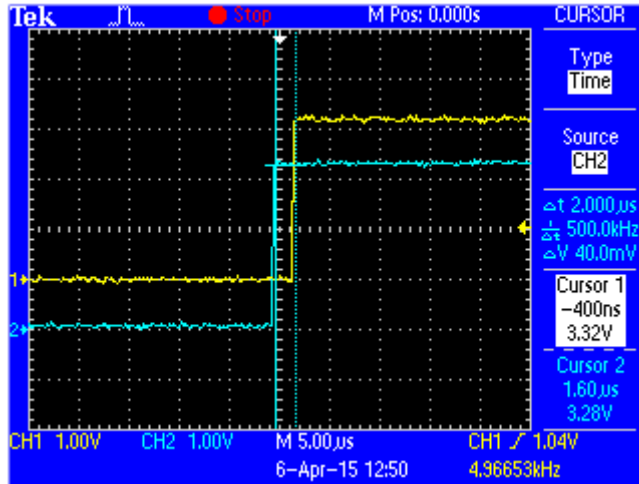


Figure 5.7: Time Delay of 2μ Seconds between the Two IGBT's

The pwm waveform generated by a controller required by an IPM module for phase W at pin no. 19 ($\overline{\text{LIN3}}$) and pin no. 20 (HIN2) of U8 as shown in below figure 5.8.

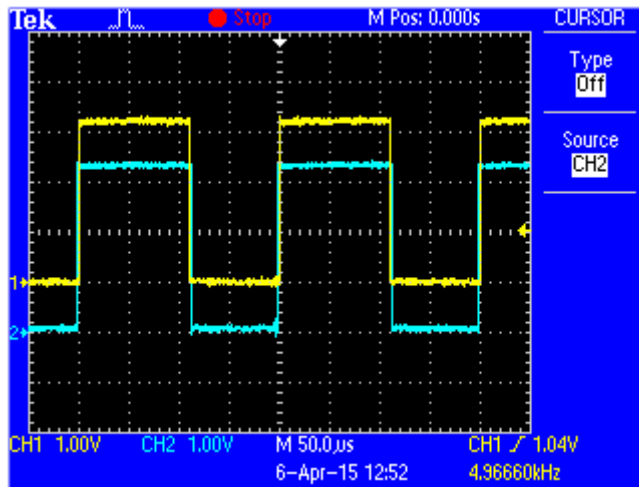


Figure 5.8. PWM Generated at Pin No. 19 and Pin No. 20 of Module

The delay time of approximately 2μ seconds between the two IGBT's of the IPM module (U8) is used to ensure that both the IGBT's are non-conductive at the same time as a result each one changes its state as shown in below figure 5.9.

The pin no. 19 ($\overline{\text{LIN3}}$) and pin no. 20 (HIN3) has been used for the readings and as a test point of U8.

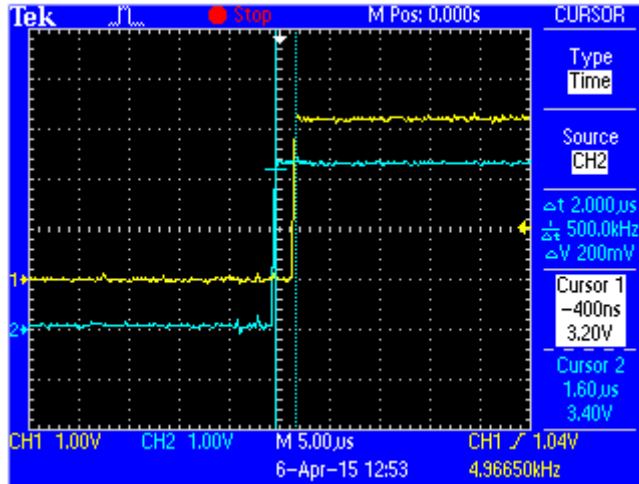


Figure 5.9: Time Delay of 2µ Seconds between the Two IGBT's

The pwm waveform generated by a controller required by an IPM module for phase U, V and W at pin no. 3 ($\overline{\text{LIN1}}$), pin no. 11 ($\overline{\text{LIN2}}$) and pin no. 19 ($\overline{\text{LIN3}}$) of U8 as shown in below figure 5.10.

