

## **CHAPTER 3**

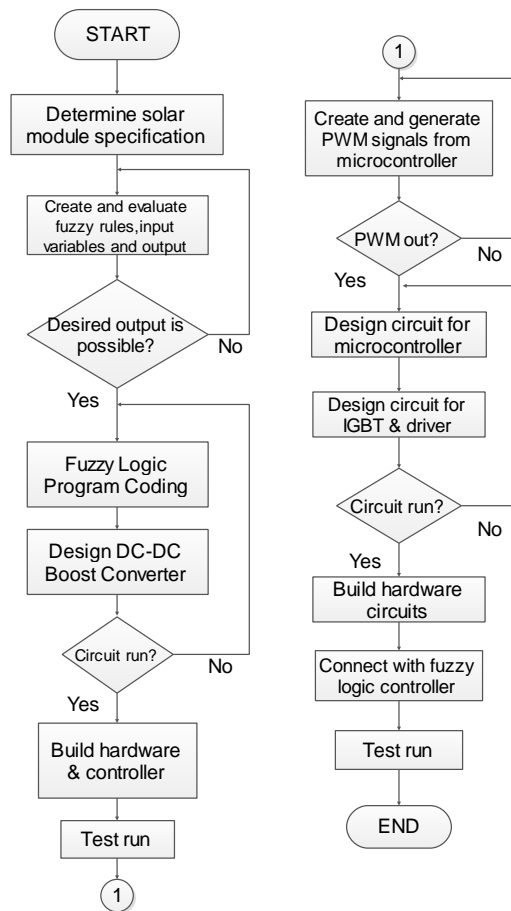
### **METHODOLOGY**

#### **3.1 INTRODUCTION**

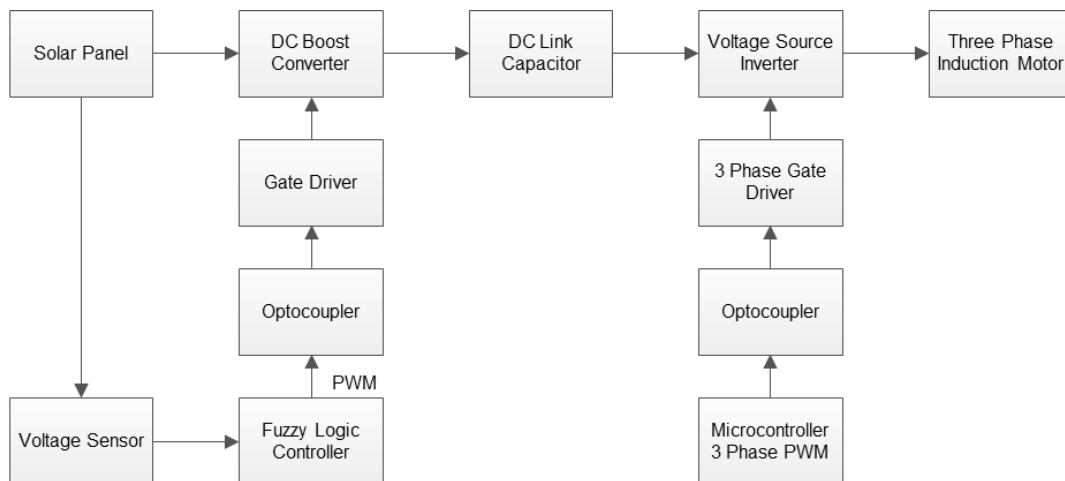
This chapter will explain about the flow chart of project, designing fuzzy logic controller and fuzzy logic algorithms. Next, it will explain electrical circuit design which included voltage divider, hall effect-based linear current sensor, and boost converter. Finally, it will continue to discuss about three phase sine PWM generated by microcontroller PIC18F4431, optocouplers, Intelligent Power Module and induction motor.

#### **3.2 PROJECT FLOW CHART AND BLOCK DIAGRAM**

Figure 3.1 is the flow chart that shows the methodology of project. The project is using solar module to get solar energy convert into electrical energy and send to fuzzy logic controller. the input voltage and current is sensed by voltage sensor and high side current shunt sensor and send to FLC. The fuzzy logic algorithms will produces PWM signal to optimize the boost converter to get desired voltage output. the fuzzy logic algorithms is using mamdani inference style to track maximum power point from solar module. After this, output voltage of boost converter will pass through DC bus capacitor to filter the output voltage ripple. Intelligent Power Module with bootstrap circuit will convert DC voltage into AC voltage for driving induction motor by the 3 phase PWM signals to gate IGBT. The optocoupler will amplifies the gate signal before send to IPM. The induction motor is controlled by the voltage source inverter by IPM.



**Figure 3.1:** Flow Chart of Project



**Figure 3.2:** Block Diagram of Project

### 3.3 FUZZY LOGIC CONTROLLED SOLAR MODULE

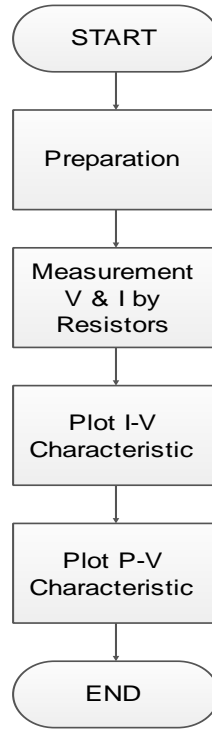
Firstly, the solar module specifications are required to be identified so that electronic components so that can proceed into next steps. The 60 cells Mono-crystalline photovoltaic

module is used in this project, which is the product name of MYS-60M/B3/CL-245. Every cells have positive power tolerance of 0 – 4.99 watts and high performance under low light conditions such as cloudy days, mornings and evenings. The data parameter of solar module is shown in Table 3.1 as below:

<b>MYS-60M/B3/CL-245</b>	
<b>Nominal Power (P<sub>MAX</sub>)</b>	245 W
<b>Voltage Maximum Power Point (V<sub>mpp</sub>)</b>	29.702 V
<b>Current Maximum Power Point (I<sub>mpp</sub>)</b>	8.107 A
<b>Open Circuit Voltage (V<sub>oc</sub>)</b>	37.191 V
<b>Short Circuit Voltage (I<sub>sc</sub>)</b>	8.449 A
<b>Max. System Voltage</b>	1000 V

