DEVELOPMENT OF DIGITAL CONTROLLER FOR BLDC MOTOR USING DSPIC CONTROLLER

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ELECTRICAL & ELECTRONICS ENGINEERING
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by

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Dissertation submitted in partial fulfillment of
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CERTIFICATION OF APPROVAL

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TRONOH, PERAK
JUNE 2010

CERTIFICATE OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained here in have not been undertaken or done by unspecified sources or persons.

(SITI KHADIJAH BINTI ABDUL AZIZ)

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ABSTRACT

This paper present a simulation report of back EMF sensing scheme, direct back EMF detection, for application of sensorless BLDC motor drives with a DSP based controller. The project is aim to investigate the performance digital controller for BLDC motor using dsPIC 33FJ32MC204 and to measure the motor control parameters through PWM and back EMF analysis. This digital signal processing integrated circuit provides developing sensored or sensorless BLDC and Permanent Magnet Synchronous Motor (PMSM) control applications. In this project, the author focus on sensorless BLDC motor. The system directly extracts the true back Electromagnetic Force (EMF) zero crossing by detecting the voltage difference between the floating phase terminal and the midpoint in the DC link. The terminal voltage of the motor is proportional to the phase back EMF on the floating phase, the DSP feature can be utilized to sense the back EMF. Digital control of the system ensures the detection of rotor electrical position when the open terminal voltage equals to half the applied voltage. A mathematical model of the drive system is analyzed. The simulated and experimental results from the online tutorial guide dsPIC 33FJ32MC204 are verified through the Real Time Data Monitoring functional that been introduced in MPLAB system. Digital Monitoring Control Interface enhanced with RTDM provides a graphical method to input and adjust motor parameters in real time and immediately see effect, without halting the application. Experimental waveforms of phase back EMF and current from a 3-phase, 24V BLDC drive system are validated with simulation result. The commutation signal of the floating phase is obtained by lagging the back EMF, zero crossing point of 30 electrical degrees. Motor starting methods are implemented in the system which the commutation angles give the commutation signal (pulse) to the motor of different phase to operate.

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LIST OF ABBREVIATION

BLDC	Brushless Direct Current
dsPIC	Digital Signal Processing Integrated Circuit
MCLV	Motor Control Low Voltage
AC	Alternating Current
DC	Direct Current
EMF	Electromotive Force
PWM	Pulse Width Modulation
DMCI	Data Monitoring Control Integral
RTDM	Real Time Data Monitoring

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Recent developments in permanent magnet (PM) materials, power electronics, fast digital signal processors (DSPs) and modern control technologies have significantly influenced the widespread use of brushless dc (BLDC) motor drives in order to meet the competitive worldwide market. The availability of smart power electronics devices, like MOSFET, IGBT and their optimal topologies has accelerated unique growth of cost effective and reliable inverter and converter systems.

This improvement brings greater efficiency in system and functionality to the point of making the BLDC a preferred solution in a broad range of application using adjustable rotation and speed drives with the existence of back EMF and pulse width modulation (PWM) concept. Software control on-line implementation of sophisticated robust controllers has advanced the art of digital control of BLDC motor drives.

The goal of this effort is to develop a test platform for development, implementation and evaluation of adaptive and advanced control techniques for brushless DC (BLDC) motors used in translation and positioning systems. The test platform will be used to test and select control techniques for BLDC motor-driven systems for various applications. The control approach to be evaluated will be implemented as a digital control algorithm in an embedded digital control processor.

1.2 Objective

1. To investigate the performance digital controller for BLDC motor using dsPIC 33FJ32MC204
2. To measure the motor control parameters through PWM and back EMF analysis.

1.3 Significant of the project

From the consumer appliance and recreation market, brushed based electrical motors have dominated with their ease of control, price/performance ratio, and reliability. The BLDC (brushless) motor, as a more recent newcomer, has been too expensive to implement for consumer appliance and recreational applications. However, with the falling prices of power electronic devices and digital control systems, these motors are now on the verge of becoming a viable, economic replacement for the antiquated brush based motor.

Brushless motors exhibit similar torque and power properties when compared to similar sized brushed motors. This drawback is easily made up by the reliability of brushless motors. Brushless motors have no electrical contact points to the rotor, which is a common failure point for brushed motors[1]. This also leads to less friction and corresponds to higher efficiency of the drive. With the motor bearings as the only physical failure point, brushless motors are the king in reliability, especially in today's warranty and price driven consumer market. The latest generation of low- power DSP devices and supporting electronics can further reduce the power needed to operate the control system of the motor.

1.4 Scope of project

The BLDC motor is essentially electronically controlled and requires rotor position information for proper commutations of current. Sensorless drive solutions have been done to eliminate the costly and fragile position sensor for BLDC motors with trapezoidal back-EMFs[2]. The virtual neutral point sensing, zero crossing, back EMF sensing and detection of freewheeling diodes conduction are main categories of part sensorless solutions for BLDC motors. A virtual neutral point sensing method of back EMF requires filtering, and tends to have poor signal to noise ratio at low speeds, such as at startup and significant commutation delays at high speeds.

In this project, the focus is on the command to control commutation sensing of motor, current, voltage and torque of the motor through back EMF and PWM concepts. Literature survey on the present state of art dsPIC controllers, different type of dsPIC manufactures and availability equipments in the market have been done to suit the motor simulation. Study on the software development of a BLDC motor and software-interfacing have been done in running the result.

The project involved simulation which is using MPLAB IDE with dsPIC 33FJ32MC204. It needs sometime to do simulation and modeling of the controllers using MPLAB software. The user interface for the software need to be defined in the command window and requires dsPIC 33FJ32MC204 device identification during the development stage of the controller. Next page show Table 1 of motor parameters that have been taken into account those are:

Table 1: Parameter names, abbreviations and description interface.

For This Parameter	Type This Abbreviation	Comment
Motor Parameters		
DIRECTION	DD 0 or DD 1	0 = Forward 1 = Backward
No. Motor Poles	MP <Value>	Number of Motor Poles
Blanking Count	BC <Value>	
Windmilling Dem	WD <Value>	
Starting Parameters		
Lock Pos.1 Time	LP1T <Value>	In 10-msec intervals
Lock Pos.2 Time	LP2T <Value>	In 10-msec intervals
Lock Pos.1 Dem	LP1D <Value>	In PWM duty cycle percentage
Lock Pos.2 Dem	LP2D <Value>	In PWM duty cycle percentage
Ramp Start Speed	RSS <Value>	Ramp Start Speed in RPM
Ramp End Speed	RES <Value>	Ramp End Speed in RPM
Ramp Start Dem	RSD <Value>	In PWM duty cycle percentage
Ramp End Dem	RED <Value>	In PWM duty cycle percentage
Ramp Duration	RD <Value>	In 10 msec intervals
Tolerance Check	TC <Value>	
Auto Re-acquire	ARA 0 or ARA 1	0 = disable 1 = enable
Starting Control	SC 0 and SC 1	0 = Voltage Control 1 = Current Control
Acquire Method	AM 0 or AM 1	0 = Method 1 1 = Method 2
ZeroX Enable Spd	ZXES <Value>	Speed at which zero crossing is enabled

Table 1 that has 3 columns showing the complete motor parameters that been considered by Microchip company to ensure the motor that is modeled with the system considers the above guided interface. For example when instructing a command for the motor system to do tasks, motor parameters direction of rotation and motor specification like number of poles need to be stated in the command window. The way of identify this command in the command window is by typing “DD0” to assign motor rotation forward and “DD1” to assign motor rotation backward. For starting motor parameters, values of lock position time and ramps can be obtain from dsPIC 33 Microchip datasheet.

CHAPTER 2

LITERATURE REVIEW

2.1 Motor

Basic description of a motor basically is rotating object in the machine or electrical equipment. It converts electrical to mechanical energy and having stator and rotor part. Motors are classified into two categories those are AC motor and DC motor. In this project, DC motor is highlighted.

DC motors are of course driven from a dc power supply which in this project AC to DC converter adapter had been purchase in running the motor. Unless otherwise specified, the input voltage to a dc motor is assumed to be constant. This is because that assumption simplifies the analysis of motors and the comparison between different types of motors.

There are 5 major types of conventional dc motor in general use those are the separate excited dc motor, shunt dc motor, permanent – magnet dc motor, series dc motor and compounded dc motor. The connection of the motor can either be delta connection (higher torque and current) or Y-connection (lower starting current). Mathematical stuff related to dc motor commonly are power, speed, slip (difference in speed), torque, frequency, power factor and efficiency (% indicate how much input electrical energy converted to output).

2.1.1 Stator and Rotor Flux

The BLDC motor is driven by rectangular voltage strokes coupled with the given rotor position. The generated stator flux, together with the rotor flux which is generated by a rotor magnet, defines the torque and thus the speed of the motor. To get the maximum generated torque, the voltage strokes must be applied to the 3-phase winding system. By this the angle between the stator flux and the rotor flux is kept close to 90 degree. To meet these criteria, the motor requires electronic control for proper operation.

2.1.2 Overview Brush DC Motor and Brushless DC Motor

a) Brush DC Motor

Characteristics of the Brush DC Motor basically are good controllability on/off. It usually has linear torque/current curve. The speed is proportionate to the voltage applied. Brush DC motor requires maintenance since low overloading capability. Besides, it consumes low heat dissipation.

b) Brushless DC Motor

Brushless DC motors were developed from conventional brushed DC motors with the availability of solid state power semiconductors. However, brushless dc motor does not directly operate off a dc voltage source. Its basic principle of operation is similar to a dc motor. Figure 1 in the next page shows that it has a rotor with permanent magnets and a stator with windings. Here, the brushes and commutator have been eliminated. Compared to brush dc motor, the windings of brushless dc motor are connected to the control electronics. Control electronics mean it replace the function of commutator and energize the proper winding.

Windings that energized will rotate around the stator thus energized stator winding. This leads the rotor magnet to switch just as the rotor aligns with the stator. From the stator, it creates rotating magnetic fields producing torque in a magnetic rotor. Brushless dc motors tend to be small which range a few watts to tens of watts, with permanent magnet rotors[2].

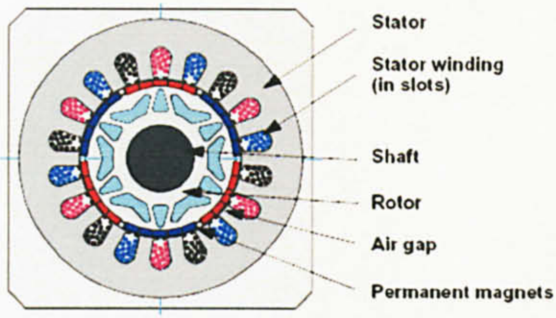


Figure 1: Brushless DC motor model and cross section of the motor

Brushless DC motors are similar to AC synchronous motors. The major difference is that synchronous motors develop a sinusoidal back EMF, as compared to a rectangular, or trapezoidal, back EMF for brushless DC motors. Both have stator created rotating magnetic fields producing torque in a magnetic rotor.

The characteristics of the BLDC motor are it is easier to remove and maintain since the heat is generated in the stator. Besides, rotor has permanent magnets versus coils thus lighter less inertia. This makes the motor easier to start and stop.

Other than that, the characteristics of brushless DC motor are:

- Linear torque/current relationship smooth acceleration or constant torque
- Higher torque ripple due to lack of information between sectors
- Low Cost to manufacture
- Simple, low-cost design for fixed-speed applications
- Clean, Fast and Efficient
- Speed proportionate to line frequency (50 or 60 Hz)
- Complex control for variable speed and torque

BLDC motors are potentially cleaner, faster, more efficient, less noisy and more reliable and require electronic control as stated in the above. Need to be consider, the brushes of a dc motor have several limitations which are brush life, brush residue, maximum speed, and electrical noise.

2.1.3 Sensorless BLDC Motor

A 'sensorless' method can be used to remove mechanical sensors by measuring voltage or current feedback. Sensorless motors are lower cost due to the lack of the sensors, but they are more complicated to drive. A sensorless motor performs very well in applications that do not require the motor to start and stop. How to eliminate Hall-Effect sensors and cabling cost by going sensorless? Take a look at how the dsPIC 33 MCU's AC/DC samples the motor phase voltages. From the voltages, the CPU determines the rotor position and drives the motor control PWM module to generate trapezoidal output signals for the 3-phase inverter circuit[2].

