AQUARIUM PUMP DRIVE BY SOLAR CELL USING MAXIMUM POWER POINT TRACKING (MPPT)

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for the award of the degree of
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Special thanks to my beloved parents

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Specially dedicated to my supervisor,

ASSOC. PROF. DR. AJISMAN APEN

on his guidance towards my project
and those who have guided or motivated me for this project

EXAMINER APPROVAL DOCUMENT

We certify that the thesis entitled **“Aquarium Pump Drive by Solar Cell Using Maximum Power Point Tracking (MPPT)”** is written by Mohd Jozaimi Izwan Bin Jalaluddin. We have examined the final copy of this thesis and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of B. Eng. (Hons.) Mechatronics Engineering. We are here with recommend that it be accepted in fulfilment of the requirements for the degree of B. Eng. (Hons.) Mechatronics Engineering.

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I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

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ABSTRACT

This thesis proposes the implementation of solar panel as an alternative that could generates electricity from sunlight exposure. The renewable energy that produced by solar could be used in supplying electricity to electrical equipment as well as becoming an alternative source apart from the available energy supplied by the utility. The main objective of this project is to supply the electrical energy to aquarium pump. Besides that, the maximum power point tracking (MPPT) is used to increase the power conversion efficiency of solar panel. Fuzzy logic controller is one of the MPPT method is used in this project and sun tracking system was added in this project to increase the power absorption by the solar panel. This sun tracking system embedded with light dependent resistor (LDR) which acts as a light sensor while the microcontroller is used for receiving and analysing input signal from LDR and sending the output signal to the DC motor. DC motor will be the medium for moving the solar panel towards the direction of the sun. The purpose of moving the solar panel towards the direction of the sun is to increase the rate of sunlight absorption by the solar panel hence increasing the electrical energy produced by solar panel. The method of fuzzy logic controller implemented using Arduino Uno to control MOSFET that contained in the dc-dc boost converter. Control signal produced by Arduino Uno will be sent to optocouple circuit as to increase the suitable voltage value to control the MOSFET. This method also presenting real-time code of fuzzy logic in Arduino language for controlling ATmega328 that contained in Arduino Uno board. The result obtained through the coding of Arduino is the variation of duty cycle of PWM signal according to the voltage of solar panel. The final result obtained from dc-dc boost converter showed that the output voltage has been regulated. Overall, the fuzzy logic controller was increases the efficiency of the overall system by24.4965%.

ABSTRAK

Tesis ini mencadangkan perlaksanaan pengunaan panel solar sebagai satu altenatif yang dapat menjanakan tenaga elektrik dari cahaya matahari. Tenaga boleh baharu yang dihasilkan oleh tenaga suria dapat digunakan untuk membekalkan tenaga elektrik kepada peralatan elektrik dan menjadi sumber tenaga alternatif selain daripada sumber tenaga yang dibekalkan oleh utiliti. Objektif utama project ini adalah untuk membekalkan tenaga elektrik kepada akuarium pum. Selain itu juga, kaedah pengesanan titik kuasa maksimum digunakan untuk meningkatkan kecekapan penukaran tenaga sesebuah panel solar. Kaedah pengawal logik kabur merupakan salah satu kaedah pengesanan titik kuasa maksimum yang digunakan dalam projek ini serta ditambah dengan sistem pengesanan matahari untuk tujuan meningkatkan kuasa penyerapan panel solar. Sistem pengesan matahari ini mempunyai perintang peka cahaya (LDR) yang digunakan sebagai sensor cahaya dan mikropengawal digunakan untuk menerima dan mentafsif signal input daripada perintang peka cahaya serta menghantar signal output kepada motor DC. Motor DC digunakan sebagai pengerak panel solar mengikut arah pergerakan matahari. Tujuan mengerakkan panel solar mengikut arah pergerakan matahari adalah untuk meningkatkan kadar penyerapan cahaya matahari oleh panel solar secara tidak langsung akan meningkat tenaga elektrik yang dihasilkan oleh panel solar. Kaedah pengawal logik kabur dilaksanakan dengan mengunakan Arduino Uno sebagai mikropengawal untuk mengawal “MOSFET” yang terdapat di dalam rangsangan penukar. Pengawalan isyarat yang dihasilkan oleh Arduino Uno akan dihantar ke litar optocouple untuk meningkatkan nilai voltan yang sesuai untuk mengawal MOSFET. Kaedah ini juga membentangkan kod masa sebenar logik kabur dalam bahasa Arduino untuk mikropengawal “ATmega328” yang terdapat di papan Arduino Uno. Keputusan yang diperolehi daripada pengekodan Arduino adalah variasi isyarat kitar tugas nadi lebar modulasi mengikut voltan panel solar. Keputusan akhir yang diperolehi daripada rangsangan penukar arus terus menunjukkan bahawa voltan keluaran dari panel solar telah dikawal dan dioptimumkan. Secara keseluruhannya, pengawal logik kabur telah meningkatkan kecekapan panel solar sebanyak 24.4965%.

TABLE OF CONTENTS

CHAPTER 3 METHODOLOGY

CHAPTER 4 RESULT AND DISCUSSIONS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

D	Duty cycle/ratio
E	Error
CE	Change of error
f_s	Switching frequency
I_{MPP}	Rated current
I_{SC}	Short circuit current
P_{MAX}	Maximum power
R_1	First resistor
R_2	Second resistor
t_{ON}	Switch on time
t_{OFF}	Switch off time
T_S	Switching period
V_d	Input voltage of dc-dc boost converter
V_{in}	Input voltage of the voltage divider
V_{MPP}	Rated voltage
V_O	Output voltage of dc-dc boost converter
V_{OC}	Open circuit voltage
V_{OUT}	Output voltage of the voltage divider
V_{PV}	Photovoltaic voltage
V_{REF}	Reference voltage

LIST OF ABBREVIATIONS

AC	Alternative current
ADC	Analog-to-digital converter
DC	Direct current
DSO	Digital Storage Oscilloscope
FIS	Fuzzy inference system
FLC	Fuzzy logic controller
GUI	Graphical user interface
IDE	Integrated development environment
I/O	Input or output
LCD	Liquid crystal display
LED	Light emitting diode
MOSFET	Metal-oxide-semiconductor field-effect transistor
MPPT	Maximum power point tracking
PV	Photovoltaic
PWM	Pulse-width modulation

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Aquarium pump is one of the electrical equipments that needed to be inside of an aquarium. It works as an air ventilation system inside of an aquarium and it is built with its own water filter system. The usage of aquarium pump consistently is needed in order to ensure the life of the living creatures in the aquarium or in other words, the oxygen content inside the aquarium is always adequate. Electrical energy is used to run the aquarium pump. Therefore, high cost of expenditure is needed to pay the electrical energy used by the aquarium pump.

Photovoltaic (PV) systems are becoming very attractive solutions to supply electrical energy to the aquarium pump. There are various ways as medium for generating electricity but some of them give bad impact to the environment such as air pollution, greenhouse effect and thinning of ozone layer. Therefore, due to energy crisis and environmental issues such as pollution and global warming effect, PV system is good choice for generating electricity. PV system has more advantages such as operating and maintenance costs for PV panel is lower, if compared to costs of other renewable energy system. It is easy to install on the ground without any interference to residential lifestyle. Unfortunately the actual energy conversion efficiency of PV module is rather low. So to overcome this problem and to get the maximum possible efficiency, the design of all the elements of the PV system has to be optimised.

In order to increase this efficiency, the maximum power point tracking (MPPT) controllers are used. Such controllers are becoming an essential element in PV systems.

A significant number of MPPT control schemes have been elaborated since the seventies, starting with simple techniques such as voltage and current feedback based MPPT to more improved power feedback based MPPT such as the perturbation and observation (P&O) technique or the incremental conductance technique. Recently intelligent based control schemes MPPT have been introduced. In this research an intelligent control technique using fuzzy logic control is associated to an MPPT controller in order to improve energy conversion efficiency. The fuzzy logic controller is one of the MPPT methods which are very suitable for photovoltaic array because fuzzy control is a range to point or range to range control unlike the classical control strategy. It helps to track maximum power from any environmental conditions and has good stability as well as the response rate is high.

However, the problem is still exists if the PV Module is installed to one fit position. To overcome this problem, sun tracking system has installed to the PV module. If the sun located at the direction that is not perpendicular to the solar panel, the power that can be generate is low compare to the when the sun located exactly perpendicular to the solar panel. Sun tracking system can move the solar panel according to sun rotation from east to west. So that, maximum electric energy convert from solar panel is gained and more efficiency will produce compare with the fixed solar system.

1.2 PROBLEM STATEMENT

Usually, aquarium pump used continuously to ensure sufficient oxygen supply in aquarium. Indirectly, this will result in high expenditure costs that needed to be paid for the used electricity by aquarium pump. Therefore, Solar energy is a good choice for supply the power to the aquarium pump, since it could be built almost anywhere with sunlight and electricity cost is cheap for own need.

Unfortunately, the efficiency level of the photovoltaic module is relatively low. So, Photovoltaic system is a need to improve the energy generation efficiency that received from the solar cell using Maximum power point tracking controller. The power that can be generated by solar panel still low if the solar panel stayed at fix position. So that, to fix this problem, sun tracking system was added to this project. The solar panel that can be generating here is high power compare to the solar panel only stay at fix position. Sun tracking system will control the position of the solar panel so that it is always perpendicular to the sun. Solar panel will generate the highest power when it perpendicular to the sun.

DC-DC converter is added as an interface between the output from the solar cell and the load. It extracts the maximum power from the solar cell and transfers it to the load by stepping up or boost as per the requirement at the load side.

1.3 OBJECTIVE

The objectives of the “Aquarium pump driven by solar cell using MPPT” project are as below.

i. To track and optimise the maximum output power of the solar panel by implementing the sun tracking system.
ii. To implement fuzzy logic controller for maximum power point tracking (MPPT).
iii. To regulate the output voltage of the solar panel using dc-dc boost converter

1.4 SCOPE PROJECT

This project is focused to design and build the prototype of photovoltaic system that can generate electricity and drive the aquarium pump. Therefore, this project will cover the scope as followed.

i. The solar panel chosen for this project is the monocrystalline solar panel.
ii. The DC motor is chosen to move solar panel according to the movement sun.
iii. The Arduino Uno Rev 3 was chosen as controller for the DC motor.
iv. Using Light Dependant Resistor (LDR) or Photoresistor as a sensor.
v. The dc-dc boost converter is generated by using diode, MOSFET and other suitable components.

vi. The Arduino Uno Rev3 is chosen for the implementation of the fuzzy logic controller.

vii. The fuzzy logic programming for hardware is designed with the Arduino language which is based on C.

viii. DC Aquarium pump chosen for this project as a load.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter are prepare a review of the past research working regarding to solar power generation using photovoltaic system, implementation of the fuzzy logic controller to increase the energy conversion efficiency from photovoltaic system and using boost converter to increase the DC voltage. Review that is highly detailed, so that, the present research effort can be rightly tailored to added to the present literature also to concentrate the direction and scope of the research that carried out.

2.2 MAXIMUM POWER POINT TRACKING SOLAR MODULE

Solar energy will be produce during the sun is shining. Usually, solar panels will produces an output is direct current (DC). Aquarium pump is electrical appliances which uses alternating current to operate. Firstly, electricity generated by photovoltaic (PV) module need to be raised the value because direct current produced is small. DC-DC Boost converter will be used to stepping up the generated voltage from the photovoltaic module and provide DC input required to the system.

Maximum power point tracker (MPPT) is usually used in photovoltaic systems. There are various MPPTs type have been introduced and developed. Fuzzy logic controller is one of the appropriate methods to get the MPP of a PV module. Fuzzy logic has a good stability and high response rate (Dr.Anil S. Hiwale, Mugdha V.Patil, and Hemangi Vinchurkar. 2014). Apart from that also, fuzzy logic will be able to improve the energy conversion efficiency. Fuzzy logic control together with DC- DC boost converter must be added among the photovoltaic module with the load to find the MPP. Moreover the properties of the photovoltaic system will changed according to the insolation level and temperature (Jaw-Kuen Shiau , Min-Yi Lee, Yu-Chen Wei, and Bo-Chih Chen. 2014). Therefore, fuzzy logic controller also needed to trace the new modified MPP in its appropriate curve during insolation and temperature alteration occurs (Jaw-Kuen Shiau , Min-Yi Lee, Yu-Chen Wei, and Bo-Chih Chen. 2014).

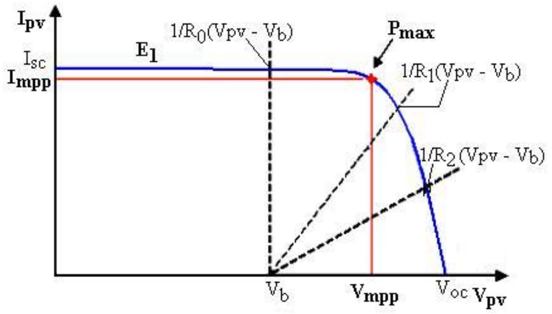


Figure 2.1: I-V Characteristic of PV system.

Source: M.S. Aït Cheikh, C. Larbes, G.F. Tchoketch Kebir and A. Zerguerras, (2007).

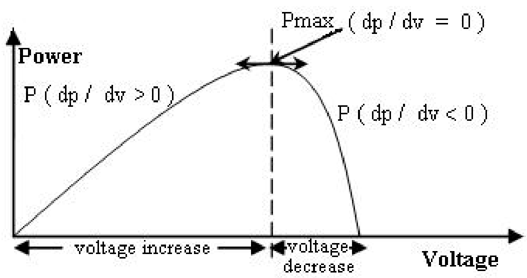


Figure 2.2: P-V Characteristic of PV system.

Source: M.S. Aït Cheikh, C. Larbes, G.F. Tchoketch Kebir and A. Zerguerras, (2007).

Pulse width modulation (PWM) control technique was added intend to control DC- DC converter. The photovoltaic arrays react as a source of power and give energy to components and afford to keep electricity supply (Abu Bakkar Siddik. A and Shangeetha. M. 2012). Unfortunately, the load of photovoltaic system heavily depends on the sunlight presence. During at night time, a current produced will flow back into photovoltaic cell from the bus. This reverse current will causes extensive damage, leakage loss or can also cause a fire. To overcome this problem, reverse current must be avoided with added blocking diode. It is very effective to avoided reverse current flow. The boost converter topology, the freewheeling diode becomes as the blocking diode to prevent the reverse current.

2.3 PHOTOVOLTAIC MODULE

Single Photovoltaic cells consist of semiconductor wafer produced from two layers usually is made from highly purified silicon. Sunlight consists of photons or solar energy particles. When photovoltaic cell is bombarded by photons, it will be reflected, makes further inroads or absorbed. Only photons that absorbed will produce electricity. When sunlight absorbed by semiconductor material in photovoltaic cell has been enough, electron will be eliminated from material atom. Usually, electrons will move into surface. When electron leaves the position, it will form hole. If many electrons that charged negative moving towards to cell surface, the result are happen imbalance charge intercellular in forward surface and back which form same voltage potential like negative and positive terminal a battery. When two grounds connecting with external burden, like electrical equipment, electric current will flow.

Photovoltaic module refer either to a solar panel consists of many photovoltaic cell wired in parallel and will be produce electricity using the photovoltaic effect. To increase the current output, photovoltaic cell can be arranged in parallel and if arranged in series, will increasing the voltage of the photovoltaic module. The arrangement of this photovoltaic cell is called photovoltaic array. The output voltage from the photovoltaic module is naturally in direct current (DC). The equivalent circuit for photovoltaic module which consists of a diode, a photo current, a parallel resistor states a leakage current, and a series resistor representing an internal resistance to the current flow (Abu Bakkar Siddik. A and Shangeetha. M. 2012).The current-voltage characteristic equation of a photovoltaic module is given as:

$$I = I_{PH} - I_O \left[\exp\left\{\frac{q}{nkT}(V + RsI)\right\} - 1\right] - \frac{(V+RsI)}{R_{SH}} \quad (2.1)$$

Where I_{PH} is a light-generated current or photocurrent, I_s is a cell saturation of dark current, q is an electron charge$(q = 1.6 \times 10^{-19}\text{C})$, k is a Boltzmann's constant$(k = 1.36 \times 10^{-23}\,\text{J/K})$, T_c is the cell's working temperature, A is an ideal factor, R_{SH} is a shunt resistance, and R_S is a series resistance. The output power of photovoltaic module is expressed by

$$\text{P} = \text{VI} = \left(\text{I}_{\text{PH}} - \text{I}_{\text{d}} - \frac{\text{V}_{\text{d}}}{\text{R}_{\text{SH}}}\right)\text{V} = (\text{I}_{\text{PH}} - \text{I}_{\text{d}})\text{V} \tag{2.2}$$

After the output voltage from the photovoltaic module is obtained, DC-DC boost converter is needed to boost the low voltage into high voltage.

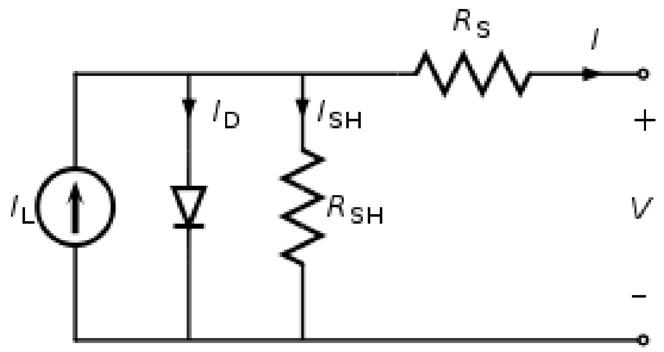


Figure 2.3: Equivalent circuit for Photovoltaic module.

Source: Dipti Bawa and C.Y. Patil, (2013).

Table 2.1: Electrical specifications of the 10W monocrystalline silicon photovoltaic panel.

Parameter	**Abbreviation**	**Value**
Maximum Power	P_{max}	10W
Rated Voltage	V_{MPP}	18V
Rated Current	I_{MPP}	0.55A
Open Circuit Voltage	V_{OC}	21.5V
Short Circuit Current	I_{SC}	0.56A

Source: Sasikala A/P Ganaisan, (2014).

There a two main manufactured materials of the solar cells which are the silicon and Gallium Arsenide. The silicon solar cells can be categorized into two crystal types which are the monocrystalline and polycrystalline. The efficiency of these cells is normally range from 12% to 18%.

The monocrystalline cells are more efficient and expensive compared to the polycrystalline cells because of the single crystal of monocrystalline. Meanwhile the efficiency of Gallium Arsenide solar cells is greater than the silicon solar cells which are about 25% to 30% for production models.

2.4 FUZZY LOGIC CONTROLLER

The nonlinear feature of Photovoltaic system is obvious from the power and current of the Photovoltaic array depends on the array terminal operating voltage. In additional, the MPP difference with a temperature and an insolation level. Due to this, the MPPT is a difficult problem. To overcome these problems, fuzzy logic controller (FLC) has been used as tracking control system. FLC needed the specialist knowledge of the operation rule for the FLC parameter setting. The controller can be only as good as the expertise involved in the design. FLC has the advantages confront the uncertainty and imprecise. Thus, the FLC can be easily made by digital microcontroller unit. FLC contains three units as fuzzification, fuzzy rules, and defuzzification. (Abu Bakkar Siddik. A and Shangeetha. M. 2012).

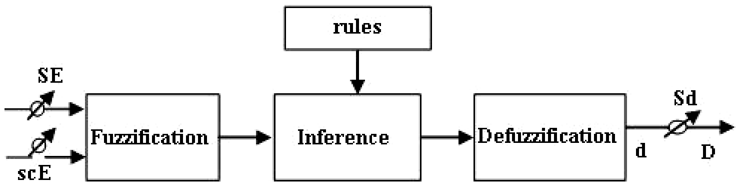


Figure 2.4: Block diagram for a Fuzzy logic controller.