**Table 3.1:** Specification data of MYS-60M/B3/CL-245 solar module

Because of advantages of controlling system in an inexact and complex data, fuzzy logic controller is very popular to track MPP in solar module system. It requires to analyze the operation of solar module by the designer. From the solar module, the output of solar module has two type of characteritrics need to be determine: current- voltage characteristic and power-voltage characteristic. Figure 3.3 shows the experimental flow chart to get the characteristics of solar module which are shown as below:



**Figure 3.3:** Data Collection of Solar Module

### 3.4 FUZZY LOGIC ALGORITHMS

In this project, fuzzy logic controller is using mamdani-style inference to produce PWM signals to boost converter. The mamdani-style inference is performed in 4 steps. Firstly, the input variables are fuzzified to get degree of those inputs. The input variable is  $V_k$  at instant times,  $K$  can be formulated into those two equations:

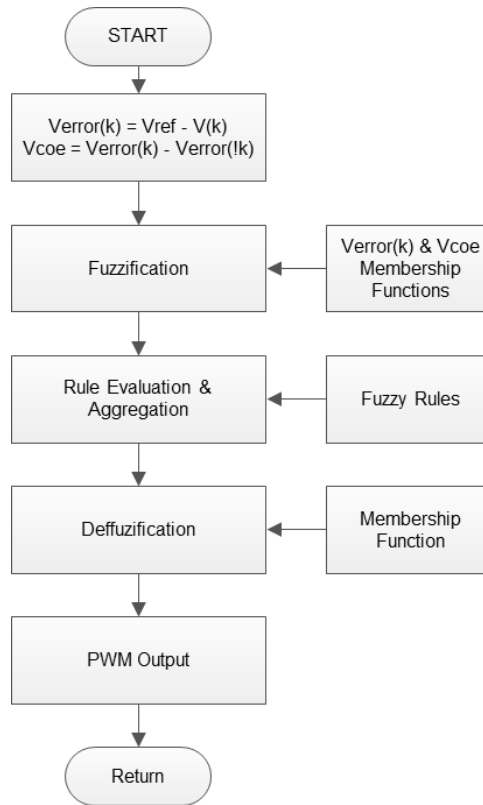
$$V_{error} = \frac{(V_{ref} - V_k)}{V_{ref}} \quad (3.1)$$

$$V_{coe} = V_{error} - V_{error(previous)} \quad (3.2)$$

The formula is based on voltage-controlled characteristic solar modules to get desired output and  $V_{ref}$  is voltage at maximum power point and  $V_k$  is voltage at instant from voltage divider. After this, it is evaluated by fuzzy rules and unify all fuzzy rule outputs.

Finally, Defuzzification is using centroid technique to get output by centre of gravity (COG) mathematically in equation 3.3. The output crisp is been calculated to get PWM signals.

$$COG = \frac{\sum_{x=a}^b \mu_A(x)x}{\sum_{x=a}^b \mu_A(x)} \quad (3.3)$$



**Figure 3.4:** Fuzzy Logic Algorithm

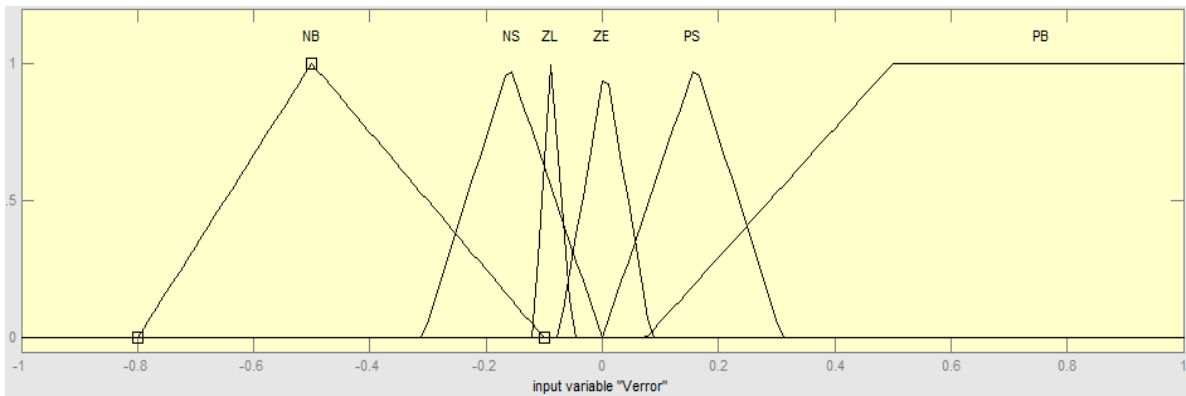
### 3.4.1 FUZZY INFERENCE SYSTEM

Fuzzy inference in this project is the process of mapping from voltage and current of solar module as inputs to output as PWM generation by using mamdani-style fuzzy inferences. Input variables of membership functions of Verror are Negative Big (NB), Negative Small (NS), Low Zero(ZL), Zero (Ze), Positive Small (PS) and Positive Big (PB) but Vcoe and output variables only five membership functions. Using MATLAB Fuzzy Logic Toolbox to create membership functions and Fuzzy Rules are shown as below as table 3.2.

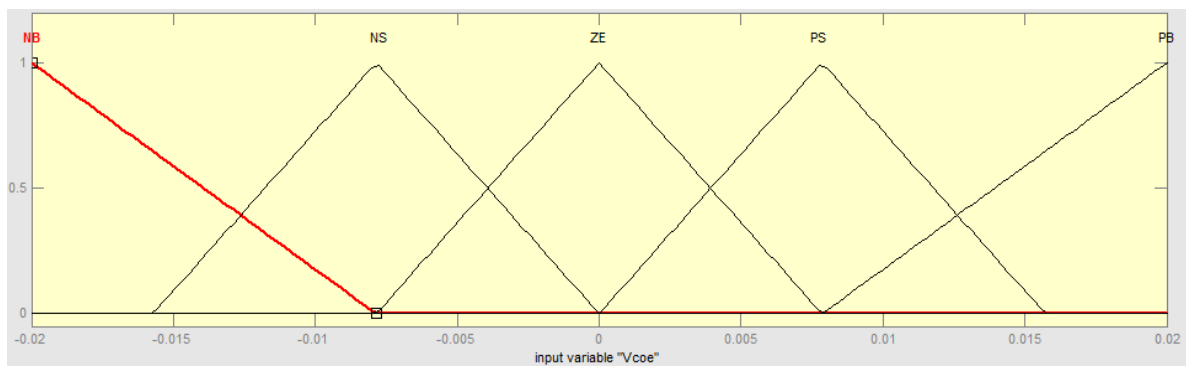
six membership functions (MF) of inputs and output in this project is more advantages than three membership functions because when the degree is near to zero area it will get very small value which is near to zero by using three membership functions. The design of five membership functions will get better result than three membership functions.