2.1.4 Back Electromotive Force (EMF)

In operation of sensorless BLDC mode, Back Electromotive Force signal information is the one read back from the motor. dsPIC 33FJ 32MC204 is compatible with all mode to control BLDC motor. In sensorless mode, in order to be able to read the BEMF information, the phase switching has to include a dead time during which no current flows in one of the motor windings. A three phase star connected BLDC motor is normally driven by a three-phase inverter using 6-steps commutation.

In order to produce maximum torque, the inverter should be commutated every 60 degrees so that current is in phase with the back EMF. The conducting interval for each phase is 120 electrical degrees, or two steps. The commutation timing is determined by the rotor position, which can be determined every 60 electrical degrees by detecting when the back EMF on the floating phase crosses the zero potential point, or "zero crossing". In six-step,120 degree, power is removed from each winding every three steps. During this dead-time phase, it is possible to detect the BEMF zero-crossing event on this non-powered winding. With this method, the BEMF voltage is referred to point M of the motor and not to ground. Due to this point is at high voltage, the microcontroller cannot read its value directly.

2.1.5 How to Control BLDC Motor

Inverters as the switches are needed to turn on the motor. It needs pulse signal in order for the motor to on. In this case, MOSFET which is embedded in the MCLV (motor control board low voltage) is being used.

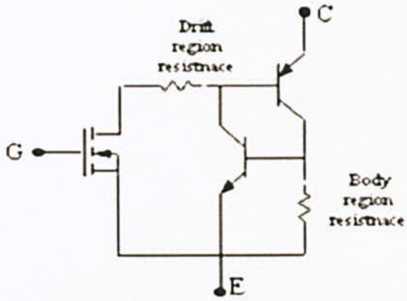


Figure 2: MOSFET as Switching Device

Figure 2 shows the MOSFET with three-terminal power semiconductor device, can be use for high efficiency and fast switching. It function is to invert voltage from DC to DC. PWM create pulse to MOSFET thus this device act as a switch. Here there are six MOSFETs that act as inverter.

MOSFET has high conduction loss and having lower switching period. The gate of this electronic device can be control by applying reverse voltage. It has been the preferred device under these conditions due to its low duty cycle, low frequency (<20 kHz), high-voltage applications (>1000V), operation at high junction temperature is allowed (>100°C) and can stands more than 5kW output power

A typical MOSFET application includes the motor control with the Frequency of more than 20 kHz, short circuit protection. Other than that, it is being used in uninterruptible power supply (UPS) which help to give constant load with typically low frequency. It is also used in the welding field. With high average current and having frequency (<50 kHz) make it reliable for this equipment. Low-power lighting also use IGBT in producing low frequency (<100 kHz).

2.1.6 Implement Switching of Power Transistors

In the development board, there are all electronics components related have been embedded. Power transistors are part of it. Figure 3 show the development board and the switching part of the motor.

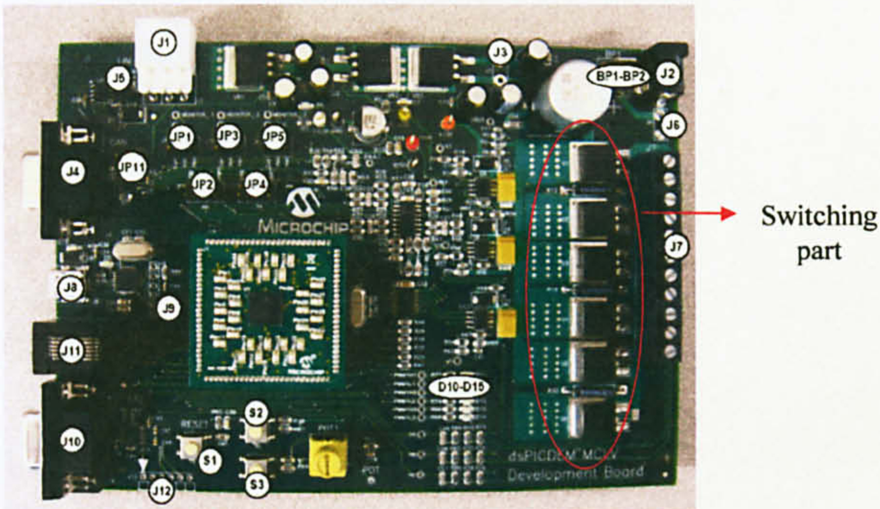


Figure 3: Development Board of Motor Control Low Voltage MA330017

With independent switching in Figure 3, only two transistors are switched on when the current is conducted from the power supply to the phase of the BLDC motor. This can be clearly observed in Figure 4 of 3-phase BLDC power stage of power transistor diagram. In one phase, the top transistor is switched on; in the second phase, the bottom transistor is switched on and the third phase is no powered. During freewheeling, all transistors are switched off.

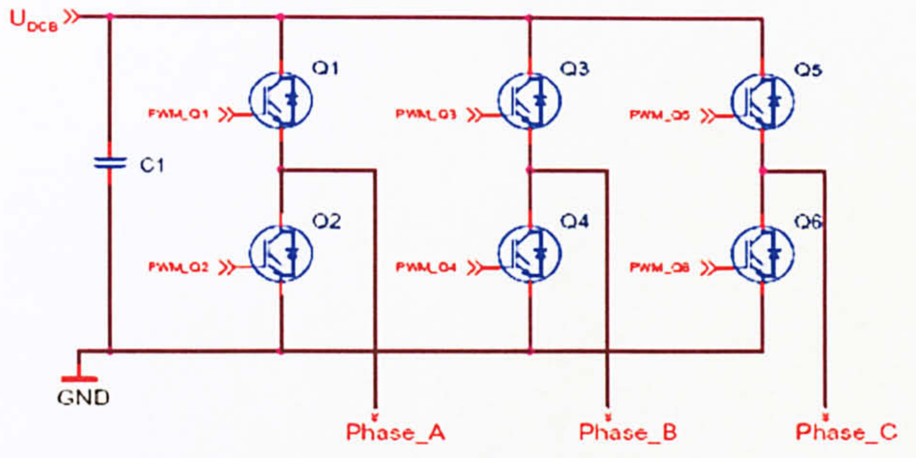


Figure 4: 3-phase BLDC power stage of power transistor

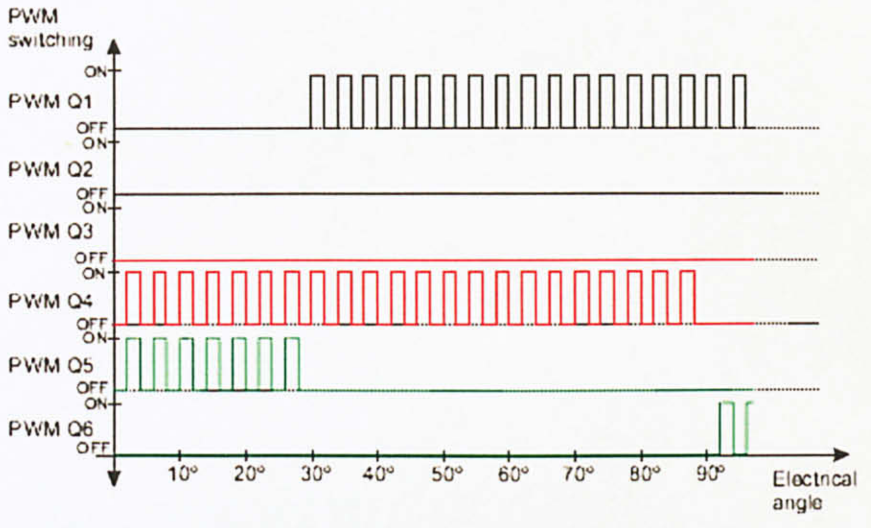


Figure 5: Electrical angle vs. PWM switching

One of the methods of commutating 3phase brushless DC motor commonly known as the "six step drive" as shown in Figure 4, 5 and 6. In this method, each phase voltage is energized for 120 degree (electrical) interval according to its rotor electrical angle as shown in Figure 6. This may be realized by the switch configuration of Figure 4. Each voltage is positive when the top switch is on and the bottom switch is off (vise versa). No voltage is injected when both switches are off, in which case the actual terminal voltage is governed by the back EMF voltage of the motor.

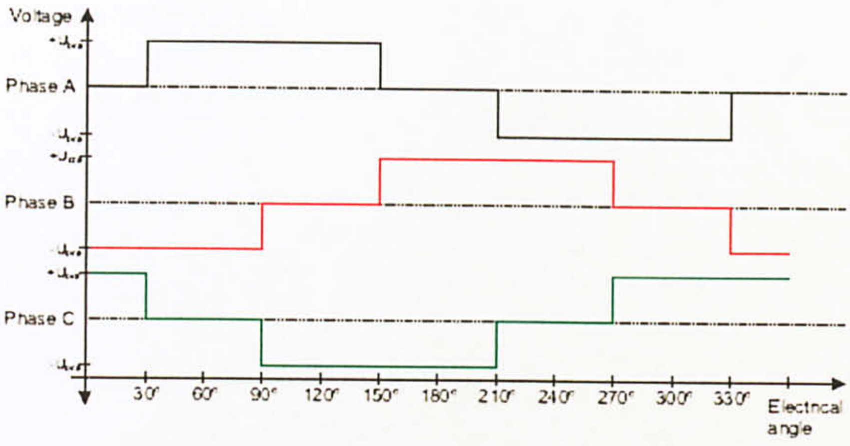


Figure 6: Voltage strokes applied onto the 3-phase BLDC motor

In other words, each phase voltage at a time takes one of three states –positive, negative or float. At every sector, only one phase is energized as positive and one of the other phases is energized as negative in order to maintain current path. In order to commutate properly, the controller needs to know the sector (60 degree interval) position of the shaft angle. When the output voltage should be controlled to commutation, pulse width modulator signal as shown in Figure 5 may apply to either sides or lower switches. When PWM is applied only to the low side switches of Figure 4, a short circuit current path is established through one of the free-wheeling diodes upper switches during PWM off time.

2.1.7 Electronic Commutation

BLDC motor is equivalent to an inverted DC commutator motor, in which the magnet rotates while the conductors remain stationary. In the DC commutator motor, the current polarity is reversed by the commutator and brushes.However, in the brushless DC motor, the polarity reversal is performed by power transistors switched in synchronization with the rotor position. Therefore, BLDC motors often incorporate either internal or external position sensors to sense the actual rotor position. The position can also be detected without sensors.

2.1.8 Pulse Width Modulation

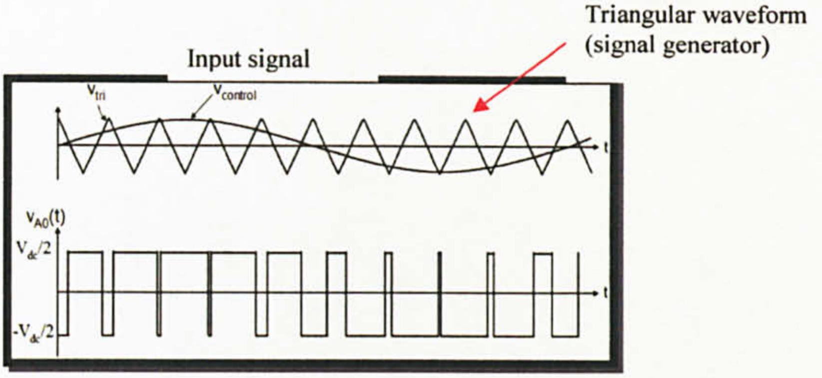


Figure 7: Signal waves of pulse width modulation

The main purpose of using PWM technique is to extract the low frequency signal from a train of high frequency signal square waves as shown in Figure 7. It is important because it is involve in the process of modifying the width of the pulse. PWM signal is used to control the MOSFETs switches gate. When using PWM to regulate motor speed or torque/current for instance, the virtual neutral point fluctuates at the PWM frequency.

The back EMF voltage theoretically can be extracted directly through motor terminal voltage. For the two phases being driven the PWM drive signal can be arranged in three ways.

1. *On the high side* - the PWM is applied only on the high side switch; the low side remains on during the step.

2. *On the low side* - the PWM is applied on the low side switch, the high side remains on during the step.

3. *On both sides* – the high side and low side are switched on/off together.

This project only touch on the low side switches of the PWM. The high-side switches are only switched to provide commutation.