Source: M.S. Aït Cheikh, C. Larbes, G.F. Tchoketch Kebir and A. Zerguerras, (2007).

The current and voltage values are normalized and scaled and also through the membership functions. Membership function values are tasked to the linguistic variables, using five fuzzy subsets: NS (negative small), NB (negative big), PS (positive small), PB (positive big), and ZE (zero) (K. Manickavasagam. 2014). The FLC implemented here uses triangular membership functions. The fuzzy logic rules for this MPPT design are shown in Table 2.2. Fuzzy logic controller with the boost converter shown in Figure 2.4, tracks the MPP of a PV module at provided atmospheric conditions efficiently and very fast. Dramatically changing in atmospheric conditions change the maximum power point unexpectedly which is tracked accurately by fuzzy logic controller (Abu Bakkar Siddik. A and Shangeetha. M. 2012). Therefore, the PV module will be produced the peak power. If this method implemented, it can improve the efficiency of the photovoltaic system by wide scale.

Table 2.2: Fuzzy logic rule base.

I_{pv} \ V_{pv}	NB	NS	ZE	PS	PB
NB	NB	NS	NS	ZE	ZE
NS	NS	NS	ZE	ZE	PS
ZE	ZE	ZE	PS	PS	PS
PS	ZE	PS	PS	PS	PB
PB	PS	PS	PS	PB	PB

Source: M.S. Aït Cheikh, C. Larbes, G.F. Tchoketch Kebir and A. Zerguerras, (2007).

2.5 MATLAB SOFTWARE

Matlab is useful software which has fourth-generation programming language. It is developed by MathWorks. This software can be used for plotting of functions and data, matrix manipulation, creation of user interface, implementation of algorithms as well as interfacing with programs written in other languages which is C, C++, Java and Fortran.

SIMULINK is a Matlab toolbox which is designated for the dynamic simulation of the linear and non-linear systems. There is toolbox especially for fuzzy logic which allows the manipulation of fuzzy systems and membership functions. Furthermore, Matlab is very efficient for neural net, fuzzy systems and genetic algorithm (M.S. Aït Cheikh, C. Larbes, G.F. Tchoketch Kebir and A. Zerguerras. 2007)

2.6 MICROCONTROLLER FOR SIGNAL CONTROL

A microcontroller can be defined as a small computer with a single integrated circuit which contains a processor core, memory and also programmable input or output peripherals. It can be said as a self-contained system and able to use as an embedded system. The switches, relays, LEDs, LCD displays, solenoids, radio frequency and also sensors for temperature, humidity or light level data become the typical input and output devices for the microcontroller. The embedded system normally has no keyboard, disks, screen and other recognizable input or output devices of personal computer.

Normally, microcontrollers are used for automatically controlled devices. Microcontrollers can be programmed in various high-level programming languages such as C programming. Almost all of the microcontrollers have at least two kinds of memory which are non-volatile memory for firmware storage and read write memory for temporary data (Amenallah Damak, Abdessalem Guesmi, and Abdelkader Mami. 2009).

2.6.1 Arduino UNO Rev3

The Arduino Uno is one of the microcontroller boards using the Atmega328. Arduino Uno has 14 digital inputs and outputs pin apart of those 6 pins can use as Pulse-Width modulation outputs. It also have 6 pins analog inputs, 16MHz crystal oscillator, USB connecter, ICSP header, reset button and power jack. It contains all needed to back up the microcontroller for example the Arduino Uno have been connected easily with a computer using USB cable and empowers in Arduino Uno by connecting the AC to DC adapter or battery to operate. The Arduino Uno board quiet easy to perform control logics or programming because it has open source software (Mohammed S. El-Moghany and Basil M. Hamed. 2012). Table 2.3 shows some specification of the Arduino Uno board.

Table 2.3: Specification of Arduino Uno Board.

Microcontroller	Atmega328
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40mA
DC Current for 3.3V Pin	50mA
Flash Memory	32KB (Atmega328) of which 0.5KB used by boot loader
SRAM	2KB (Atmega328)
EEPROM	1KB (Atmega328)
Clock Speed	16MHz

Source: Dipti Bawa and C.Y. Patil, (2013).

2.7 DC MOTOR

DC motors are very similar to DC generators. In fact, DC generators can be operated as DC motors by simply connecting a supply of rated DC voltage to the output terminal. In a similar fashion, a DC motor can be operated as a DC generator by simply connecting a prime mover to the shaft and a load to the DC terminals. DC motors offer some of the highest torque to horsepower ratios of all motors.

Instead of connecting the armature to a load, however, the armature is connected to a DC voltage supply. Armature and field flux are created with such a relationship that the armature rotates. The DC motor also uses a commutator. As the armature rotates, the brushes are connected, alternately, to each side of the armature loop. The connection is made in such a way that the armature field reverses polarity so that the motor rotation is continued.

NEMA defines the standard ratings for DC motors including items such as kilowatt ratings, speed, and voltage. The standards provide a level playing field so that purchasers can compare features and characteristics. Motors may be of the permanent magnet, series-connected, shunt-connected, or compound-connected type. Each type has its own specific features and capabilities.

Motors have distinct speed and torque relationships, depending on the connection. The series motor has the highest torque and the worst speed regulation. The shunt motor has the lowers torque and a very flat speed characteristic. All DC motors have higher torque per horsepower then the other motor types.

2.8 AQUARIUM PUMP

There are various types of equipment an accessory needed in an aquarium. One of them is aquarium pump. Aquarium pump is water circulation equipment. Typical aquarium pumps flow air and water by using an electromagnet to rapidly vibrate a rubber diaphragm. Unfortunately, it will produce noisy sound during moving water and air. It works as an air ventilation system inside of an aquarium. This pump will increasing oxygen amount inside the aquarium, thus allowing all living creatures in the water to receive enough oxygen. The usage of aquarium pump consistently is needed in order to ensure the life of the living creatures in the aquarium or in other words, the oxygen content inside the aquarium is always adequate.

Aquarium pump is one of the electrical appliances which require DC and AC voltage to operate. There are many kinds of aquarium pump in market. In this project, DC aquarium pump was used as a load.

2.9 CONCLUSIONS

Overall, this chapter had discussed about all the blocks or parts of this project separately with detailed description, figures and tables. The sources that were used for this chapter had stated clearly with the citations. This chapter is mainly to improve the understanding on variables involved in this project. Fuzzy logic reflects the thinking of people and models our common sense. It also models our decision making and the sense of words.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter expressed regarding the methods and techniques in order to accomplish the objectives of this project. Furthermore, this chapter also discusses the process flow of the project which is about the solar cell power optimisation system with the relevant steps. The explanations of the software development and hardware development with the electrical circuit diagrams also included in this chapter.

3.2 FLOW CHART OF THE PROJECT

First of all, create and design the fuzzy rules for the solar cell power optimisation. The software development used to create the fuzzy rules is the Fuzzy Logic Toolbox in MATLAB/SIMULINK. However, MATLAB was only used for optimised the membership function of the fuzzy logic controller by using hit and trial method. The Arduino language code was written for the implementation of FLC in hardware. After that, design the complete electrical circuit of the system.

The software development used for the circuit design is the ISIS Proteus and Pspice. Some parts of the electrical circuits had undergone simulation in that software. The next step is constructing the hardware of the electrical circuit. Some part of the circuit had undergone testing. After that upload the fuzzy logic Arduino language code in the ATmega328 microcontroller present in the Arduino board and connect the solar panel with the complete electrical circuit. Finally, test the prototype and improve it if needed.

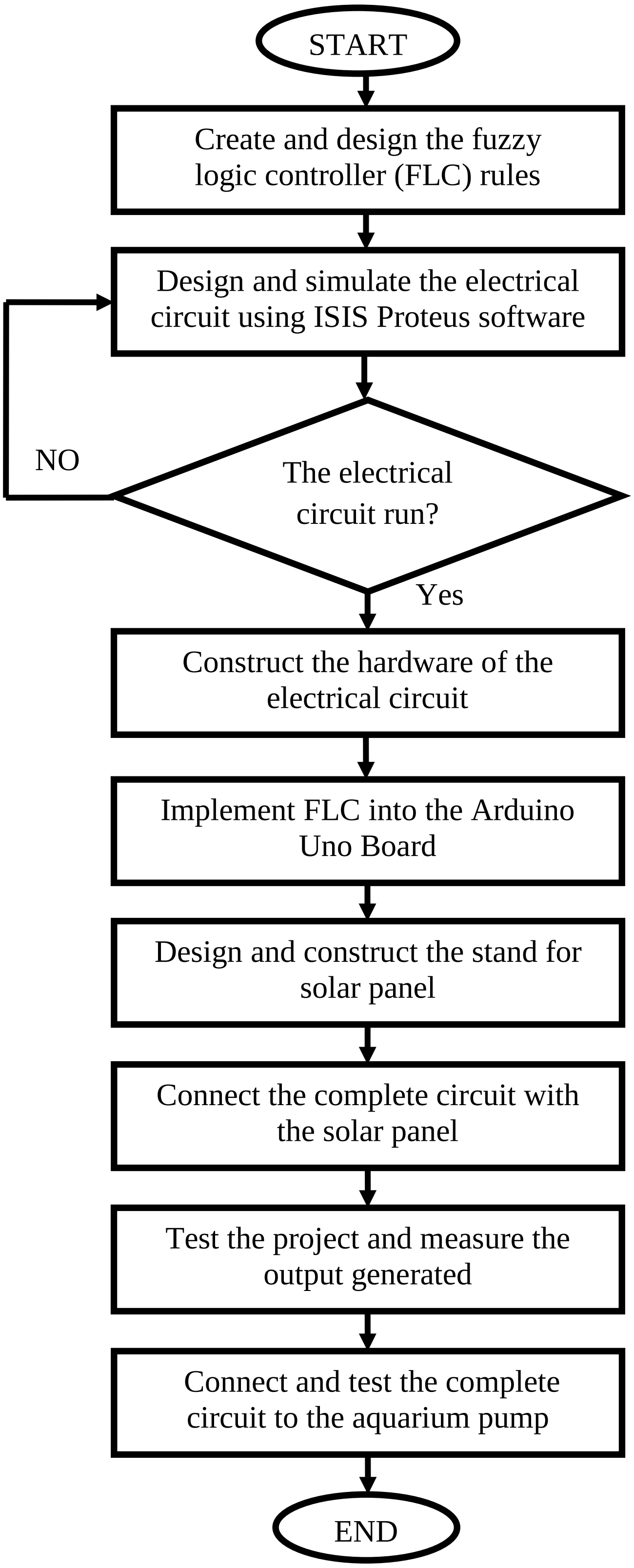
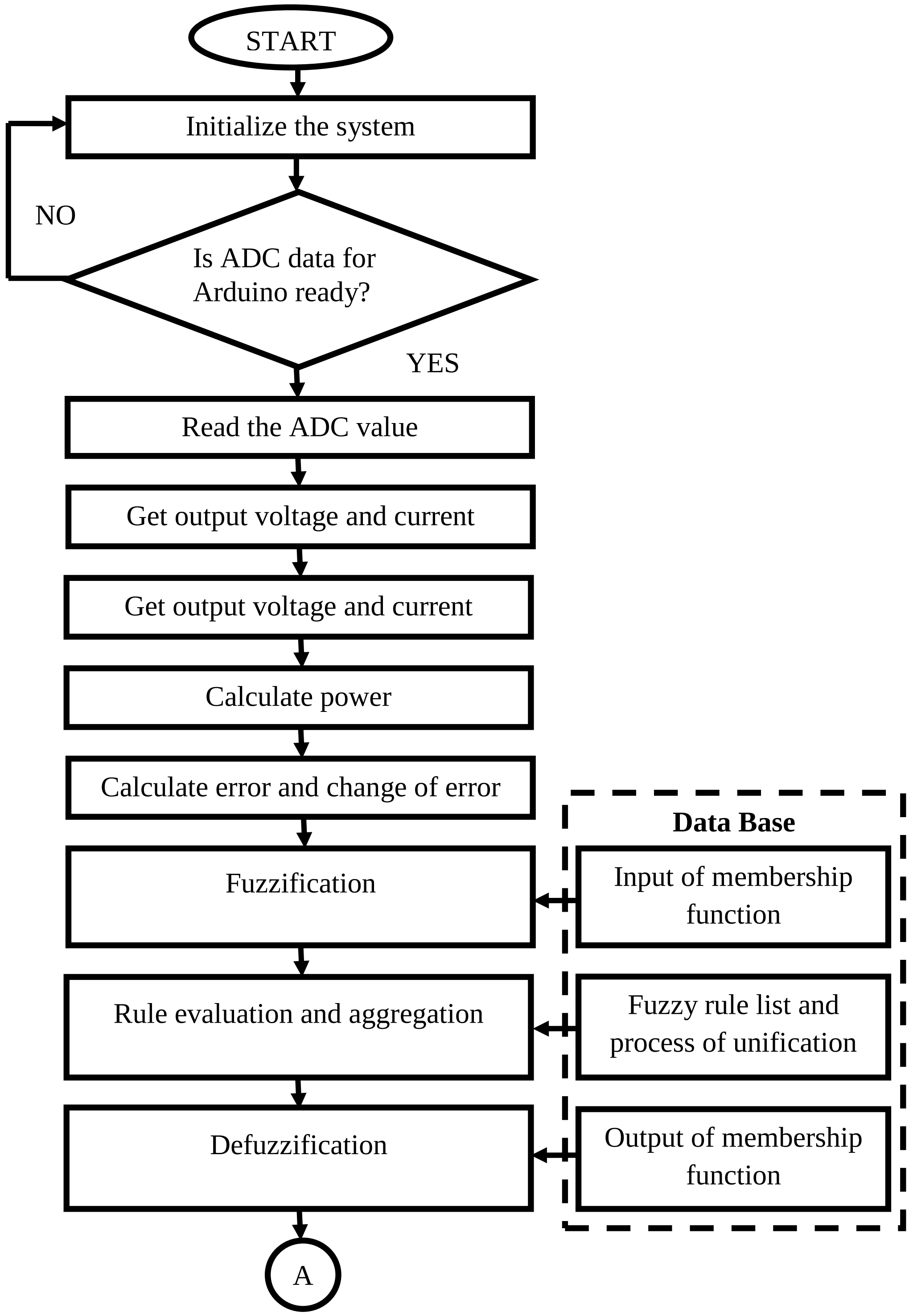


Figure 3.1: Flowchart of the project.

3.3 FLOW CHART OF THE SYSTEM

3.3.1 Flow Chart of the Fuzzy Logic Controller



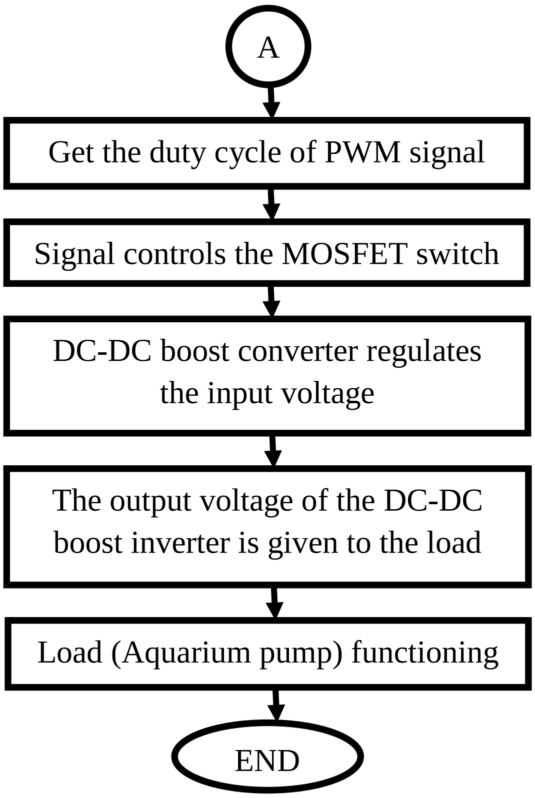


Figure 3.2: Flowchart of the fuzzy logic controller.

3.3.2 Flow Chart of the Sun Tracking System

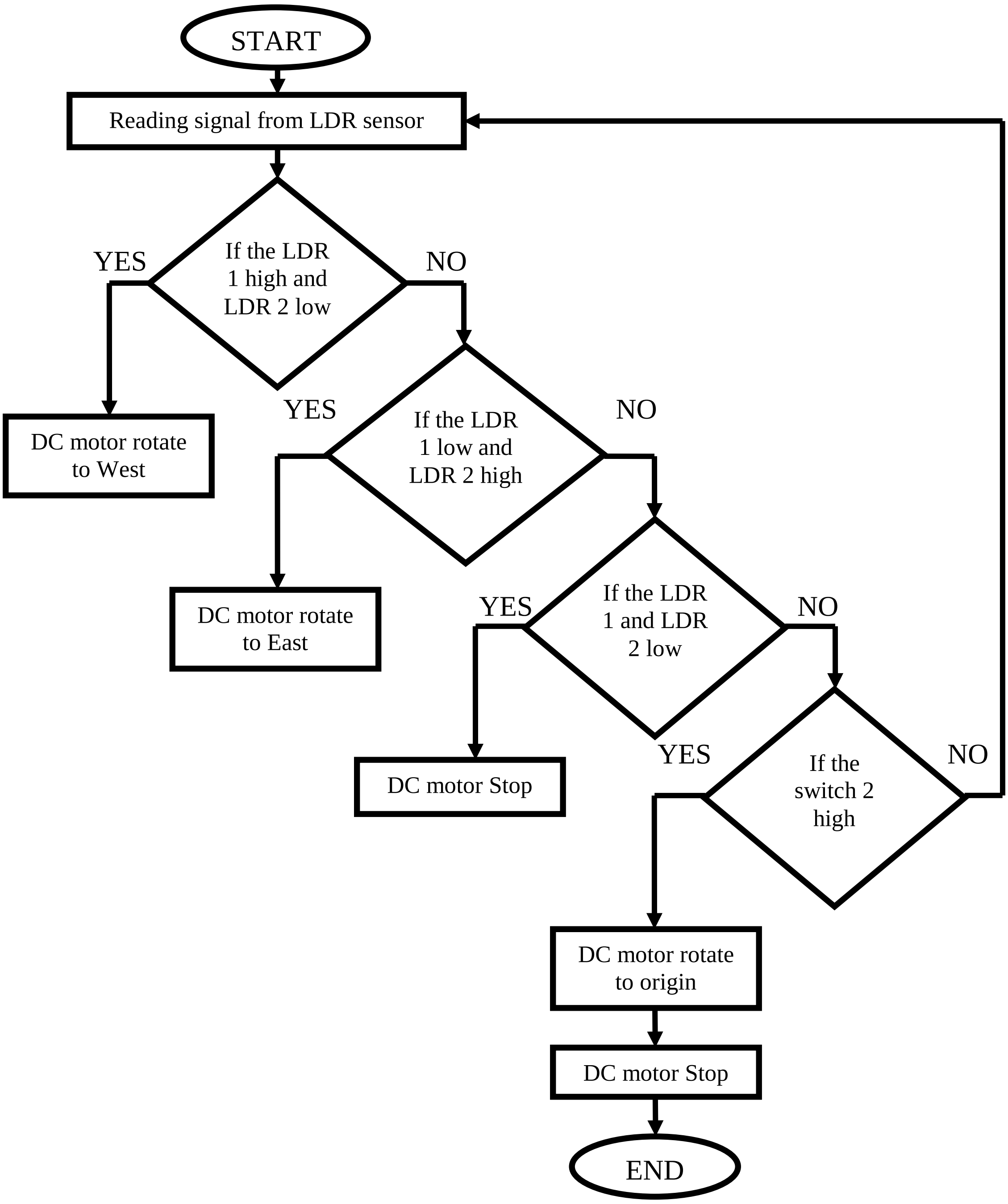


Figure 3.3: Process flowchart of the complete system.