		COE				
		NB	NS	ZE	PS	PB
ERROR	NB	NB	NB	NB	NS	NS
	NS	NB	NS	NS	NS	ZE
	ZL	NS	ZL	ZL	ZL	ZE
	ZE	PS	ZE	ZE	ZE	ZE
	PS	PS	PS	PS	ZE	ZE
	PB	PB	PB	PS	PS	PS

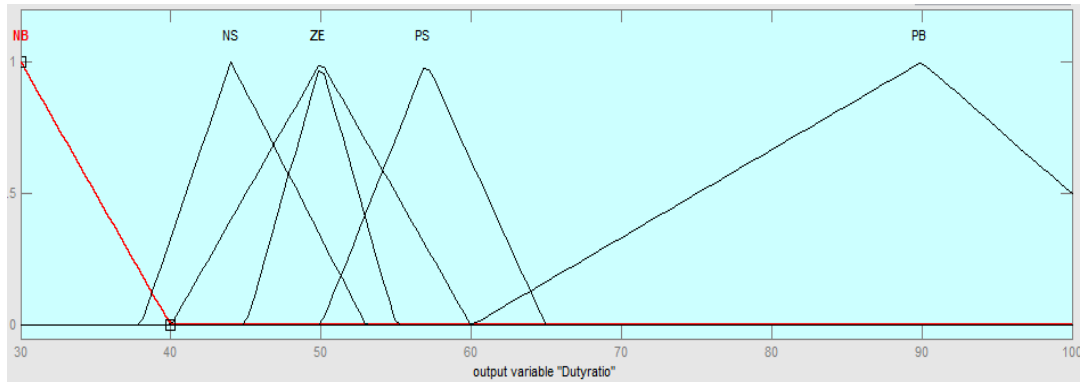
**Table 3.2:** Fuzzy Rule Evaluation



**Figure 3.5:** Verror Membership Functions

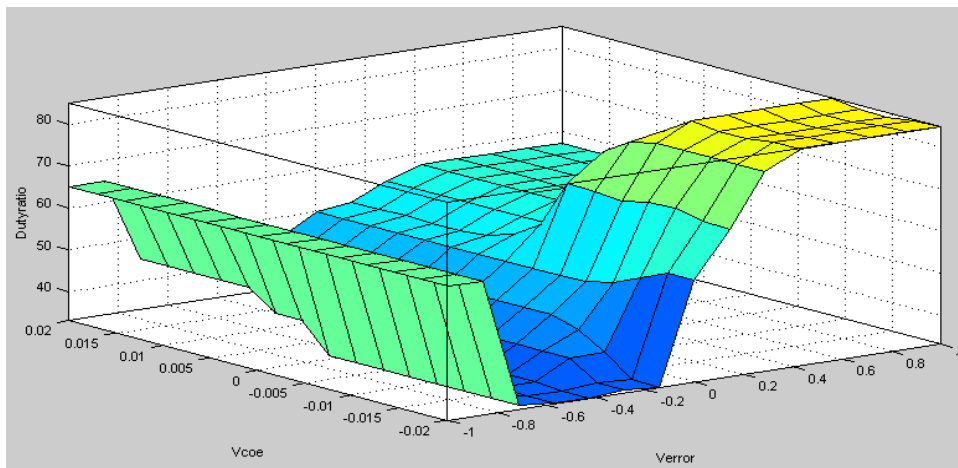


**Figure 3.6:** Vcoe Membership Functions



**Figure 3.7:** Dutyratio as Output Variable

Using MATLAB Fuzzy Toolbox to determine every rule outputs, we can get rules viewer by simulation of model. Besides that, it can let fuzzy rules evaluation become visualized into 3D surface viewer. Rule evaluation in figure 3.8 and simulation modeling by MATLAB in figure 3.9.



**Figure 3.8:** Surface Viewer

### 3.5 ELECTRICAL DESIGN - DC BOOST CONVERTER

To boost higher output voltage than input voltage from solar module will consider the DC-DC boost converter. The switching device will receives PWM signal which is generated by Fuzzy Logic Controller. DC-DC boost converter acts like a charge controller where it is controlled by fuzzy logic controller. Fuzzy Logic algorithms is dependent to input variables such as maximum power and generate the duty cycles to power MOSFET boosts desired output voltage.

When it is steady state and PWM signal sends to gate MOSFET, the operation of boost converter will results desired output so that the voltage will send to dc bus filter and load. The formula to find duty cycle for boost converter is:

$$D = 1 - \frac{V_s}{V_o} \quad (3.4)$$

Criteria calculation of boost converter with input voltage is the output voltage of solar module and desired output voltage is 60.0V. Assuming input current ripple is under 10% and maximum output voltage ripple,  $\Delta V_{out}$  is under 1%.

Estimated inductance:

$$L = \frac{V_{in} \times (V_{out} - V_{in})}{\Delta i_L \times f_s \times V_{out}} \quad (3.5)$$

Inductor's current ripple:

$$\Delta i_L = (0.2 \text{ or } 0.4) \times I_{o(max)} \times \frac{V_{out}}{V_{in}} \quad (3.6)$$

Minimum output capacitor:

