Design of a Cost Efficient Solar Charge Controller for Solar Photovoltaic System

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DECLARATION

We hereby declare that the thesis titled “Design of a solar charge controller for solar photovoltaic system” has been written based only on the works and results found by us. This is our original work and was not submitted elsewhere for the award of any other degree or any other publication.

Signature of Supervisor

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ABSTRACT

A photovoltaic system is a power system designed to supply usable solar power by means of photovoltaic. Now-a-days it is vastly used to reduce the dependency on traditional power sources. In this thesis, a modified photovoltaic system will be proposed to increase the use of solar energy. A control system will be designed to control the power system. It is envisioned that this system will reduce the consumption of grid power, which can be accumulated for cost minimization and power optimization.

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CHAPTER 1

INTRODUCTION

The Sun is a reliable, pure and inexhaustible source of energy. Solar energy is the cleanest and most abundant renewable energy source available on earth. Solar power is the energy from the sun that is converted into thermal or electrical energy. Solar radiation produced through nuclear fusion reactions in the Sun's core provide light and heat that keep alive all the living beings on earth.

Our civilization has reached to its Modern age, we are now in need of energy sources like never before. The rapid change in energy cost, concern over population, environmental degradation and limitation of resources has increased dramatically. Use of fossil fuels causes the greenhouse emissions, inefficient use of energy and release of harmful pollutants to the atmosphere made people realize that non-renewable energy sources are not sufficient hence they should use the renewable energy sources concerning the safety of our environment.

1.1 Background

First photovoltaic (PV) solar panels have been designed and used mainly in space technology, as the production costs of such panels were very high. As the time passes, the photovoltaic cells can be produced cheaper and cheaper and their efficiency is rising. This is also a reason why they are being used much more frequently and it is not rare to see them on the rooftops any more. Photovoltaic solar systems can be divided into two basic categories – grid connected and off-grid solar systems. The grid connected systems feed the electricity produced by solar panels to the grid using an inverter. When the electricity is needed during night or periods with little sunlight, the energy is taken back from grid. In off-grid systems, the excess electricity is usually stored in batteries during the day and batteries are used to power the appliances in times when photovoltaic panels do not produce enough energy. Solar charge controllers play an important part in isolated solar systems. Their goal is to ensure the batteries are working in optimal conditions, mainly to prevent overcharging (by disconnecting solar panel when batteries are full) and too deep discharge (by disconnecting the load when necessary). The aim of this thesis is to design a solar regulator that could control more lead-acid batteries at the same time. The design is limited to lead acid batteries, as they are currently the most used type in the isolated photovoltaic applications due to their high capacity and very good price per capacity compared with other battery types.

1.2 Motivation

The energy infrastructure of Bangladesh is quite low, insufficient and inappropriately managed. The per capita energy consumption of our country is one of the lowest in the world which is 321 kWH. Noncommercial energy sources such as wood fuel, animal waste and crop residues are estimated to account for over half of the country's energy consumption. Bangladesh has small oil and coal reserves, but we have large natural gas resources. Commercial energy consumption is mostly natural gas (around 66%), followed by oil, hydropower and coal.

Electricity is the most dominating source of power for most of the country’s economic activities. Bangladesh’s installed electric capacity was 12339 MW in January, 2016. Only three-fourth of which is considered to be ‘available’. Only 62% of the population access electricity with a per capita availability of 321 kWh per annum. The crisis that our country face while producing electricity include administrational corruption, high system losses, procrastination of the process of establishing new plants, low plant efficiencies, eccentric power supply, electricity theft, blackouts, and inadequacy of funds for power plant maintenance. That’s how our countries generation plants have been incapable of meeting system demand over past decade. According to official estimates the country generates 5600-6350 MW of electricity against a daily need of 7500 MW in average. Solar energy is an effective solution since its economical and it provides clean energy in terms of pollution and health issues.

Considering all these facts we are motivated to do this project as it will be beneficiary in every ways for the local people. Through effective maintenance our people can possibly get rid of the electricity crisis.

1.3 OBJECTIVE

The overall objective of this project is to design and establish an efficient solar charge controller. This emphasis on the microcontroller, sensors and other electronic equipment necessary to monitor and adjust power while consuming the least power possible.

1.3.1 Efficient

For increase the solar efficiency more we usually use two method in our solar controller. They are:
1) Three steps charge controlling and
2) MPPT method.

The solar panel is the largest and most expensive part needed to test and implement the project. Therefore finding an inexpensive module with an optimal power rating is going to be imperative to the entire project’s performance and cost. Solar panel efficiency and power output needs to surpass the battery charging requirements during normal operating conditions, in order for the charge controller system to be fully tested. The panel should also be powerful enough to provide a quick charge, in order to shorten the battery charging time in various operational states and weather conditions. Power output depends on panel efficiency, so efficiency is the main objective in selecting a PV panel.

1.3.2 User friendly

The system will be designed to Plug-and-Play and will be a user friendly setup. Size and portability reasons will be considered that will make the system very easy to setup in an outdoor environment such as a remote location without any access to electricity. The charge controller connections will be minimum and clearly marked for a quick setup and a safe experience. In addition, the charge controller will incorporate a LCD screen which will constantly allow users to monitor important operational variables such as input voltage, output voltage, input current, output current, battery charging and panel temperature.

1.3.3. Low-Cost

Production cost will be a foremost objective in design and implementation. Limiting the number of circuit components will allow for a simpler circuit, which in turn will reduce the PCB size, design and Production cost. Since a smaller casing will be needed, due to circuit size, the packaging cost will subsequently be lowered.

1.4 THESIS OUTLINE

The chapter for this charge Controller are:

Chapter 2: overview of solar panel system, solar charge controller, software algorithm and battery.
Chapter 3: design principles: circuit construction, software implementation and load testing.
Chapter 4: circuit implementation: equipment, circuit diagram and PCB.
Chapter 5: software implementation: code explanation and block diagram.
Chapter 6: lab testing: pictures and explanation.
Chapter 7: field testing: pictures and explanation, I-V characteristics for our charge controller and i-v characteristics for ordinary charge controller.
Chapter 8: ordinary charge controller testing: testing procedure, data analysis and test result.
Chapter 9: cost analysis.
Chapter 10: comparison between our charge controller and ordinary charge controller.
Chapter 11: limitation.

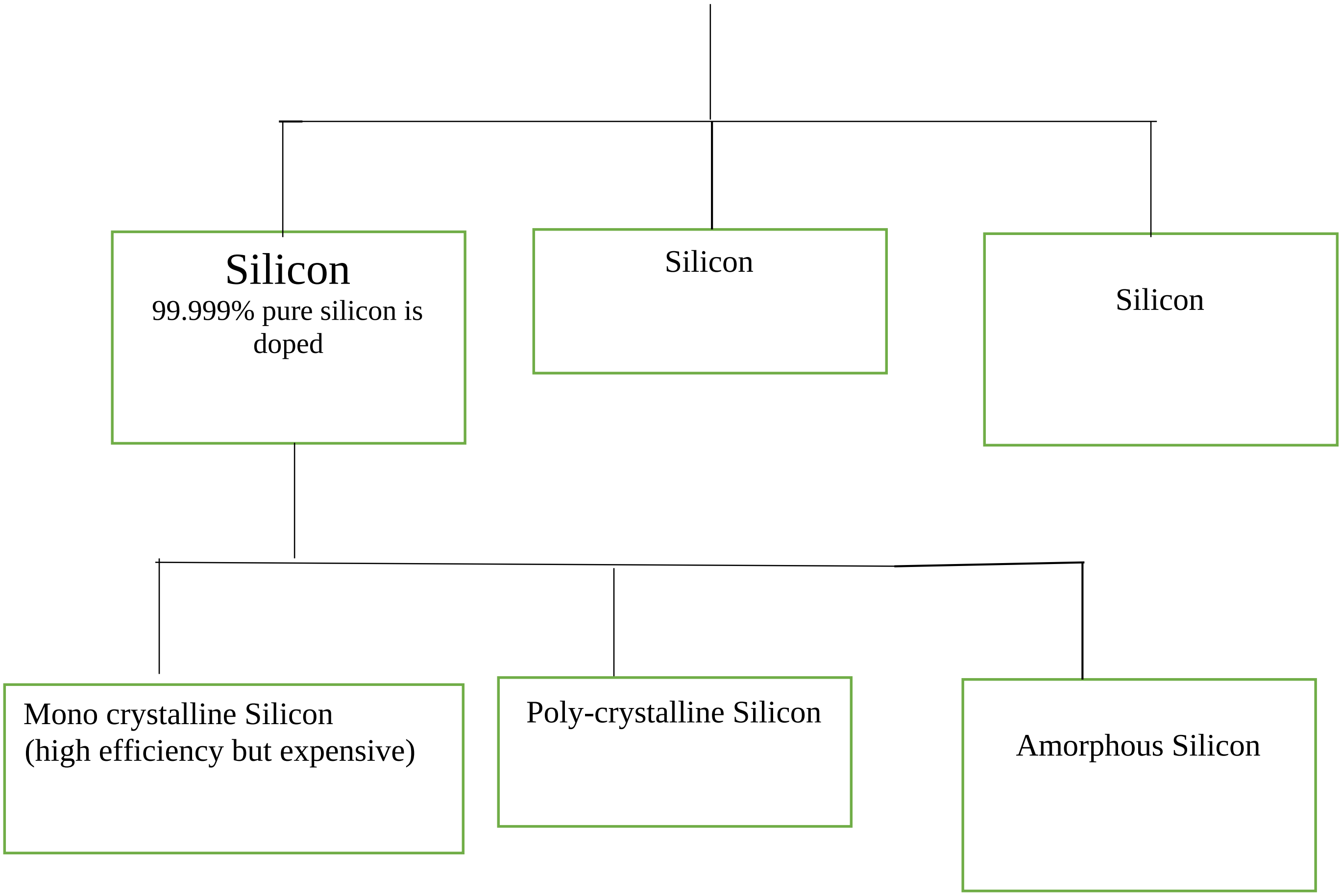
CHAPTER 2

OVERVIEW

2.1 OVERVIEW OF SOLAR PANEL SYSTEM

Solar photovoltaic use cells made of silicon or certain types of semiconductor materials which converts the light energy, absorbed from sunshine, into DC electricity. To make up for intermittency and night time, store of the generated electricity into battery is needed.

PV Cell materials



2.1.1 Mono-crystalline Silicon Panel

The first type of crystalline silicon used in solar panels is mono-crystalline. Even though it's not the most commonly used, but this technology is one of the oldest and most proven in compared to the others. As the name implies this type of solar cells are made from the same silicon crystal, which is very pure and has less irregularities and imperfections than polycrystalline solar cells. This type of silicon is produced using the Czochralski process where seed crystal silicon is dipped into molten silicon and withdrawn very slowly. This process produces a two meter long cylindrical single-crystal ingot as the molten silicon crystallizes around the seed. The silicone can be intrinsic or doped with impurities depending on its future use. The ingot is then sliced into thin wafers. These same wafers are also used for semiconductor device fabrication.

Considering the square shape of a solar cell, a lot of silicone material is wasted in the process; hence the main drawback of this type of solar cell is its price point. This manufacturing process is also more complicated and more silicon is used to make mono-crystalline solar cells. These last facts contribute to a high price per panel compared to the rest of the solar panels in this review. However, due to the lack of imperfections and cell structure this type of solar panel is the most efficient, with percentages averaging around 11% - 16%. Efficiency is the factor at which absorbed light is converted to electricity.

Because of the higher efficiency level these panels perform better and have been proven to last longer than the rest of the silicon technology panels. These panels are estimated to last at least 25 years. And some have been proven to last up to 50 years, so the higher price is justified by the returned energy cost that these panels produce during their long life. Another positive factor about these panels is the fact that the user will get the most watts per square foot of panel used, since these panels are so efficient. As a result these panels are a good choice when limited space is an issue. Mono-crystalline solar panels are very fragile, and care must be given during the shipping and installation processes.