3.4 BLOCK DIAGRAM OF THE SYSTEM.

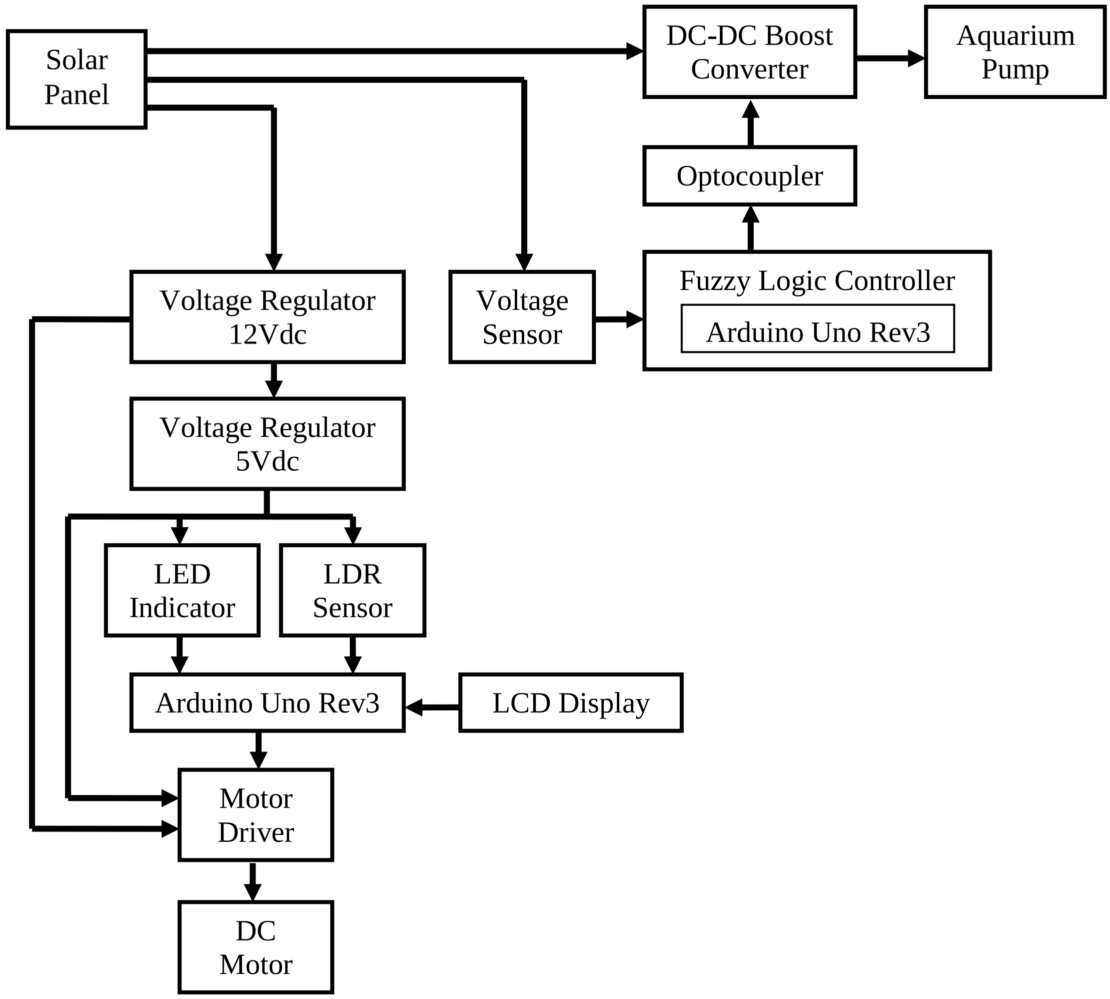


Figure 3.4: Block diagram of the overall system.

3.5 FUZZY LOGIC ALGORITHM DESIGN WITH FUZZY LOGIC TOOLBOX IN MATLAB/SIMULINK

First of all, the fuzzy logic algorithm or rules should be design according to the project. The fuzzy logic algorithm is differing for every system. Since this project is about optimising the maximum power of the solar cell, then the solar cell characteristics should be considered. The inputs of the fuzzy logic controller for this project are the error (E) and change of error (CE) meanwhile the output is the PWM duty cycle for the MOSFET.

The current versus voltage curve in Figure 3.5 below shows the maximum voltage and current of the photovoltaic panel. The maximum power point (MPP) can be calculated with maximum current and voltage.

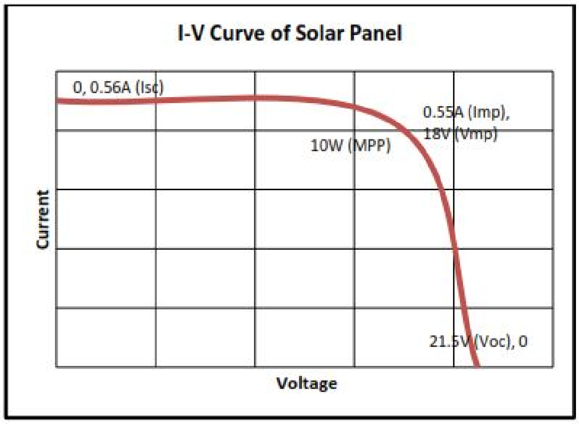


Figure 3.5: I-V curve for solar panel.

Furthermore, the rules of fuzzy logic can be design with the help of power versus voltage curve of the solar panel.

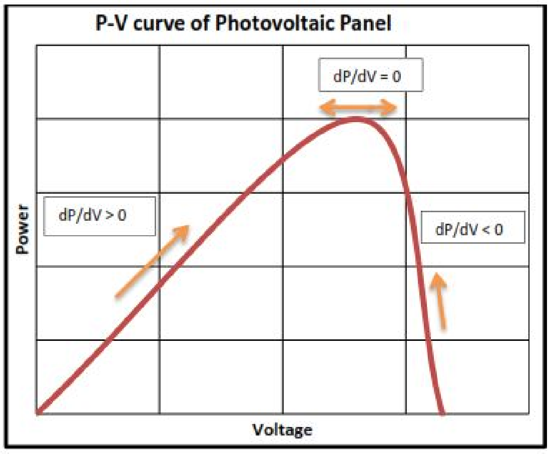


Figure 3.6: P-V curve for solar panel.

The rules can be design according to the dp/dv. If dp/dv > 0, then the controller will transform the duty cycle so that can increase the voltage until the power achieved the maximum value or dp/dv = 0. Moreover, if dp/dv < 0, then the controller will change duty cycle to reduce the voltage until the power achieved its maximum value. There is another simple method apart from the method explained above. The maximum power of the PV panel has the maximum voltage. Thus, the duty cycle can be change according to the output voltage by creating a reference voltage.

The fuzzy logic toolbox in the MATLAB/SIMULINK software will help to design the fuzzy rules and membership functions of the FLC. It has the FIS Editor which is an effective Graphical User Interface (GUI) tool that simplifies the design of the FLC. The FIS editor contains Surface Viewer, Rule Viewer, Rule Editor and Membership Editor. These Membership Editor as well as Rule Editor have been used to design fuzzy logic algorithms. The Surface Viewer and Rule Viewer show the view of membership functions in the form of rule and surface respectively.

The fuzzy logic control contains three units which are fuzzification, inference mechanism and defuzzification. This FLC uses the Mamdani method which is widely accepted for capturing expert knowledge in fuzzy rules. It allows user to describe the expertise in a human-like manner unlike the Sugeno method which is computationally effective and works with optimisation and adaptive techniques.

3.5.1 Fuzzification

The fuzzification is to change the crisp inputs into the linguistic variables by means of fuzzy subsets. Thus, the membership function values are expressed by linguistic variables using fuzzy subsets which are NL (negative large), NS (negative small), ZE (zero), PS (positive small) and PL (positive large). A reference voltage is fixed and the output voltage of the solar panel is measured by FLC. The error, E and the change of error, CE are calculated using the reference voltage and output voltage of photovoltaic panel.

The E and CE are the inputs of the FLC and they are based on numerical variables which have their range of values and are used to modify the fuzzy parameter to optimise the system operation. This E value is normalized by and input scaling factor such that the input values are between -1 and 1. The formulae for E and CE are as follows.

$$\text{Error, E} = V_{REF} - V_{PV} \quad (3.1)$$

$$\text{Change of error, CE} = E(k) - E(k-1) \quad (3.2)$$

Where V_{PV} and V_{REF} are the output voltage and reference voltage of solar panel respectively. Meanwhile, E (k) and E (k – 1) are the values of error at the instant (k) and (k – 1).

3.5.2 Inference Mechanism

Fuzzy inference can be definable as a mapping process from the inputs to an output which using the fuzzy sets theory. Rule aggregation and evaluation of the rule outputs included in the fuzzy inference as well. Rule base has been designed with the fuzzy subsets. The fuzzy control is implemented with the triangular membership functions. The duty cycle has been changed according to the output voltage of the photovoltaic panel. For example, if the error and change of error is positive, it means the output voltage of photovoltaic panel is low. Thus, duty cycle must be increases to get a maximum voltage. The complete rule base can be seen in Table 3.1 below.

Table 3.1: Rule base.

E \ CE	NL	NS	ZE	PS	PL
NL	ZE	ZE	PL	PL	PL
NS	ZE	ZE	PS	PS	PS
ZE	PS	ZE	ZE	ZE	NS
PS	NS	NS	NS	ZE	ZE
PL	NL	NL	NL	ZE	ZE

Figure below shows the membership functions of the inputs and the output.

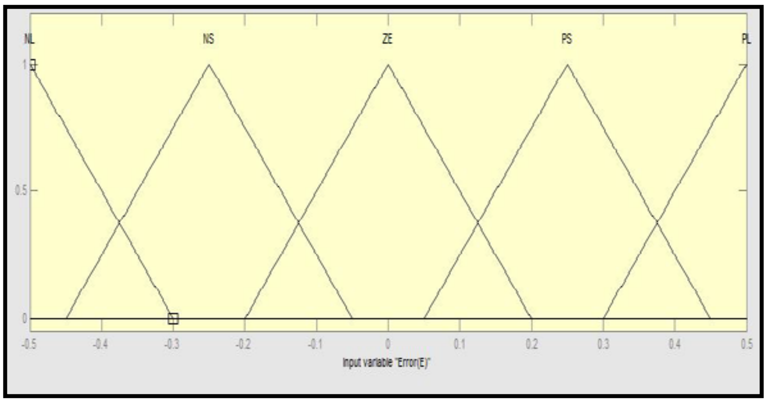


Figure 3.7: Error (E).

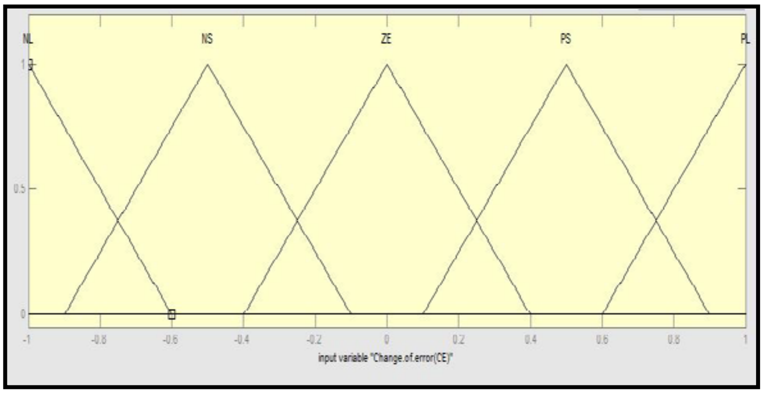


Figure 3.8: Change of error (CE).

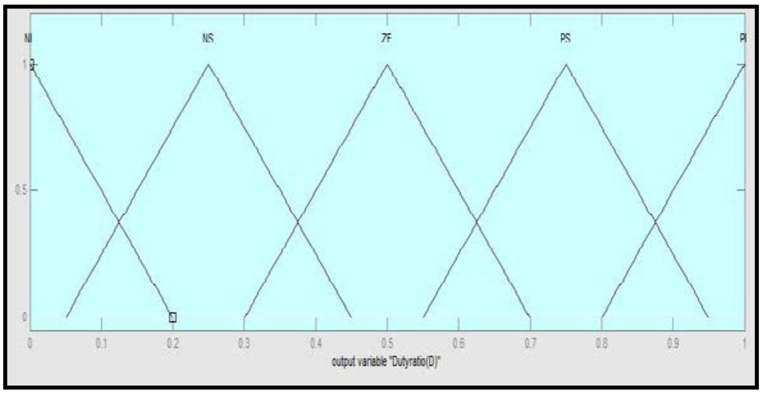


Figure 3.9: Duty ratio (D).

The rule viewer of 2 inputs and 1 output are as follow.

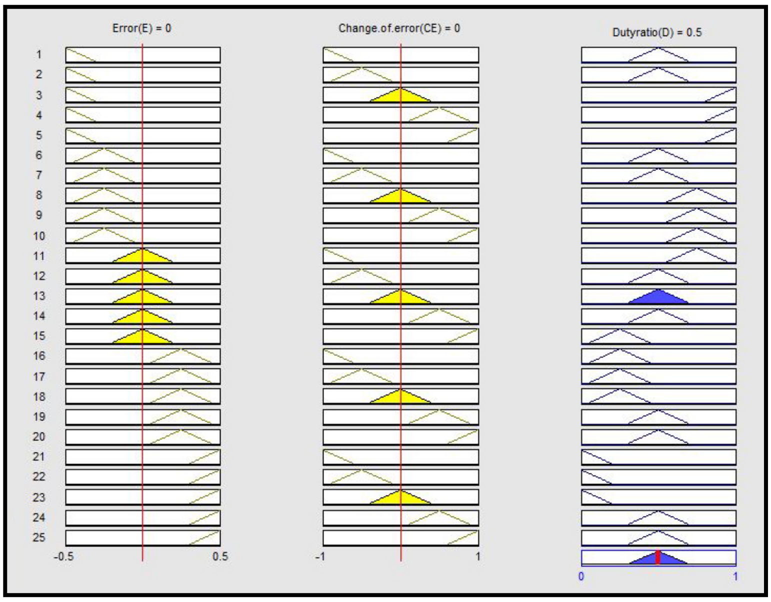


Figure 3.10: Rule viewer.

Figure 3.10 below shows the surface viewer of the membership functions.

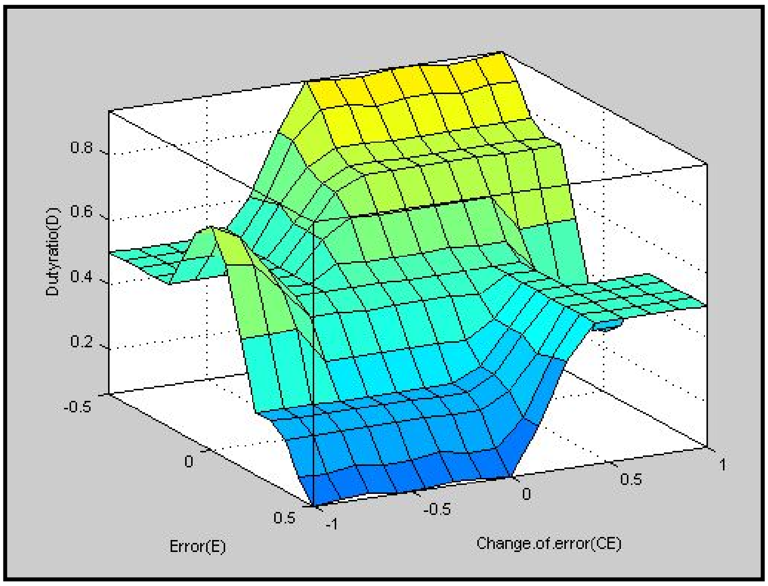


Figure 3.11: Surface viewer.

3.5.3 Defuzzification

The defuzzification converts the inference mechanism into the actual output which is a crisp number for the process. Mamdani method is been implemented in this study which can be developed by the centroid method. The output of fuzzy logic controller, duty ratio, D is compared with the sawtooth waveform to generate a pulse for MOSFET switch in the dc-dc boost converter.

3.6 ELECTRICAL CIRCUIT DESIGN

3.6.1 Voltage Divider

A voltage divider also known as divisor that is potential. It is linear circuit which produces output voltage that is part of input voltage. Voltage division is referred to the voltage division between divisor components. Voltage part usually used to create reference voltage or to get proportional low voltage signal with voltage measured. Apart from that, voltage divider really accurate if made with only resistor for frequency during and direct relatively low. Association between the input voltage and the output voltage available by using Ohm's Law.

$$V_{OUT} = (R_2/(R_1 + R_2)) \times V_{IN} \tag{3.3}$$

Where V_{IN} and V_{OUT} is the input and output voltage of the voltage divider respectively while R_1 and R_2 are the resistors.

The voltage divider that was designed for this project is shown below. This voltage divider network is applied as a sensor to detect voltage between the photovoltaic panel and controller. In this divider, 180kΩ and 47kΩ resistors were chosen to get the output voltage of maximum 5V from the input voltage, 25V. The output voltage of this network is used as a maximum input voltage to the A/D conversion for the controller

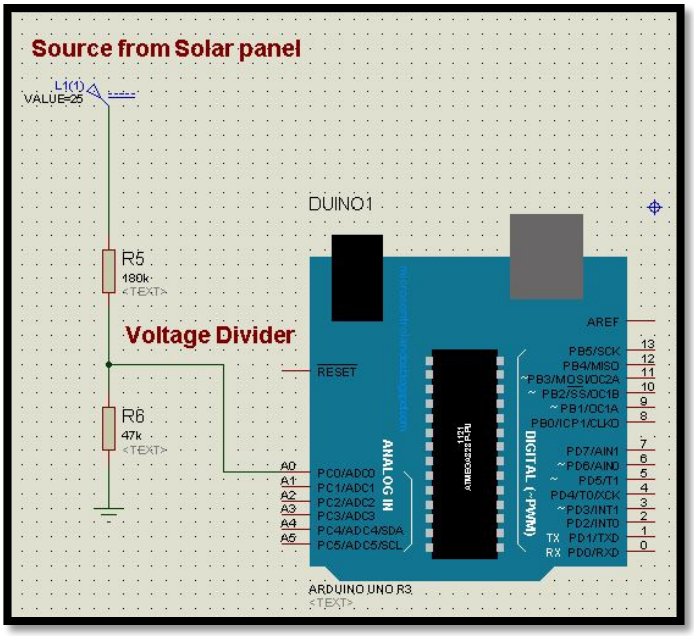


Figure 3.12: Schematic Diagram for Voltage Divider Connection using Proteus Program.

3.6.2 Voltage Regulator

It is use to convert DC voltage from solar panel to 12Vdc and 5Vdc. This 12Vdc and 5Vdc will supply to the motor drive circuit and LDR sensor circuit. The main components are L7805 and L7812 voltage regulator.

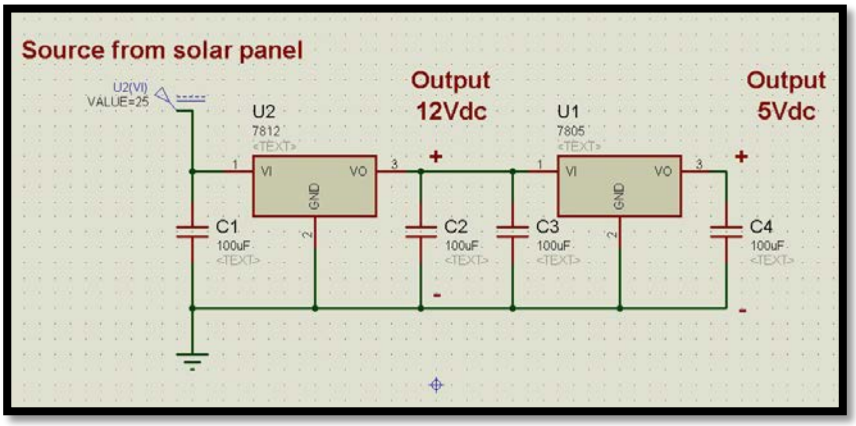


Figure 3.13: Schematic Diagram for Voltage Regulator Circuit using Proteus Program.