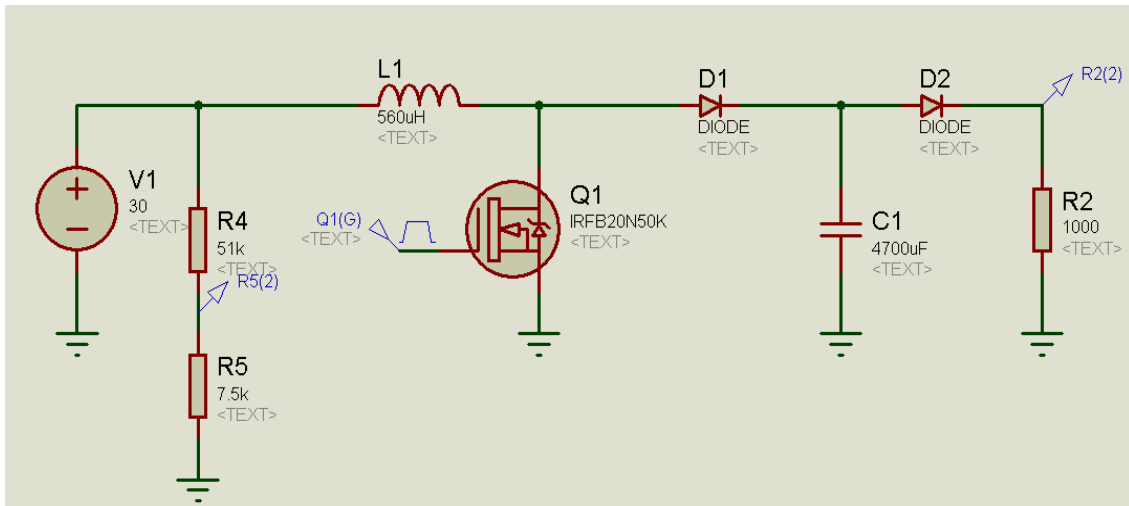
$$C_{out (min)} > \frac{I_{out} \times D}{f_s \times \Delta V_{out}} \quad (3.7)$$

The selections of components for boost converter are using above calculations and select 560 uH inductor and 4700  $\mu$ F capacitor with rating voltage of 100 V in frequency of 20 KHz. In this project is using ISIS Proteus software in figure 3.9 to simulate the output voltage of boost converter and figure 3.10 is design circuit diagram of the boost converter by using Isis Proteus software.





**Figure 3.9:** ISIS Proteus 7.0

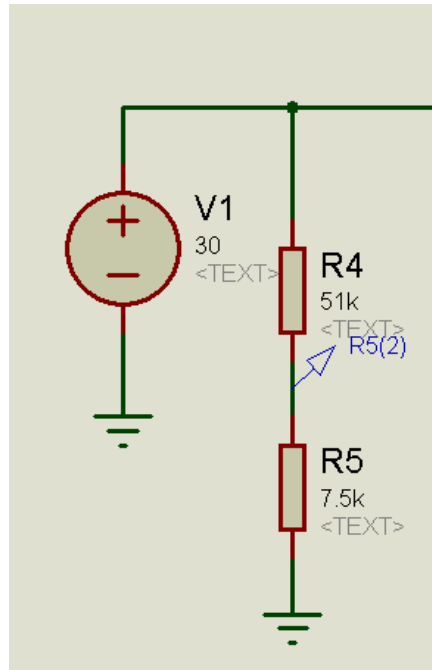


**Figure 3.10:** DC-DC Boost Converter Design

### 3.5.1 VOLTAGE DIVIDER

Output voltage of solar module need to produced to suitable rating voltage and send to controller. it acts as voltage sensor which will produce the voltage which is the fraction of actual voltage. the equation of voltage divider is shown as figure 3.11. The voltage divider is designed in this project and maximum output voltage is 5V, and maximum input voltage is the open circuit voltage of solar module. Two resistors are used for this project and has the value of 51 K $\Omega$  and 7.5 K $\Omega$  is used after using equation 3.9 to calculate it.

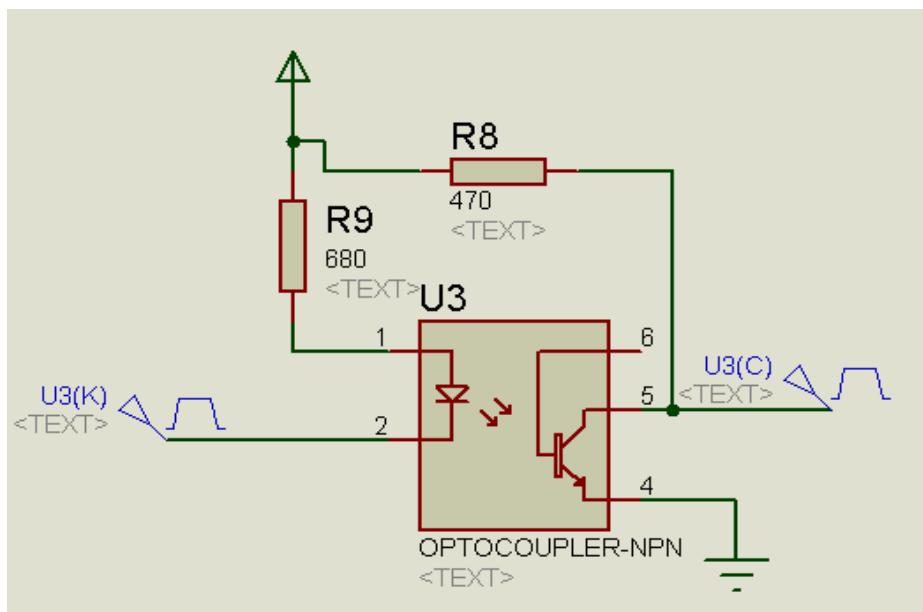
$$V_0 = \frac{R_2}{R_1 + R_2} V_{in} \quad (3.9)$$



**Figure 3.11:** Voltage Divider

### 3.5.2 OPTOCOUPLER CIRCUIT

The 4N25 optocoupler is used to isolate the output PWM Arduino from semiconductor MOSFET in V<sub>GS</sub>. Microcontroller generates the PWM in 5V as ON-OFF pattern of duty cycle and placing optocoupler with 5V power supply. The circuit is shown as below in figure 3.12.



**Figure 3.12:** Optocoupler Circuit

### 3.6 FUZZY LOGIC CONTROLLER

Fuzzy logic controller is the microcontroller that receives input variables of solar module and does fuzzy logic algorithms to generate PWM signal. PWM signal is send to MOSFET to boost converter to change duty cycle. A fuzzy logic algorithm is the process mapping of fuzzy inference by using method of Mamdani inference style. The Arduino Uno R3 is chosen to act as fuzzy logic controller in this project.