These panels will be used to implement this project. Most online solar panel retailers have recently dropped the prices for these panels to competitive levels with the prices of the Polycrystalline panels, making this panel a sensible choice for this project.

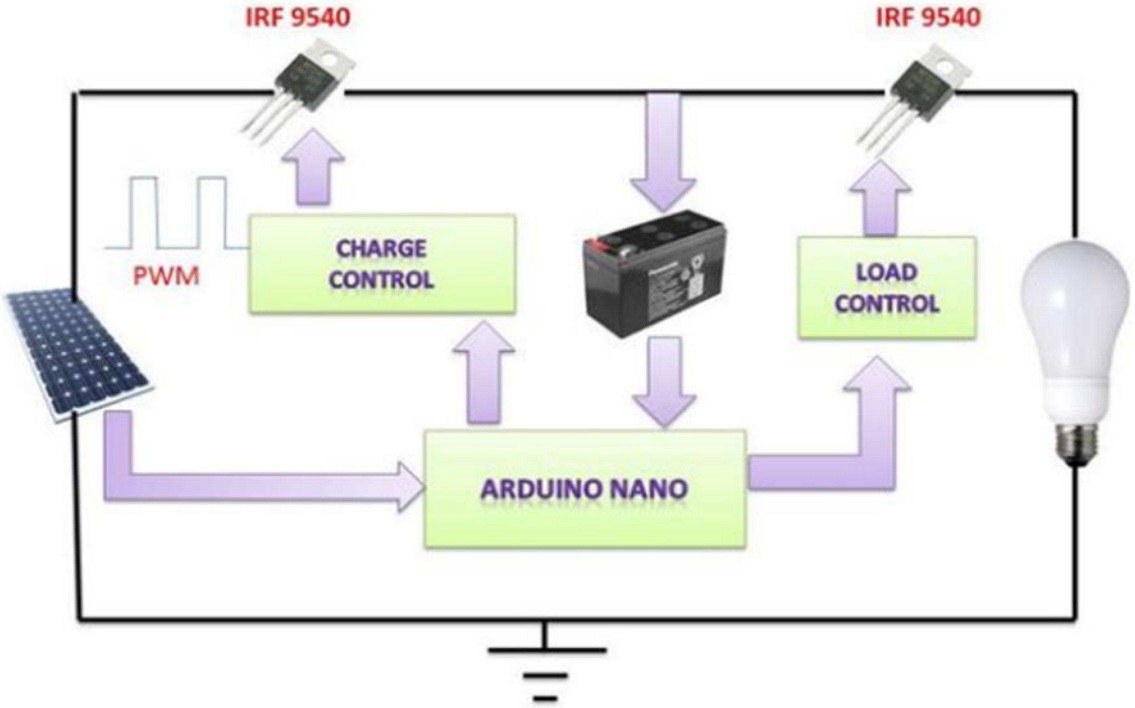


Figure 1: basic solar system

2.1.2 Polycrystalline Silicon Panel

Next in the silicon solar cell category is polycrystalline silicon. Polycrystalline solar panels are the most common type of solar panel in home installations today, due to their low cost and average power efficiency. In this fabrication process molten silicon is usually casted and then cooled in a rectangular shape for a more profitable outcome. The block is then sliced similarly to the mono crystalline ingot to create the thin solar cells. As the name implies the ingot is made of multiple crystals resembling pieces of shattered glass due to the manufacturing process. This process is a faster and a lot easier to implement. As a result, these types of silicon cells are cheaper and therefore cost less to produce in comparison to mono-crystalline cells. The lower grade semiconductor used in fabrication and the imperfections drop the solar cell performance.

Efficiency is the main disadvantage of polycrystalline solar panels. They convert only 10%-14% of the solar energy that hits their surface. Efficiency for these solar panels drops in comparison to their mono-crystalline counterpart because of the energy loss at the separation or fusion points between two adjacent crystals. Polycrystalline panels like mono-crystalline panels perform poorly in shade or low light conditions. These panels account for most of the market shares in the solar panel manufacturing industry in the past decade.

2.1.3 Amorphous Silicon and Thin Film Panel

Thin film technology is newer than the crystal silicon technology discussed previously. Amorphous silicon or other non-silicon semiconductors are used, instead of crystal silicon. The semiconductor is placed between flexible laminate, glass or steel plates. The flexible laminate is most commonly used to produce these panels. Thin film solar panels are cheaper and faster to produce since the entire panel is considered a solar cell, unlike traditional panels constructed of numerous solar cells. The manufacturing process makes these panels the most readily available solar panel on the market.

The flexible laminate makes these panels bendable and therefore easier to mount on uneven surfaces and also more durable to extreme weather condition like a hailstorm. This factor is extremely important for thin film technology, considering that these panels are often laid on house roofs to replace traditional roofing materials. In case of damage the thin films panels with continue to work at a lesser rate, while crystalline silicon panels stop working altogether if a single cells is damaged. Another advantage of thin film panels is their weight. Thin film panels weigh less than crystalline silicon panels, making them easier to mount and work with for residential use. Another advantage that thin film panels have is their performance in hotter climates. Thin film semiconductors used today like Copper Indium Gallium Selenide do not lose as much efficiency as their temperature increases. Because of this ability to withstand hotter temperatures thin film systems have an added advantage over the crystalline rivals in hot climates like the southeast. This also makes it easier to design solar panel systems as the solar panels perform closer their manufactures rating without factoring high temperature as much. Thin film panels perform better than the competition in shade or low light conditions. So in conclusion the main advantages of thin film panels are: cost, weight, durability, flexibility, high heat and shade performance.

However, as with all the solar panels in this review, thin film panels have their disadvantages. The most significant disadvantage is their efficiency, which is also the main reason why this new technology has not replaced older silicon technology. Thin film technology efficiency ranges between 4% - 7%. This means that in order to produce the same amount of electricity twice as many thin film panels are needed in comparison with polycrystalline panels and almost three times as many when compared to mono-crystalline. Last of all disadvantages of thin film technology is longevity. Because the technology is fairly new, it is unknown how these panels perform over time.

2.1.4 Photovoltaic Effect in Solar Cells

In order to fully understand the photovoltaic effect and make a better decision on the most expensive part of this project, a brief review is needed to show how solar panels convert solar energy to usable electricity for the end user. The photovoltaic cell is usually constructed of some light absorbing material, which is usually silicon or some other type of semiconductor. All semiconductors are associated with a specific band gap. The potential difference between the lowest energy level on the conduction band Ec and the highest energy level on the valence band Ev is called band gap energy or Eg. Electrons with enough input energy can jump this band gap from their usual steady state spot on the valence band to an excited state on the conduction band. These electrons are responsible for the direct current that the solar cells produce. Solar energy packets or photons that contain different amounts of energy correspond to different wavelengths of the solar spectrum. When the photon energy matches that of the semiconductor band gap, the semiconductor material absorbs these photons. Consequently photons with higher energy levels than Eg are also absorbed but their excess energy is reflected or dissipated in the form of heat (wasted energy) and photons with lower energy levels than Eg are not able to get absorbed at all.

Ultimately the goal of a solar cell designer is to choose a semiconductor material with optimal band gap energy near the middle of the energy spectrum for solar radiation. No single semiconductor has a band gap that can respond to sunlight's full range, from the low-energy infrared through the visible light to the high-energy ultraviolet. Full-spectrum solar cells have already been invented, but not at a suitable consumer price. Scientists at the Solar Energy Materials Research

Group in the Materials Sciences Division (MSD) at the U.S. Department of Energy's Lawrence Berkley National Laboratory have tested and produced a GaNAs solar cell that responds to almost the entire solar spectrum. The main objective in this new technology is to produce a solar cell that stacks three different semiconductors with different energy band gaps. These semiconductors are usually connected in series.

A solar cell can be compared to a diode because of the p-type and n-type semiconductor materials used to fabricate them. As in all diodes there are two metal contacts attached to each side of this p-n junction. When the electron-hole pair is formed across the p-n junction, a forward voltage or photo voltage is created between the two photovoltaic cell terminals. Traditional photovoltaic cells are usually protected from the outside elements with a protecting layer such as glass or clear plastic cover. A clear encapsulate is used to attach the rest of the cell to the glass. Then an antireflection coat covers the top or front contact (n-type terminal), which is connected to the n-type silicon. Below the n-type silicon layer is the p-type layer needed to form the p-n junction in-between them, depicted in Figure XX. The p-type terminal or bottom contact lies beneath all the above-mentioned layers.

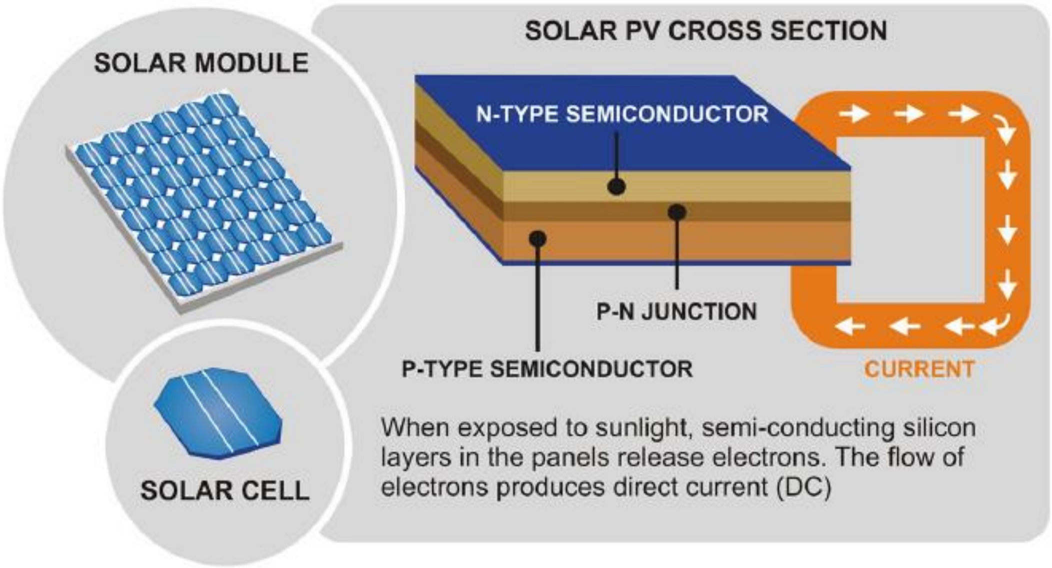


Figure 2: Inside a Photovoltaic Cell

2.1.5 Photovoltaic Panel Performance

From the previous part of this review it is quite clear the solar panels in all the various makes and models are not very efficient at converting solar energy. So panel performance and means to increase it are very important to this project. All solar panels suffer from naturally inherited issues such as temperature effect, electron-hole recombination rate, and light absorption efficiency. Electron hole recombination is the main reason why mono-crystalline cells perform better than polycrystalline ones. The impurity concentration and structure abnormality associated with multiple crystal silicon increases electron-hole recombination rate, which in turn, decreases panel efficiency.

Temperature is another negative factor that affects solar panel performance. As mentioned earlier, crystalline silicon panels suffer the most when their cell temperature rises. The main reason why researchers use non-silicon semiconductor materials on thin film panels is to reduce panel sensitivity to temperature. Ironically, solar panels perform at their best on a cold and sunny day. Unfortunately those days are very few and far in between in hot and sunny Central Florida. Therefore this project will have to take great consideration of temperature effects on the selected solar panel. As the semiconductor temperature goes up so does its conductivity. Higher conductivity reduces the electric field at the silicon p-n junction, which in turn reduces the voltage across a solar cell. A smaller cell voltage translates to a smaller power output, which also means lower efficiency. Solar panels will usually have a temperature coefficient, which is usually the rate of power reduction for every degree the above normal operating temperature of 25 degrees Celsius.