3.6.3 Light Sensor

Photo transistor is a cadmium sulphide (Cds) types or gallium arsenide (GaAs) type that use to detect the light from sun for this project. The photo transistor is based on the p-n diode. The value of resistance for photo transistor is inversely proportional to the amount of light intensity. Photo transistor is connecting with a resistance in series and the output voltage at the junction between photo transistor and resistance. The connection is show in Figure 3.14. The output voltage is increasing when the amount of the light intensity is increasing. As source sunlight increases will cause the resistivity of the sensor decreases.

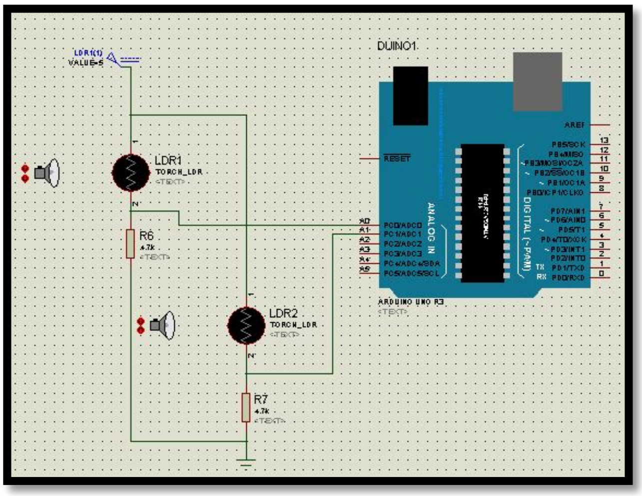


Figure 3.14: Schematic Diagram for LDR Sensor Connection using Proteus Program.

3.6.4 DC-DC Boost Converter

The converter steps up the low DC output voltage which was gained from the solar panel. It also regulates the voltage. The output voltage derived from the solar panel will be converted into the input voltage of the DC-DC boost converter. Fuzzy logic PWM signal will control the on or off time of the MOSFET switch of the converter. Software based on fuzzy logic will control the DC-DC converter, which in turn acts as a charge controller. The fuzzy logic control will track solar panel derived output voltage and determines the maximum power as well as controls the boost converter.

The duty cycle (D) of the MOSFET is adjusts with the fuzzy logic controller by generating the PWM signal. The voltage gets from the boost converter will be the final output voltage and it will be send to the load. The DC to DC boost converter had been designed to get a higher output voltage. The input voltage of the DC to DC boost converter will be varied from 0 to 21.5V; however the MPP voltage of the photovoltaic panel is 18V. Pspise and proteus software will use in this project to make simulation before construct the actual DC to DC boost converter. The duty cycle is calculated by:

$$\frac{V_{OUT}}{V_d} = \frac{1}{1-D} \tag{3.4}$$

Where V_d is the input voltage, V_{OUT} is the output voltage and the D is the duty cycle.

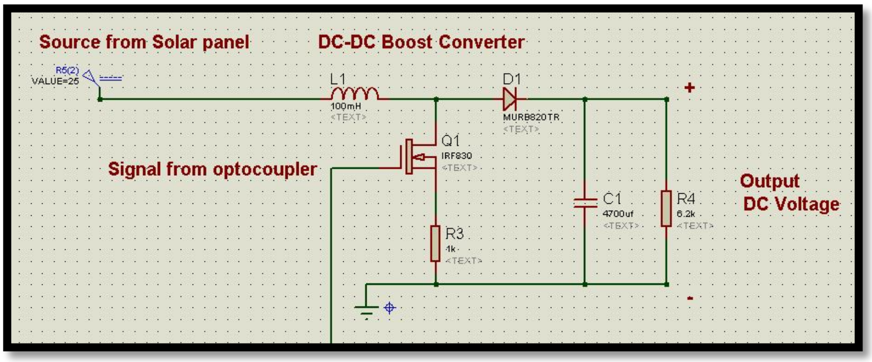


Figure 3.15: Schematic Diagram for DC-DC Boost Converter Connection using Proteus Program.

3.6.5 Optocoupler

Optocoupler is an electronic device that designed to transfer electrical signals by using light waves to provide coupling with electrical isolation between its input and output. It is used to isolate the two part of circuit to prevent high voltages from one part of the circuit from damaging the electronics component that use much smaller voltages on the other side of circuit. It constructed of an infrared emitting LED chip that is optically in-line with a light-sensitive silicon semiconductor chip, all enclosed in the same package. Therefore, the main purpose of optocouplers used in this project is to increase the value of peak voltage, Vpp of the PWM signal from the Arduino Uno.

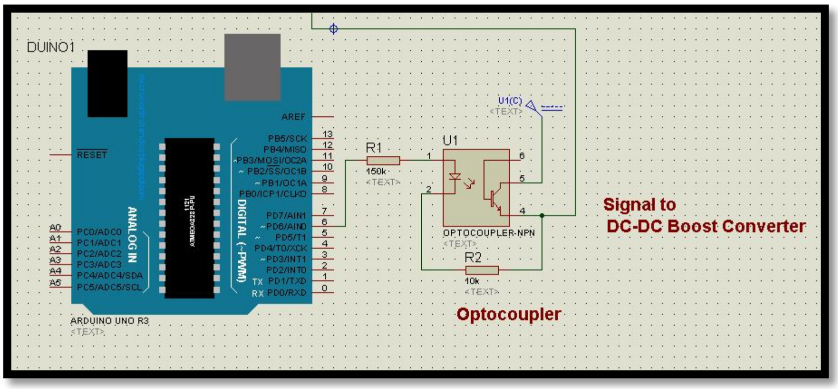


Figure 3.16: Schematic Diagram for Optocoupler Connection using Proteus Program.

3.6.6 LCD Display

Liquid Crystal Display or LCD is used in this system is to display the movement of the DC motor. It can display for example motor move to west, motor move to east, motor perpendicular and motor stop. This LCD Display functions as an indicator for this system. 3.3V from Arduino Uno must connect to the LCD pin to turn on the LCD display. Figure 3.17 show LCD Pin Diagram.

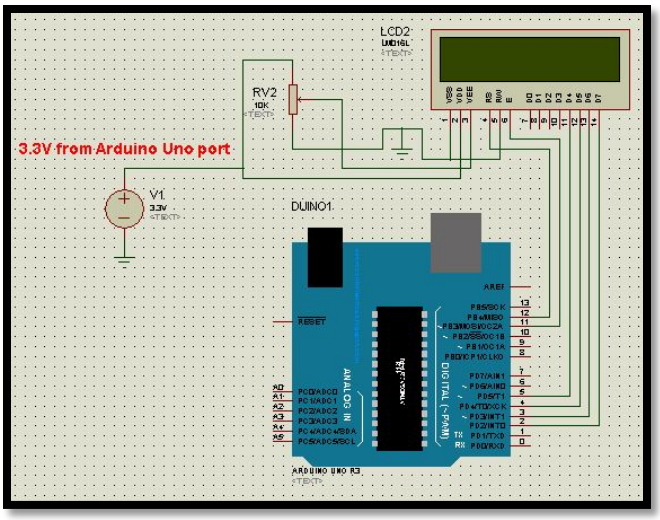


Figure 3.17: Schematic Diagram for LCD Display Connection using Proteus Program.

3.6.7 LED as Indicator

LED or light emitting diode is a two lead semiconductor light source. In this project, it used as an indicator for the solar panel movement. Three colours of LED used in this project red, blue and yellow. Table 3.2 show the detail function of LED.

Table 3.2: Functions of LED.

NO.	LED Colour	Descriptions
1.	Red	Solar panel moving to west
2.	Blue	Solar panel moving to east
3	Yellow	Solar panel moving to the origin place

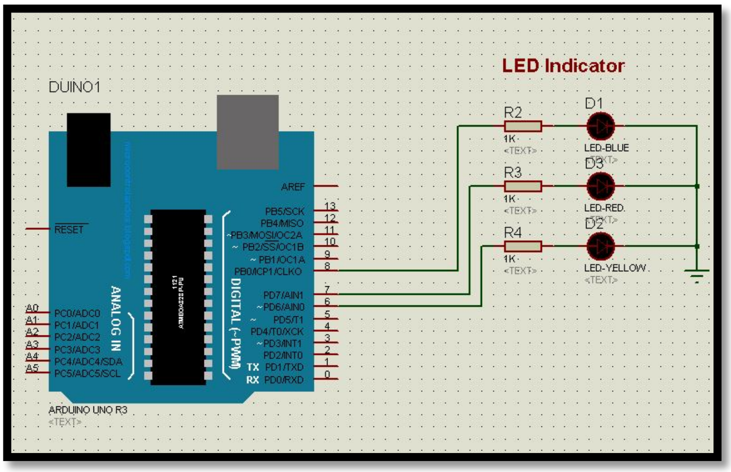


Figure 3.18: Schematic Diagram for LED Connection using Proteus Program.

3.6.8 Motor Driver

The common method used to drive the DC motor in two directions is using H-bridge motor driver. In this project, L293D is used as a DC motor driver. It is inexpensive and simplest for low current motors. It has two H-bridges, one on the left side and one on the right of the chip. It can control two motor. Arduino Uno is needed to control the signal before give to the motor driver. Connecting two direction pins from L293D to digital pins at Arduino Uno to control the directions or turn the motor on and off. Put one pin high and the other pin low, the motor rotate in one direction. Reverse the state of the pins to make the motor rotate to other direction. The motor off when put both pins low. Capacitor was added across power and ground close to the motor to prevent the microcontroller resetting whenever the motor turns on. The capacitor will smooth out the voltage dips that occur when the motor turn on. This capacitor is called a decoupling capacitor. Usually a 10-100μF capacitor will work.

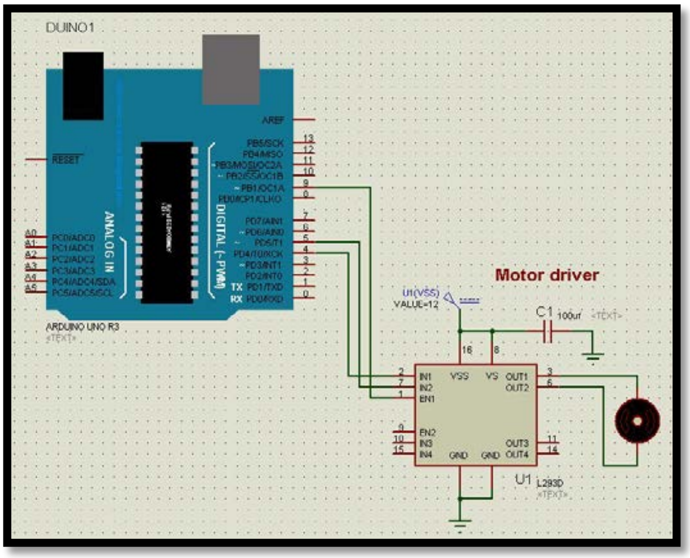


Figure 3.19: Schematic Diagram for Motor Driver Connection using Proteus Program.

3.7 IMPLEMENTATION OF FUZZY LOGIC CONTROLLER

FLC is the main part of the project system. It helps to track and optimise the maximum output power from the photovoltaic panel. The controller used in this project is the Arduino Uno Rev3. The optimised membership function data created with MATLAB Fuzzy logic Toolbox had been used in writing Arduino language code and uploaded in the ATmega328 microcontroller present in the Arduino board. The software used for writing the code is Arduino IDE version 1.0.5.

3.7.1 The Arduino IDE Software

The software used for this project to write the source code for the Arduino controller is the Arduino IDE version 1.0.5. IDE is the Integrated Development Environment that runs on regular personal computers as well as allows writing programs/codes for Arduino using C or C++. Arduino is very simple to write code and easy uploading programming into the I/O controller because the open-source Arduino environment. The environment is written in Java based on Processing, avr-gcc and other open source software. Apart from that too, just a single click, it is capable to uploading and compiling programs into board.

The code that had been written for this project is about the FLC with error and change of error as an inputs and duty cycle as the output. The code is attached in the Appendix for reference. Two functions must be defined to make run able cyclic executive programs which are setup and loop.

3.8 DESIGN AND CONSTRUCT MECHANICAL STRUCTURE

For this project, the software used to design the structure is Catia. This program is able to draw the mechanical structure in two dimensions and three dimensions. First, design the structure for the mechanical structure for prototype. After finish design the structure, selecting the material for the prototype and calculate it is safety to exist the mass of stepper motor and solar panel. After that, choose the mechanical components for this project. Finally, construct the mechanical structure for this project.

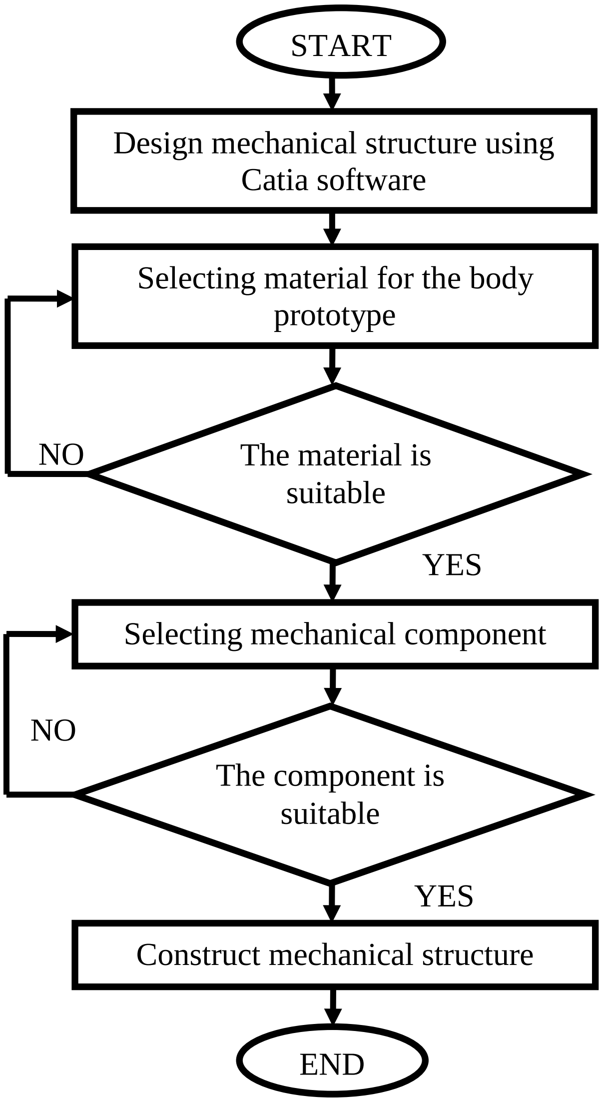


Figure 3.20: Flowchart of the design and construct mechanical structure.

3.8 CONCLUSIONS

Overall, this chapter had discussed the design of overall system of the project in terms of electronic circuits and hardware overview of solar panel. It also elaborated and explained the design of fuzzy logic algorithm for MPPT of photovotaic panel with the Arduino.

CHAPTER 4

RESULT AND DISCUSSIONS

4.1 INTRODUCTION

This chapter explains the results and discussions of this project. This project mainly focused on the maximum power point tracking controller and the sun tracking system. MPPT method used in this project is fuzzy logic controller. The sun tracking system was added in this project to increase the rate of sunlight absorption by the solar panel. The prototype had been tested and some of the data from the hardware was collected. The maximum power point has been optimised by fuzzy logic controller. Sun tracking system was designed to make the solar panel moving according to the sun movement. The fuzzy logic programming was designed with the Arduino language using the Arduino IDE software. The PWM duty cycle is the output of the controller and it has been changed or controlled according to the output voltage of solar panel.

4.2 VOLTAGE DIVIDER AS VOLTAGE SENSOR

The voltage divider circuit has been used to turns a large voltage from solar panel into smaller voltage. It also has been used as a voltage sensor for the solar or photovoltaic panel. The components used for the voltage divider are 180KΩ and 470kΩ ceramic resistors which can withstand up to 10W of power. This divider had partition the output voltage of solar panel to a maximum 5V.

The voltage from solar panel has been scaled to 0-5V because the maximum input voltage of the Arduino Uno controller is 5V only. The output voltage of the divider will be the input voltage of the controller. The voltage obtained after the partition is shown in Table 4.1. Moreover, the real circuit of the voltage divider can be seen in Figure 4.1.

Table 4.1: Comparison between the input and output voltage of the divider.

Vpv (V)	Vout from Divider (V)
0.0	0.0000
2.5	0.5176
5.0	1.0352
8.5	1.7599
13.0	2.6916
19.5	4.0374
25.0	5.1762

Figure 4.1: Voltage Divider Circuit.

4.3 OPTOCOUPLER

The optocoupler circuit acts as driver for the MOSFET to increase the peak voltage, Vpp of the PWM signal from the Arduino controller. The Arduino only can give 5V of Vpp. The driver is needed because the minimum switching voltage of the IRF830 MOSFET in the DC-DC boost converter is 10V and the optocoupler can drive until 12 Vpp with the V of the Arduino controller. The circuit consists of 4N25 optocoupler, 10KΩ and 150Ω resistors.

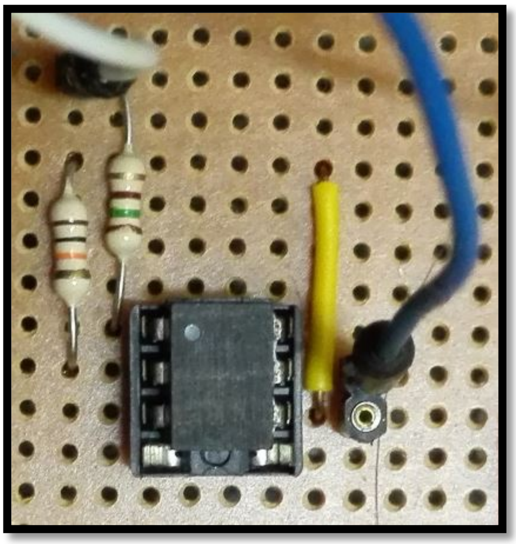


Figure 4.2: Optocoupler Circuit.

4.4 DC-DC BOOST CONVERTER

The dc-dc boost converter circuit is designed to regulate the output voltage of the solar panel. The circuit included parts of components such as 100uH radial inductor, IRF830 MOSFET, MUR860 diode, 4700uF Capacitor, 1kΩ and 6.2kΩ resistors. The boost converter had regulated the voltage of the solar panel according to the value of duty cycle which can obtain from the fuzzy logic controller where the duty cycle will be send to the MOSFET in the converter.

The dc-dc boost converter has been chosen for PV system because it is low cost, simple and high efficient as well. Moreover, it is adopted as a regulator for this system.

Figure 4.3 shows the real circuit of the boost converter which was designed in a strip board.

Figure 4.3: DC-DC Boost Converter Circuit.

4.5 SENSOR TRACKING

LDR is used to construct the tracking sensor of this system. LDR usually gives variation in resistance with the change in light intensity. LDR operates on 5Vdc. In this project, two LDRs are mounted on the solar panel with a shadowing element in between. LDRs used to sense the position of the sun in one direction for example east and west. This shadowing element helps in determining the accurate light falling on the respective LDRs. Since the light intensity received by both the LDRs would be different every time the sun moves, the output of the two LDRs is compared. The system determines which LDR has received more light than the other through ADC and drives the DC motor towards the direction of the sun.