Arduino Uno R3 in figure 3.13 is one of microcontroller that is easier to build to run in real life environment with sensor and analog output/input. It has a simple integrated development environment (IDE) that using C or C++ programming language to write out the fuzzy logic algorithm. The data specifications of Arduino Uno are shown as below:



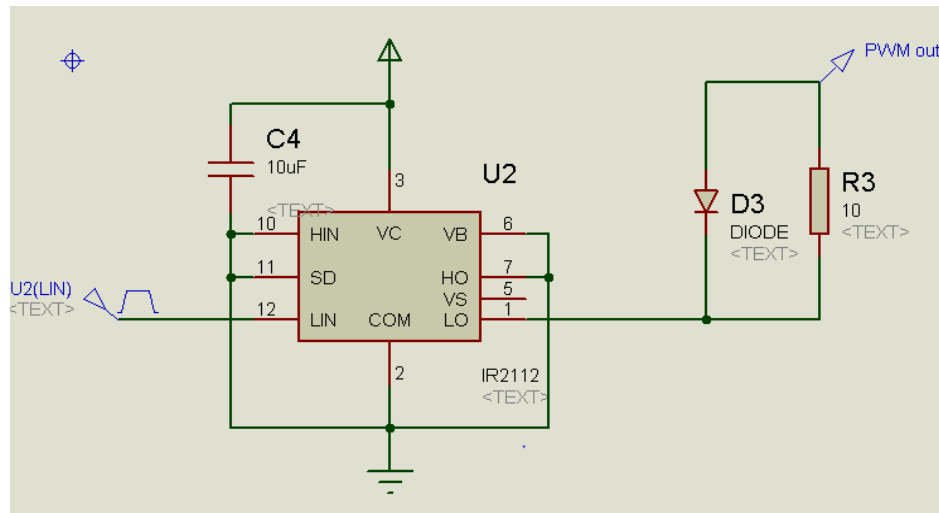
**Figure 3.13:** Arduino Uno R3

<b>Microcontroller</b>	<b>ATmega328</b>
<b>Operating Voltage</b>	5 V
<b>Input Voltage (recommended)</b>	7 - 12 V
<b>Input Voltage (limits)</b>	6 - 20 V
<b>Digital I/O Pins</b>	14 (6 provide PWM output)
<b>Analog Input Pins</b>	6
<b>DC Current per I/O Pin</b>	40mA
<b>DC Current for 3.3V Pin</b>	50mA
<b>Flash Memory</b>	32 KB (ATmega328), 0.5KB used by <a href="#">bootloader</a>
<b>SRAM</b>	2 KB (ATmega328)
<b>EEPROM</b>	1 KB(ATmega328)
<b>Clock Speed</b>	16 MHz

**Table 3.3:** Arduino Uno R3 Specification Data

### 3.6.1 IR2112 HIGH SIDE AND LOW SIDE DRIVER

The PWM output from Fuzzy Logic Controller will sent to IR2112 gate driver to increase the  $V_{pp}$  to 12 V for turn on and off gate MOSFET. The circuit is designed and shows as below in figure 3.14.



**Figure 3.14:** IR2112 High Side and Low Side Driver

### 3.7 VOLTAGE SOURCE INVERTER

After getting DC output voltage from boost converter, the voltage will pass through to DC link filter as DC voltage to inverter. The inverter was controlled by frequency and varying voltage will change speed of induction, it is called voltage source inverter and using microcontroller to generate PWM signals to control speed.

#### 3.7.1 THREE PHASE PWM ALGORITHM

Three phase PWM is using same clock frequency to generate out duty cycle. PWM module in microcontroller can do SINE function and produce sine PWM waveform for each phase as one of PWM techniques for DC-AC inverter. Each phase of high side and low side PWM is using same offset degree of PWM in pair mode. In this project, 20 MHz clock frequency to PIC18F4431 is used for generate 1.2 KHz PWM signals is enough for this project.

#### 3.7.2 MICROCONTROLLER CIRCUIT

The microcontroller PIC18F4431 is used in this project for generating 3 phase PWM. Using MicroCode which is integrated development environment to write coding, PICBasic compiler to complete hex file so that it can transfer program into PIC18F4431 with PICKit 2 software. Six PWM signals which are high sides and low sides PWM will be generated in this project. The Figure 3.16 shows the circuit diagram of microcontroller circuit and buttons to change frequency of PWM outputs.

Liquid-crystal display indicates the duty cycles of PWM. The buttons got 2 functions which are increasing or decreasing duty cycle when running the induction motor. There are 3 high side PWM outputs at B0, B2, B4 and 3 low side PWM outputs at B1, B3, and B5 of PIC18F4431 in figure 3.15.

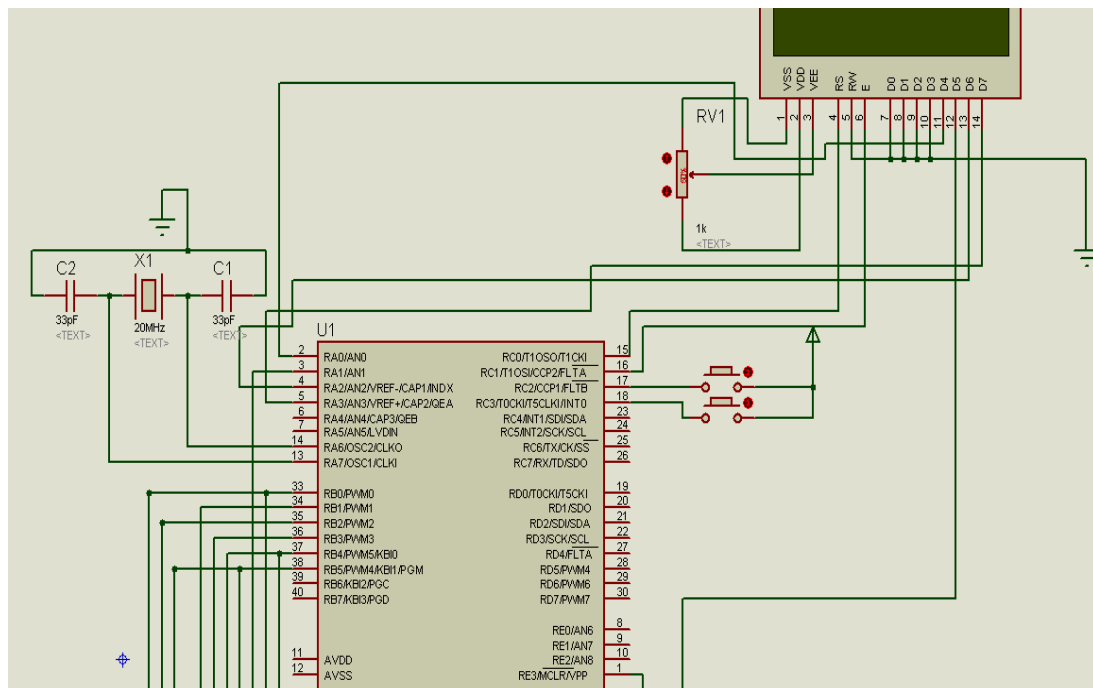
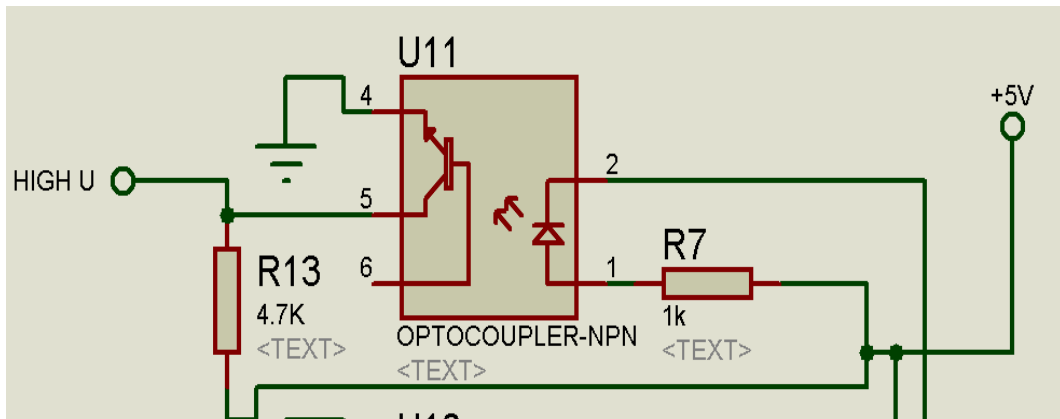