2.2 DSPIC - Digital Signal Processor Integrated Circuit

The online simulation MPLAB control of the motor is implemented in a dsPIC. This system is designed around the Microchip dsPIC33F series. The user interface is necessary to tune the different parameters used in the sensorless BLDC motor control applications. There are 45 user parameters that can be modified in the applications[3]. The previous user interface application uses RS-232 port on the dsPIC 33FJ32MC204 connected to a communication terminal. Now dsPIC 33FJ32MC204 is being used to control the motor.

The communication terminal is then used to change parameters in the user interface. All the parameters that were set on on the PICDEM MC1 Motor Control Development Board using LCD can now set through the serial interface [3]. The parameters are categorized by:

i) Motor parameters – current, voltage terminal, back EMF commutation sensing, phase angles.

ii) Control parameters – parameters that relate to the different PI or PID control parameters used in the software

iii) Limit parameters – parameters that relate to the various limit settings in the software

2.2.1 Software Development

Compiler for this project is MPLAB V 8.30 from Microchip company. Recently C language is being used as the command for the BLDC motor. Software written in modular form using C code allows expansion driving application. The background loop that constitutes the main code consists simply of initializing the peripherals, including the Phase Lock Loop (PLL), interrupt control and event manager.

The remainder of the code includes the PWM-ISR (Pulse width modulation-interrupt service routines). The motor system's time based interrupt invoke the ISRs every PWM cycle[4]. All calculation for motor should be done within PWM cycle in a cycle- by-cycle manner. The calculation might use fixed-point math to reduce computational requirements.

2.2.2 Equipments and tools

MPLAB and C30 versions used:

i. MPLAB version 8.10
ii. C30 version 3.10

Hardware used with part numbers:

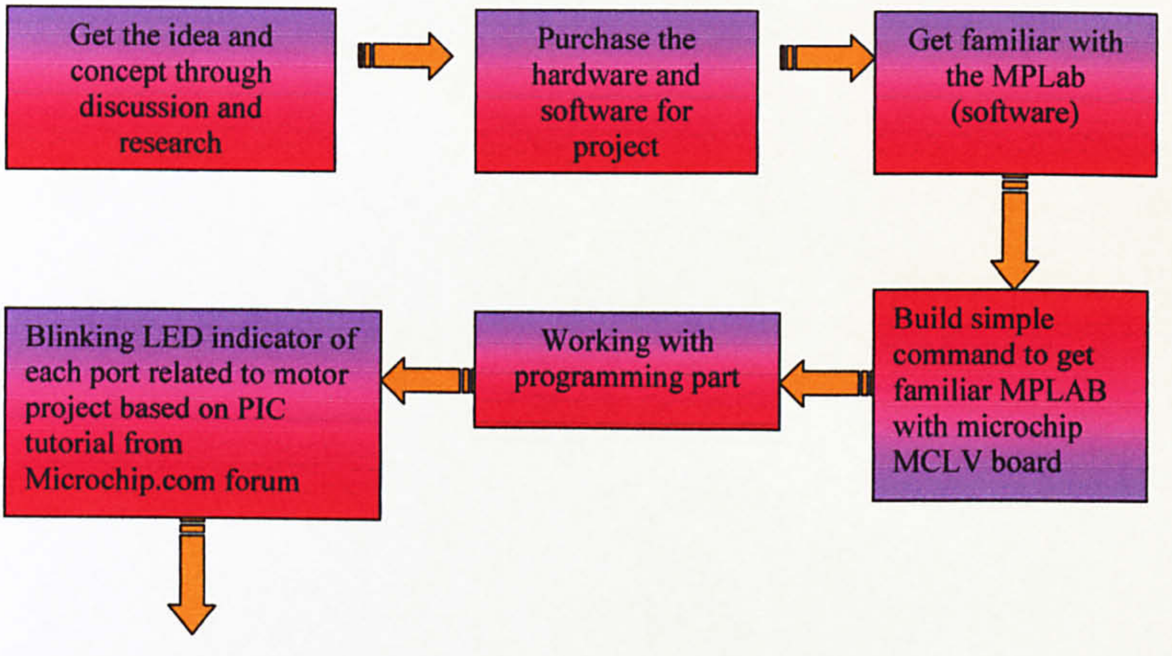
i. dsPICDEM MCLV Development Board (MA330017)
   dsPIC 33FJ32MC204
ii. 24V power supply
iii. 24V Emerson Hurst BLDC Motor (AC 300020)
iv. AC/DC converter adapter
v. Serial, R232 cable, USB
vi. Debugger adapter
vii. MPLAB ICD2 (debugger)

CHAPTER 3

METHODOLOGY

3.1 Procedure Identification

In doing the research, there are several methodologies that are taken into account. In the appendix section, the author had stated the Gantt chart of the flow of work project has done. Through consultation with related lecturers, the author has come out with some information on the project. The flow of project work done is summarized as follow:



(a)

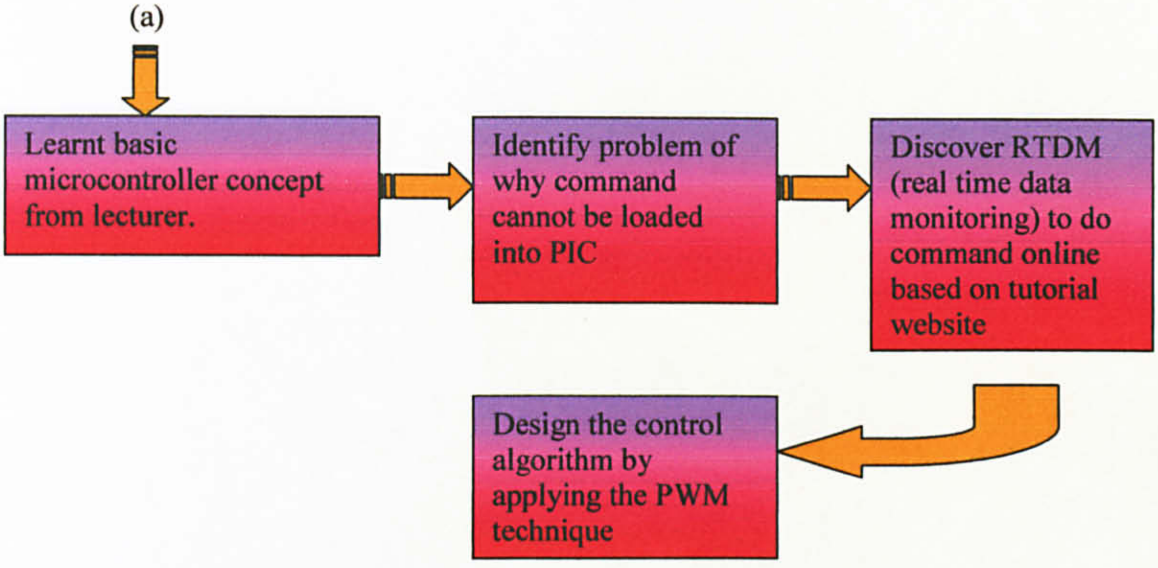


Figure 8: Flow of procedures identification

For development process command with MPLAB IDE v8.30 software, there are 4 steps that need to be considered:

i) Program the application code into the target application, using MPLAB ICD2 as the current debug tool.
ii) Debug the application.
iii) Modify the source code, rebuild the project and repeat until the application performs as designed.
iv) Select MPLAB ICD 2 as the current programmer and program the part for use in the target application

A sequence of methodology is required to perform simulation of a model. The author had met Information System master student and Programming lecturer to analyze the coding that had been gained. Analyzing the coding involved declare variable, assign function and looping of function. Figure 9 in the next page briefly explain in term of overall process flow of the project.

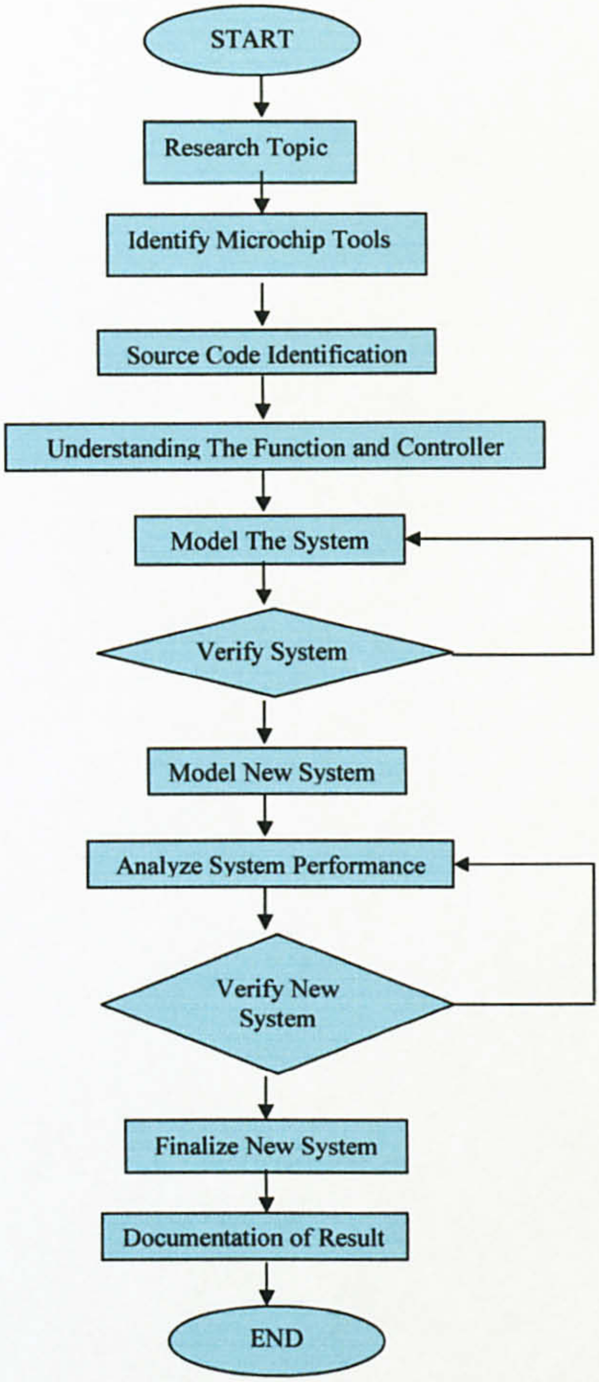


Figure 9: Project Flow Chart

From Figure 9, there are several steps of project flow that need to follow those are:

Step 1) The research information regarding the project topic had been done through meetings with lecturers, master students, and technicians. References on research papers of local and abroad students who had done slightly the same area of project also being noted.

Step 2) Microchip tools of dsPICDEM MCLV Development Board (MA330017), dsPIC 33FJ32MC204, Serial, R232 cable USB, Debugger adapter and MPLAB ICD2 (debugger) being purchased. Other component that had being purchased are 24V Emerson Hurst BLDC Motor (AC 300020) and AC/DC converter adapter[5]. The equipments that had been purchased mainly from Microchip Company are being identified clearly to avoid wrong purchasing equipment or unsuitable equipments with the system.

Step 3 and step 4) MPLAB IDE and ICD2 manual help the author to do the source code identification. Support website of Microchip Company also being surfed to understand the function of each code.

Step 5) In modeling the system, development process command with MPLAB IDE v8.30 software has been used. There are 4 steps that need to be considered:

i. Program the application code into the target application, using MPLAB ICD2 as the current debug tool[6].

   Several dsPIC 33FJ32MC204 software programming steps involved before reaching the debugging process:

   - Selecting the device
   - Creating the project
   - Setting up language tools
   - Setting up template and linker file for the project
   - Creating code
   - Testing code with the ICD2 debugger

ii. Debug the application.
iii. Modify the source code, rebuild the project and repeat until the application performs as designed.
iv. Select MPLAB ICD 2 as the current programmer and program the part for use in the target application

Step 6) The author had met Information System master student and Programming lecturer to analyze the coding that had been gained. Analyzing the coding involved declare variable, assign function and looping of function[7].

Step 7 and step 8) After basic configuration of the system had been clarified and done, new system being modeled. One of the steps to analyze the system performance is through LED indication of the development board when functional command being instructed to the port or circuit components[7].

Prior to model the system through MPLAB to run the motor, flow chart of how the system run need to do. Figure 10 below shows the reference flow chart of how the system detects the back EMF between commutations.