Every solar panel has an I-V curve or I-V characteristics associated with it. The area under the I-V curve is approximately the maximum power that that a panel would produce if it would operate at maximum voltage or open-circuit voltage and maximum current or short-circuit current.

In order to increase or maintain an optimal efficiency the solar panel temperature needs to stay low and close to room temperature range. There is a lot of research being done in cooling methods used to lower panel temperature. There are active and passive-cooling methods suggested in maintaining a lower panel temperature. Pumping a coolant or some type of refrigerant through the backside of the panels is an active method. Attaching a heat sink or cooling fins is a passive way of dissipating heat from the panels. Usually these methods are not very cost effective in comparison to the gained efficiency or power from the panels.

The last inefficiency associated with solar panels is their ability to absorb light. It is a well-known fact that solar panels cannot make use of the entire light spectrum. Some light is lost due to reflection, which is why antireflection coatings used on top of every solar cell. As mentioned earlier the semiconductor will absorb only the amount of light that has matching or higher wavelength energy to the semiconductor band gap. This makes more than half of the spectrum of light available useless to the solar panels. Band gap engineering is one of the methods used to increase the light absorption efficiencies. The design engineer can maximize power by maximizing photocurrent or photo voltage individually. To maximize photocurrent, it is desirable to capture as many photons from the spectrum of solar radiation as possible. A small band gap may then be selected so that even photons with lower radiation energies can excite electrons into the conduction band. However, the small band gap results in a lower photo voltage.

Additionally, the photons with higher energies will have much of their energy wasted as heat, instead of conversion into electrical energy. Alternatively, the designer can choose a higher band gap, but then will not capture any photon energy less than that band gap, resulting in a lower photocurrent and, in turn, reducing the output current of the device. In designing conventional single junction solar cells, these two competing issues are balanced by choosing optimal band gaps near the middle of the energy spectrum for solar radiation.

Conveniently, high-quality wafers of silicon, with a band gap of 1.1 eV, and GaAs, with a band gap of about 1.4 eV, are readily available and have nearly the optimal band gap for solar energy conversion in a conventional single-junction solar cell.

2.2 Overview of Solar Charge Controller

A charge controller is an essential thing for nearly all power devices that use electric or lead acid battery to prevent overcharging, over discharging or overflow of current. Overflow and overcharging both can reduce the lifespan, durability and performance of the battery. Safety risk can also be occurred. Some controllers have display where battery condition and flow of power can be monitored.

Sometimes PV panels pass a little bit current in reverse direction which may cause discharge from the battery without any purpose. Though this loss is less significant however it can be prevented by using charge controller. Some controllers have relay to prevent this loss which is switched off at night to block the flow of reverse current. And some controllers have transistors which allow the current to flow in only one direction. It prevents reverse current without any extra effort or cost.

If a battery is fully charged, it cannot store more energy coming from the PV panel. If the energy supply remains the same, then the battery voltage can be very high. This condition increase the chances to overheat the battery which may cause small explosion or load (such as lights, home appliances etc) can be damaged. Charge controller actually reduces the flow of energy to the battery when the battery reaches to a specific voltage. Some controllers regulate the flow of energy to the battery by switching the current fully on or fully off. This is called "on/off control." Others reduce the current gradually. This is called "pulse width modulation" (PWM). Quite a few charge controls have a "PWM" mode. PWM is often used as one method of float charging. Instead of a steady output from the controller, it sends out a series of short charging pulses to the battery

- a very rapid "on-off" switch. The controller constantly checks the state of the battery to determine how fast to send pulses, and how long (wide) the pulses will be. In a fully charged battery with no load, it may just "tick" every few seconds and send a short pulse to the battery. In a discharged battery, the pulses would be very long and almost continuous, or the controller may go into "full on" mode. The controller checks the state of charge on the battery between pulses and adjusts itself each time. It maintains a full charge but minimizes battery overheat and damages.

A circuit is overloaded when the current flow is higher than it can safely level. This can cause overheating and fire hazard can be happen. Overload can be caused by a short circuit in the wiring, or by a faulty appliance (like a frozen water pump). Most of the charge controllers have overload protection built in, usually with a push-button reset.

2.3 Lead Acid Battery

It was first invented in 1859 by a French physicist Gaston plante. A lead-acid battery is an electrical storage device that uses a reversible chemical reaction to store energy. It uses a combination of lead plates or grids and an electrolyte consisting of a diluted sulphuric acid to convert electrical energy into potential chemical energy and back again.

Battery must have a case that is electrically insulated and mechanically strong enough to support the weight of its component parts. All batteries are composed of individual cells. A cell might be considered the smallest unit of a battery that is capable of generating a voltage and performing the functions of a battery on its own.

The individual battery cells are composed of plates and insulators. The plates are composed of the conductive grid and the active material. There are two polarities of plate, both positive and negative. One pair of opposite polarity plates is sandwiched around some type of insulator, called a separator. The composition of the separator varies.

Electrolyte is a source of free electrons; actually the captive electrons within the electrolyte are waiting to be liberated as a result of a chemical reaction.

Before an initial charge, the lead electrodes of lead-acid batteries are both the same and the electrolyte is sulphuric acid. When they are initially charged, the cathode is oxidized into lead (II) oxide, while the anode remains unchanged.

Subsequent discharging changes both electrodes to lead sulfate and the sulfuric acid is diluted. Recharging simply restores the previous state (the electrodes return to lead and lead oxides). When the batteries are overcharged (charged even after most of the sulfate has been converted), the excess energy is used to split the water in the electrolyte into hydrogen and oxygen gases.

Battery capacity, C, refers to the number of ampere-hours that a charged battery is rated to supply at a given discharge rate. A battery's rated capacity is generally used as the unit for expressing charge and discharge current rates, i.e., a2.5 amp-hour battery charging at 500mA is said to be charging at a C/5 rate.

2.3.1 Types

According to the purpose of the lead acid battery, they are divided into four types-

1. Deep cycle battery
2. Starter battery
3. Flooded battery
4. Valve regulated lead-acid (VRLA)

Deep cycle battery

A deep-cycle battery is a lead-acid battery designed to be regularly deeply discharged using most of its capacity. They are the key component in various types of renewable energy systems that require the storage of electricity. A deep-cycle battery is designed to discharge between 45% and 75% of its capacity, depending on the manufacturer and the construction of the battery. Although these batteries can be cycled down to 20% charge, the best lifespan vs cost method is to keep the average cycle at about 45% discharge.

Starter battery

A starter battery is designed to deliver large bursts of power for a while to start an engine. Once the engine is started, the battery is charged by the charging system that is driven the engine. Starter batteries are intended to have a low depth of discharge on each use. They are constructed of many thin plates with thin separators between the plates, and may have a higher specific gravity electrolyte to reduce internal resistance.

Flooded battery

In this type of battery the gases and vapors are allowed to escape from the container.

Valve regulated lead-acid (VRLA)

VRLA batteries remain under constant pressure of 1-4 psi. This pressure helps the recombination process under which 99+% of the Hydrogen and Oxygen generated during charging are turned back into water. The two most common VRLA batteries used today are the Gel and Absorbed Glass Mat (AGM).

2.3.2 Battery conditions

Usually all types of batteries experience several phenomenon, which affect their performance:

Self-discharge – usually all batteries discharge automatically in ideal state.

Gassing – happens when batteries are overcharged and it is caused by hydrolysis
of water from the electrolyte into hydrogen and oxygen.

Sulfation – refers to crystallization of lead sulfate that is released on the plates when the battery is discharged. When in crystalline form, it cannot take part in the chemical reaction and effectively blocks the access of electrolyte to electrodes. It causes the battery capacity to drop over time and it is accelerated by leaving the battery in an uncharged state.

Freezing – the electrolyte can freeze, especially when the battery is discharged when it contains more water. The freezing point therefore depends on a state of charge of battery. Freezing can mechanically damage the battery.

Dehydration – happens when the flooded battery loses water due to overcharging. The water has to be replenished, so that the electrodes do not dry up. Therefore it is not desirable to overcharge flooded batteries significantly.

2.3.3 Charging

Basically we used 3 stages to charge the battery and the battery we use here is
6 cells,12V battery. Those stages are-
1) constant-current charge/bulk charging,
2) Constant voltage charging/absorption,
3) Float charge.

Constant-current charge/bulk charging

During the Bulk phase of the charge cycle, the voltage gradually rises to the Bulk level (usually 14.4 to 14.6 volts) while the batteries draw maximum current which remains constant in this stage. Here, in this project we considered 14.4 volt as bulk level voltage and we charged our battery at 14.6 volt. When Bulk level voltage is reached the absorption stage begins.

Constant voltage charging/absorption

During this phase the voltage is maintained at Bulk voltage level for a specified time (usually an hour) while the current gradually tapers off as the batteries charge up. When the battery reaches the bulk charge set voltage, the PWM begins to hold the voltage constant (14.4volt) to avoid overheating and over gassing the battery.

Float charge

After the absorption time passes the voltage is lowered to float level (usually 13.4 to 13.7 volts) and the batteries draw a small maintenance current until the next cycle. This is ideal charge procedure. We get 13.5 volt as or float point in our project.

Load will be disconnected when the battery voltage decreases below typically 10.5V when loaded. It is good to change the voltage levels according to battery temperature, as the voltage values have a significant temperature characteristics, it is safe to charge most of lead-acid batteries by currents up to C/10h, where C is the battery capacity in Ah.

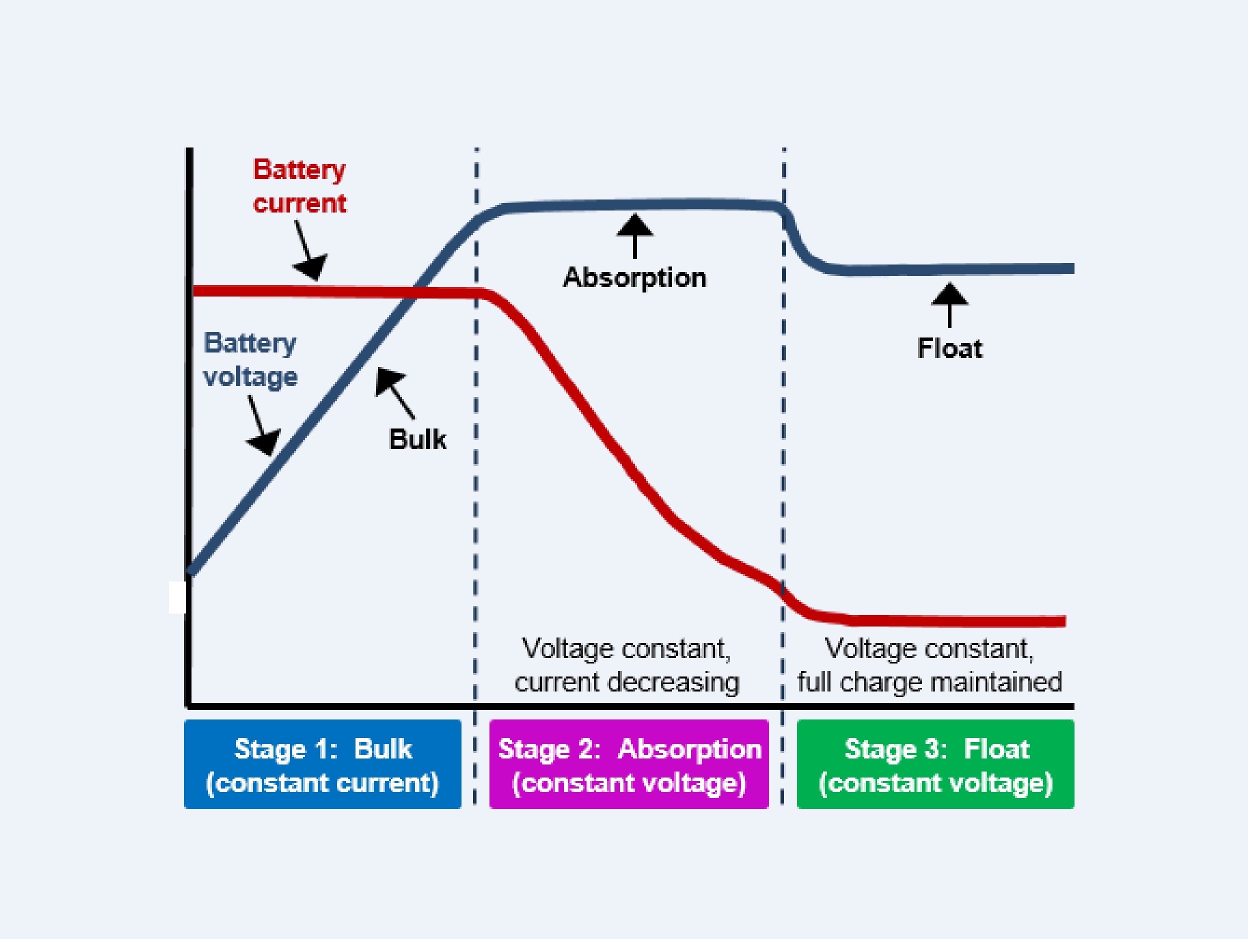


Figure 3: The diagram of charging stages of lead-acid battery

CHAPTER 3

DESIGN PRINCIPLE

3.1 Circuit Construction:

At first, we use arduino based controller to construct our solar charge controller. But our main goal of this thesis is to minimize the total cost of the charge controller. So we decided to use microcontroller (PIC16F690)

3.1.1 Block Diagram

We had to change our primary block diagram due to the change on the circuit based on intended functionality of 3 stage charge controlling mentioned in the previous chapter.