Figure 3.15: Microcontroller Circuit

### 3.7.3 OPTOCOUPLER

6 PWM signals as 3 phase sine PWM are generated by microcontroller. The ON- side PWM voltage from microcontroller is 5V which is not enough for motor driver gate signal. To amplify the PWM voltage, 6 optocouplers 4N25 are used for this project. Each optocoupler is supplied by 9 V, and PWM signal passes through it so that get 15 V to gate of IGBT motor driver. The circuit diagram is shown in Figure 3.16.

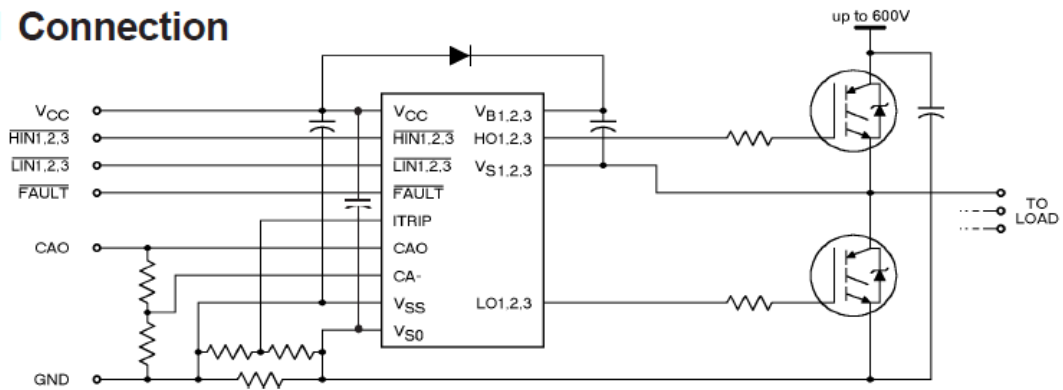


**Figure 3.16:** Optocoupler Circuit

### 3.7.4 IR2130 H-BRIDGE DRIVER

The three phase gate driver IR2130 module can able to smooth the output PWM and increase the  $V_{pp}$ . The typical connection is shown as figure 3.17. The high side PWM is connected to HIN pin and come out from HO and required voltage supply to send to it with bootstrap circuit as shown as below. The low side PWM is connected to LIN pin and come out from LO pin.

#### Typical Connection



**Figure 3.17:** Typical Circuit of IR 2130 Gate Driver

### 3.7.5 INSULATED-GATE BIPOLAR TRANSISTOR (IGBT) MODULE

Three insulated-gate bipolar transistor module SKM 200GB123D is used in this project which consists of six IGBTs inside the module as shown in figure 3.18. In this project, IGBT module worked as inverter to converter DC voltage to AC voltage for driving three phase induction motor.

It can also have pins for power supply of 15V for motor driver and input DC voltage to IGBTs. The PWM signals will connect to gate signals of drive circuit.

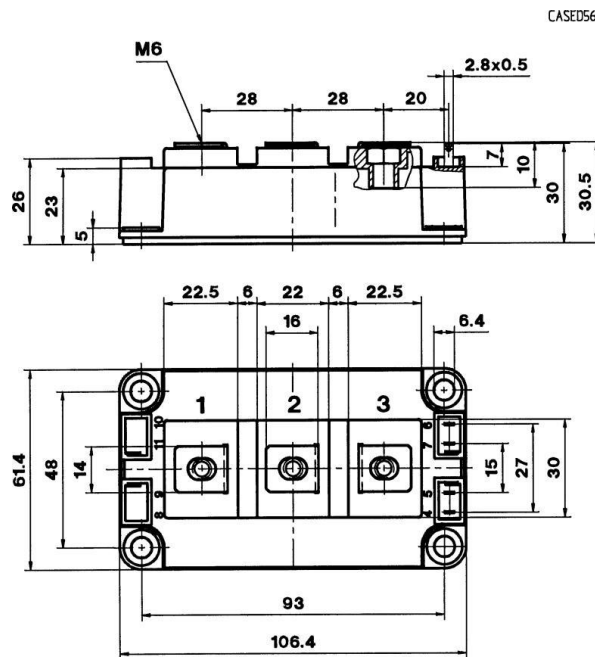


Figure 3.18: SKM 200GB123D Module

### 3.7.6 INDUCTION MOTOR CIRCUIT

The output voltage of inverter from IGBT modules will be connected to three phase induction motor. Y connection of induction motor is used in this circuit. The direction of induction motor can be changed by changing connection. The controlled speed of three phase induction motor can be adjusted by pressing buttons to change the duty cycle.