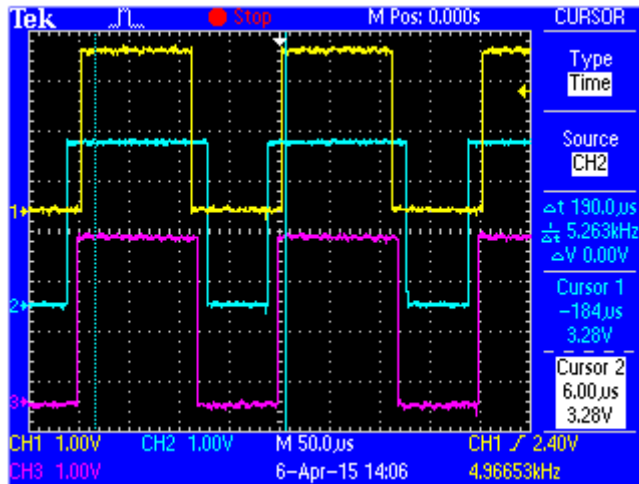


Figure 5.10: PWM Generated at Pin No. 3, Pin No. 11 and Pin No. 19 of Module

The pwm waveform generated by a controller required by an IPM module for phase U, V and W at pin no. 4 (HIN1), pin no. 12 (HIN2) and pin no. 20 (HIN3) of U8 as shown in figure 5.11.

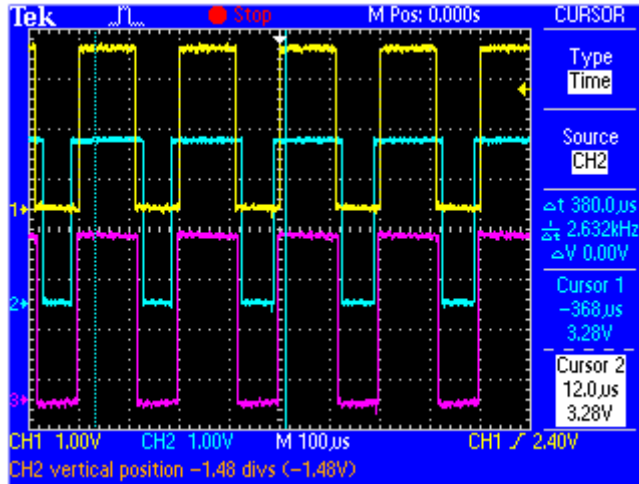


Figure 5.11: PWM Generated at Pin No. 4, Pin No. 12 and Pin No. 20 of Module

Over voltage protection: To prevent the dc bus shorting a limit has been set for a dc bus voltage, which in software is set to be 415VDC. If the applied voltage reaches to 415VDC, it will automatically shut off the control card thus preventing the shorting of DC bus voltage as shown in this figure 5.12. After reaching the set limit of the DC bus voltage, the controller will stop generating the PWM signal and thus motor will not drive.

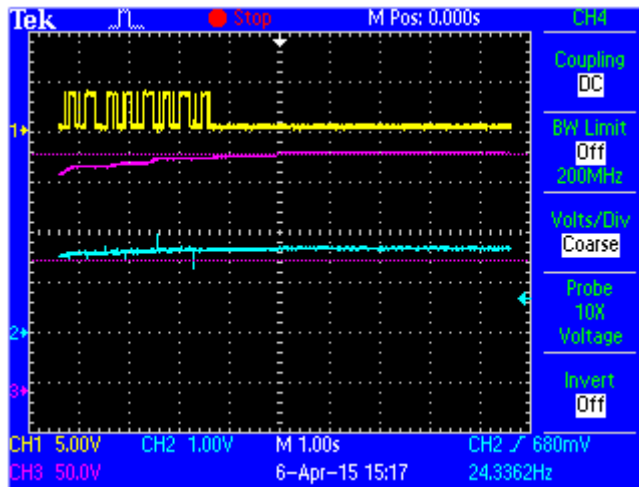


Figure 5.12: DC Bus Over Voltage Protection

For the over current protection: the over current protection circuit has been used. In which the current sensing resistors are used at the output side of the control card. This resistors provides the the voltage drop which is linearly proportional to the flow of current of the motor. This drop in voltage is then compared with reference voltage with the help of comparator. If the current drawn is more than 120% than the feedback signal is sent to the controller which will stop

generating the PWM waveform. The IPM module stops its working and this will shutdown the entire system at that moment.

The required 3-phase and 120° phase shift output square wave form from the inverter section used to drive the motor. This wave form is tested from the output connector J4 of the control card as shown in figure 5.13.