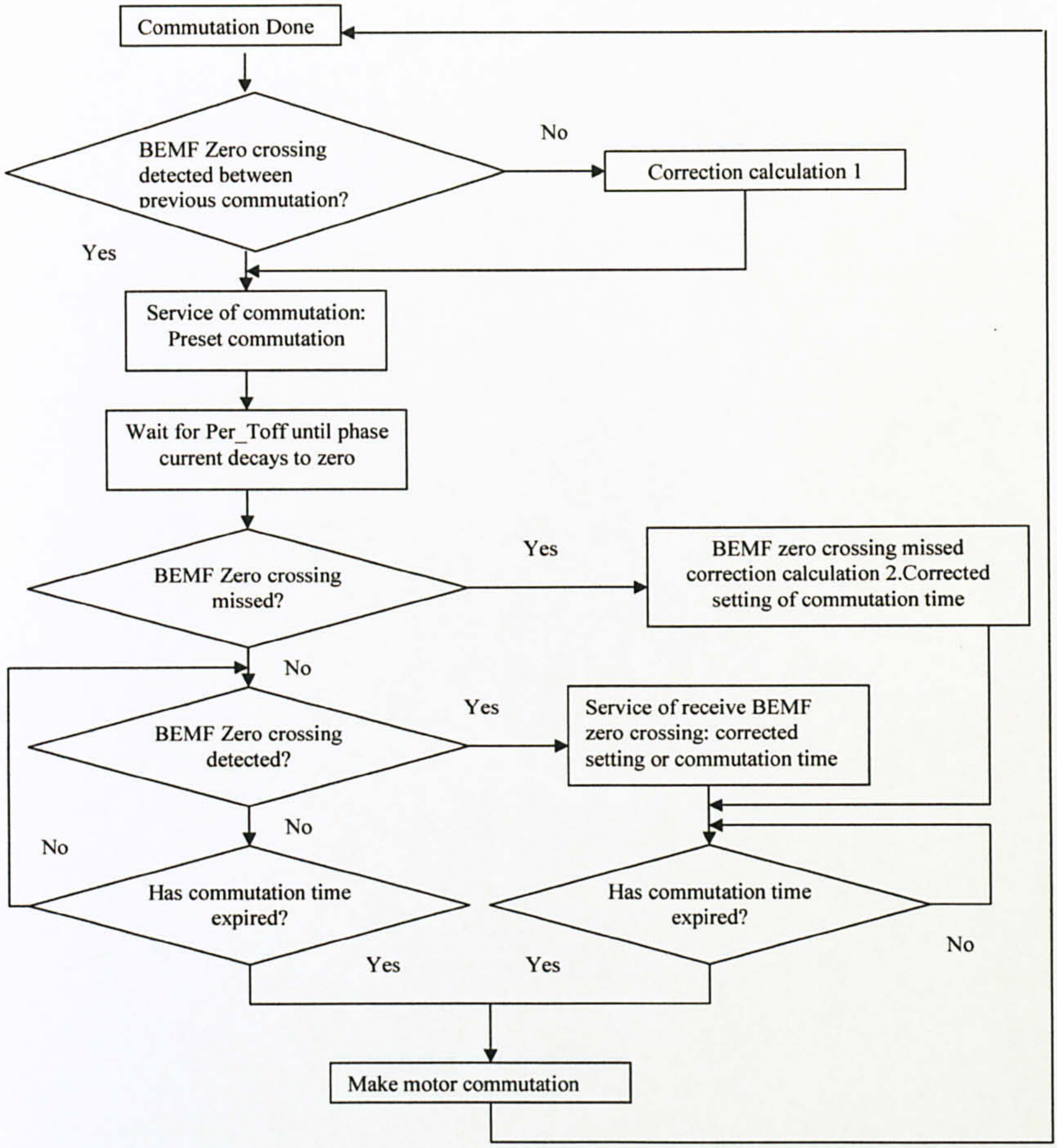


Figure 10 : References flow chart of the system

Step 9 and step 10) Verification of new system by consulting supervisor, related field lecturers and master student. Online tutorial of MPLAB Microchip help the author to finalize the system through Real Time Data Monitoring without halting the real system of the motor.

Even though online simulation is being done, the information of specification PIC 44-to-100 pins from the development and detail information of BLDC motor from Emerson need to be capture and locate in the command system. This is to ensure the performance of simulated online motor control that had been gained will be exactly with the real motor performance[8].

Communication aspects between tutorial MPLAB online software with digital signal processing 33FJ32MJ204 are carefully being identified. In controlling the simulated motor system, initialization of the device peripherals needs to take into consideration as below:

- PWM configuration to drive the motor
- Timer to generate a synchronous update of the PWM.

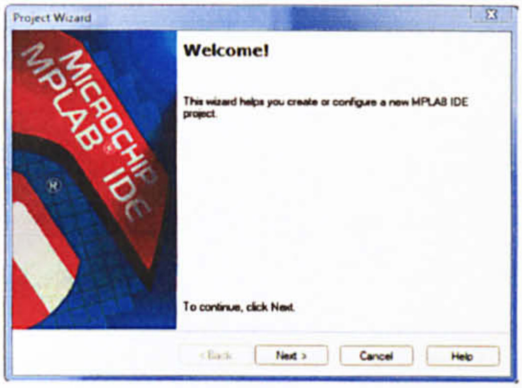
Step 11) Documentation of the result includes graphical simulation, analytical view of the system and numerical interpretation.

3.2 An Overview of Embedded Systems

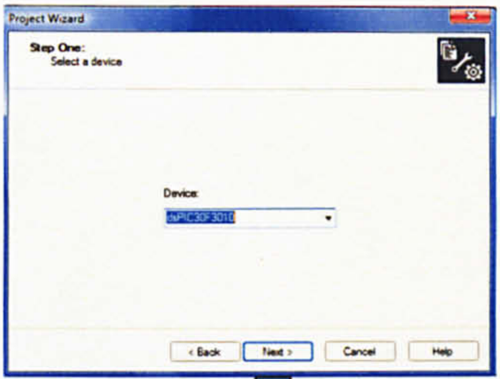
An embedded system is typically a design making use of the power of a small controller, like the microcontroller or Digital Signal Processor (DSP). These controllers combine a microprocessor unit with some peripherals, plus some additional circuits on the same chip to make a small control module; this may require few other external devices. This single device can then be embedded into other electronic and mechanical devices for low-cost digital control.

The command windows for the step of debugging:

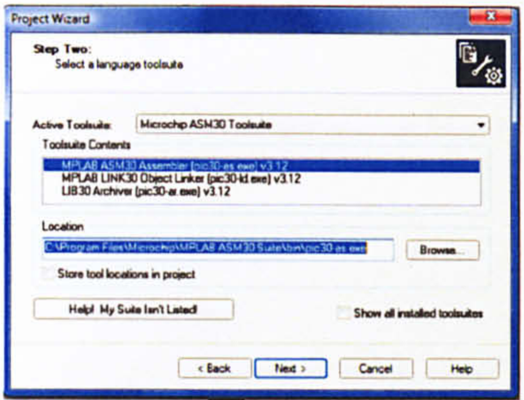
Set up wizard and tools



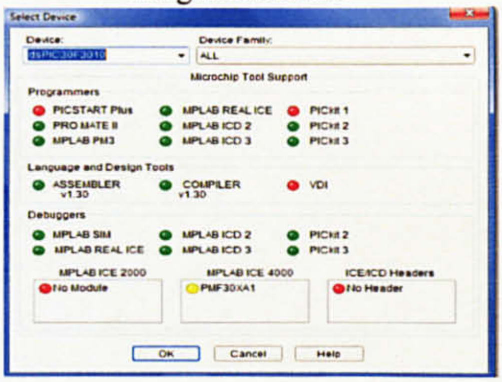
Selecting device



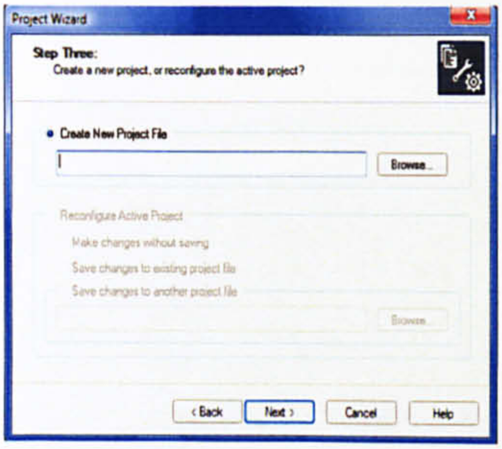
Setting up language tool



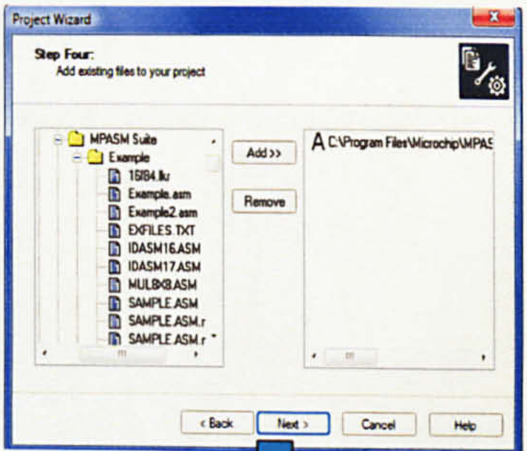
Choosing the correct integrated circuit



Creating the project



Set up linker and source file



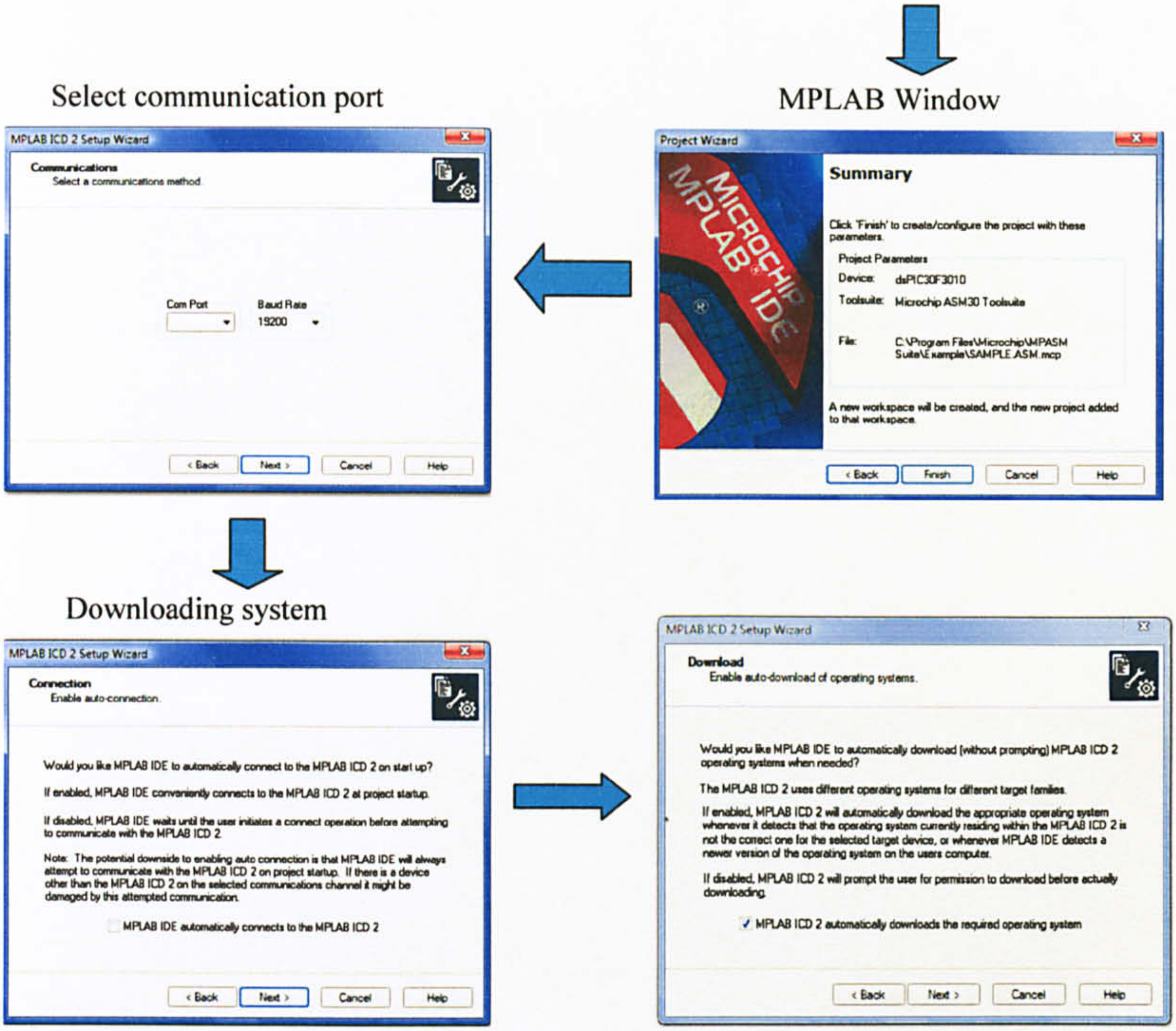


Figure 11 : Step taken to begin with MPLAB debugger system

MPLAB window procedure to debug the system in early stage is shown in Figure 11. While Figure 12 it shows the on-chip analog-to-digital converter records phase currents, dc bus voltage information, and other data from both inverters. The circular equipment that connect the development board with the computer is the ICD2 Debugger from Microchip Company. Encoder interface modules in the DSP controller accept the encoder feedback. The on-chip power electronics peripherals provide glue-less interface to the inverters, simplifying the overall system design.