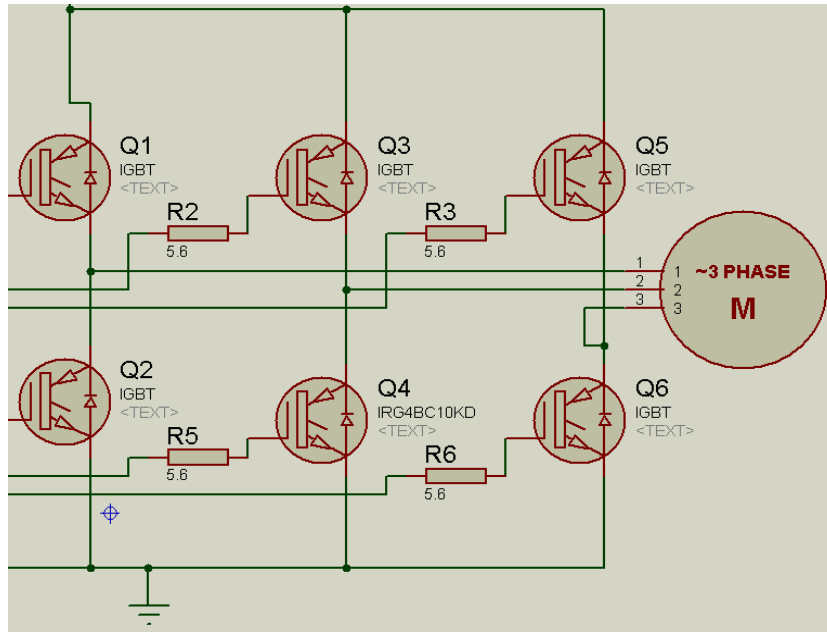


Figure 3.19: Induction Motor Circuit Diagram

### 3.8 OVERALL PROJECT CIRCUIT

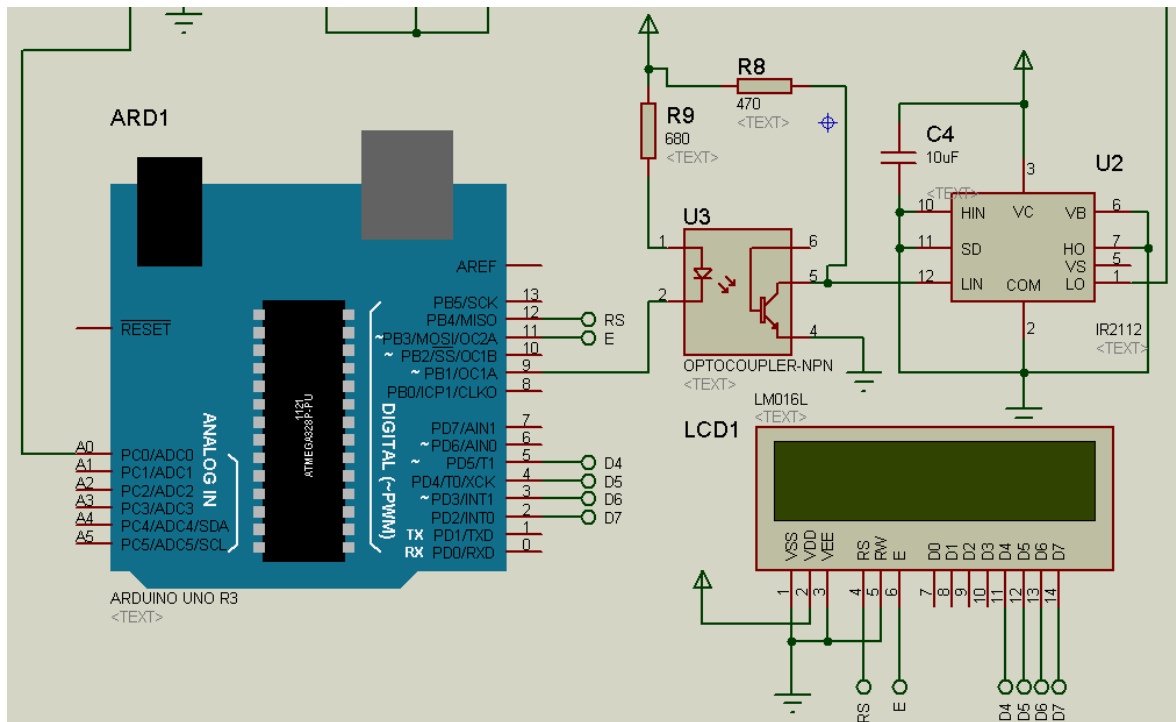


Figure 3.20: Fuzzy Logic Controller, Optocoupler and Power supply



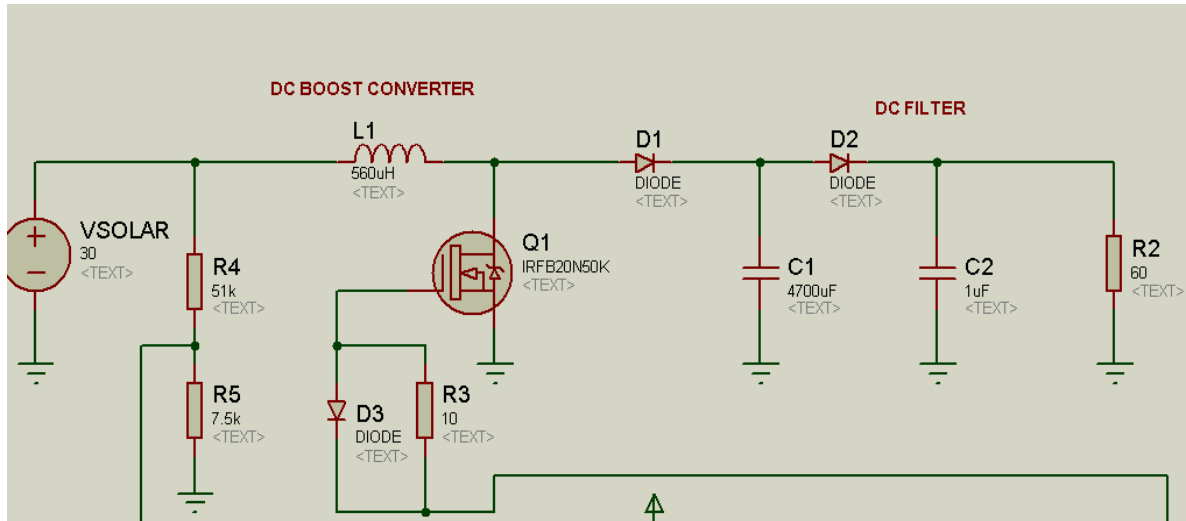