3.1.2 Preliminary Block Diagram

The heart of the 2 stage charge controller is Arduino nano board. The arduino MCU senses the solar panel and battery voltages. According to this voltages it decides how to charge the battery and control the load.

The amount of charging current is determined by difference between battery voltage and charge set point voltages. The controller uses two stages charging algorithm. According to the charging algorithm it gives a fixed frequency PWM signal to the solar panel side p-MOSFET. The frequency of PWM signal is 490.20Hz (default frequency for pin-3). The duty cycle 0-100% is adjusted by the error signal.

The controller gives HIGH or LOW command to the load side p-MOSFET according to the dusk/dawn and battery voltage.

3.1.3 Updated Block Diagram

In our primary steps we used 2 stage charging system where an arduino is used. There we found some inconvenience, the vital issue among them was – in 2 stage charging when the battery voltage is below 13.6 volt the battery is still consumed by the load which damage the battery. But if we use the 3 stage charging system then it will automatically start charging the battery.

Another reason to usea microcontroller instead of an arduino is that it minimizes the total cost. Here we used PIC16F690 Microcontroller.

We used a solar panel and a battery of 12V, but to connect a microcontroller with our system we must reduce it to 5V. For this we used the voltage divider and connected the solar panel and the battery to the microcontroller port ADC1or RA1/AN1 and ADC2 or RA0/AN0 consecutively.

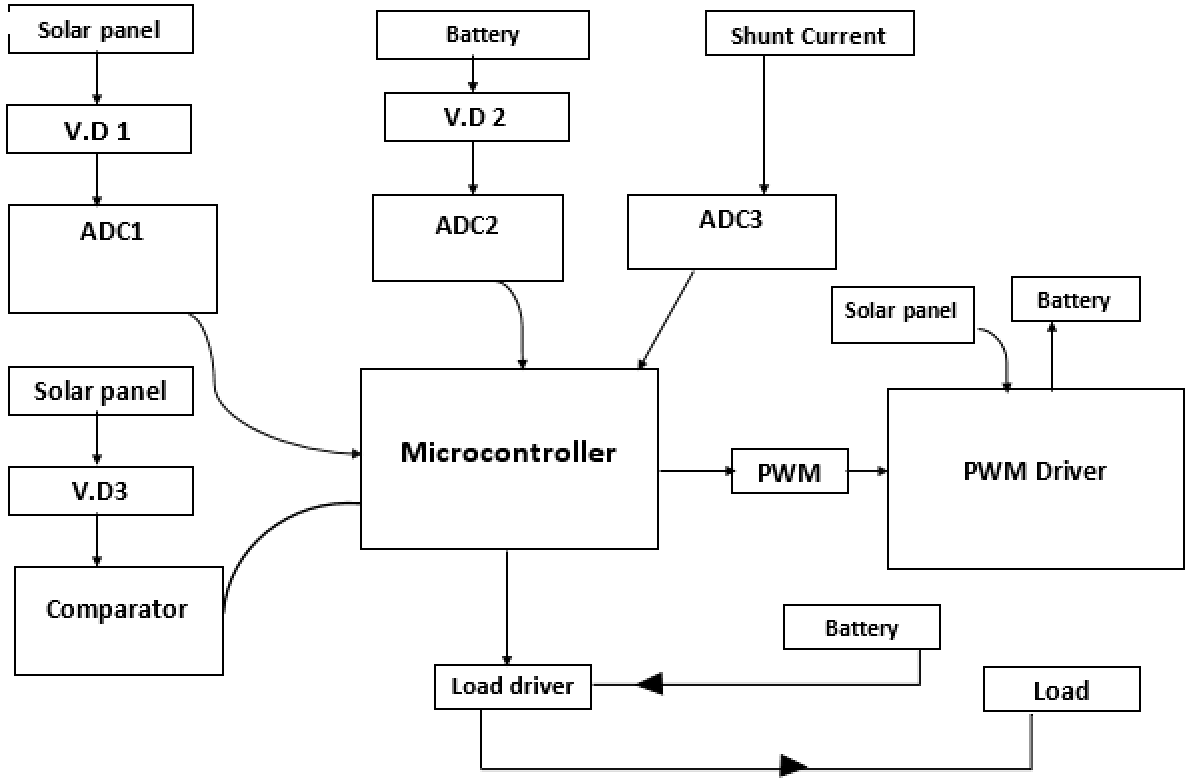


Figure 4: updated block diagram of solar charge controller

CHAPTER 4

Cost Analysis

In our designed circuit, we used 5 capacitors, 2 variable resistors,1 Microcontroller, 4 transistors, 2 Diode, 3 MOSFET, 1 LCD, 1 Photocouplor, 2 Hit sink, 1 voltage regulator, 7 Resistors,1 temperature sensor.

Bill of Materials:

Item Group	Items	Value	Quantity	Unit price	Price
Capacitor	C1,c2	10uF-60V	2	5	10
	C3	100uF-16V	2	8	16
	C4	0.1uF-25V	1	3	3
	C5	100uF-60V	1	20	20
Variable Resistor	Vr1,vr2	10k-Ohm	2	10	20
Resistor	R1,R2	4.7k-Ohm	2	1	2
	R3	10k-Ohm	1	1	1
	R4	18K-Ohm	1	1	1

	R5	100K-Ohm	1	1	1
	R6	15K-Ohm	1	1	1
	R7	12K-Ohm	1	1	1
Microcontroller	Ic2	PIC16F690	1	90	90
Transistor	T1	BD135	1	10	10
	T2,T3,T4	2N5551	4	5	20
Diode	D1,D2	1N4007	3	2	6
MOSFET	M1,M2,M3	IRF3205	3	35	105
LCD	Dis1	16x2	1	200	200
Photocuplour	P1	PC817	2	12	24
Hit sink			2	20	40
Voltage Regulator	Ic1	LM3805	1	15	15
Temperature Sensor	Ic3	LM35	1	50	50
PCB			1		50
			Total items =35 units		Total =686 tk.

The price of the Solar Charge Controller we built is 686tk, whereas the price of the commercial solar charge controller we bought is 800tk. Commercial Solar charge controllers that are available in the market does not provide the real MPPT/PWM written in them. It works just as a simple circuit and the efficiency of those controllers is very low compared to their price.

Normally we can get solar charge controller at a price between 300-3000tk in the market. Though it doesn’t provide the actual quality is promises. Hence we made our attempt to do this project and we made our solar charge controller which is actually a PWM Charge Controller that is more efficient and its price is comparatively lower than commercial MPPT/PWM Charge Controller.

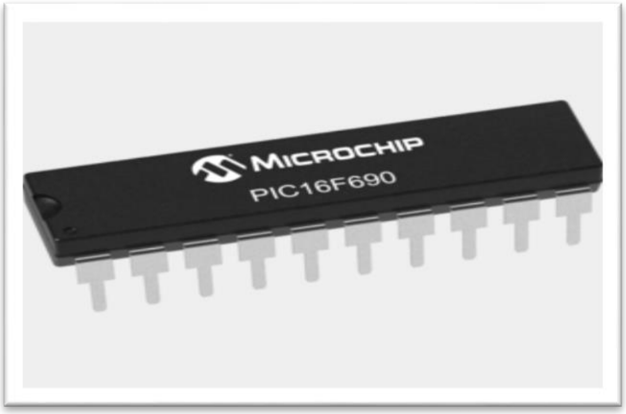
CHAPTER 5

Circuit Implementation

5.1 Equipment:

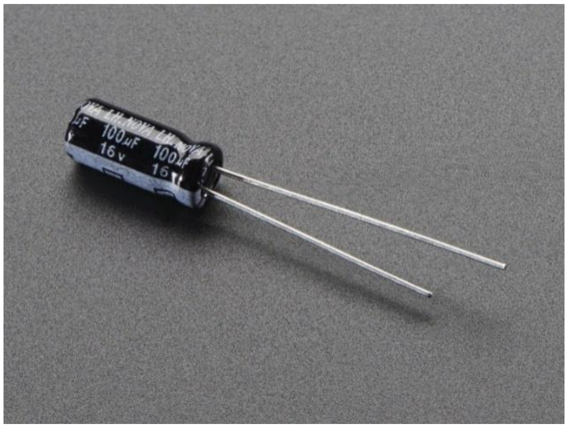
PIC16F690 Microcontroller:

The PIC (Programmable Interface Controller) line of microcontrollers are used to develop the semiconductor division of General Instruments Inc .The first PIC‟s were a programmable, high output current, input/output controller built around a RISC (Reduced Instruction Set Code) architecture which have a major improvement over existing microcontroller. It ran proficiently at one instruction per internal clock cycle, and the clock cycle was derived from the oscillator divided by 4. PICs could run with a high oscillator frequency of 20 MHz early and this made them relatively fast for an 8-bit microcontroller but 20 mA of source and sink current capability on each I/O (Input/Output) pinwastheir main feature. Advertising high I/O currents of only 1-milliampere (mA) source and 1.6 mA sink was typical micros of the time.



Capacitor:

Capacitor is a simple passive device that is used to store electricity. It is a component which has the ability to store energy in the form of an electrical charge producing a potential difference across its plates much like a small rechargeable battery. There are many different kinds of capacitors available from very small capacitor beads used in resonance circuits to large power factor correction capacitors and they all do the same thing, they store charge. In this circuit, we used 4 values of capacitor they are10uF, 100uF, 0.1uF, 100uF- 60v.



Variable resister:

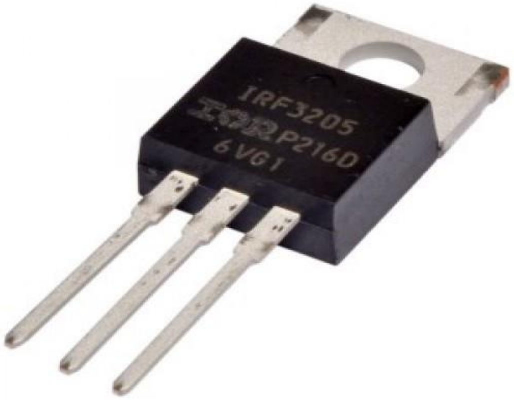
A variable resistor is a device that is used to change the resistance in an electronic circuit according to our needs. It can be used as a three terminal as well as a two terminal device but mostly they are used as a three terminal device. They are mostly used for device calibration. In our circuit, we use 10k variable resistor.