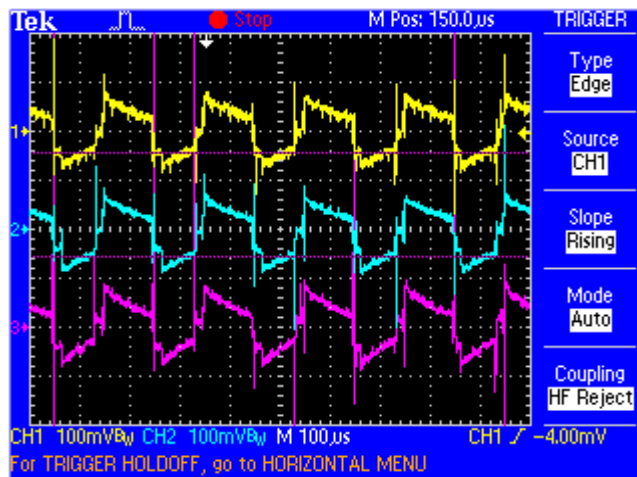


Figure 5.13: Generated Waveform to Drive the Motor at Output Connector

The HIOKI power factor analyzer test set up is used to check the voltage characteristics at the output connector J4. The 3-phase, 3-wire, 3-meters technique is used with reference frequency of 50Hz and reference voltage of 415V. The 3 channels have been used for appropriate reading of output voltage as shown in the figure 5.14.

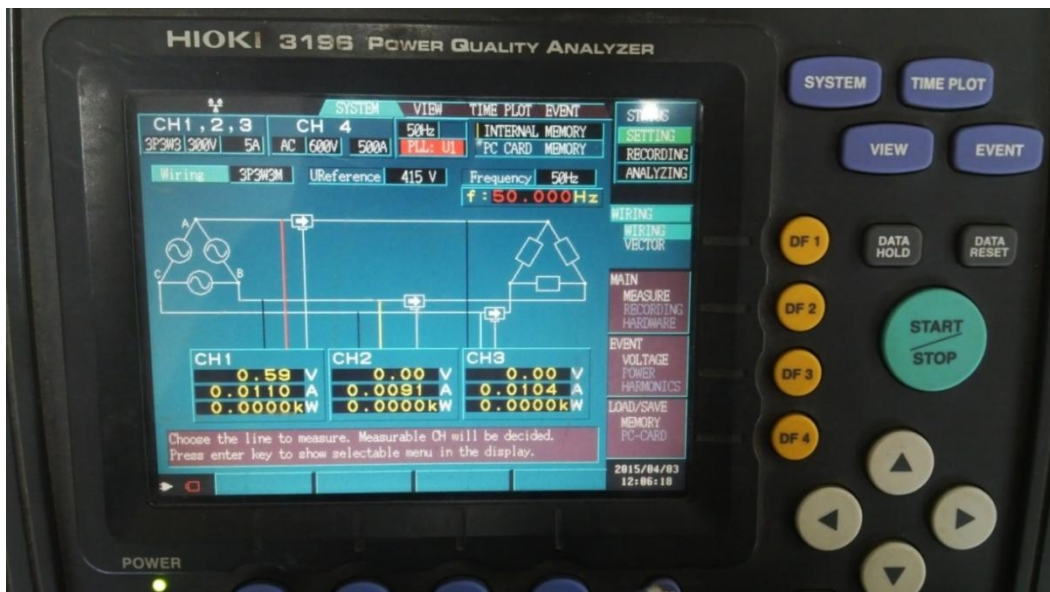


Figure 5.14: Hioki Test Setup Configuration

As a result the output voltage waveform is shown below in figure 5.15 with frequency of 40.781 Hz.



Figure 5.15: Hioki Output Voltage Characteristics

5.5 Why it is called Low Cost AC Drive System

The system is designed with the ARM Cortex®-M3 processor, which is the latest generation of ARM processors for embedded systems. The STM32F103 controller is used which provides a low-cost platform for MCU implementation with low-power consumption, while giving the best computational performance and advanced features. It is a 32 bit controller with 72 MHz of maximum frequency, single cycle of multiplication and hardware division. It has 256 to 512 Kb of flash memory with up to 64Kb of SRAM and a flexible static memory controller having 4 chip select. It also supports compact flash, SRAM, PSRAM, NOR and NAND memories. It is a low power controller with many features like sleep, standby, stop modes, 12-channel DMA controller, temperature sensor, debug mode, upto 112 fast I/O ports, 11 timers, 13 communication interfaces and a lot more features at a low cost [27].