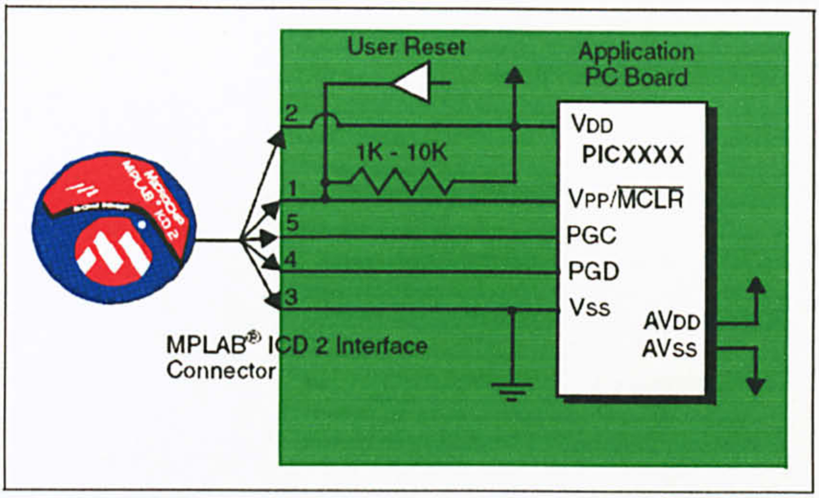


Figure 12: MPLAB ICD2 connections to target board

To generate the necessary signals for two voltage inverters, the hardware set up uses six PWM outputs. The on-chip Quadrature Encoder Pulse (QEP) interfaces in the DSP connect to each of the motor encoders.

3.2.1 Communicating with digital signal processing 33FJ32MJ204

In controlling the simulated motor system, Initialization of the device peripherals needs to take into consideration as below:

- PWM configuration to drive the motor
- Timer to generate a synchronous update of the PWM.

3.2.2 Hardware setup:

a) Jumpers JP1, JP2 and JP3 on encoder (replace Hall sensor)
b) J6 installed to supply power from J2 to J7

c) The Emerson Hurst BLDC motor are connected to quadrature encoder interface connector on the right side as follows:

i. RED +5V

ii. BLACK GND

iii. WHITE QE A

iv. BROWN QE B

v. GREEN QE C

d) +24V (power for motor) is connected to J2

e) The Hurst BLDC winding are connected as follow:

i. GREEN 'G'

ii. RED 'M1'

iii. BLACK 'M2'

iv. WHITE 'M3'

f) dsPIC 33FJ32MC204 PIM configuration:

The device names, pin counts and peripheral availability of each device are listed appendix at the end of this report.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Simulation and Graphical

The author learn on the usage of microchip hardware and software through support link provided http://support.microchip.com. Since the codes could not be loading into the motor development board, sample link is provided to help student in studying the expected output perfomance should be. Free evaluation sample is access at http://sample.microchip.com and training link at www.microchip.com/training.

Based on the source code that the author investigates, some discussion could be clarified. In constructing the command, the author needs to consider the definition for each function.

Explaination on the few steps of MPLAB program:

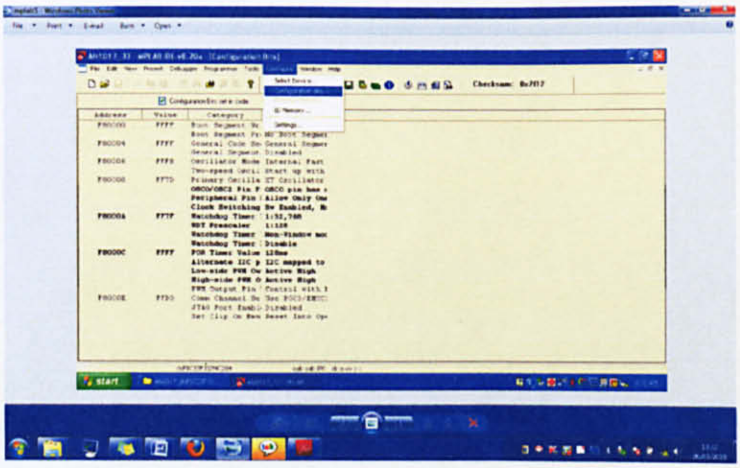


Figure 13: C30 compiler

Figure 13 shows the pop up window of C30 compiler. Like an assembler, the compiler translates human-understandable statements into ones and zeros for the microcontroller to execute. Unlike an assembler, the compiler does not do a one-to-one translation of machine mnemonics into machine code.

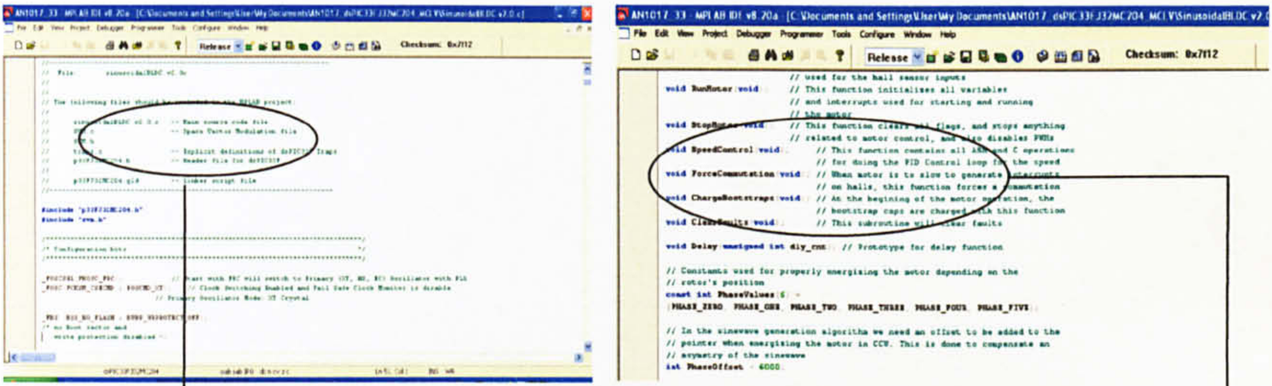


Figure 14: Command window of MPLAB identify main code

Defining main code at the beginning part of the program. By this, the code will only being called through external souce code that had been define.

Main source code file

Space vector modulation file

Header file of dsPIC 33FJ32MC204

Linker script file

Define: StepMotor(void)

SpeedControlMotor(void)

ForceCommutation(void)

PWM(void)

BackEMF(void)

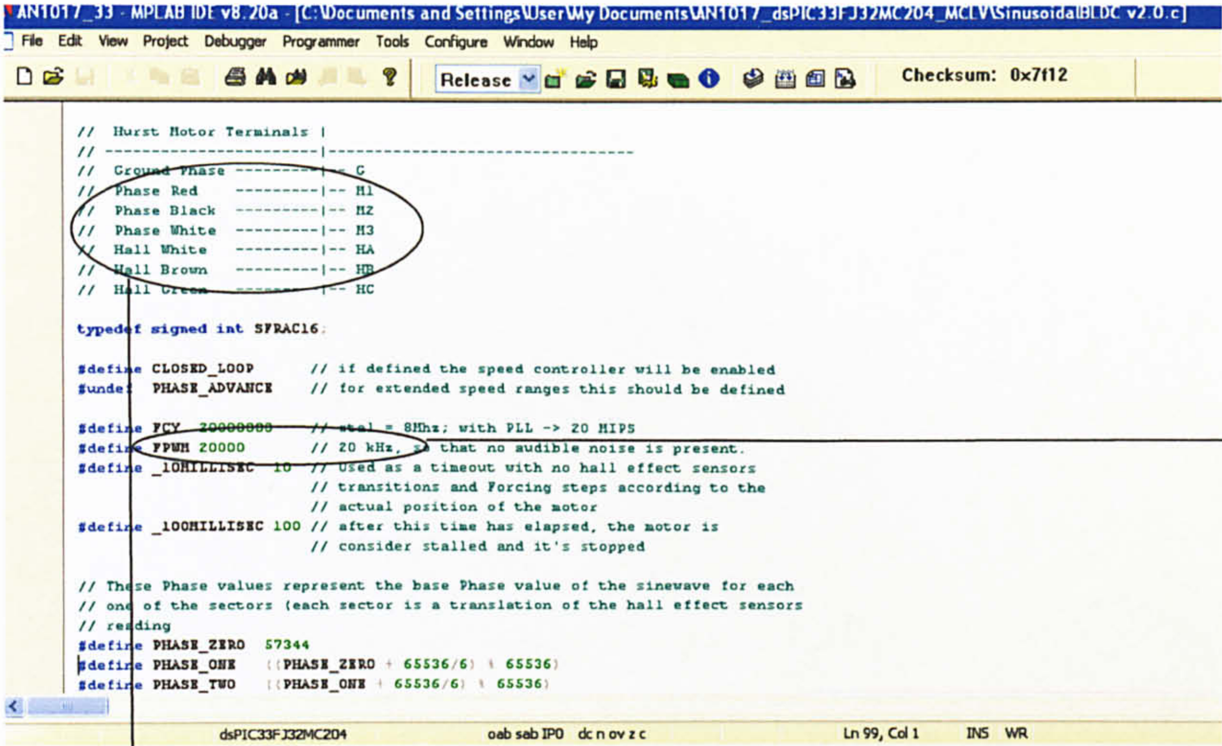


Figure 15:Command window of MPLAB defining functions in main code

Identification for each motor port is define as M1 = PHASE_ZERO

M2 = PHASE_ ONE

M3 = PHASE_TWO

Three phase motor winding

HA/ QE1 = PHASE_THREE

HB/QE2 = PHASE_FOUR

HC/QE3 = PHASE_FIVE

Setting mode motor controller to be sensored or sensorless

Pulse width modulator with 20Khz frequency is

Being used so that no audible noise present in the output wave form.

Part of controller command that had been considered when running the system:

```
// Period Calculation
// Period = (TMRClock * 60) / (RPM * Motor_Poles)
// For example>
// Motor_Poles = 10                                        625
// RPM = 6000 (Max Speed)                          3000
// Period = ((20,000,000 / 64) * 60) / (6000 * 10) = 312.5
// RPM = 60 (Min Speed)
// Period = ((20,000,000 / 64) * 60) / (60 * 10) = 31250
```

In this project condition, the maximum speed of the motor is considered 3000 rpm

Identification timer clock of the system

$$\text{Period} = \frac{\text{Timer clock x 60}}{\text{Radius per minute x number of motor poles}}.$$

The above Figure 15 defines the functions involved in main code those are Step Motor(void), Speed Control Motor(void), Force Commutation(void), PWM(void) and BackEMF(void)[9].

To do the period calculation of the motor controller, the author noted the 6 poles of the motor, calculation on the maximum speed performance radius per minute (rpm) and considering the timer clock system involve on that particular time. Below is the simple calculation for understanding of the period taken.Other correction on the calculation performance of the motor is being done to make the controller compatible with the system[10].

This MPLAB C compiler takes standard C statements, such as “if(x==y)” and “temp=0x27” and converts them into dsPIC30/33XXXX machine code. The compiler incorporates a good deal of intelligence in this process. It can optimize code using routines that were employed on one C function to be used by other C functions.