Resistor:

Resistor is an electrical component which reduces the electric current.It may be used to reduce current flow and at the same time, may act to lower voltage levels within circuits. Resistors are used to limit current flow, to adjust signal levels, bias active elements, and terminate transmission lines among other uses in electronic circuits, that many watts of electrical power can dissipate as heat by high-power resistors. In this circuit we used 2 10K resistors.

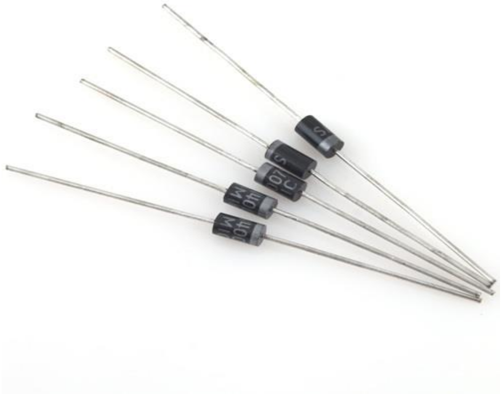
MOSFET:

The MOSFET (Metal Oxide Semiconductor Field Effect Transistor) transistor, a semiconductor device, is widely used for switching and amplifying electronic signals in the electronic devices. The MOSFET is a core of integrated circuit and because of these very small sizes, MOSFET can be designed and fabricated in a single chip. The MOSFET is a four terminal device and those are source(S), gate (G), drain (D) and body (B) terminals. The body of the MOSFET is frequently connected to the source terminal so making it a three terminal device like field effect transistor. The MOSFET is very far the most common transistor and it can be used in both analog and digital circuits. In this circuit, we use 3 IRF3205 MOSFET.



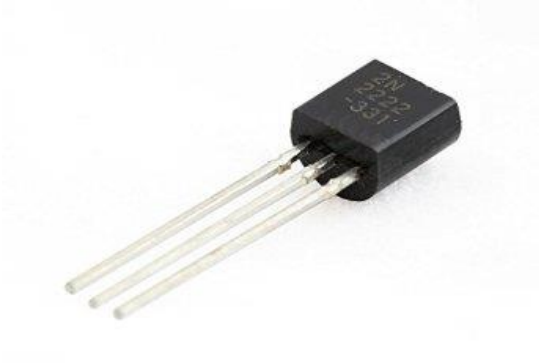
Diode:

An electrical device which is allowing current to move through it in one direction with far greater ease than in the other is called *diode*. In modern circuit design, the most common kind of diode is the *semiconductor* diode. The term “diode” is customarily reserved for small signal devices, I ≤ 1 A and the term *rectifier* is used for power devices, I > 1 A. In this circuit we use 1N4007 and 3060PT



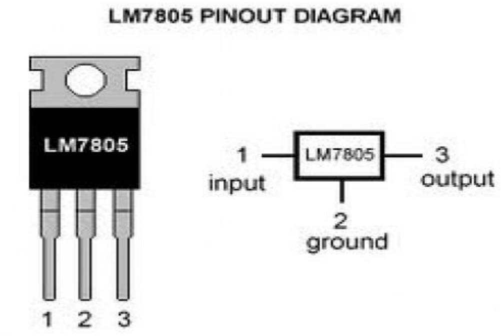
Transistor:

An electronic device that regulates current or voltage flow and acts as a switch or gate for electronic signals is called transistor. Transistors consist of three layers of a semiconductor material, each capable of carrying a current. In this circuit, we use 2 transistor 2N2222A, BD135.



Voltage Regulator:

Voltage regulator is an electrical device which maintains the voltage of a power source within acceptable limits. To keep voltages within the recommended range, the voltage regulator is needed and it can be tolerated by the electrical equipment using that voltage**.**



LCD 2x16:

LCD (liquid crystal display) is the technology used for displays. LCDs allow displays to be much thinner than cathode ray tube (CRT) technology like light-emitting diode (LED) and gas-plasma technologies.

Photo Cuplour:

A photocoupleris a passive optical component that can combine or split transmission data (optical power) from optical fibers. It is designed to transfer electrical signals by using light waves in order to provide coupling with electrical isolation between its input and output. To prevent rapidly changing voltages or high voltages on one side of a circuit from distorting transmissions or damaging components on the other side of the circuit is the main purpose of a photocoupler. We used PC817 in our circuit.

Hit sink:

A heat sink is a passive heat exchanger. It transfers the heat generated by an electronic or a mechanical device to a fluid medium, often air or a liquid coolant, where it is dissipated away from the device, so allowing regulation of the device's temperature at optimal levels. High-power semiconductor devices such as power transistor and optoelectronics such as lasers and light emitting diodes (LEDs) heat sinks are used, where the heat dissipation ability of the component itself is inadequate to moderate its temperature.

5.2 Circuit Diagram:

There is no panel or similar instrument available in PROTEUS. Therefore, a DC current source represented the panel. The source had constant current of 5A.

The voltage regulator LM3805 was omitted from the simulation, as there is no pin 19 or VDD pin in PIC16F690 in PROTEUS. The purpose of the voltage regulator is to feed 5V to the microcontroller. Above this voltage microcontroller will burn.

We used a solar panel and a battery of 12V, but to connect a microcontroller with our system we must reduce it to 5V. For this we used the voltage divider and connected the solar panel and the battery to the microcontroller port ADC1or RA1/AN1 and ADC2 or RA0/AN0 consecutively.

To measure the charging current we used shunt current in our project. That shunt current is connected to the microcontroller using ADC3 or RC2 pin of PIC16F88.

Voltage obtained from the solar panel will come to the comparator using voltage divider rule. Comparator will be connected to the microcontroller pin RA4 which is also a ADC pin. We are using comparator to detect day or night time. If the battery voltage is more than 6v then it will be considered as day time, otherwise microcontroller will consider as night.

Load driver will determine whether the load is on or off. If the battery voltage is less than 10.5volt then load will be disconnected automatically. Battery is considered as input and load is considered as output of a load driver. Load driver is connected with RC6 pin of microcontroller.

Charging current is controlled using a PWM driver. We will consider the solar panel voltage as the input and battery as the output. PWM is connected with RC7 pin of microcontroller.

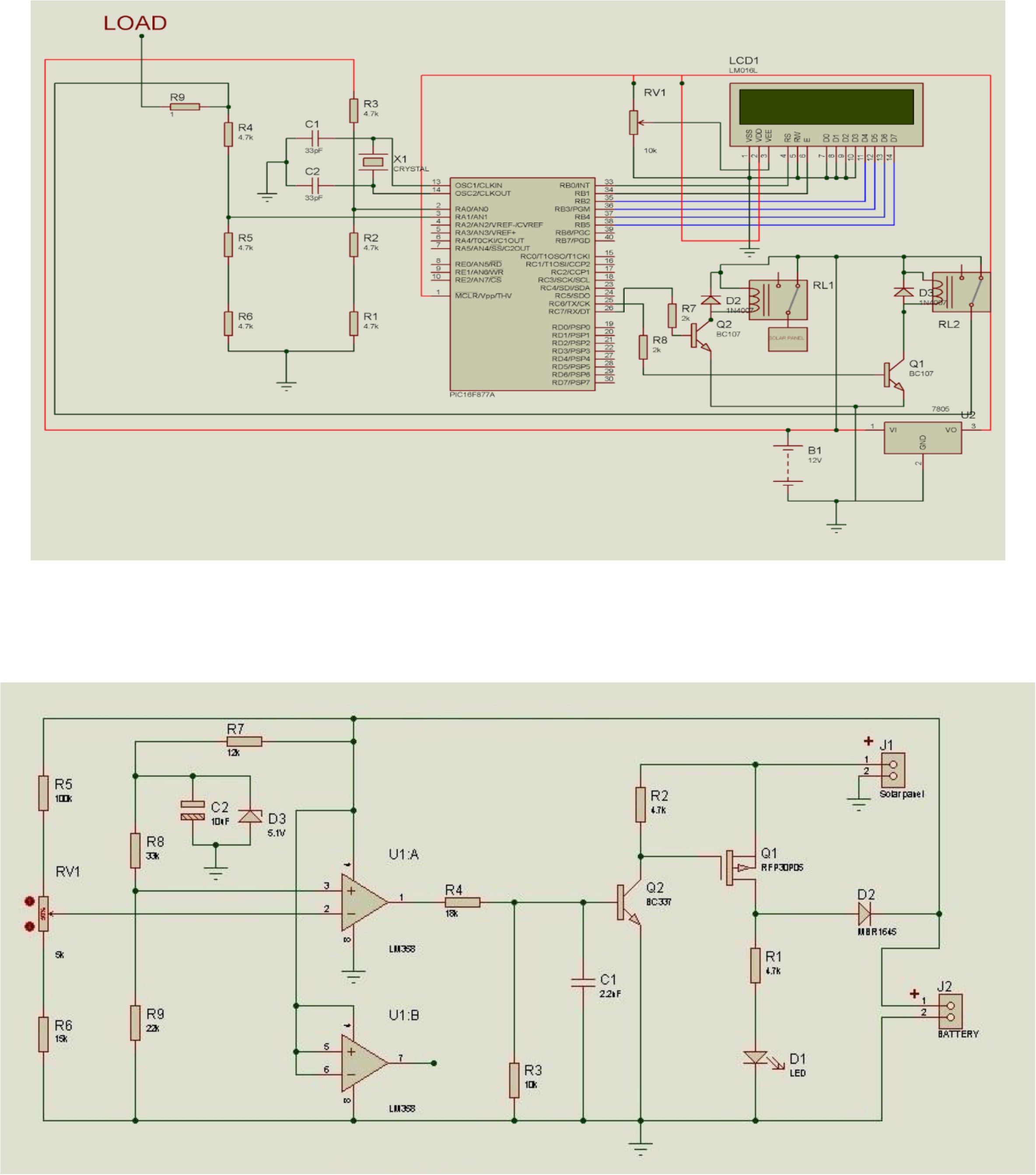
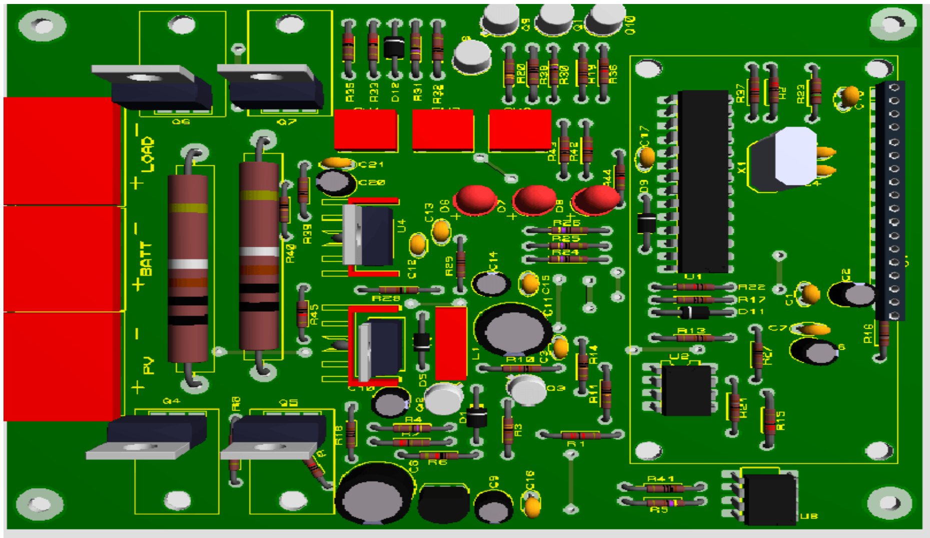


Fig 4: main circuit diagram

5.3 PCB:

The simulation was done, after the all components of the circuit have been added. It was done using different values of the load. With each load value the value was recorded. It corresponds to the exact value of the PWM.