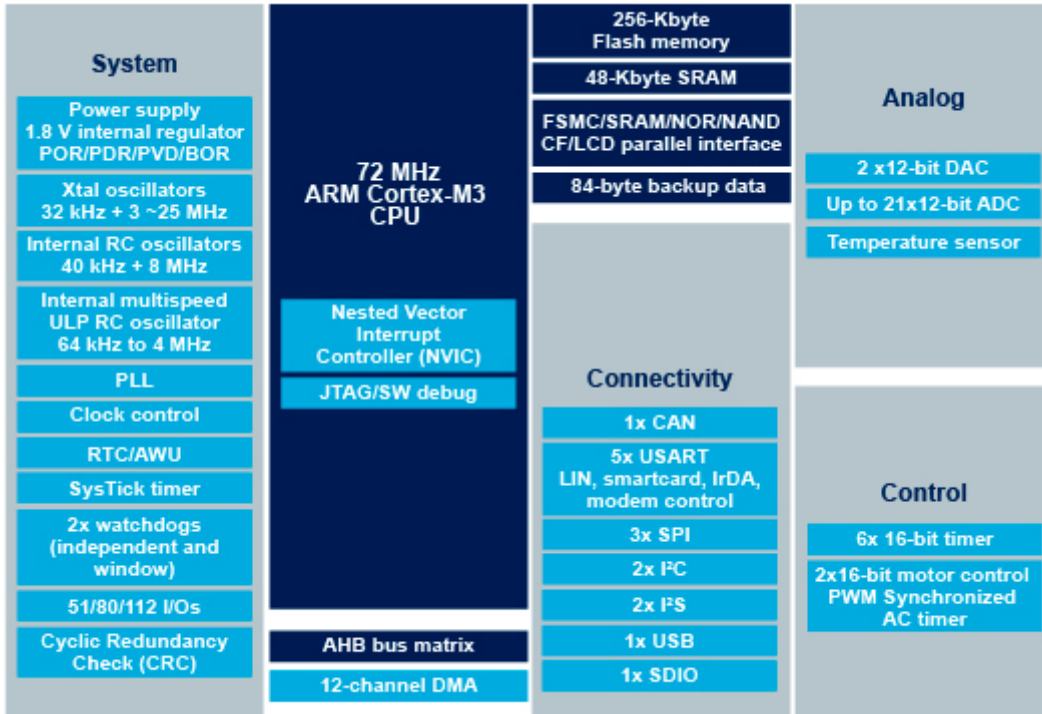


Figure 5.16: System Architecture of STM32 Controller at Low Cost [27]

CONCLUSION AND FUTURE SCOPE

Conclusion

In this dissertation, design and development of a power processing unit for low power ac drive has been described. In addition to this, different types of electrical machines and widely used control techniques have also been discussed. This dissertation will serve as a basic study for those researchers who want to work in the design and development of a low power ac drive with a system having a low cost as an advantage and thus enable them to understand the basics of ac drive, the benefits, terminology and various control techniques that are widely used for ac drives. Furthermore, at the heart of this control card, the main device presented is a fully evaluated and populated design that consists of a 3 phase inverter bridge of 600V IGBT power module, the design and working principle of this module have also been described in this dissertation. The dissertation also highlights theory algorithms, V/F control library functions, state machine operations and many features of the STM32F103 microcontroller which comes with the set of peripherals that makes them suitable for performing both with PM and AC induction motor

control. With this the motor control board or the system has been uniquely designed to get power inversion reliably. This will help in reducing the PCB space occupation as well as the assembly costs with higher reliability that will lead to the low power and low cost AC drive. Thus the developed system described in this dissertation can be used for the applications in power tools, high power pumps, power fans used in air conditioning and other industrial drives.

Future Scope

Any work, whatsoever precise and accurate it may be, has always some scope of improvement. On the same line, the developed motor control card for low power and low cost ac drive has a scope of improvement. Some of the future aspects on which this work can be extended are:

1. The developed system in this dissertation drives the motor at the speed up to 2400 RPM which may be increased in future by using more accurate components.
2. Furthermore, elimination of transient results in harmonic distortions may also be improved by using the techniques of intelligent control system.
3. In the developed system smart features like smart shut down function, comparators for fault protection against over current and short circuits protection, Op-amps for advanced current sensing are only used so as to attain a low cost which may be further increased by using some other devices and sensors.

PUBLICATIONS

➤ *To Communicate*

[1] Manish Maheshwari, Jainy Sachdeva, Ramakant Mahajan, “Design for Low Power and Low Cost AC Drive using STM32 Microcontroller and Intelligent Power Module”

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