The compiler can re-arrange code, eliminate code that will never be executed, share common code fragments among multiple functions, and can identify data and registers that are used inefficiently, optimizing their access

Source text is compiled into blocks of program code and data which are then "linked" with other blocks of code and data, then placed into the various memory regions of the dsPIC30/33XXXX microcontroller. This process is called a "build," and it is often executed many times in program development as code is written, tested and debugged.

However, the problem encountered when burn the code. This is assume to happen due to a heavy command with the size of 15KB compared to the space board of 12KB.

It is very tough to do command in ICD2 mplab. By using this, the user need to develop this command step by step and it takes longer time. The advance technology of microchip company nowadays use MPLAB with MATLAB where it provides more advance tools with block diagram of dsPIC ports.

In controlling the performance of the BLDC motor, the author need to consider the

- Reliable timer that operates from its own internal window oscillator
- Enhancement of motor control peripheral with up to eight channels of motor control PWMs that are either center-aligned or edge-alligned
- Since there are two part of BLDC motor,sensor and sensorless, the Quadrature Encoder Indicator (QEI) is need to consider in eliminating the hall sensor.
- This improves system performance and reduces software overhead.

From the work that had been done, the author manage to run the source code related to back EMF zero crossing in the MPLAB ICD2. However, since a problem occur in loading the code into the dsPIC, the expected back Electromotive Force (EMF) trapezoidal wave form that microchip company had been gained through online MPLAB tutorial.

By using the motor leads of a BLDC motor, the "zero-crossing" of the BEMF signal appears insectors 0 through 5[11]. Each sector corresponds to a 60-degree portion of the electrical cycle. There is a 30-degree offset between the BEMF zero-crossings.

Fundamental of back EMF has been stated by

$E = 4.44\,k\ f\,T\,\omega$ volts

The electromotive force induced by the rotating field in the stator phase

The electromotive force refered to stator of an equivalent rotor phase , $E' = sE$

Referring to rotor

Pulse width modulation waveform:

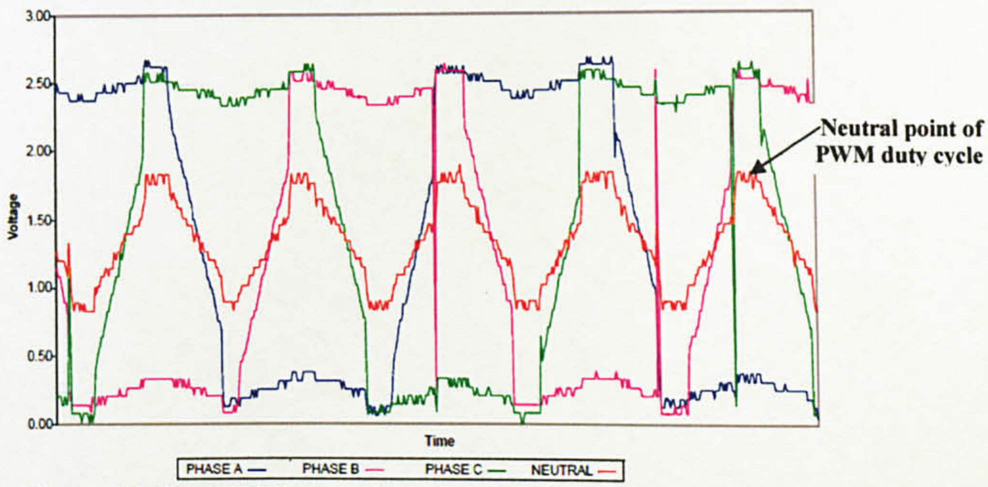


Figure 16: Back EMF signal versus virtual neutral point when the pwm duty cycle is equal to 100%

Figure 16 explains the Back EMF signal versus virtual neutral point when the PWM duty cycle is equal to 100%. These show the three waveforms of each phases a,b,and c. Initially the PWM carrier frequency is set at 32 kHz in the MPLAB c command[12]. The experimental comfirm the validity of the result.

The real graph tripazoidal wave form actually consist of noise. The phase back EMF of the floating winding of the motor then is extracted from the winding terminal voltge during off PWM. Having the capacitor in the motor control development bord at the inverter side of the circuit eliminate the noise.

Another formula for BEMF:

$$\mathbf{BEMF = NlrB\omega}$$

Where:

N = number of windings per phase
l = length of the rotor
r = internal radius of the rotor
B = rotor magnetic field
ω = angular velocity

In voltage mode, the 12-bit timer PWM siganal compare each phases which gives voltage to be applied to the motor. PWM signal is applied to the switches. The internal clock time is considered. In next two page show step 5 of the window system. It shows the current limitation implemented with related phases voltage. In current mode, 12 bits timer PWM signal gives the reference current to be applied to the motor. The internal clock is used for applied mosfet switches. The current is regulated by comparing the reference current and the feedback current from the BLDC motor.

Figure 17 shows the back EMF signals with the BEMF sampling signal and PWM signal.There are refering to the terminal voltage signals of each phases. The contrast of U (neutral voltage) , U (terminal voltagephases) and PWM waveforms in the self-controlled mode can be seen clearly. Zero crossing point that lies through neutral point signal verify that good performance of the motor. It can be improved by back EMF detection method and the start-up motor. From the circuit embedded in the development board, we can link with the equation:

$$U = 0 - ri - L\frac{di}{dt} - U$$

U is the neutral voltage
r is the resistence exist on the circuit board
L inductance
U is the each phase backEMF

Balance three-phase system would be
$U + U + U = 0$
As per calculated by the system.

It is important to note that this terminal voltage is referenced to the ground, insteead of the floating neutral point. Since the true back EMF is extracted from the motor terminal voltage, the zero crossing of the phase back EMF can be detected very precisely.

Figure 17 is based on the Mid-Point voltage reconstruction and is also based on detecting the instances when the back EMF of an inactive phase is zero. Therefore, the back EMF sensing method described can only be implemented using trapezoidal BEMF signals in order to have zero crossing. Back EMF signal conditioning and the power switch gate are so much related.In this case, it mean that the 6 mosfets linked to each other in switching the motor is important in sensing back EMF of the rotor.

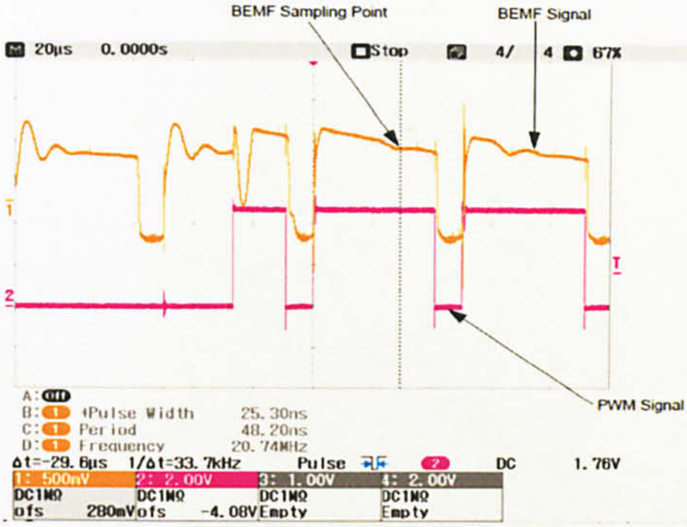


Figure 17: Back EMF sampling point at 80% of duty cycle

This graph is based on the Mid-Point voltage reconstruction and is also based on detecting the instances when the back EMF of an inactive phase is zero. Therefore, the BEMF sensing method described can only be implemented using trapezoidal BEMF signals in order to have zero crossing events.

BEMF signal conditioning and the power switch gate are so much related.In this case, it mean that the 6 mosfets linked to each other in switching the motor is important in sensing back EMF of the rotor. Figure 17 and 18 show how the sampling point back EMF with related to the particular percentage of PWM duty cycle for inverter switching.

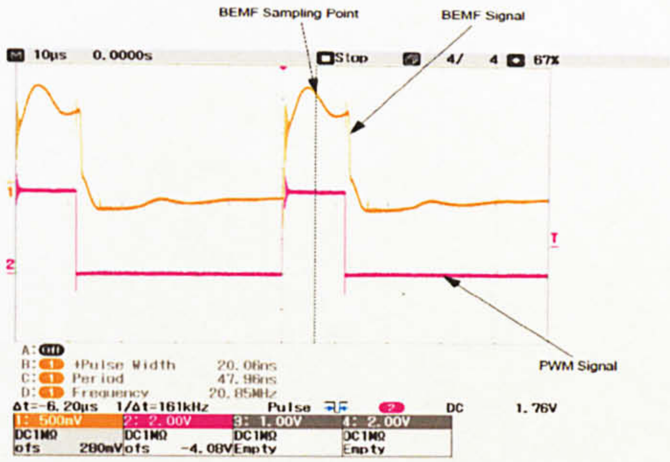
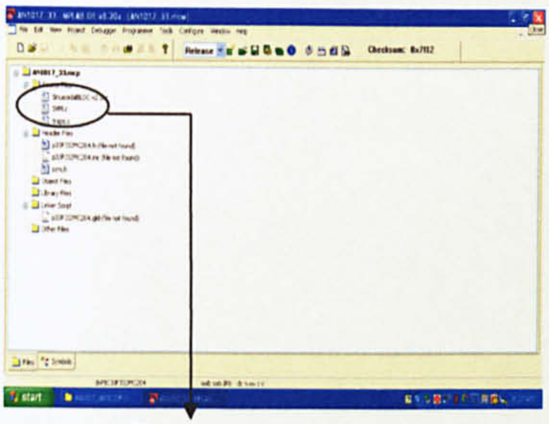
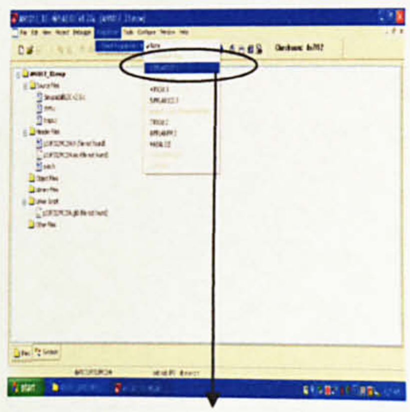


Figure 18: Comapring the 80% result with the 20% duty cycle

Below are some procedure taken to observe the graphical simulation performance of the BLDC motor.



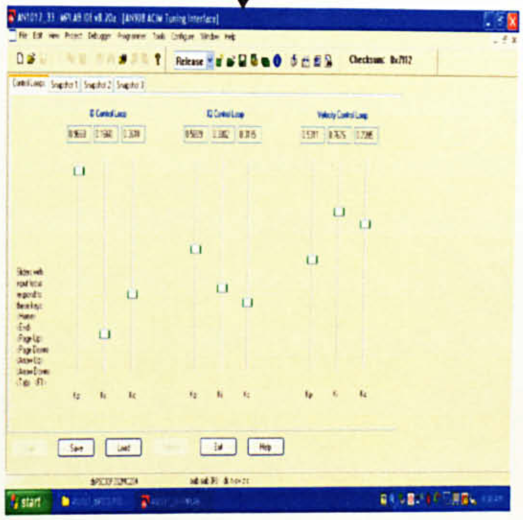
Step 1 :The main source code of this program (Sinusoidal BLDC)
ICD2



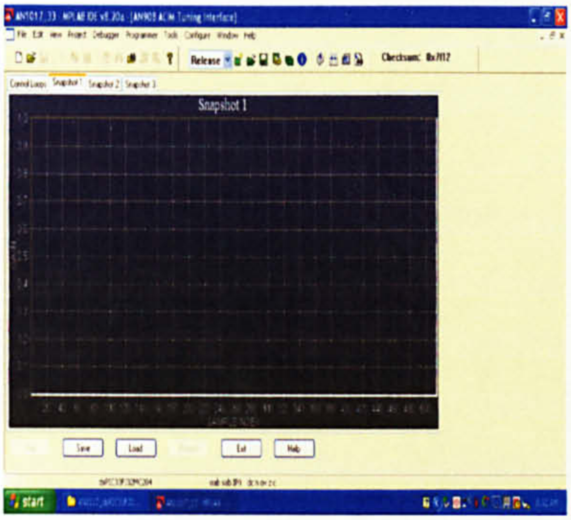
Step 2: Cable mplab software type handling with AN1017 is the MPLAB

(b)