CHAPTER 6

Software Implementation

High-level languages or PIC microcontrollers native machine language (Assembly) can be used to program in PIC microcontrollers. We choose the C language for our thesis, using the software MICRO C. Better control and greater efficiency is the advantages of C language. The interface with the programmer is quite simple and easy to understand is the another reason for using C language.

6.1 Code Implementation:

By using PIC writer software, The PIC 16F690 microcontroller can be programmed. The following code was written and implemented in the microcontroller:

Block Diagram:

Firstly, we have to start the program. After that we have to configure input output pin, ADC module and LCD module. The program will initialize default value and constant. Then program will read the panel voltage. If panel voltage is greater than 6V battery will start charging, if not, then battery will read the voltage again. Suppose panel voltage is greater than 6V and battery is charging. Now program will check whether battery voltage is greater than 14.4 V or not, if greater than 14.4 volt then stop charging. Then program will check battery voltage is less than 10.8v or not, if less than 10.8v program will disconnect the load. After that battery will charge again and program will check whether the battery voltage is greater than 13.6V or not, if it is 13.6V then the load will connected. After that the program will check charging status of the battery, if charging battery voltage is less than 14.2V than battery will charge at bulk phase which is constant current. If greater than 14.2v than it will start charging state 2 which is absorption or constant voltage phase. After that program will read the charge current, if charging current less than or equal to 100mA than program will stop charging. Now if charging battery voltage is less than 14.2 than battery will charge at charge stage 3 or floating charge. Then again program will read the load current and check whether the current is greater than 10A, if current greater than 10A than load disconnect. If current less than 10A then load reconnect. After that program will read temperature. If temperature greater than 60 degree than charge and load will disconnect. If no than the program will read the panel voltage again and continue the whole procedure.

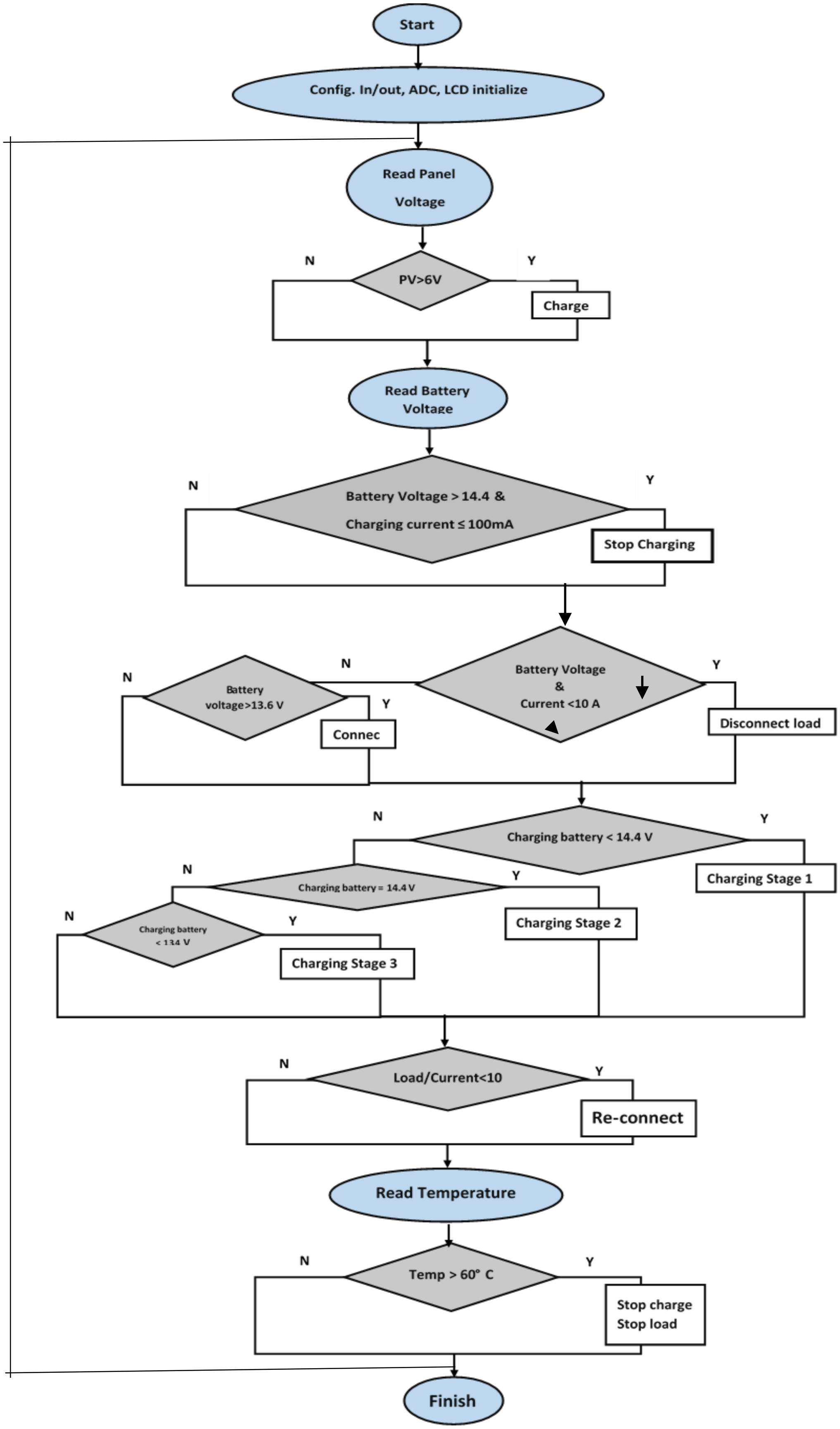

Start
Config. In/out, ADC, LCD initialize
Read Panel Voltage
N
PV>6V
Y
Charge
Read Battery Voltage
N
Battery Voltage > 14.4 &
Charging current ≤ 100mA
Y
Stop Charging
N
Battery voltage>13.6 V
Y
Connec
N
Battery Voltage & Current <10 A
Y
Disconnect load
N
Charging battery < 14.4 V
Y
Charging Stage 1
N
Charging battery = 14.4 V
Y
Charging Stage 2
N
Charging battery < 134 V
Y
Charging Stage 3
N
Load/Current<10
Y
Re-connect
Read Temperature
N
Temp > 60° C
Y
Stop charge
Stop load
Finish

Fig 5: block digram of designed solar charge controller

Software Algorithm:

1. Start
2. Configure input/output
3. Configure ADC Module
4. Configure LCD Module
5. Initialize default value and constant
6. Read Panel Voltage
7. If Panel Voltage> 6V then Charge Battery
8. Else Go forward
9. Read Battery Voltage
10. If Battery Voltage> 14.4V then stop charging
11. Else Go Forward
12. If Battery Voltage< 10.8V then Disconnect Load
13. Else Go Forward
14. If Battery Voltage>13.6V then Connect Load
15. Else Go Forward
16. Charging Battery Voltage<14.4V then Go “Charging Stage 1”
17. Else Go Forward
18. If Charging Battery Voltage = 14.4V then Go “Charging Stage 2”
19. Else Go Forward
20. Read Charge Current
21. If Charging Current<= 100mA then “Stop Charging”
22. Else Go Forward
23. Charging Battery Voltage<13.4V then “Charging Stage 3”
24. Else Go Forward
25. Read Load Current
26. If Load Current > 10A then “Disconnect Load”
27. Else Go Forward
28. If Load Current<= 10A then “Reconnect”
29. Else Go Forward
30. Read Temperature
31. If Temperature > 60 °C then “ Stop Charging & Load”
32. Else Go to point 6

Software code:

The following code is the main part of the code which is written and implemented in the microcontroller:

```
void main()
{
      char i;

      // make RB7 and RB6 as output
      TRISB = 0x3F;
      PORTB = 0;

      // make all AN pin as analog, Vref = Vdd
      ADCON1 = 0x00;

      // reset Charge FET and Load FET
      CHARGE_FET1_PORT = 0;
      CHARGE_FET2_PORT = 0;
      LOAD_FET_PORT = 0;
      CHARGE_FET1_TRIS = 0;
      CHARGE_FET2_TRIS = 0;
      LOAD_FET_TRIS = 0;
      SOLAR_IN_TRIS = 1;


      // Initialize LCD
      Lcd_Init();

      // default settings
      Lcd_Cmd(_LCD_CLEAR);
      Lcd_Cmd(_LCD_CURSOR_OFF);

      // reset flag bits to default state
      FullChargeFlag = 0;
      ChargingFlag = 1;
      OverLoadFlag = 0;
      OverTemperatureFlag = 0;
      BoostChgDoneFlag = 0;
      FloatChargingFlag = 0;

      // Try to Initialize the system
      BaseVoltage = 0xFF;
      while(BaseVoltage == 0xFF){ShowInitMsg();}

      while(1)
      {
            ReadTemperature();
            ReadBattVoltage();
            ReadPanelVoltage();
            ReadChargeCurrent();
            ReadLoadCurrent();
```

```
            // Controll CHARGE_FET2
            if(SOLAR_IN_PORT == 0 && FullChargeFlag == 0)
            {
                  CHARGE_FET2_PORT = 1;
            }
            else
            {
                  CHARGE_FET2_PORT = 0;
            }

            // if DayTime
            if(1)
            {
                  // Temperature
                  if(Temperature >= MaxTemperature)
                  {
                        LOAD_FET_PORT = 0;
                        CHARGE_FET1_PORT = 0;
                        CHARGE_FET2_PORT = 0;
                        OverTemperatureFlag = 1;

                        // wait until Temperature become Low
                        while(OverTemperatureFlag)
                        {
                              // show Temperature
                              ReadTemperature();
                              WordToStr(Temperature, txt);
                              WriteLCD(1,1,"Temperatur: ");
                              LCD_Chr_CP(txt[2]);
                              LCD_Chr_CP(txt[3]);
                              LCD_Chr_CP(0xDF);
                              LCD_Chr_CP('C');
                              WriteLCD(2,1,"High Temp       ");
                              BUZZER_ON();
                              Delay_ms(1000);
                              BUZZER_OFF();
                              Delay_ms(1000);
                              if(Temperature <
MIN_TEMP){OverTemperatureFlag = 0;}
                        }
                  }

                  // Load On/Off
                  if(BattVoltage < LoadOffVoltage)
                  {
                        LoadOnFlag = 0;
                        LOAD_FET_PORT = 0;
                  }
                  if(BattVoltage >= LoadOnVoltage)
                  {
                        LoadOnFlag = 1;
                        LOAD_FET_PORT = 1;
                  }
```

```
                  // Re-Charge if Battery voltage @ Low Level
                  if(BattVoltage <= ReChargeVoltage)
                  {
                        BoostChgDoneFlag = 0;
                        FloatChargingFlag = 0;
                        FullChargeFlag = 0;
                  }

                  // Do a Boost-Charge
                  if(!BoostChgDoneFlag)
                  {
                        if(BattVoltage > BoostChgVoltage)
                        {
                              CHARGE_FET1_PORT = 0;
                              ChargingFlag = 0;
                              FullChargeFlag = 1;
                              BoostChgDoneFlag = 1;
                        }
                        else
                        {
                              CHARGE_FET1_PORT = 1;
                              ChargingFlag = 1;
                              FullChargeFlag = 0;
                        }
                  }
            }

            // update current Frame with
Voltage/Current/Temperature/UserMsg sequecially
            UpdateFrame();
      }
}
```

CHAPTER 7

Field Test

7.1 Result and Analysis:

The Fill Factor of a solar panel is the ratio of the solar cells actual power output (Vmp × Imp) versus its 'dummy' power output (Voc × Isc). This is a key parameter in evaluating the performance of solar cells. Typical commercial solar cells have a fill factor > 0.70. Reject crystalline cells like those found on eBay, or grade B cells, have a fill factor usually between 0.4 to0.65, and in amorphous solar cells or thin film cells between 0.4 to 0.7. The fill factor can also be used to determine the series resistance of a solar cell.

Usually electrical components like – MOSFET, DIODE, Register etc. is not ideal. Because internal heat is produced in each components. As a result the Fill Factor of a Solar Charge Controller decreases and lessen the efficiency.