LDR can be connected in a divider circuit to give the voltage output through a 10KΩ resistor. Under the light, the resistance across the LDR is very low. The voltage between LDR and resistor is fed to the Arduino as input voltage. Figure 4.4 show the real circuit of the sensor tracking.

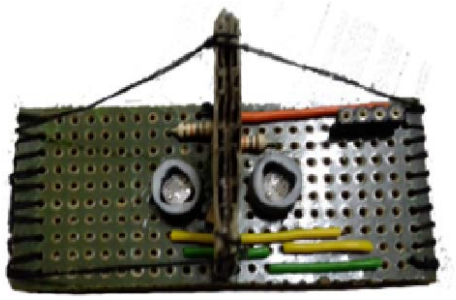


Figure 4.4: Sensor Tracking Circuit.

4.6 DC GEAR MOTOR AND ITS DRIVER

DC gear motor has been used for the movement of the solar panel. Table 4.2 show the specification of this DC gear motor. DC gear motor has high torque compare with the other DC motor. DC gear motor is operated through a driver which gets the signal from the Arduino Uno. Motor driver used in this project is L293D. This driver used to drive the DC motor in two directions for example clockwise or counter clockwise. The motor driver circuit included parts of components such as L293D and 100µf capacitor. Figure 4.5 show the real circuit of the motor driver.

Table 4.2: DC Gear Motor Specification.

Voltage	12Vdc
Output Power	1.1Watt
Rated Speed	12RPM
Rated Current	410mA
Rated Torque	1176mN.m
Gear Ratio	270:1
Shaft Diameter	6mm

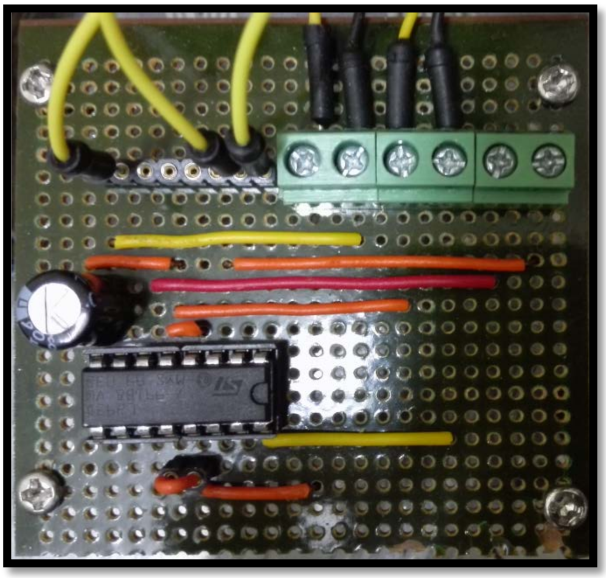


Figure 4.5: Motor Driver Circuit.

4.7 MICROCONTROLLER FOR FUZZY LOGIC

The microcontroller used in this project is the ATmega328 which is included in the Arduino Uno Rev3 board. The Arduino Uno has been used to upload a fuzzy logic C program where the program can optimise the power of the solar by controlling the duty cycle of MOSFET in boost converter according to the output voltage of the solar panel. The first input of the controller is the output voltage of solar panel. The second input is the reference voltage. The inputs for the fuzzy logic program are the error and change of error.

The calculations for these inputs have been written in methodology. The output of the controller and also fuzzy logic program is the PWM duty cycle for the MOSFET. Before connect the controller with solar panel and boost converter, it is connected with DC power supply for the input voltage and Digital Storage Oscilloscope (DSO) for checking the PWM output. The required debugging was done to see the final PWM output at DSO.

4.8 OUTPUT OF FUZZY LOGIC CONTROLLER

Table 4.3 show the data collected from the Arduino Uno controller using the DC Power Supply for the input voltage replaced the solar panel as well as Digital Storage Oscilloscope to show the PWM response with the value of duty cycle. This method has been conducted to test the fuzzy logic program or coding. The duty cycle had changed according to the value of error and change of error.

Table 4.3: Data Collected With The Controller And Fuzzy Logic Program.

Vpv (V)	Vref (V)	Error	Change of Error	Duty Cycle Digital Value (0-255)
7.40	18	0.59	0.37	205
14.05	18	0.22	-0.26	96
3.65	18	0.80	0.21	254
9.40	18	0.48	0.48	220
13.05	18	0.28	0.22	150
20.00	18	-0.11	0.00	127
16.95	18	0.06	0.17	136
20.00	18	-0.11	-0.91	0

The PWM output signal from the Arduino Uno had been captured on a DSO. As told before, the duty cycle had varied according to the error and change of error of the fuzzy logic while the PWM responses were differed according to the duty cycle from the controller. Figure 4.6, 4.7 and 4.8 shows some responses for different duty cycle percentage value.

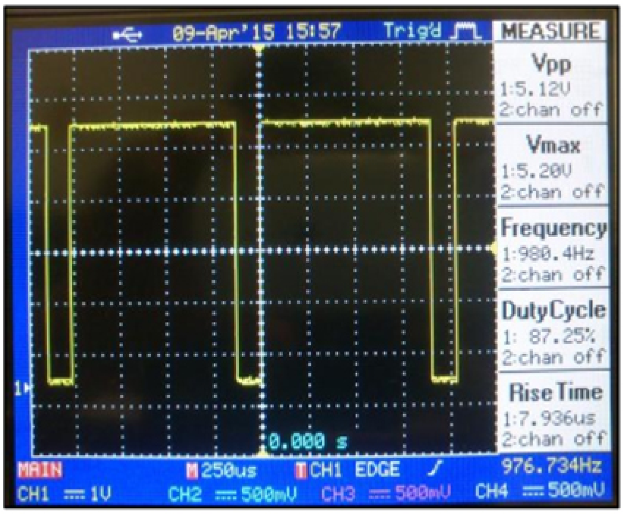


Figure 4.6: PWM output for high duty cycle (87.25%).

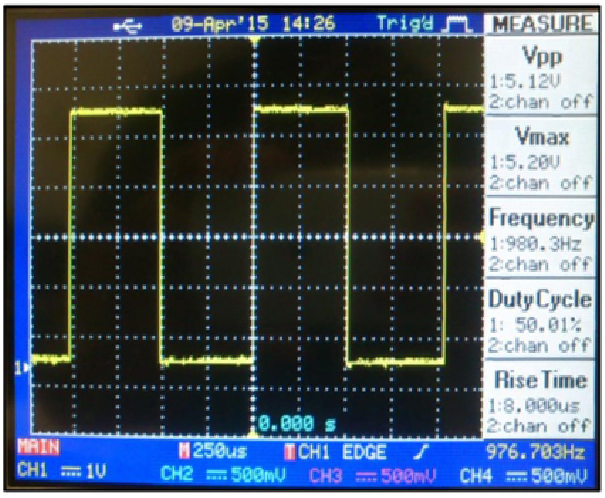


Figure 4.7: PWM output for average duty cycle (50.01%).

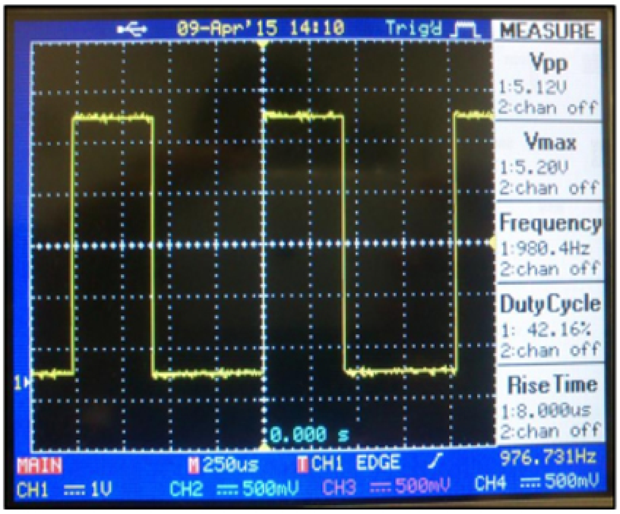


Figure 4.8: PWM output for low duty cycle (42.16%).

4.9 OUTPUT OF OPTOCOUPLER

The peak voltage of PWM signal has been increased by the optocoupler to an approximately 12V. This voltage can switch the MOSFET at the DC-DC boost converter circuit. The response obtained from the optocoupler circuit can be seen in the Figure 4.9, 4.10 and 4.11 as well.

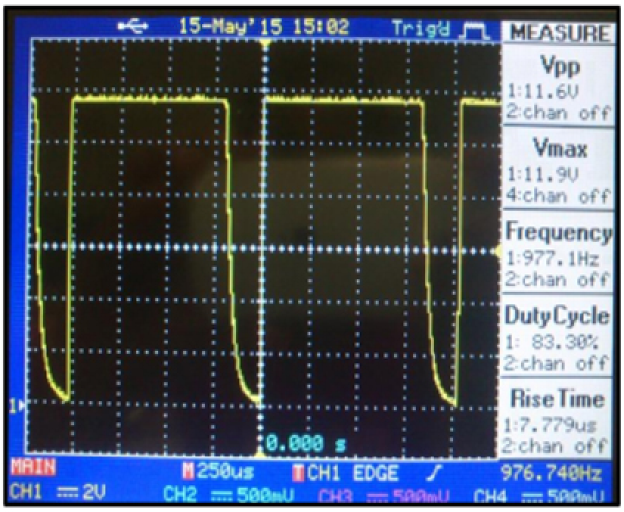


Figure 4.9: PWM output for high duty cycle.

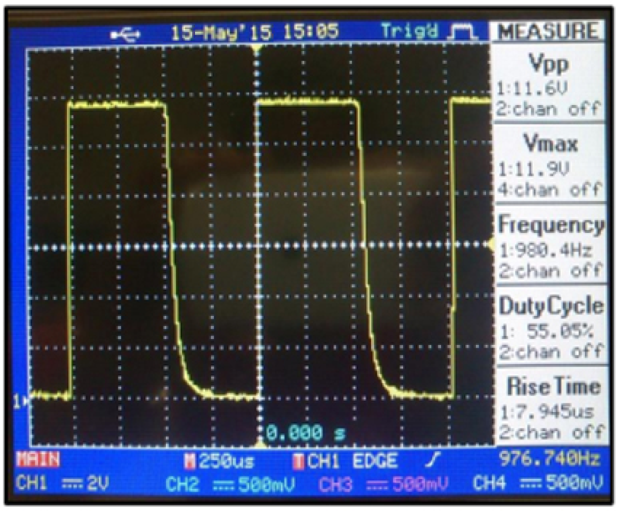


Figure 4.10: PWM output for average duty cycle.

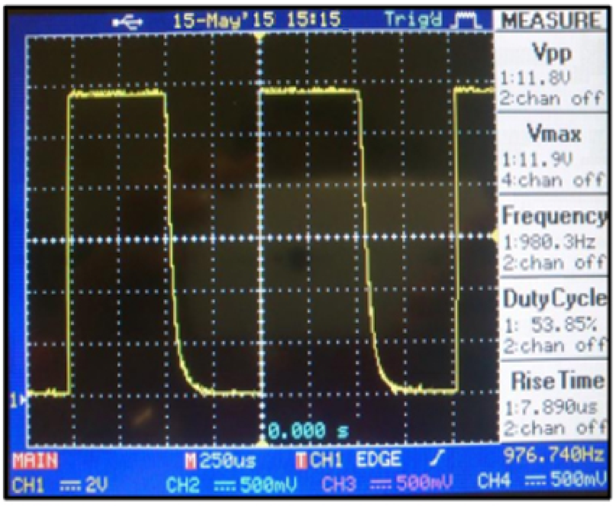


Figure 4.11: PWM output for low duty cycle.

4.10 COMPLETE PROJECT TEST

Figure 4.12 show the testing that was done for the complete designed system. The complete system included fuzzy logic controller and sun tracking system. The solar panel output values with and without sun tracking system was collected and compared. The output voltage from the solar panel with sun tracking system has been more stable than the output voltage obtained directly from the solar panel without sun tracking system. Table 4.4 shows the comparison between the output values with and without sun tracking system.

Table 4.4: Output power with and without sun tracking system.

Time of the day	**Solar Panel output values without sun tracking system**			**Solar Panel output values with sun tacking system**		
	Voltage V(V)	**Current I(A)**	**Power P(W)**	**Voltage V(V)**	**Current I(A)**	**Power P(W)**
8.00 am	8.75	0.067	0.586	11.54	0.169	1.950
10.00 am	12.85	0.192	2.467	12.02	0.274	3.293
11.00 am	12.49	0.258	3.222	11.84	0.287	3.398
11.30 am	12.25	0.262	3.210	11.86	0.286	3.392
12.00 pm	12.75	0.258	3.289	11.89	0.288	3.424
1.00 pm	12.79	0.244	3.121	11.85	0.283	3.354
3.00 pm	12.87	0.233	2.999	11.78	0.283	3.334
5.00 pm	12.71	0.101	1.284	12.07	0.177	2.136
7.00 pm	9.61	0.034	0.327	11.76	0.106	1.247
Total	**107.07**	**1.649**	**20.505**	**106.61**	**2.153**	**25.528**

Through the data collection, the efficiency of the overall system with the sun tracking system can be calculated as:

$$\mathbf{Efficiency} = \left[\frac{(25.528 - 20.505)}{20.505} \times 100\right] = 24.4965\%$$

It has been observed that the efficiency of the system increases by 24.4965% when implemented fuzzy logic controller with the sun tracking system.

Figure 4.12: Experimental setup of the overall system.

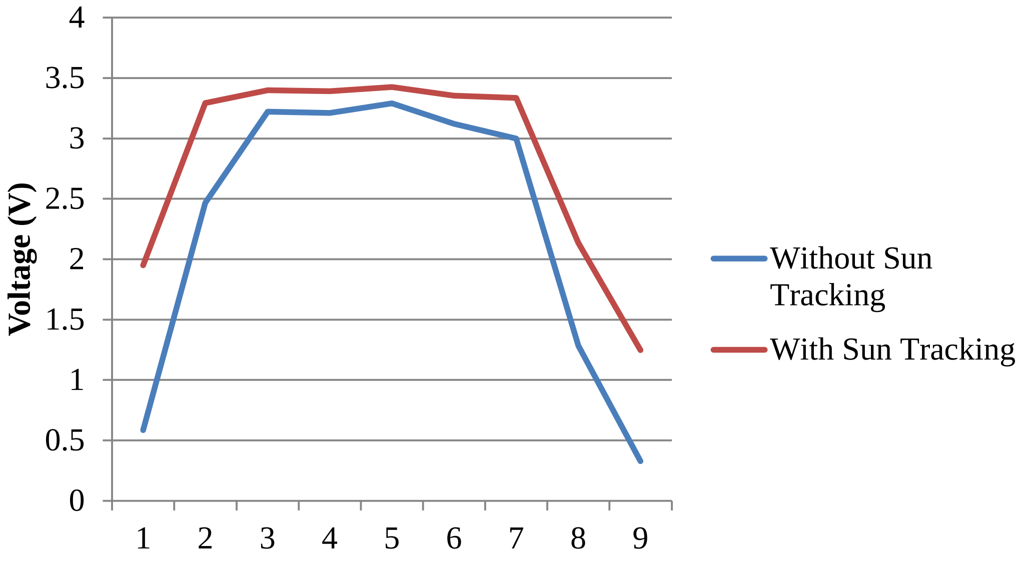


Figure 4.13: The graph for voltage through the solar panel with and without sun tracking system.

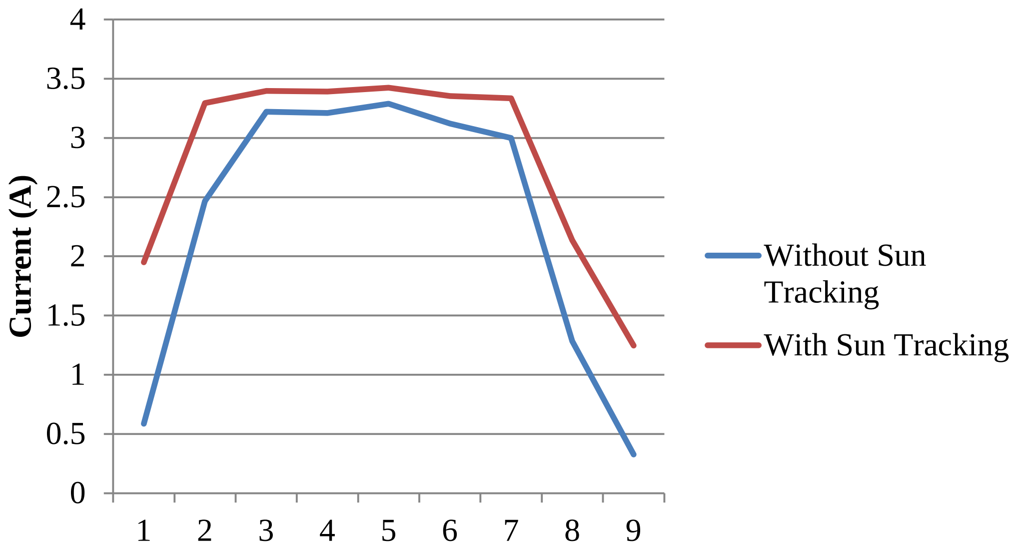


Figure 4.14: The graph for current through the solar panel with and without sun tracking system.

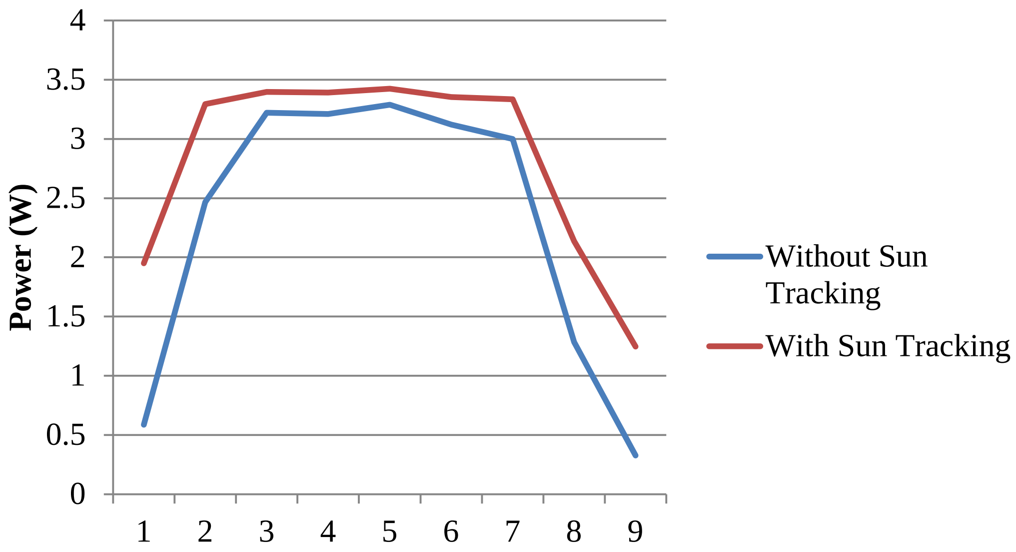


Figure 4.15: The graph for power through the solar panel with and without sun tracking system.

4.11 CONCLUSIONS

Overall, this chapter had explained about each of the circuit in the system as well as showed the real circuits separately. The output from each circuit also had been discussed. The complete project had been tasted with the sunlight energy. The data of the final output voltage of solar panel controlled by FLC with sun tracking system and the output voltage of solar panel controlled by FLC without sun tracking system was compare.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

This chapter concludes all the significant findings of this project. This chapter also gives some recommendations and suggestions for the future improvement of the project.

5.2 CONCLUSIONS

Conclusively, the objectives of this project were achieved. The project “Aquarium pump drive by solar cell using maximum power point tracking (MPPT)” was successfully designed and produced. The system contains four main parts which are solar panel, dc-dc boost converter, fuzzy logic controller and sun tracking system. The controller is able to control the duty cycle of the PWM signal and send to the MOSFET in boost converter. Moreover, the boost converter is able to regulate the voltage of solar panel according to the MOSFET signal.