Figure 3.21: Boost Converter and DC Link Film Capacitor

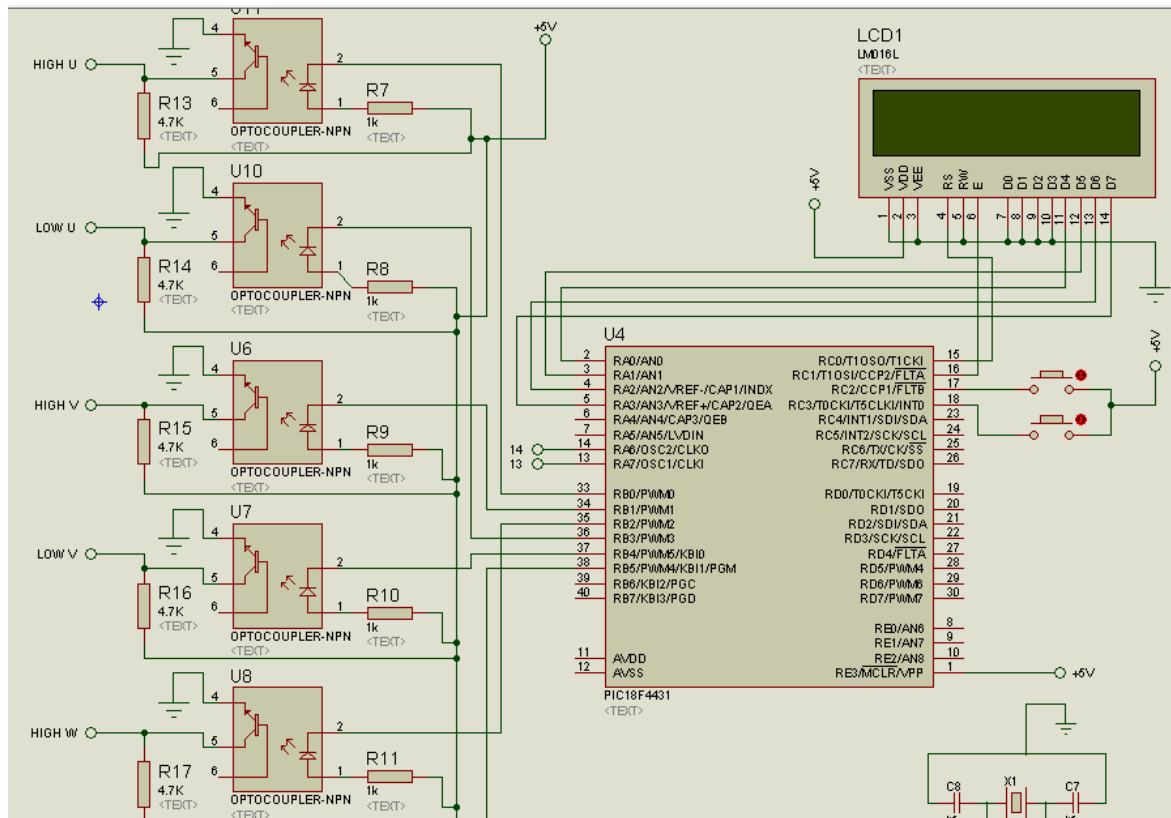
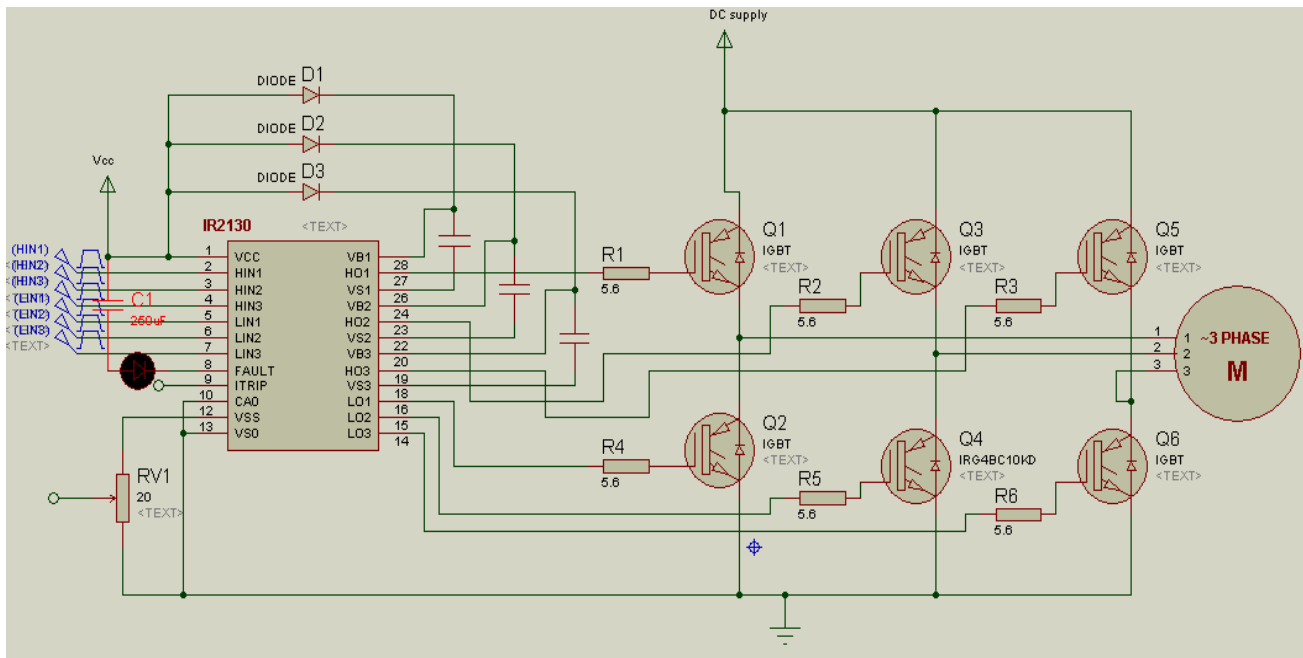


Figure 3.23: Control Circuit of Voltage Source Inverter



**Figure 3.23:** IR2130 Gate Driver, Six IGBT Module and Induction Motor