Solar efficiency is the ratio of energy output from the solar cell to input energy from the sun. it is usually depend on the the spectrum and intensity of the incident sunlight and the temperature of the solar cell. Solar efficiency can be defined as:

$$P_{max} = V_{OC} I_{SC} FF$$

$$\eta = \frac{V_{OC} I_{SC} FF}{P_{in}}$$

Where:

V_{oc} =open-circuit voltage;
I_{sc} =short-circuit current;
FF = fill factor and;
η= the efficiency;
Pmax = Maximum Power and
Pin = Input Power

Fill factor use to determine the maximum power of the solar cell. It is defined as the ratio of the maximum power from the solar cell to the product of V_{oc} and I_{sc}.

$$FF = \frac{Imp.Vmp}{Isc.Vsc}$$

I-V Characteristics (Designed and Commercial):

I-V curve is given below where first two figure is for 18 watt on a sunny day and a gloomy day. The other two figure is for 24 watt on a sunny day and a gloomy day respectively.

We calculated Fill Factor and efficiency of designed and commercial Solar Charge Controller.

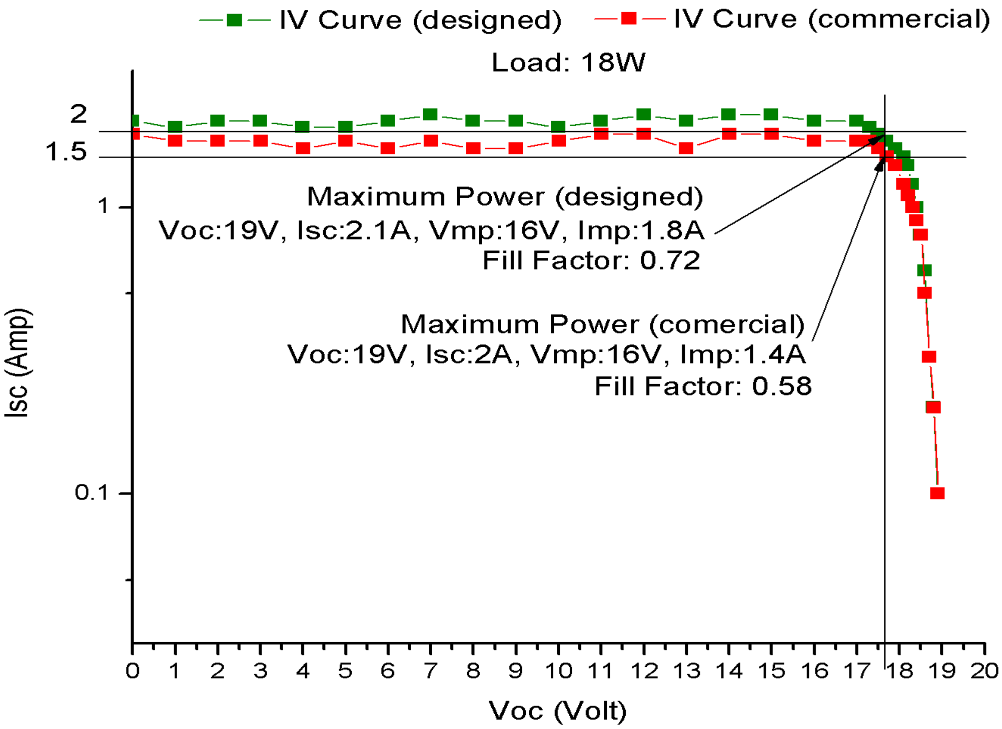


Figure 6: I-V Characteristic for 18 watt

Day 1 (18 watt)

Designed:

$$FF = \frac{Imp.Vmp}{Isc.Voc} = \frac{1.8A \times 16V}{2.1A \times 19V} = 0.72$$

$$\eta = \frac{VocIocFF}{Pin} \times 100\% = \frac{19V \times 2.1A \times 0.72}{100} \times 100\% = 28.73\ \%$$

Commercial:

$$FF = \frac{Imp.Vmp}{Isc.Voc} = \frac{1.4A \times 16V}{2A \times 19V} = 0.58$$

$$\eta = \frac{Voc.Ioc.FF}{Pin} \times 100\% = \frac{19V \times 2A \times 0.58}{100} \times 100\% = 22.04\ \%$$

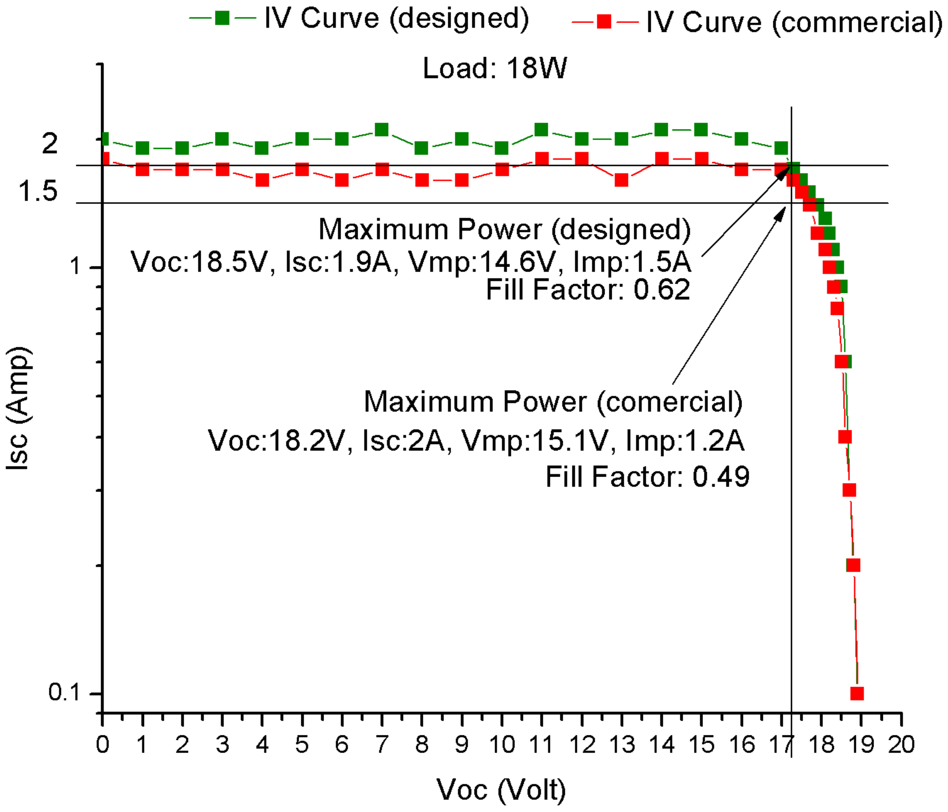


Figure 7: I-V Characteristic for 18 watt (Gloomy Day)

Day 5 (18 watt)

Designed:

$$FF = \frac{Imp.Vmp}{Isc.Voc} = \frac{1.5A \times 14.6V}{1.9A \times 18.5V} = 0.62$$

$$\eta = \frac{Voc.Ioc.FF}{Pin} \times 100\% = \frac{18.5V \times 1.9A \times 0.62}{100} \times 100\% = 21.79\ \%$$

Commercial:

$$FF = \frac{Imp.Vmp}{Isc.Voc} = \frac{1.2A \times 15.1V}{2A \times 18.2V} = 0.49$$

$$\eta = \frac{Voc.Ioc.FF}{Pin} \times 100\% \;=\; \frac{18.2V \;\times 2A \;\times 0.49}{100} \times 100\% \;= 17.84\ \%$$

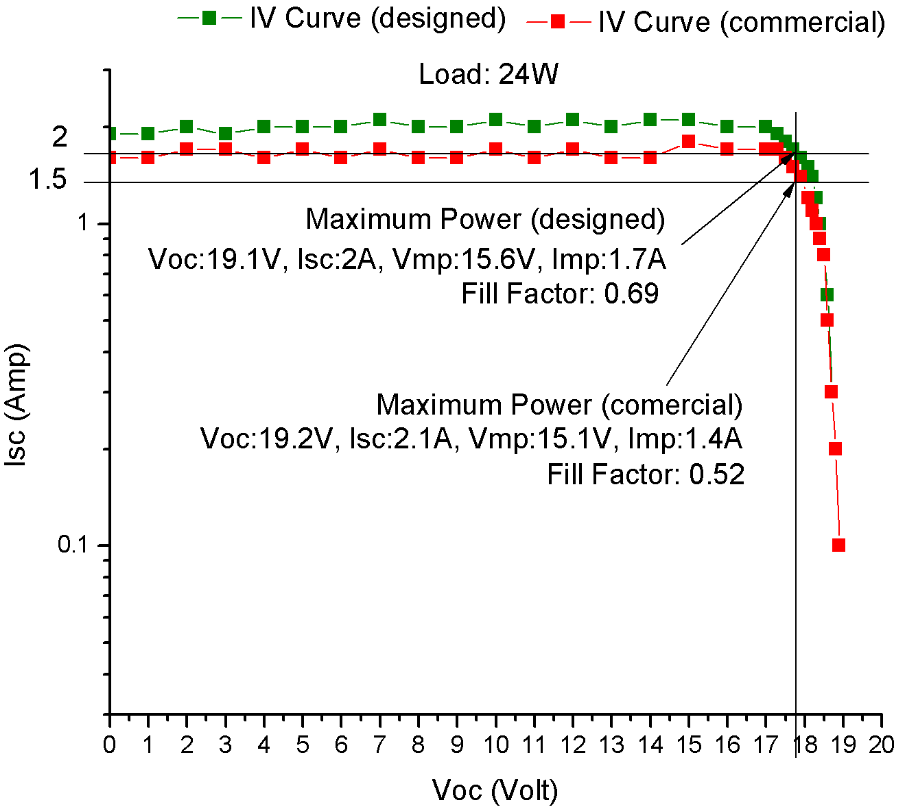


Figure 8: I-V Characteristic for 24 watt (sunny day)

Day 2 (24 Watt)

Designed:

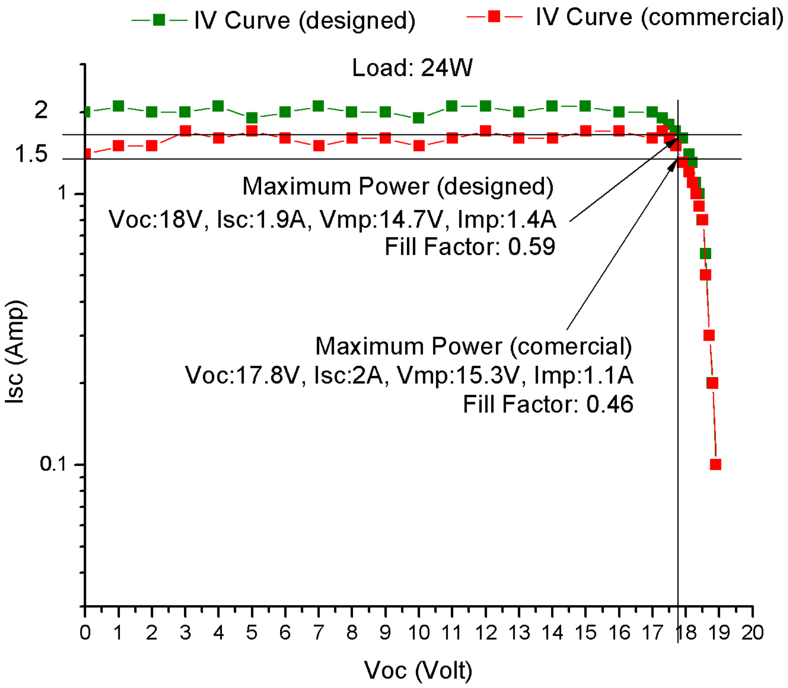
$$FF = \frac{Imp.Vmp}{Isc.Voc} \;=\; \frac{1.7A \;\times 15.6V}{2A \;\times\; 19.1V} \;= 0.69$$

$$\eta = \frac{Voc.Ioc.FF}{Pin} \times 100\% \;=\; \frac{19.1V \;\times 2A \;\times 0.69}{100} \times 100\% \;= 26.36\ \%$$