Through the above research, the fuzzy logic controller increases the efficiency of the overall system by24.4965%. DC gear motor used for control the position of the solar panel and increases the power absorption of the solar panel. MPPT is tracked efficiently throughout the day with the change in sun and solar panel position. Fuzzy logic demonstrates efficient control, faster response and good conversion of human or operator knowledge. Arduino Uno turned out to be an easy platform implement the fuzzy logic controller.

5.3 RECOMMENDATIONS

This project had successfully designed. However, there are some improvements that can be implementing for a better efficient system then the current designed system. Below are some recommendations for the future improvements.

i. Use a bigger solar panel with high maximum power to obtain a better result.
ii. Increase the linguistic variables in membership functions of fuzzy logic inputs and output to get a more effective variation of duty cycle.
iii. Implement two axis solar tracker systems to get more efficiency of the solar panel.

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APPENDIX A

ARDUINO UNO REV3 CODE

Appendix A.1 Fuzzy logic controller

```
/*  PREPARED BY:     MOHD JOZAIMI IZWAN BIN JALALUDDIN
    SV:                        ASSOC. PROF. DR. AJISMAN APEN
   PROJECT TITTLE:  AQUARIUM PUMP DRIVE BY SOLAR CELL USING MPPT
   PROGRAMMING TITTLE:       FUZZY LOGIC CONTROLLER
   UNIVERSITY:         UNIVERSITI MALAYSIA PAHANG (UMP)
   YEAR :                    2015
*/

#define Rf 3.6
#define In A0
#define Out 6

float Ref;                              // Reference value
float voltage;                          // Voltage from PV Panel
float vol;                              // Real voltage value after convert from 0-1023 to 0-5V
float e;                                // Error (Input 1 for fuzzy logic controller)
float ce;                               // Change of Error (Input 2 for fuzzy logic controller)
float dat[2]={0,0};                     // Storage variable for error values of k and k-1
float dutyRatio;                        // Output of the fuzzy logic controller
boolean i=false;                        // The setup routine runs once when you press reset:

void setup()
{
   Serial.begin(9600);                  // Initialize the analog pins for input

                                        // Set pin as input for reference voltage
   pinMode(Rf, INPUT);                  // Set pin as input for voltage of PV panel
   pinMode(In, INPUT);                  // Initialize the analog pin for output
                                        // Set pin as output for MOSFET dutyratio
   pinMode(Out, OUTPUT);

                                        //Read the reference value from the input, Rf
   Ref=Rf*1023/5;
   Serial.print("The Reference value = ");
   Serial.println(Ref);
```

```
}

                                    // The loop routine runs over and over again forever:
void loop()
{
                                    // Read the output voltage of PV panel
   voltage = analogRead(In);
   vol=((float)voltage*5/1023);
   Serial.print("The actual voltage of PV panel = V");
   Serial.println(vol);

   // Calculate the error by comparing the vol with Ref and finally normalized it
   e=(float)(Ref-voltage)/3.6;
   e=(e*5)/1023;
   Serial.print("The Error value = ");

   Serial.println(e);
   dat[i]=e;

   // Calculate the Change of Error by comparing current error and the the previous error
   ce=dat[i]-dat[!i];
   i=!i;
   Serial.print("The Change of Error value = ");
   Serial.println(ce);

   // Apply fuzzy logic system
   dutyRatio= PVpower_optimization(e,ce);

   // Obtain the crisp value of the output from the fuzzy logic controller
   dutyRatio=(dutyRatio+1)*255/2;

   // Get the output value from the fuzzy logic system
   analogWrite(Out, (int)dutyRatio);

   // Send the PWM output
   Serial.print("The crisp value of dutyratio = ");
   Serial.println((int)dutyRatio);
   delay(1000);
}

// Fuzzy Inference
float PVpower_optimization(float er,float cer)

{
  float x0[3],x1[3],x2[3];
  float dutyRatio;
  float aggre;

// Fuzzification & Rule Evaluation
```

```
 for(int i=0;i<3;i++)
   {
   x0[i]=0;
   x1[i]=0;
   x2[i]=0;
   }

// Input 1(Error)
 if(er<-0.8)
   {
   x0[0]=-1.25*er-0.25;
   }
 if((er>-0.8) && (er<-0.2))
   {
   x0[0]=-1.25*er-0.25;
   x0[1]=1.25*er+1;
   }
 else if((er>-0.2) && (er<0))
   {
   x0[1]=1.25*er+1;
   }
 else if((er>0)&&(er<0.2))
   {
   x0[1]=-1.25*er+1;
   }
 else if((er>0.2) && (er<0.8))
   {
   x0[1]=-1.25*er+1;
   x0[2]=1.25*er-0.25;
   }
 else if((er>0.8) && (e<1))
   {
   x0[2]=1.25*er-0.25;
   }

 // Input2(Change of Error)
 if((cer>-0.7) && (cer<-0.56))
   {
   x1[0]=-1.786*cer-0.25;
   }
 if((cer>-0.56) && (cer<-0.14))
   {
   x1[0]=-1.786*cer-0.25;
   x1[1]=1.786*cer+1;
   }
 else if((cer>-0.14) && (cer<=0))
 {
   x1[1]=1.786*cer+1;
   }
```

```
 else if((cer>0) && (cer<0.14))
   {
   x1[1]=-1.786*cer+1;
   }
 else if((cer>0.14) && (cer<0.56))
   {
   x1[1]=-1.786*cer+1;
   x1[2]=1.786*cer-0.25;
   }
 else if((cer>0.56) && (cer<0.7))
   {
   x1[2]=1.786*cer-0.25;
   }

// Aggregation
// Output
 for(int i=0;i<3;i++)
   {
 for(int j=0;j<3;j++)
     {
 if((x0[i]!=0 )&& (x1[j]!=0))
         {
 if((i+j)<2)
 {
 aggre=x2[0];
 x2[0]=x0[i]<x1[j]?x0[i]:x1[j];
 x2[0]=aggre>x2[0]?aggre:x2[0];
             }
 else if((i+j)==2)
             {
 aggre=x2[1];
 x2[1]=x0[i]<x1[j]?x0[i]:x1[j];
 x2[1]=aggre>x2[1]?aggre:x2[1];
             }
 else if((i+j)>2)
             {
 aggre=x2[2];
 x2[2]=x0[i]<x1[j]?x0[i]:x1[j];
 x2[2]=aggre>x2[2]?aggre:x2[2];
             }
         }
     }
  }

 // Defuzzification
 dutyRatio=((-1*x2[0])+(0*x2[1])+(1*x2[2]))/(x2[0]+x2[1]+x2[2]);
 return dutyRatio;
}
```

Appendix A.2 Sun Tracking System

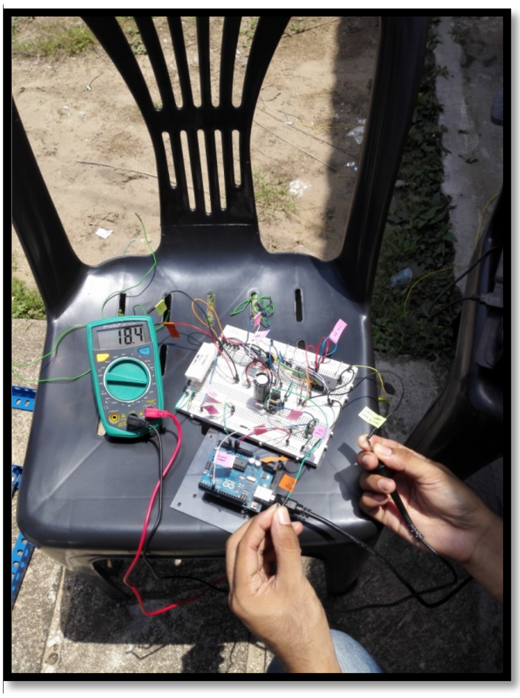
```
/*  PREPARED BY:     MOHD JOZAIMI IZWAN BIN JALALUDDIN
    SV:              ASSOC. PROF. DR. AJISMAN APEN
   PROJECT TITTLE:   AQUARIUM PUMP DRIVE BY SOLAR CELL USING MPPT
   PROGRAMMING TITTLE:     SUN TRACKING SYSTEM
   UNIVERSITY:       UNIVERSITI MALAYSIA PAHANG (UMP)
   YEAR :            2015
*/
#include <LiquidCrystal.h>          //include the library to use a LCD display
LiquidCrystal lcd (13, 12, 11, 10, 1, 0);
float vout1 = 0.0;
float vout2 = 0.0;
float vin1 = 0.0;
float vin2 = 0.0;
int value1 = A0;
int value2 = A1;
const int switch1Pin = 2;             // switch EAST input
const int switch2Pin = 3;             // switch WEST input
const int motor1Pin = 4;              // H-bridge leg 1 (pin 2, 1A)
const int motor2Pin = 5;              // H-bridge leg 2 (pin 7, 2A)
const int enablePin = 9;              // H-bridge enable pin
const int led1Pin = 6;                // LED clock wise
const int led2Pin = 7;                // LED counter clock wise
const int led3Pin = 8;                // LED go to origin
const int LDR1Pin = A0;               // LDR EAST
const int LDR2Pin = A1;               // LDR WEST

void setup() {

   // set all the other pins you're using as inputs:
   pinMode(switch1Pin, INPUT);      // set the switch EAST as an input:
   pinMode(switch2Pin, INPUT);      // set the switch WEST as an input:
   pinMode(LDR1Pin, INPUT);         // LDR EAST as an input
   pinMode(LDR2Pin, INPUT);         // LDR WEAST as an input

   // set all the other pins you're using as outputs:
   pinMode(motor1Pin, OUTPUT);
   pinMode(motor2Pin, OUTPUT);
   pinMode(enablePin, OUTPUT);
   pinMode(led1Pin, OUTPUT);
   pinMode(led2Pin, OUTPUT);
   pinMode(led3Pin, OUTPUT);

   // set enablePin as output so that the motor speed can controll:
   pinMode(enablePin, OUTPUT);
```

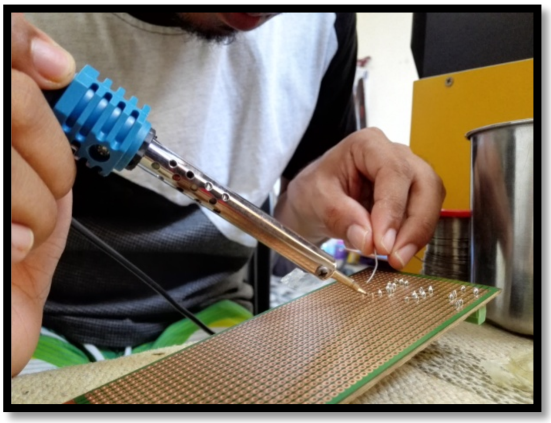
```
  // set LCD
  lcd.begin(16,2);
  lcd.print(" -SUN TRACKING-");
}
void loop() {
  //read the value at analog input
  value1 = analogRead(LDR1Pin);
  value2 = analogRead(LDR2Pin);
  vout1 = (value1*5.0)/1024.0;
  vout2 = (value2*5.0)/1024.0;
  vin1 = vout1;
  vin2 = vout2;

  // if LDR EAST detect light, LDR WEST detect light:
  if ((vin1 >= 4.10) && (vin2 >= 4.10 )) {

    // motor stop
    digitalWrite(motor1Pin, LOW);  // set leg 1 of the H-bridge low
    digitalWrite(motor2Pin, LOW);   // set leg 2 of the H-bridge low
    digitalWrite(led1Pin, LOW);
    digitalWrite(led2Pin, LOW);
    digitalWrite(led3Pin, LOW);
    lcd.setCursor (0, 1);
    lcd.print ("PERPENDICULAR");
    delay(1000);

  }
 // if LDR EAST detect light, LDR WEST can't detect light:
 else if ((vin1 >= 4.10) && (vin2 < 4.09 )){

    // motor turn clock wise
    analogWrite(enablePin, 255);       // Run in full speed
    digitalWrite(motor1Pin, LOW);   // set leg 1 of the H-bridge low
    digitalWrite(motor2Pin, HIGH);  // set leg 2 of the H-bridge high
    digitalWrite(led1Pin, HIGH);
    digitalWrite(led2Pin, LOW);
    digitalWrite(led3Pin, LOW);
    lcd.setCursor (0, 1);
    lcd.print ("turn to the WEST");
    delay(1000);

  }
  // if LDR EAST can't detect light, LDR WEST detect light:
  else if ((vin1 < 4.0.9) && (vin2 >= 4.10 )) {

    // motor turn counter clock wise
    analogWrite(enablePin, 255);       // Run in full speed
    digitalWrite(motor1Pin, HIGH);  // set leg 1 of the H-bridge high
    digitalWrite(motor2Pin, LOW);   // set leg 2 of the H-bridge low
```

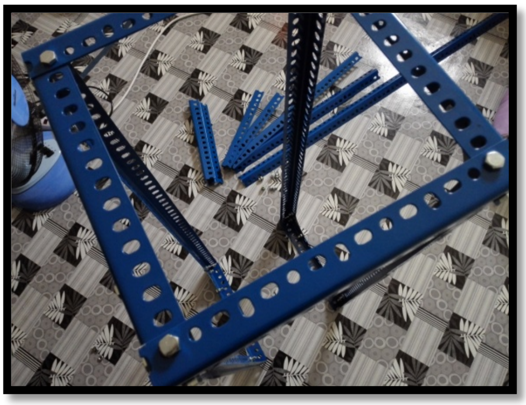
```
    digitalWrite(led1Pin, LOW);
    digitalWrite(led2Pin, HIGH);
    digitalWrite(led3Pin, LOW);
    lcd.setCursor (0, 1);
    lcd.print ("turn to the EAST");
    delay(1000);

   }
   // if the switch WEST is high, motor will turn to origin:
   else if (digitalRead(switch2Pin) == HIGH)  {

    analogWrite(enablePin, 255);      // Run in full speed
    digitalWrite(motor1Pin, HIGH);  // set leg 1 of the H-bridge high
    digitalWrite(motor2Pin, LOW);   // set leg 2 of the H-bridge low
    digitalWrite(led1Pin, LOW);
    digitalWrite(led2Pin, LOW);
    digitalWrite(led3Pin, HIGH);
    lcd.setCursor (0, 1);
    lcd.print ("  Turn to ORIGIN");
    delay(1000);
   }
   // if the switch EAST is high, motor will STOP:
   else if (digitalRead(switch1Pin) == HIGH)  {

    digitalWrite(motor1Pin, LOW);   // set leg 1 of the H-bridge low
    digitalWrite(motor2Pin, LOW);   // set leg 2 of the H-bridge high
    digitalWrite(led1Pin, LOW);
    digitalWrite(led2Pin, LOW);
    digitalWrite(led3Pin, LOW);
    lcd.setCursor (0, 1);
    lcd.print ("SOLAR PANEL STOP");
  }
}
```

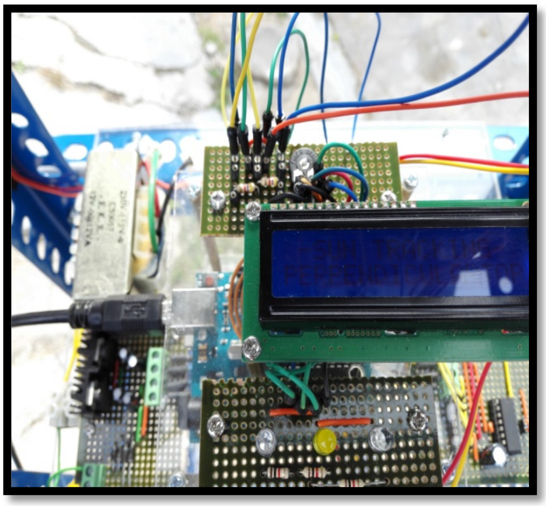
APPENDIX B

PHOTOS OF THE PROJECT







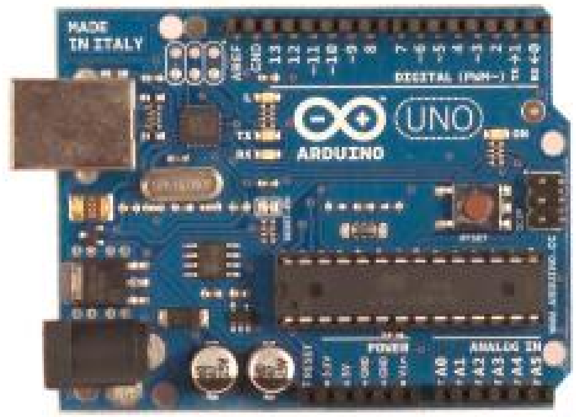


APPENDIX C

DATASHEET OF SOME IMPORTANT ELECTRONIC COMPONENTS

Appendix C.1 Arduino Uno Rev3

Arduino UNO



Product Overview

The Arduino Uno is a microcontroller board based on the ATmega328 (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. The Uno differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega8U2 programmed as a USB-to-serial converter.

"Uno" means one in Italian and is named to mark the upcoming release of Arduino 1.0. The Uno and version 1.0 will be the reference versions of Arduino, moving forward. The Uno is the latest in a series of USB Arduino boards, and the reference model for the Arduino platform; for a comparison with previous versions, see the Index of Arduino boards.

Index

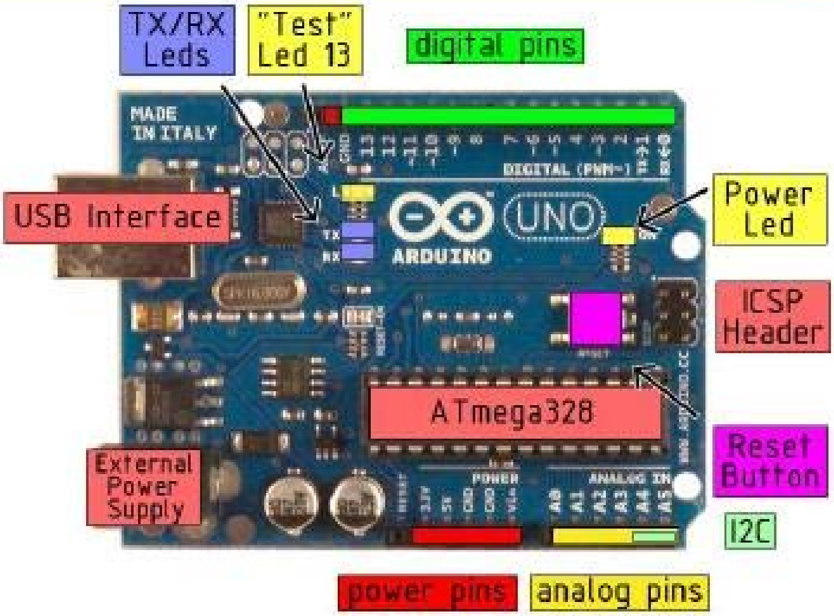
Technical Specification

EAGLE files: arduino-duemilanove-uno-design.zip Schematic: arduino-uno-schematic.pdf

Summary

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

the board



Power

The Arduino Uno can be powered via the USB connection or with an external power supply. The power source is selected automatically.

External (non-USB) power can come either from an AC-to-DC adapter (wall-wart) or battery. The adapter can be connected by plugging a 2.1mm center-positive plug into the board's power jack. Leads from a battery can be inserted in the Gnd and Vin pin headers of the POWER connector.

The board can operate on an external supply of 6 to 20 volts. If supplied with less than 7V, however, the 5V pin may supply less than five volts and the board may be unstable. If using more than 12V, the voltage regulator may overheat and damage the board. The recommended range is 7 to 12 volts.