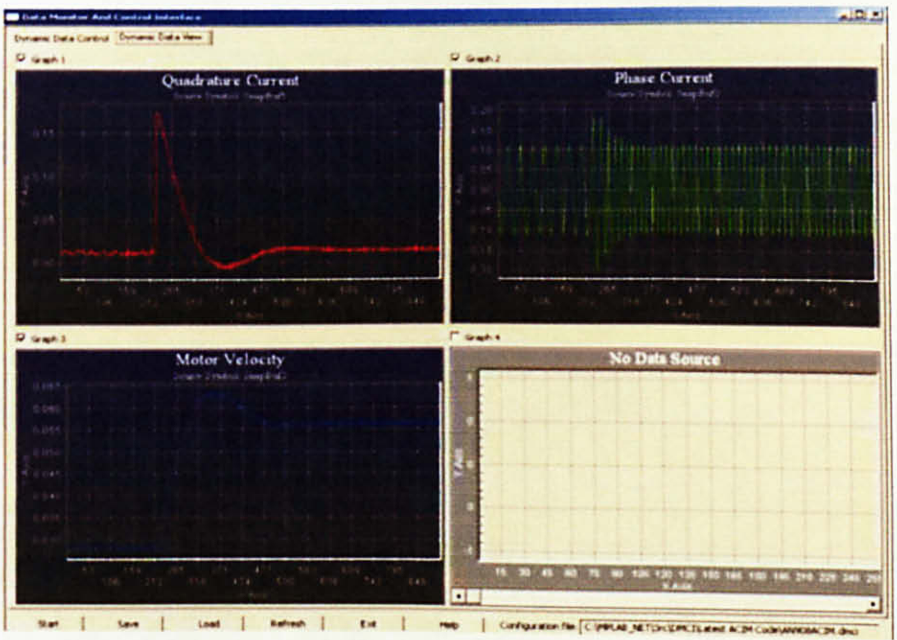
(b)



Step 3: After build command success, window will appear the slider gain. Kp(proportional gain), Kc(controller gain) and Ki (integral gain)



Step 4: The oscillator screen window appear to output the graph of motor performance-basically the phase current and voltage



Step 5: Expected output graph when the code is load into dsPIC 33FJ32MC204 Motor would perform its duty as per show in the graph.

The previous page of Step 5 shows the performance of the motor showing the quadrature current that go through the motor, phase current and motor velocity. This result is gained through to motor control with digital signal controllers dsPIC 33FJ32MC204 online viewer. The Data Monitoring and Control Interface (DMCI) is being used at this moment. DMCI provides quick dynamic integration with the MPLAB IDE for the motor performance depending on variable control range values, on/off states of commutation. It includes:

i) slider control controls like shown in step 3.
   - Command on gains being construct to suit with different performance of motor.
ii) input controls
iii) 4 graphical monitoring

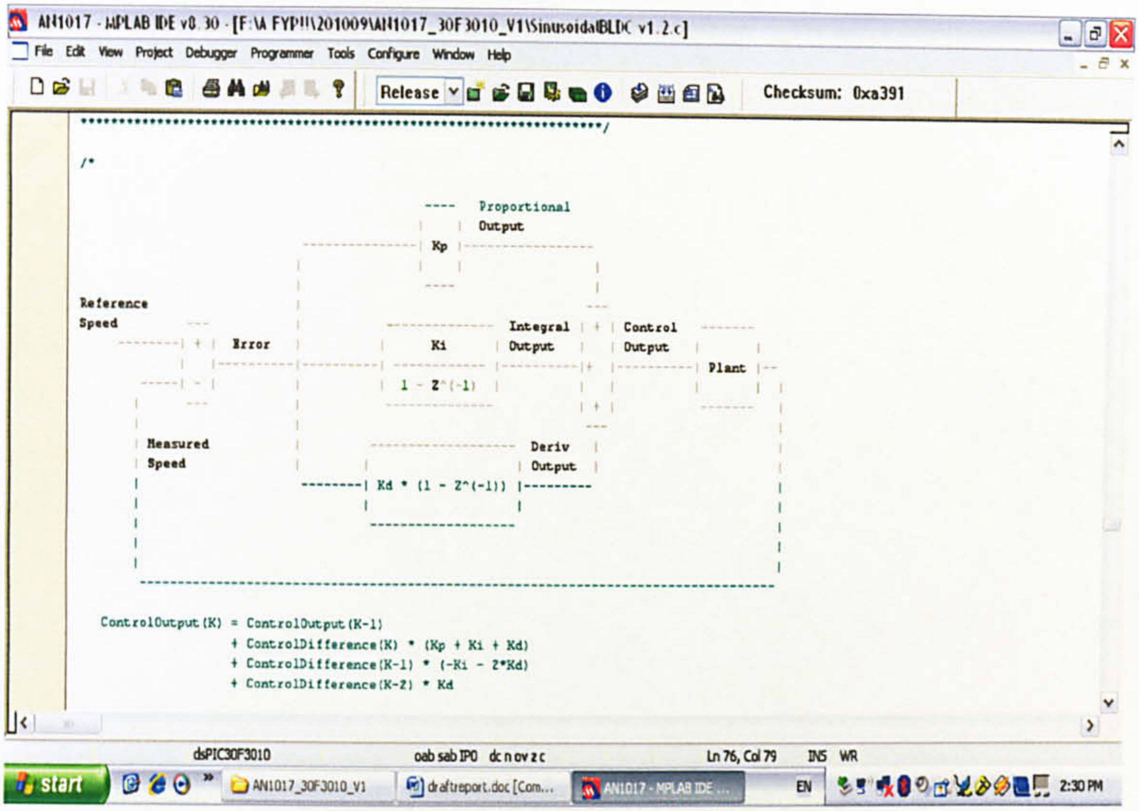


Figure 19 : Propotional Integral Derivative Controller

ControlOutput(K) = ControlOutput(K-1)

+ ControlDifference(K) * (Kp + Ki + Kd)

+ ControlDifference(K-1) * (-Ki - 2*Kd)

+ ControlDifference(K-2) * Kd

Using PIDCoefficients:

PIDCoefficients[0] = Kp + Ki + Kd

PIDCoefficients[1] = -(Kp + 2*Kd)

PIDCoefficients[2] = Kd

and leting:

ControlOutput -> ControlOutput(K) and ControlOutput(K-1)

ControlDifference[0] -> ControlDifference(K)

ControlDifference[1] -> ControlDifference(K-1)

ControlDifference[2] -> ControlDifference(K-2)

ControlOutput = ControlOutput

+ ControlDifference[0] * PIDCoefficients[0]

+ ControlDifference[1] * PIDCoefficients[1]

+ ControlDifference[2] * PIDCoefficients[2]

This implementation of the PID controls the speed and the performance of the dsPIC features and BLDC motor. When adjusting the PID gains; it is responsible to avoid maximum value of PID coefficient. The above values represent fractional values of motor performance and also tell software to run in which direction, CW (clockwise) or CCW (counter clockwise)[13].

4.2 Specification of the Motor

From the result that obtained, the author comes out with the specification of the Brushless DC motor[14]:

Table 2: Motor specification

Motor characteristics	**Motor Type**	**6 poles, 3 phase, Start connection**
	Speed range	3000 rpm
	Maximum line voltage	48 V
	Phase current	2A
	L-L Resistance	4.02 ohm
	Torque constant	0.08 Nm/A
	Voltage constant	7.24 Vpeak
Drive characteristics	Speed range	3000 rpm
	Input voltage	24 V
	Maximum output current	5A

4. 3 Analytical Performance

Below is the torque speed characteristic of BLDC motor. There are two torque parameters used to define a BLDC motor, peak torque (Tp) and rated torque (Tr). During the operations, the BLDC motor can be loaded up to the rated torque where the torque remains constant for a speed range up to the rated speed. When the motor starts from stationary to accelerate, it demand more torque than the rated torque. During this period, extra torque is required to overcome the inertia of the load and rotor it self.

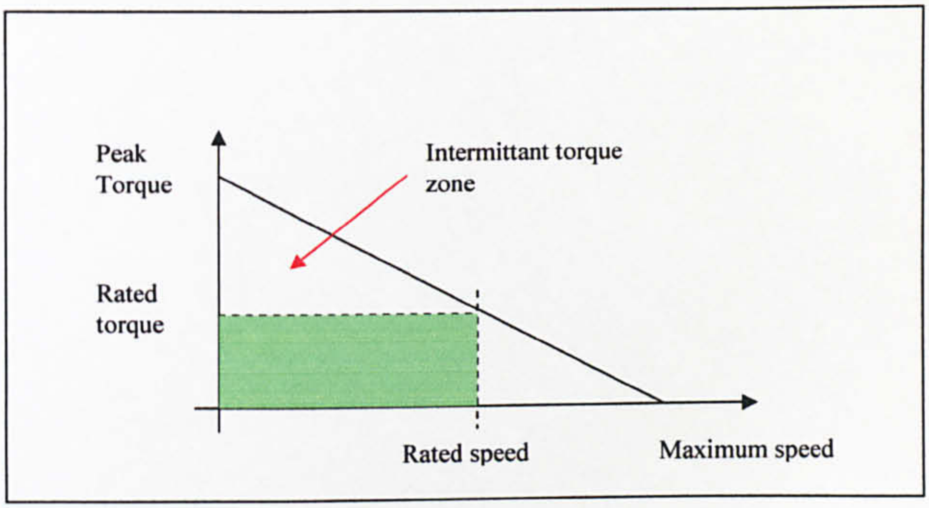


Figure 20: Torque and speed characteristic of BLDC motor

CHAPTER 5

CONCLUSION

A control system for sensorless BLDC motor involved in detecting back EMF. It also involved in driving commutation in a correct sequence. Back EMF having the relation with commutation point will influence the current flowing in the development board component to control the motor.

Performance of the motor system can be gain through this MPLAB system that had been implemented. Through Real Time Data Monitoring (RTDM) that had been introducing in this software, the motor performance can be estimated.

The true back EMF can be detected in the unused phase during the off time of PWM on the other two phases. This is because the unused phase terminal voltage is directly proportional to that phase's back EMF during the interval.

This unique back EMF sensing method has superior performance to the others which rely on neutral voltage information, providing much wider motor speed range.

For further recommendation, MPLAB with MATLAB need to purchase in order to load the programmed motor system into the motor control board to observe the physical performance of Hurst BLDC motor from Emerson Company. This part will be further by the master student who is doing the same research on this topic.

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APPENDICES

APPENDIX 1
Final Year Project II Gantt Chart

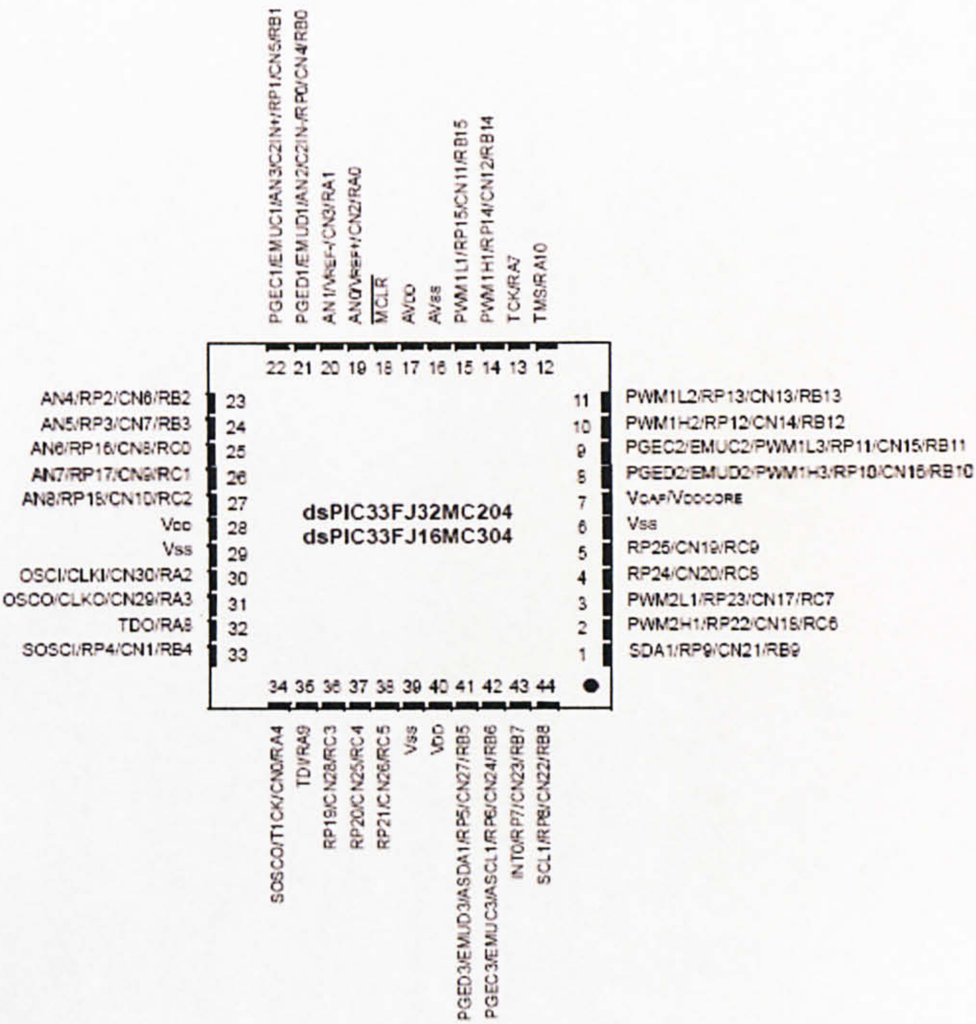
ACTIVITIES	WEEKS														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1)Discussion with master Student and robocon team to deal with microchip MPLAB a) Meeting supervisor - get a briefing on final semester FYP progress	■														
2.Deal to use microprocessor Lab in running the project through out the semester and get permission to leave project equipment in the lab		■													
3. Synchronize source of MCLV board, Emerson Hurst BLDC motor data sheet			■												
4) Meet microcontroller lecturer and tutor to get better understanding on each combination of command crammed in c30 compiler				■											
5. Run the software with related Command a) Debug MPLAB ICD2					■	■	■	■							
6) Power analyzation a) Back EMF b) PWM c) speed d) rotation							■	■	■	■	■	■	■	■	■