The power pins are as follows:

- **VIN.** The input voltage to the Arduino board when it's using an external power source (as opposed to 5 volts from the USB connection or other regulated power source). You can supply voltage through this pin, or, if supplying voltage via the power jack, access it through this pin.
- **5V.** The regulated power supply used to power the microcontroller and other components on the board. This can come either from VIN via an on-board regulator, or be supplied by USB or another regulated 5V supply.
- **3V3.** A 3.3 volt supply generated by the on-board regulator. Maximum current draw is 50 mA.
- **GND.** Ground pins.

Memory

The Atmega328 has 32 KB of flash memory for storing code (of which 0,5 KB is used for the bootloader); It has also 2 KB of SRAM and 1 KB of EEPROM (which can be read and written with the EEPROM library).

Input and Output

Each of the 14 digital pins on the Uno can be used as an input or output, using pinMode(), digitalWrite(), and digitalRead() functions. They operate at 5 volts. Each pin can provide or receive a maximum of 40 mA and has an internal pull-up resistor (disconnected by default) of 20-50 kOhms. In addition, some pins have specialized functions:

- **Serial: 0 (RX) and 1 (TX).** Used to receive (RX) and transmit (TX) TTL serial data. TThese pins are connected to the corresponding pins of the ATmega8U2 USB-to-TTL Serial chip .
- **External Interrupts: 2 and 3.** These pins can be configured to trigger an interrupt on a low value, a rising or falling edge, or a change in value. See the attachInterrupt() function for details.
- **PWM: 3, 5, 6, 9, 10, and 11.** Provide 8-bit PWM output with the analogWrite() function.
- **SPI: 10 (SS), 11 (MOSI), 12 (MISO), 13 (SCK).** These pins support SPI communication, which, although provided by the underlying hardware, is not currently included in the Arduino language.

- **LED: 13.** There is a built-in LED connected to digital pin 13. When the pin is HIGH value, the LED is on, when the pin is LOW, it's off.

The Uno has 6 analog inputs, each of which provide 10 bits of resolution (i.e. 1024 different values). By default they measure from ground to 5 volts, though is it possible to change the upper end of their range using the AREF pin and the analogReference() function. Additionally, some pins have specialized functionality:

- **I^2C: 4 (SDA) and 5 (SCL).** Support I^2C (TWI) communication using the Wire library.

There are a couple of other pins on the board:

- **AREF.** Reference voltage for the analog inputs. Used with analogReference().
- **Reset.** Bring this line LOW to reset the microcontroller. Typically used to add a reset button to shields which block the one on the board.

See also the mapping between Arduino pins and Atmega328 ports.

Communication

The Arduino Uno has a number of facilities for communicating with a computer, another Arduino, or other microcontrollers. The ATmega328 provides UART TTL (5V) serial communication, which is available on digital pins 0 (RX) and 1 (TX). An ATmega8U2 on the board channels this serial communication over USB and appears as a virtual com port to software on the computer. The '8U2 firmware uses the standard USB COM drivers, and no external driver is needed. However, on Windows, an *.inf file is required..

The Arduino software includes a serial monitor which allows simple textual data to be sent to and from the Arduino board. The RX and TX LEDs on the board will flash when data is being transmitted via the USB-to-serial chip and USB connection to the computer (but not for serial communication on pins 0 and 1).

A SoftwareSerial library allows for serial communication on any of the Uno's digital pins.

The ATmega328 also support I2C (TWI) and SPI communication. The Arduino software includes a Wire library to simplify use of the I2C bus; see the documentation for details. To use the SPI communication, please see the ATmega328 datasheet.

Programming

The Arduino Uno can be programmed with the Arduino software (download). Select "Arduino Uno w/ ATmega328" from the **Tools** > **Board** menu (according to the microcontroller on your board). For details, see the reference and tutorials.

The ATmega328 on the Arduino Uno comes preburned with a bootloader that allows you to upload new code to it without the use of an external hardware programmer. It communicates using the original STK500 protocol (reference, C header files).

You can also bypass the bootloader and program the microcontroller through the ICSP (In-Circuit Serial Programming) header; see these instructions for details.

The ATmega8U2 firmware source code is available . The ATmega8U2 is loaded with a DFU bootloader, which can be activated by connecting the solder jumper on the back of the board (near the map of Italy) and then resetting the 8U2. You can then use Atmel's FLIP software (Windows) or the DFU programmer (Mac OS X and Linux) to load a new firmware. Or you can use the ISP header with an external programmer (overwriting the DFU bootloader).

Automatic (Software) Reset

Rather than requiring a physical press of the reset button before an upload, the Arduino Uno is designed in a way that allows it to be reset by software running on a connected computer. One of the hardware flow control lines (DTR) of the ATmega8U2 is connected to the reset line of the ATmega328 via a 100 nanofarad capacitor. When this line is asserted (taken low), the reset line drops long enough to reset the chip. The Arduino software uses this capability to allow you to upload code by simply pressing the upload button in the Arduino environment. This means that the bootloader can have a shorter timeout, as the lowering of DTR can be well-coordinated with the start of the upload.

This setup has other implications. When the Uno is connected to either a computer running Mac OS X or Linux, it resets each time a connection is made to it from software (via USB). For the following half-second or so, the bootloader is running on the Uno. While it is programmed to ignore malformed data (i.e. anything besides an upload of new code), it will intercept the first few bytes of data sent to the board after a connection is opened. If a sketch running on the board receives one-time configuration or other data when it first starts, make sure that the software with which it communicates waits a second after opening the connection and before sending this data.

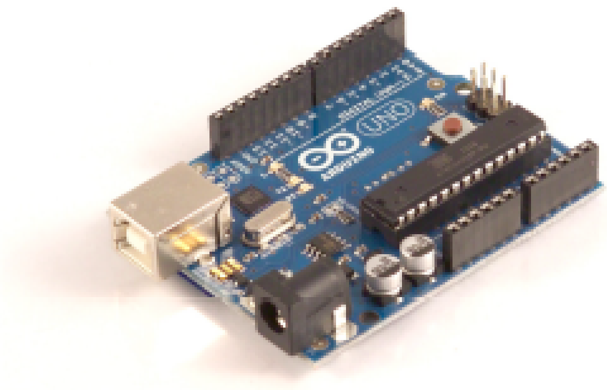
The Uno contains a trace that can be cut to disable the auto-reset. The pads on either side of the trace can be soldered together to re-enable it. It's labeled "RESET-EN". You may also be able to disable the auto-reset by connecting a 110 ohm resistor from 5V to the reset line; see this forum thread for details.

USB Overcurrent Protection

The Arduino Uno has a resettable polyfuse that protects your computer's USB ports from shorts and overcurrent. Although most computers provide their own internal protection, the fuse provides an extra layer of protection. If more than 500 mA is applied to the USB port, the fuse will automatically break the connection until the short or overload is removed.

Physical Characteristics

The maximum length and width of the Uno PCB are 2.7 and 2.1 inches respectively, with the USB connector and power jack extending beyond the former dimension. Three screw holes allow the board to be attached to a surface or case. Note that the distance between digital pins 7 and 8 is 160 mil (0.16"), not an even multiple of the 100 mil spacing of the other pins.



How to use Arduino

Arduino can sense the environment by receiving input from a variety of sensors and can affect its surroundings by controlling lights, motors, and other actuators. The microcontroller on the board is programmed using the Arduino programming language (based on Wiring) and the Arduino development environment (based on Processing). Arduino projects can be stand-alone or they can communicate with software on running on a computer (e.g. Flash, Processing, MaxMSP).

Arduino is a cross-platoform program. You'll have to follow different instructions for your personal OS. Check on the Arduino site for the latest instructions. *http://arduino.cc/en/Guide/HomePage*

Linux Install **Windows Install** **Mac Install**

Once you have downloaded/unzipped the arduino IDE, you can Plug the Arduino to your PC via USB cable.

Blink led

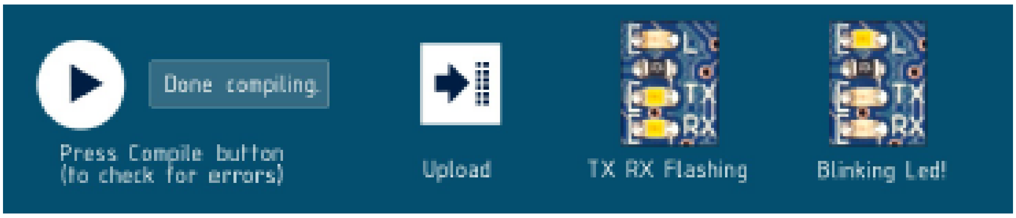
Now you're actually ready to "burn" your first program on the arduino board. To select "blink led", the physical translation of the well known programming "hello world", select

File>Sketchbook> Arduino-0017>Examples> Digital>Blink

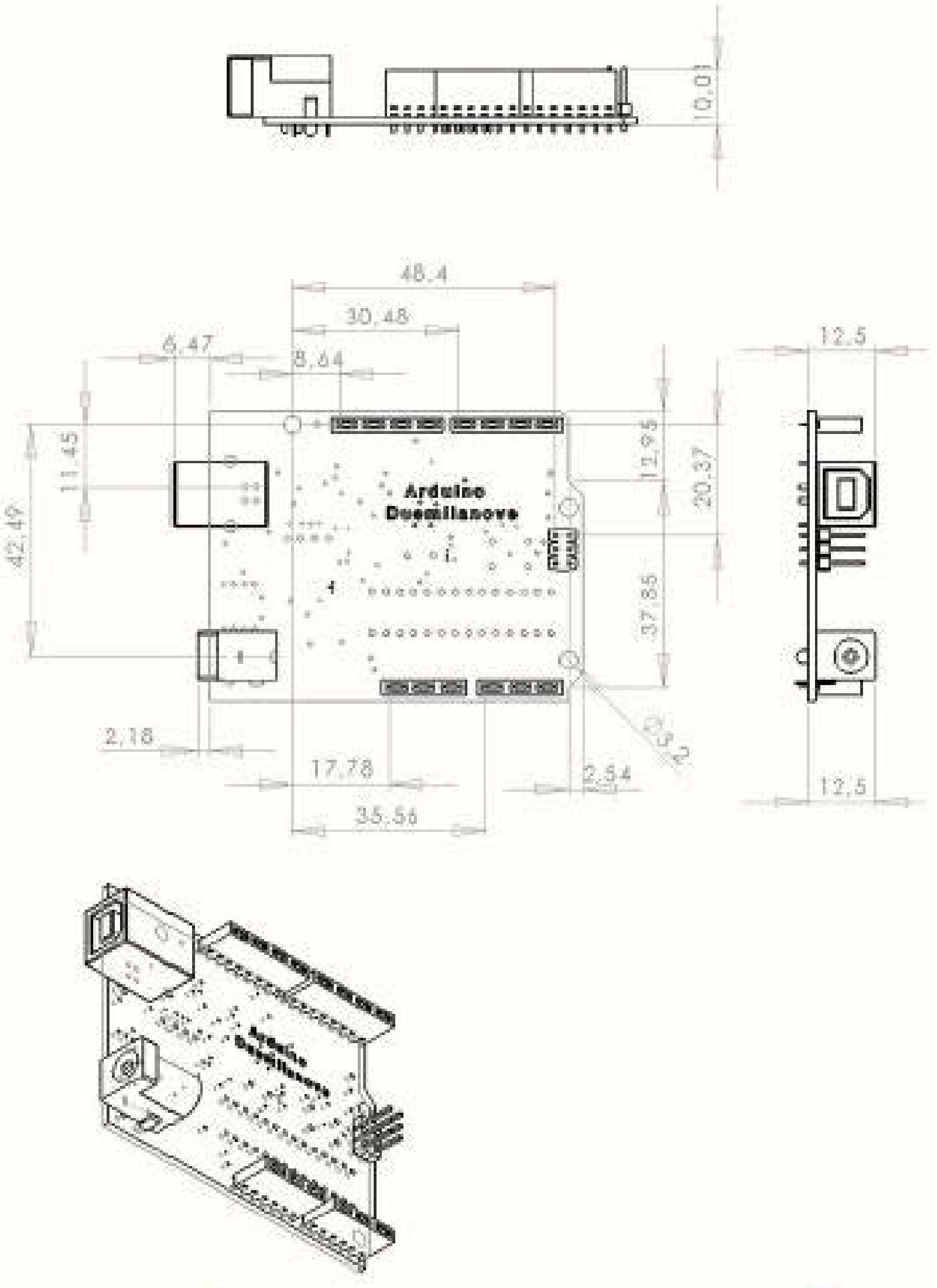
Once you have your skecth you'll see something very close to the screenshot on the right.

In Tools>Board select

Now you have to go to **Tools>SerialPort** and select the right serial port, the one arduino is attached to.



Dimensioned Drawing



Appendix C.2 MOSFET (IRF830)

VISHAY.

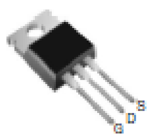
IRF830, SiHF830

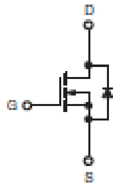
Vishay Siliconix

Power MOSFET

PRODUCT SUMMARY		
V_{DS} (V)	500	
$R_{DS(on)}$ (Ω)	V_{GS} = 10 V	1.5
Q_g (Max.) (nC)	38	
Q_{gs} (nC)	5.0	
Q_{gd} (nC)	22	
Configuration	Single	

TO-220AB





N-Channel MOSFET

FEATURES

- Dynamic dV/dt Rating
- Repetitive Avalanche Rated
- Fast Switching
- Ease of Paralleling
- Simple Drive Requirements
- Compliant to RoHS Directive 2002/95/EC

Pb Available RoHS* COMPLIANT

DESCRIPTION

Third generation Power MOSFETs from Vishay provide the designer with the best combination of fast switching, ruggedized device design, low on-resistance and cost-effectiveness.

The TO-220AB package is universally preferred for all commercial-industrial applications at power dissipation levels to approximately 50 W. The low thermal resistance and low package cost of the TO-220AB contribute to its wide acceptance throughout the industry.

ORDERING INFORMATION	
Package	TO-220AB
Lead (Pb)-free	IRF830PbF
	SiHF830-E3
SnPb	IRF830
	SiHF830

ABSOLUTE MAXIMUM RATINGS (T_C = 25 °C, unless otherwise noted)

PARAMETER			SYMBOL	LIMIT	UNIT
Drain-Source Voltage			V_{DS}	500	V
Gate-Source Voltage			V_{GS}	± 20	V
Continuous Drain Current	V_{GS} at 10 V	T_C = 25 °C	I_D	4.5	A
		T_C = 100 °C		2.9	A
Pulsed Drain Current[a]			I_{DM}	18	A
Linear Derating Factor				0.59	W/°C
Single Pulse Avalanche Energy[b]			E_{AS}	280	mJ
Repetitive Avalanche Current[a]			I_{AR}	4.5	A
Repetitive Avalanche Energy[a]			E_{AR}	7.4	mJ
Maximum Power Dissipation	T_C = 25 °C		P_D	74	W
Peak Diode Recovery dV/dt[c]			dV/dt	3.5	V/ns
Operating Junction and Storage Temperature Range			T_J, T_{stg}	- 55 to + 150	°C
Soldering Recommendations (Peak Temperature)	for 10 s			300[d]	°C
Mounting Torque	6-32 or M3 screw			10	lbf · in
				1.1	N · m

Notes

a. Repetitive rating; pulse width limited by maximum junction temperature (see fig. 11).
b. V_{DD} = 50 V, starting T_J = 25 °C, L = 24 mH, R_g = 25 Ω, I_{AS} = 4.5 A (see fig. 12).
c. $I_{SD} \leq 4.5$ A, dI/dt ≤ 75 A/μs, $V_{DD} \leq V_{DS}$, $T_J \leq 150$ °C.
d. 1.6 mm from case.

* Pb containing terminations are not RoHS compliant, exemptions may apply

THERMAL RESISTANCE RATINGS				
PARAMETER	SYMBOL	TYP.	MAX.	UNIT
Maximum Junction-to-Ambient	R_{thJA}	-	62	°C/W
Case-to-Sink, Flat, Greased Surface	R_{thCS}	0.50	-	
Maximum Junction-to-Case (Drain)	R_{thJC}	-	1.7	

SPECIFICATIONS (T_J = 25 °C, unless otherwise noted)							
PARAMETER	SYMBOL	TEST CONDITIONS		MIN.	TYP.	MAX.	UNIT
Static							
Drain-Source Breakdown Voltage	V_{DS}	V_{GS} = 0 V, I_D = 250 μA		500	-	-	V
V_{DS} Temperature Coefficient	$\Delta V_{DS}/T_J$	Reference to 25 °C, I_D = 1 mA		-	0.61	-	V/°C
Gate-Source Threshold Voltage	$V_{GS(th)}$	V_{DS} = V_{GS}, I_D = 250 μA		2.0	-	4.0	V
Gate-Source Leakage	I_{GSS}	V_{GS} = ± 20 V		-	-	± 100	nA
Zero Gate Voltage Drain Current	I_{DSS}	V_{DS} = 500 V, V_{GS} = 0 V		-	-	25	μA
		V_{DS} = 400 V, V_{GS} = 0 V, T_J = 125 °C		-	-	250	
Drain-Source On-State Resistance	$R_{DS(on)}$	V_{GS} = 10 V	I_D = 2.7 A[b]	-	-	1.5	Ω
Forward Transconductance	g_{fs}	V_{DS} = 50 V, I_D = 2.7 A[b]		2.5	-	-	S
Dynamic							
Input Capacitance	C_{iss}	V_{GS} = 0 V, V_{DS} = 25 V, f = 1.0 MHz, see fig. 5		-	610	-	pF
Output Capacitance	C_{oss}			-	160	-	
Reverse Transfer Capacitance	C_{rss}			-	68	-	
Total Gate Charge	Q_g	V_{GS} = 10 V	I_D = 3.1 A, V_{DS} = 400 V, see fig. 6 and 13[b]	-	-	38	nC
Gate-Source Charge	Q_{gs}			-	-	5.0	
Gate-Drain Charge	Q_{gd}			-	-	22	
Turn-On Delay Time	$t_{d(on)}$	V_{DD} = 250 V, I_D = 3.1 A R_g = 12 Ω, R_D = 79 Ω, see fig. 10[b]		-	8.2	-	ns
Rise Time	t_r			-	16	-	
Turn-Off Delay Time	$t_{d(off)}$			-	42	-	
Fall Time	t_f			-	16	-	
Internal Drain Inductance	L_D	Between lead, 6 mm (0.25") from package and center of die contact		-	4.5	-	nH
Internal Source Inductance	L_S			-	7.5	-	
Drain-Source Body Diode Characteristics							
Continuous Source-Drain Diode Current	I_S	MOSFET symbol showing the integral reverse p - n junction diode		-	-	4.5	A
Pulsed Diode Forward Current[a]	I_{SM}			-	-	18	
Body Diode Voltage	V_{SD}	T_J = 25 °C, I_S = 4.5 A, V_{GS} = 0 V[b]		-	-	1.6	V
Body Diode Reverse Recovery Time	t_{rr}	T_J = 25 °C, I_F = 3.1 A, dI/dt = 100 A/μs[b]		-	320	640	ns
Body Diode Reverse Recovery Charge	Q_{rr}			-	1.0	2.0	μC
Forward Turn-On Time	t_{on}	Intrinsic turn-on time is negligible (turn-on is dominated by L_S and L_D)					

Notes

a. Repetitive rating; pulse width limited by maximum junction temperature (see fig. 11).

b. Pulse width ≤ 300 μs; duty cycle ≤ 2 %.

Appendix C.3 Power Diode (MUR860)

FAIRCHILD SEMICONDUCTOR®

MUR840, MUR860, RURP840, RURP860

Data Sheet ***November 2013***

8 A, 400 V - 600 V, Ultrafast Diodes

Description

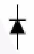
The MUR840, MUR860, RURP840, RURP860 is an ultrafast diode with low forward voltage drop. This device is intended for use as freewheeling and clamping diodes in a variety of switching power supplies and other power switching applications. It is specially suited for use in switching power supplies and industrial application.

Ordering Information

PART NUMBER	PACKAGE	BRAND
MUR840	TO-220AC-2L	MUR840
RURP840	TO-220AC-2L	RURP840
MUR860	TO-220AC-2L	MUR860
RURP860	TO-220AC-2L	RURP860

NOTE: When ordering, use the entire part number.

Symbol



Features

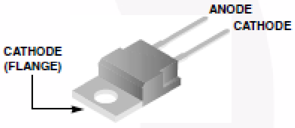
- Ultrafast Recovery t_{rr} = 70 ns (@ I_F = 8 A)
- Max Forward Voltage, V_F = 1.5 V (@ T_C = 25°C)
- 400 V, 600 V Reverse Voltage and High Reliability
- Avalanche Energy Rated
- RoHS Compliant

Applications

- Switching Power Supplies
- Power Switching Circuits
- General Purpose

Packaging

JEDEC TO-220AC



Absolute Maximum Ratings $T_C = 25^oC$, Unless Otherwise Specified

		MUR840 RURP840	MUR860 RURP860	UNIT
Peak Repetitive Reverse Voltage	V_{RRM}	400	600	V
Working Peak Reverse Voltage	V_{RWM}	400	600	V
DC Blocking Voltage	V_R	400	600	V
Average Rectified Forward Current ($T_C = 155^oC$)	$I_{F(AV)}$	8	8	A
Repetitive Peak Surge Current (Square Wave, 20kHz)	I_{FRM}	16	16	A
Nonrepetitive Peak Surge Current (Halfwave, 1 Phase, 60Hz)	I_{FSM}	100	100	A
Maximum Power Dissipation	P_D	75	75	W
Avalanche Energy (See Figures 10 and 11)	E_{AVL}	20	20	mJ
Operating and Storage Temperature	T_{STG}, T_J	-65 to 175	-65 to 175	^oC
Maximum Lead Temperature for Soldering				
Leads at 0.063 in. (1.6mm) from case for 10s	T_L	300	300	^oC
Package Body for 10s, see Tech Brief 334	T_{PKG}	260	260	^oC

Electrical Specifications $T_C = 25^oC$, Unless Otherwise Specified

SYMBOL	TEST CONDITION	MUR840, RURP840			MUR860, RURP860			UNIT
		MIN	TYP	MAX	MIN	TYP	MAX	
V_F	I_F = 8 A	-	-	1.3	-	-	1.5	V
	I_F = 8 A, $T_C = 150^oC$	-	-	1.0	-	-	1.2	V
I_R	V_R = 400 V	-	-	100	-	-	-	µA
	V_R = 600 V	-	-	-	-	-	100	µA
	V_R = 400 V, $T_C = 150^oC$	-	-	500	-	-	-	µA
	V_R = 600 V, $T_C = 150^oC$	-	-	-	-	-	500	µA
t_{rr}	I_F = 1 A, dI_F/dt = 200 A/µs	-	-	60	-	-	60	ns
	I_F = 8 A, dI_F/dt = 200 A/µs	-	-	70	-	-	70	ns
t_a	I_F = 8 A, dI_F/dt = 200 A/µs	-	32	-	-	32	-	ns
t_b	I_F = 8 A, dI_F/dt = 200 A/µs	-	21	-	-	21	-	ns
Q_{rr}	I_F = 8 A, dI_F/dt = 200 A/µs	-	195	-	-	195	-	nC
C_J	V_R = 10 V, I_F = 0 A	-	25	-	-	25	-	pF
$R_{\theta JC}$		-	-	2	-	-	2	$^oC/W$

DEFINITIONS

V_F = Instantaneous forward voltage (pw = 300 µs, D = 2%).

I_R = Instantaneous reverse current.

T_{rr} = Reverse recovery time (See Figure 9), summation of $t_a + t_b$.

t_a = Time to reach peak reverse current (See Figure 9).

t_b = Time from peak I_{RM} to projected zero crossing of I_{RM} based on a straight line from peak I_{RM} through 25% of I_{RM} (See Figure 9).

Q_{rr} = Reverse recovery charge.

C_J = Junction Capacitance.

$R_{\theta JC}$ = Thermal resistance junction to case.

pw = pulse width.

D = duty cycle.

Typical Performance Curves

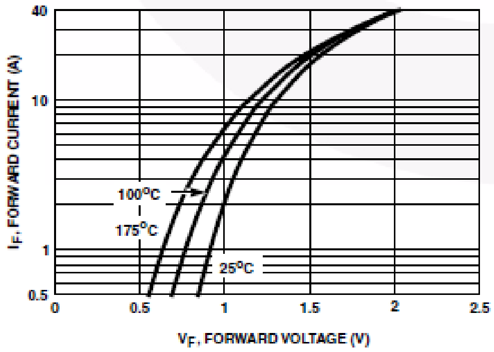


FIGURE 1. FORWARD CURRENT vs FORWARD VOLTAGE

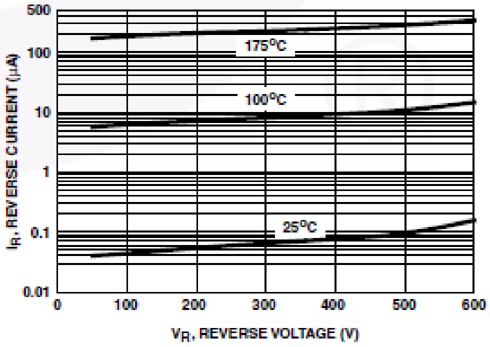


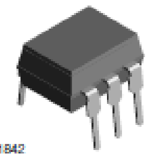
FIGURE 2. REVERSE CURRENT vs REVERSE VOLTAGE

Appendix C.4 Optocoupler (4N25)

4N25, 4N26, 4N27, 4N28

Vishay Semiconductors

Optocoupler, Phototransistor Output, with Base Connection



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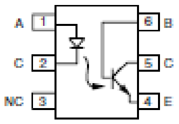


FEATURES

- Isolation test voltage 5000 V_{RMS}
- Interfaces with common logic families
- Input-output coupling capacitance < 0.5 pF
- Industry standard dual-in-line 6 pin package
- Compliant to RoHS directive 2002/95/EC and in accordance to WEEE 2002/96/EC

e3 RoHS COMPLIANT

APPLICATIONS

- AC mains detection
- Reed relay driving
- Switch mode power supply feedback
- Telephone ring detection
- Logic ground isolation
- Logic coupling with high frequency noise rejection

DESCRIPTION

The 4N25 family is an industry standard single channel phototransistor coupler. This family includes the 4N25, 4N26, 4N27, 4N28. Each optocoupler consists of gallium arsenide infrared LED and a silicon NPN phototransistor.

AGENCY APPROVALS

- UL1577, file no. E52744
- BSI: EN 60065:2002, EN 60950:2000
- FIMKO: EN 60950, EN 60065, EN 60335

ORDER INFORMATION

PART	REMARKS
4N25	CTR > 20 %, DIP-6
4N26	CTR > 20 %, DIP-6
4N27	CTR > 10 %, DIP-6
4N28	CTR > 10 %, DIP-6

ABSOLUTE MAXIMUM RATINGS (1)

PARAMETER	TEST CONDITION	SYMBOL	VALUE	UNIT
INPUT				
Reverse voltage		V_R	5	V
Forward current		I_F	60	mA
Surge current	t ≤ 10 µs	I_{FSM}	3	A
Power dissipation		P_{diss}	100	mW
OUTPUT				
Collector emitter breakdown voltage		V_{CEO}	70	V
Emitter base breakdown voltage		V_{EBO}	7	V
Collector current		I_C	50	mA
	t ≤ 1 ms	I_C	100	mA
Power dissipation		P_{diss}	150	mW

ABSOLUTE MAXIMUM RATINGS [(1)]				
PARAMETER	TEST CONDITION	SYMBOL	VALUE	UNIT
COUPLER				
Isolation test voltage		V_{ISO}	5000	V_{RMS}
Creepage distance			≥ 7	mm
Clearance distance			≥ 7	mm
Isolation thickness between emitter and detector			≥ 0.4	mm
Comparative tracking index	DIN IEC 112/VDE 0303, part 1		175	
Isolation resistance	V_{IO} = 500 V, T_{amb} = 25 °C	R_{IO}	10^{12}	Ω
	V_{IO} = 500 V, T_{amb} = 100 °C	R_{IO}	10^{11}	Ω
Storage temperature		T_{stg}	- 55 to + 125	°C
Operating temperature		T_{amb}	- 55 to + 100	°C
Junction temperature		T_j	125	°C
Soldering temperature [(2)]	max.10 s dip soldering: distance to seating plane ≥ 1.5 mm	T_{sld}	260	°C

Notes

[(1)] T_{amb} = 25 °C, unless otherwise specified.
Stresses in excess of the absolute maximum ratings can cause permanent damage to the device. Functional operation of the device is not implied at these or any other conditions in excess of those given in the operational sections of this document. Exposure to absolute maximum ratings for extended periods of the time can adversely affect reliability.

[(2)] Refer to reflow profile for soldering conditions for surface mounted devices (SMD). Refer to wave profile for soldering condditions for through hole devices (DIP).

ELECTRICAL CHARACTERISTICS [(1)]							
PARAMETER	TEST CONDITION	PART	SYMBOL	MIN.	TYP.	MAX.	UNIT
INPUT							
Forward voltage [(2)]	I_F = 50 mA		V_F		1.3	1.5	V
Reverse current [(2)]	V_R = 3 V		I_R		0.1	100	µA
Capacitance	V_R = 0 V		C_O		25		pF
OUTPUT							
Collector base breakdown voltage [(2)]	I_C = 100 µA		BV_{CBO}	70			V
Collector emitter breakdown voltage [(2)]	I_C = 1 mA		BV_{CEO}	30			V
Emitter collector breakdown voltage [(2)]	I_E = 100 µA		BV_{ECO}	7			V
I_{CEO}(dark) [(2)]	V_{CE} = 10 V, (base open)	4N25			5	50	nA
		4N26			5	50	nA
		4N27			5	50	nA
		4N28			10	100	nA
I_{CBO}(dark) [(2)]	V_{CB} = 10 V, (emitter open)				2	20	nA
Collector emitter capacitance	V_{CE} = 0		C_{CE}		6		pF
COUPLER							
Isolation test voltage [(2)]	Peak, 60 Hz		V_{IO}	5000			V
Saturation voltage, collector emitter	I_{CE} = 2 mA, I_F = 50 mA		$V_{CE(sat)}$			0.5	V
Resistance, input output [(2)]	V_{IO} = 500 V		R_{IO}	100			GΩ
Capacitance, input output	f = 1 MHz		C_{IO}		0.6		pF

Notes

[(1)] T_{amb} = 25 °C, unless otherwise specified.
Minimum and maximum values are testing requirements. Typical values are characteristics of the device and are the result of engineering evaluation. Typical values are for information only and are not part of the testing requirements.

[(2)] JEDEC registered values are 2500 V, 1500 V, 1500 V, and 500 V for the 4N25, 4N26, 4N27, and 4N28 respectively.

Appendix C.5 Radial Inductor (100µH)

C&D TECHNOLOGIES
POWER ELECTRONICS DIVISION

2200R Series

Radial Lead Inductors

FEATURES

- RoHS compliant
- Radial format
- Up to 1.62A Idc
- 10µH to 68mH
- Low DC resistance
- Miniature size
- PCB mounting
- MIL-I-23053/5 class I sleeving
- Fully tinned leads
- Supplied in bags of 100
- Compatible with RoHS soldering systems
- Backward compatible with Sn/Pb soldering systems
- Custom parts available

DESCRIPTION

The 2200R Series is a general purpose range of inductors suitable for low to medium current applications. Their small footprint makes them ideal for high density applications where a chip inductor will not cope with the power requirement.

SELECTION GUIDE

Order Code	Inductance, (1kHz, 0.1Vac)	DC Current[1]	DC Resistance	Q at f kHz		SRF
	±10%	Max.	Max.	Nom.		Nom.
	µH	A	Ω	Q	f	MHz
22R103C	10.0	1.62	0.05	40	1000	21.2
22R153C	15.0	1.35	0.07	30	500	19.4
22R223C	22.0	1.08	0.09	30	500	17.0
22R333C	33.0	0.90	0.14	25	500	11.4
22R473C	47.0	0.77	0.22	25	500	10.9
22R683C	68.0	0.77	0.28	70	100	10.6
22R104C	100.0	0.67	0.39	65	100	8.9
22R154C	150.0	0.52	0.54	80	100	6.2
22R224C	220.0	0.43	0.83	90	100	5.4
22R334C	330.0	0.38	1.21	95	100	4.5
22R474C	470.0	0.31	1.65	100	100	3.2
22R684C	680.0	0.25	2.64	105	100	3.0
22R105C	1.0mH	0.17	3.63	120	100	2.5
22R155C	1.5mH	0.13	6.40	130	100	2.1
22R225C	2.2mH	0.11	8.58	130	50	1.9
22R335C	3.3mH	0.10	10.0	125	150	1.2
22R475C	4.7mH	0.081	13.2	130	150	0.95
22R685C	6.8mH	0.072	22.0	135	150	0.85
22R106C	10.0mH	0.063	37.4	140	150	0.62
22R156C	15.0mH	0.054	49.5	145	150	0.51
22R226C	22.0mH	0.045	82.5	100	50	0.34
22R336C	33.0mH	0.036	110.0	90	50	0.28
22R476C	47.0mH	0.027	154.0	80	50	0.25
22R686C	68.0mH	0.018	242.0	70	50	0.20

TYPICAL CORE/WIRE CHARACTERISTICS

Inductance Temperature Coefficient	Resistance Temperature Coefficient	Curie Temperature (T_C)	Saturation Flux (B_{sat})
350ppm	3900ppm	190°C	325mT

ABSOLUTE MAXIMUM RATINGS

Operating free air temperature range	-25°C to 70°C
Storage temperature range	-40°C to 125°C

SOLDERING INFORMATION[2]

Peak wave solder temperature	300°C for 10 seconds
Pin finish	Bright tin

All specifications typical at T_A=25°C

1 Maximum DC current occurs when either the inductance falls to 90% of its nominal value or when its temperature rise reaches 30°C, whichever is sooner.

2 For further information, please visit www.cd4power.com/rohs

RoHS COMPLIANT 2002/95/EC

For full details go to www.cd4power.com/rohs

MAGNETIC PRODUCTS

www.cd4power.com

Technical enquiries email: mk@cdtechno.com, tel: +44 (0)1908 615232

KMP_2200RC_A02 Page 1 of 2

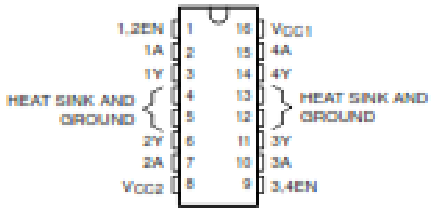
Appendix C.6 Motor Driver (L293D)

L293, L293D
QUADRUPLE HALF-H DRIVERS

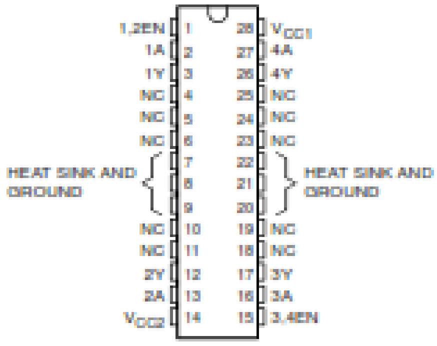
SLRS008B – SEPTEMBER 1986 – REVISED JUNE 2002

- **Featuring Unitrode L293 and L293D Products Now From Texas Instruments**
- **Wide Supply-Voltage Range: 4.5 V to 36 V**
- **Separate Input-Logic Supply**
- **Internal ESD Protection**
- **Thermal Shutdown**
- **High-Noise-Immunity Inputs**
- **Functional Replacements for SGS L293 and SGS L293D**
- **Output Current 1 A Per Channel (600 mA for L293D)**
- **Peak Output Current 2 A Per Channel (1.2 A for L293D)**
- **Output Clamp Diodes for Inductive Transient Suppression (L293D)**

N, NE PACKAGE
(TOP VIEW)



DWP PACKAGE
(TOP VIEW)



description

The L293 and L293D are quadruple high-current half-H drivers. The L293 is designed to provide bidirectional drive currents of up to 1 A at voltages from 4.5 V to 36 V. The L293D is designed to provide bidirectional drive currents of up to 600-mA at voltages from 4.5 V to 36 V. Both devices are designed to drive inductive loads such as relays, solenoids, dc and bipolar stepping motors, as well as other high-current/high-voltage loads in positive-supply applications.

All inputs are TTL compatible. Each output is a complete totem-pole drive circuit, with a Darlington transistor sink and a pseudo-Darlington source. Drivers are enabled in pairs, with drivers 1 and 2 enabled by 1,2EN and drivers 3 and 4 enabled by 3,4EN. When an enable input is high, the associated drivers are enabled and their outputs are active and in phase with their inputs. When the enable input is low, those drivers are disabled and their outputs are off and in the high-impedance state. With the proper data inputs, each pair of drivers forms a full-H (or bridge) reversible drive suitable for solenoid or motor applications.

On the L293, external high-speed output clamp diodes should be used for inductive transient suppression.

A V_{CC1} terminal, separate from V_{CC2}, is provided for the logic inputs to minimize device power dissipation.

The L293and L293D are characterized for operation from 0°C to 70°C.

TEXAS INSTRUMENTS

POST OFFICE BOX 655303 • DALLAS, TEXAS 75265

APPENDIX D

GANTT CHART

Appendix D.1 Gantt chart of FYP1

Month		**September**				**October**				**November**				**December**			
Activities \ Week		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Register FYP1 title	Plan																
	Actual																
Discussion on Project	Plan																
	Actual																
Simple analysis of criteria project	Plan																
	Actual																
Submission Executive summary	Plan																
	Actual																
Submission milestone 1	Plan																
	Actual																
Draw and sketch the design	Plan																
	Actual																
Decide design of the project	Plan																
	Actual																
Looking component specification	Plan																
	Actual																
Literature review	Plan																
	Actual																
Submission milestone 2	Plan																
	Actual																
Detail design for the project	Plan																
	Actual																
Methodology	Plan																
	Actual																
Submission milestone 3	Plan																
	Actual																
Ordering Component	Plan																
	Actual																
Editing all milestone	Plan																
	Actual																
Submission milestone 4	Plan																
	Actual																
Prepare slide	Plan																
	Actual																
Presentation	Plan																
	Actual																
Submit final report	Plan																
	Actual																

Appendix D.2 Gantt chart of FYP2

Month		**March**				**April**				**May**				**June**			
Activities \ Week		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Design and implement the simulation and hardware	Plan	■	■	■	■												
	Actual	■	■	■	■	■											
Circuit testing	Plan					■	■										
	Actual					■	■	■									
Implement programming	Plan							■	■								
	Actual							■	■	■							
Set-up sun tracking system	Plan						■	■	■	■	■						
	Actual							■	■	■	■						
Milestone 5 Submission	Plan						■										
	Actual						■	■									
Corrected the draft chapter 4	Plan							■									
	Actual							■	■								
Conclusion and recommendation	Plan								■	■							
	Actual									■	■						
Product Assemble	Plan										■	■					
	Actual										■	■	■				
Product Testing	Plan											■					
	Actual											■	■				
Collect data and compare	Plan											■					
	Actual											■	■				
Milestone 6 Submission	Plan									■							
	Actual									■							
Pre-presentation	Plan											■					
	Actual											■					
Poster presentation	Plan												■				
	Actual												■				
Milestone 7 Submission	Plan												■	■			
	Actual												■	■	■		
Final report Submission	Plan															■	
	Actual															■	