APPENDIX 2

Pin diagram dsPIC 33FJ32MC204

APPENDIX 2

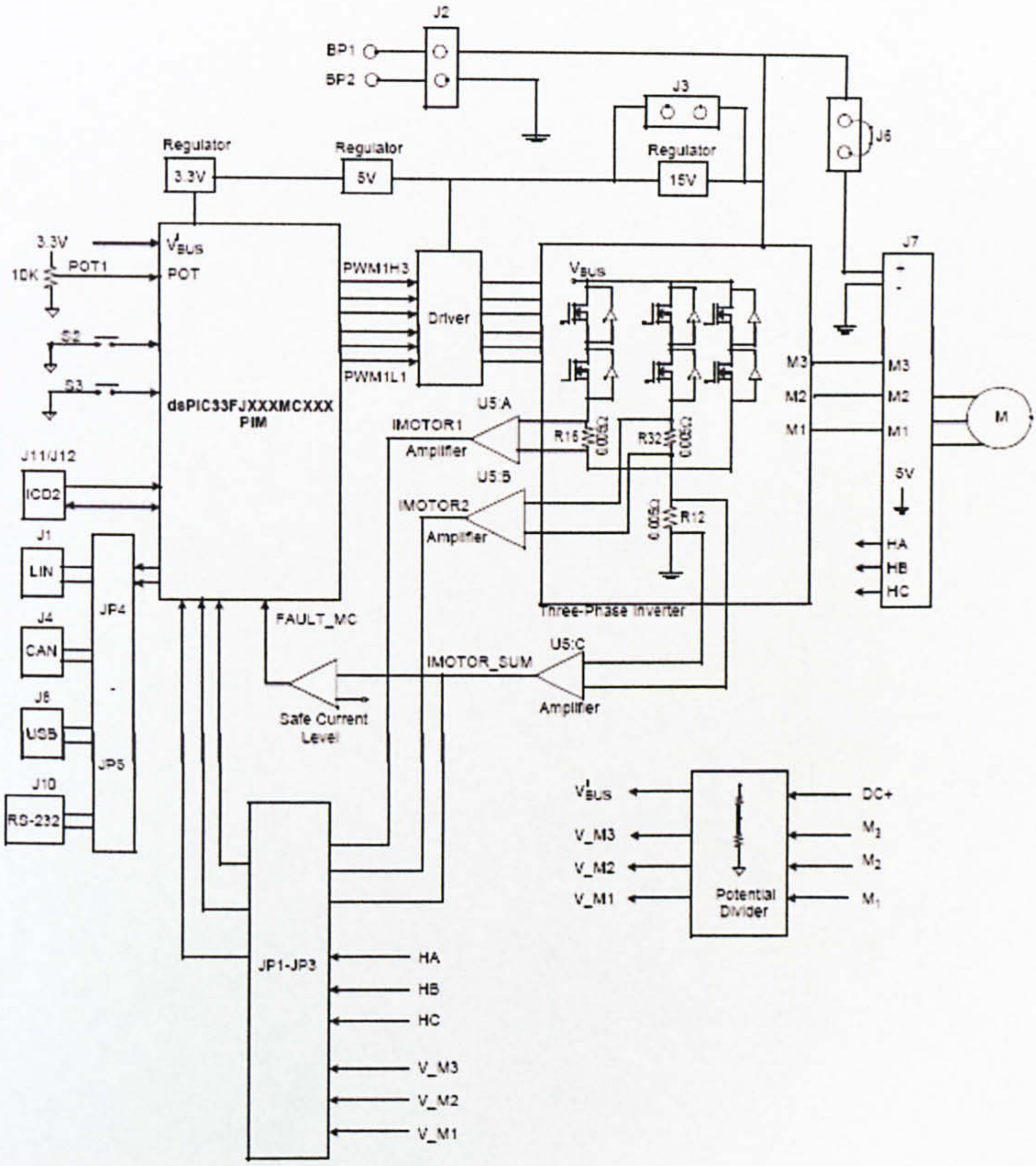
Pin diagram dsPIC 33FJ32MC204

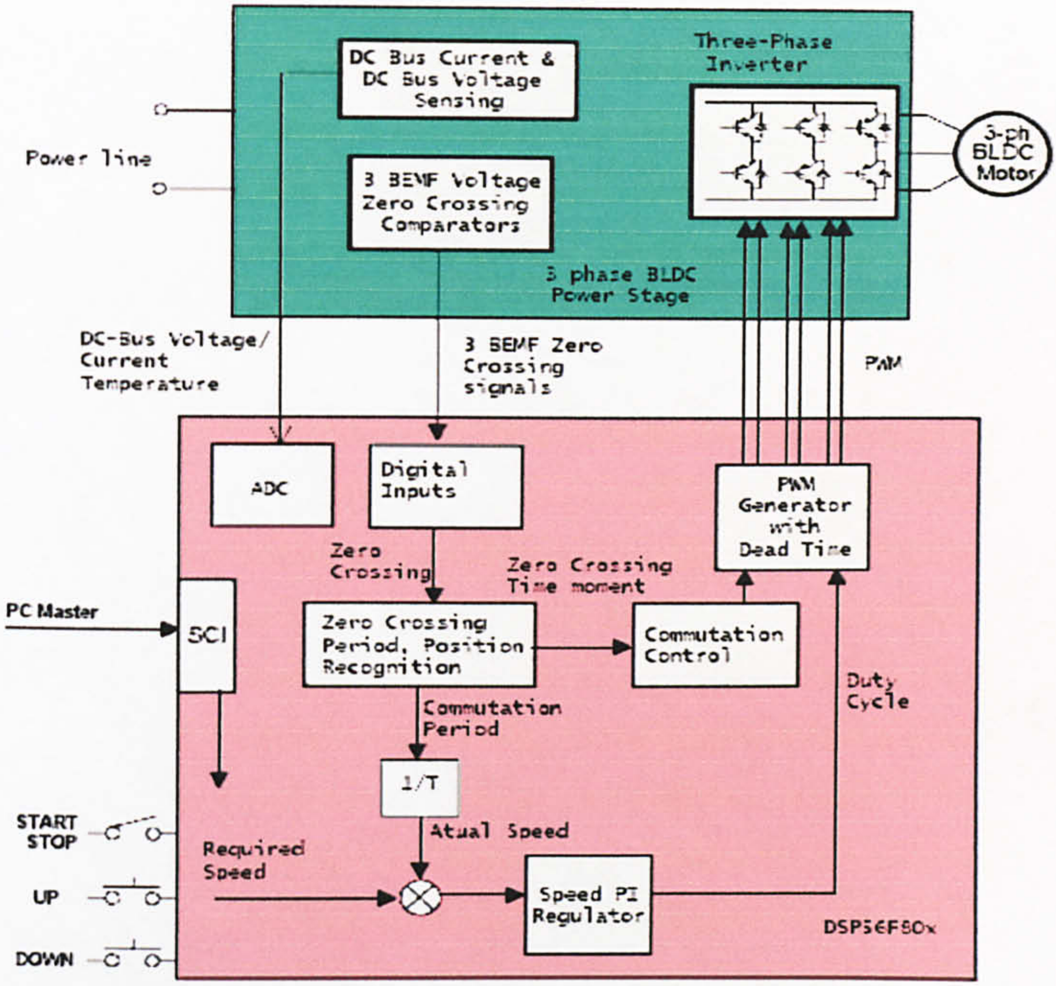


PGEC1/EMUC1/AN3/C2IN+/RP1/CN5/RB1
PGED1/EMUD1/AN2/C2IN-/RP0/CN4/RB0
AN1/VREF-/CN3/RA1
AN0/VREF+/CN2/RA0
MCLR
AVDD
AVSS
PWM1L1/RP15/CN11/RB15
PWM1H1/RP14/CN12/RB14
TCK/RA7
TMS/RA10
AN4/RP2/CN6/RB2
AN5/RP3/CN7/RB3
AN6/RP16/CN8/RC0
AN7/RP17/CN9/RC1
AN8/RP18/CN10/RC2
VDD
VSS
OSCI/CLKI/CN30/RA2
OSCO/CLKO/CN29/RA3
TDO/RA8
SOSCI/RP4/CN1/RB4
dsPIC33FJ32MC204
dsPIC33FJ16MC304
PWM1L2/RP13/CN13/RB13
PWM1H2/RP12/CN14/RB12
PGEC2/EMUC2/PWM1L3/RP11/CN15/RB11
PGED2/EMUD2/PWM1H3/RP10/CN16/RB10
VCAP/VDDCORE
VSS
RP25/CN19/RC9
RP24/CN20/RC8
PWM2L1/RP23/CN17/RC7
PWM2H1/RP22/CN18/RC6
SDA1/RP9/CN21/RB9
SOSCO/T1CK/CN0/RA4
TDI/RA9
RP19/CN28/RC3
RP20/CN25/RC4
RP21/CN26/RC5
VSS
VDD
PGED3/EMUD3/ASDA1/RP5/CN27/RB5
PGEC3/EMUC3/ASCL1/RP6/CN24/RB6
INT0/RP7/CN23/RB7
SCL1/RP8/CN22/RB8

APPENDIX 3

Related BLDC motor integrated circuit schematic diagram


J2
BP1
BP2
J3
J6
Regulator
3.3V
Regulator
5V
Regulator
15V
3.3V
10K
POT1
VBUS
POT
S2
S3
dsPIC33FJXXXMCXXX
PIM
PWM1H3
PWM1L1
Driver
VBUS
J7
M3
M2
M1
M
5V
HA
HB
HC
U5:A
IMOTOR1
Amplifier
R15
R32
U5:B
IMOTOR2
Amplifier
R12
J11/J12
ICD2
J1
LIN
JP4
J4
CAN
J8
USB
JP5
J10
RS-232
FAULT_MC
Three-Phase Inverter
U5:C
IMOTOR_SUM
Safe Current
Level
Amplifier
VBUS
V_M3
V_M2
V_M1
Potential
Divider
DC+
JP1-JP3
HA
HB
HC
V_M3
V_M2
V_M1



DC Bus Current &
DC Bus Voltage
Sensing
Three-Phase
Inverter
3-ph
BLDC
Motor
Power line
3 BEMF Voltage
Zero Crossing
Comparators
3 phase BLDC
Power Stage
DC-Bus Voltage/
Current
Temperature
3 BEMF Zero
Crossing
signals
PWM
ADC
Digital
Inputs
PWM
Generator
with
Dead Time
Zero
Crossing
Zero Crossing
Time moment
PC Master
SCI
Zero Crossing
Period, Position
Recognition
Commutation
Control
Duty
Cycle
Commutation
Period
1/T
START
STOP
Atual Speed
Required
Speed
UP
Speed PI
Regulator
DSP56F80x
DOWN