Commercial:

$$FF = \frac{Imp.Vmp}{Isc.Voc} \;=\; \frac{1.4A \;\times 15.1V}{2.1A \;\times\; 19.2V} \;= 0.52$$

$$\eta = \frac{Voc.Ioc.FF}{Pin} \times 100\% \quad = \quad \frac{19.2V \ \times 2.1A \ \times 0.52}{100} \times 100\% \ = 20.97\ \%$$



Maximum Power (designed)
Voc:18V, Isc:1.9A, Vmp:14.7V, Imp:1.4A
Fill Factor: 0.59

Maximum Power (comercial)
Voc:17.8V, Isc:2A, Vmp:15.3V, Imp:1.1A
Fill Factor: 0.46

Figure 9: I-V Characteristic for 24 watt (gloomy day)

Day 3 (24 watt)

Designed:

$$FF = \frac{Imp.Vmp}{Isc.Voc} \quad = \quad \frac{1.4A \ \times 14.7V}{1.9A \ \times \ 18V} \ = 0.59$$

$$\eta = \frac{Voc.Ioc.FF}{Pin} \times 100\% \quad = \quad \frac{18V \ \times 1.9A \ \times 0.59}{100} \times 100\% \ = 20.18\ \%$$

Commercial:

$$FF = \frac{Imp.Vmp}{Isc.Voc} \quad = \quad \frac{1.1A \ \times 15.3V}{2A \ \times \ 17.8V} \ = 0.46$$

$$\eta = \frac{Voc.Ioc.FF}{Pin} \times 100\% \quad = \frac{17.8V \ \times 2A \ \times 0.46}{100} \times 100\% \ = 16.38\ \%$$

CHAPTER 8

Comparison

8.1 Designed and Commercial Comparison:

- Our efficiency is better than the commercial charge controller.
- Our controller can charge battery faster than commercial controller.
- Though our costing is little bit high than commercial controller, our user get better output than the commercial one which reduces cost for the long turm using.

CHAPTER 9

Limitations

- Practically our efficiency should come 30w to 34w but we did not get that because of our components. Our components are not ideal and for that we did not get our desired output.
- If panel voltage is less than 11V, it will not work that much.
- Our main focusing point was to increase efficiency. To increase efficiency, our costing becomes slightly low.

CHAPTER 10

Future Works

We will reduces those limitations from our controller and we have a plan to develop an android apps which will provide battery panel , solar panels charges as well as their conditions and it will provide historical data about yearly most efficient times for charging.

Chapter 11

Conclusion

We want to track the maximum power point by using PWM charge controller. We use microcontroller for construction the circuit. Microcontroller make it more efficient.

Boundaries of the Current Job

Though the present charge controller can charge the battery, it has many restrictions.

1. Current overflow occurred many times
2. It also faced burnout.
3. Firstly the PCB is not so efficient.

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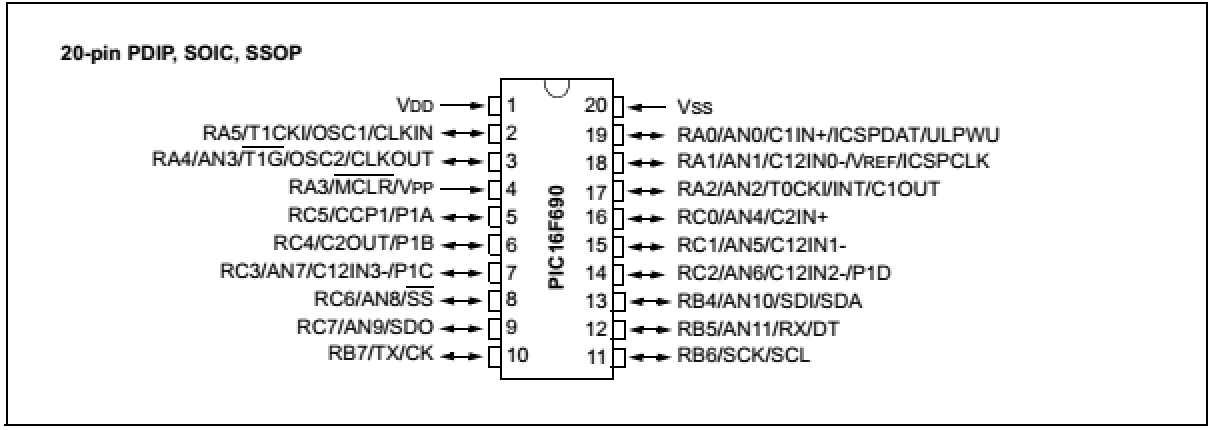
APPENDICES

PIC16F690 Microcontroller:

PIC16F690 Pin Diagram (PDIP, SOIC, SSOP)



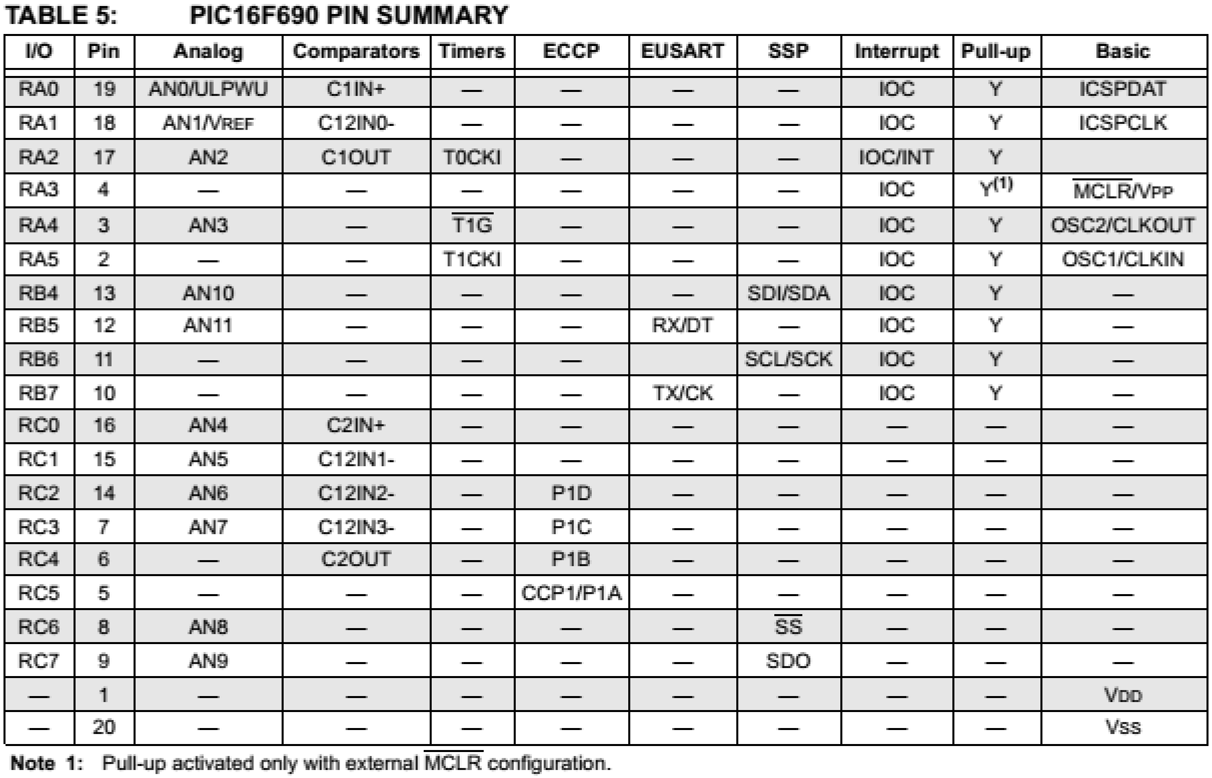


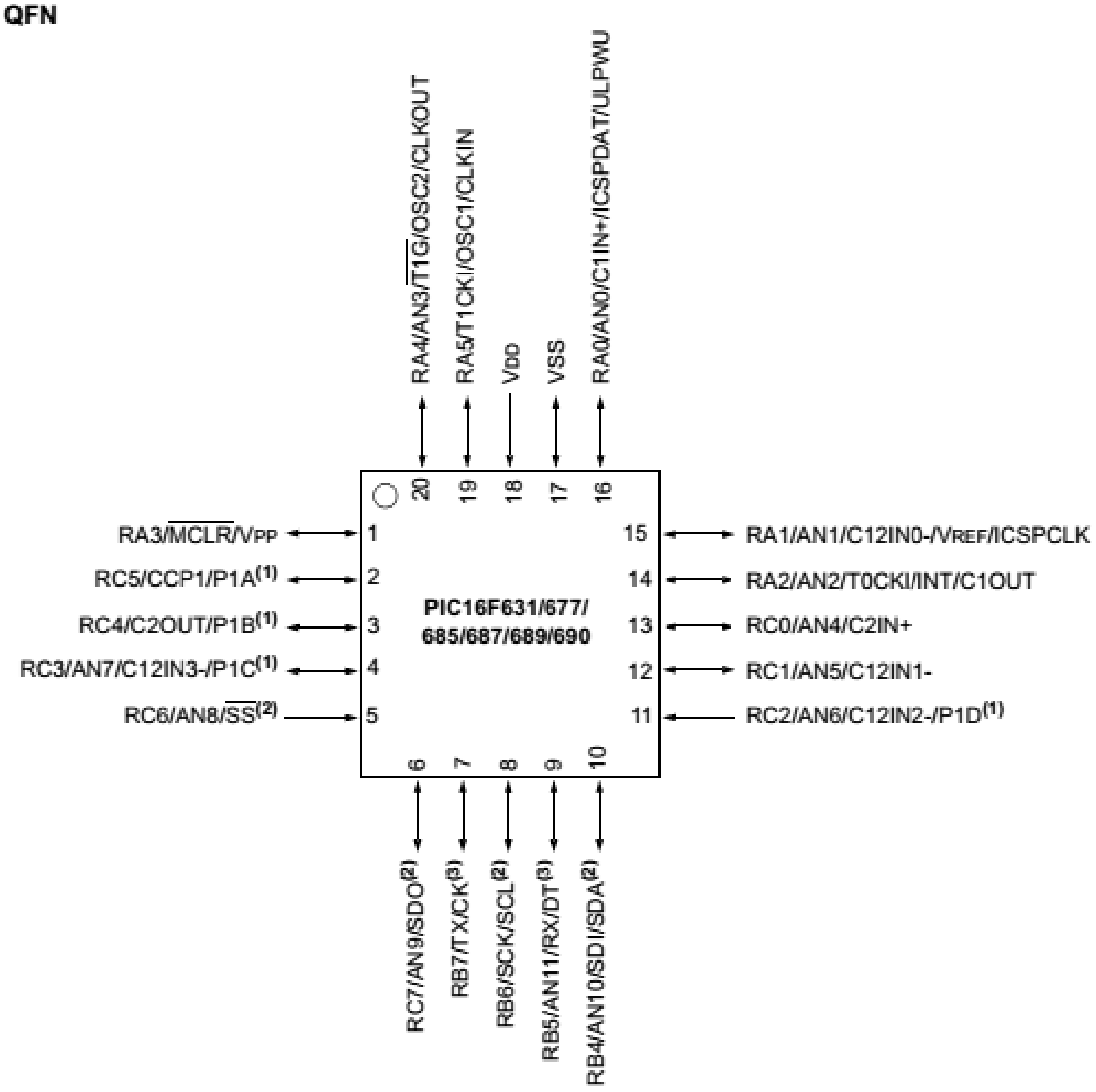
TABLE 5: PIC16F690 PIN SUMMARY

I/O	Pin	Analog	Comparators	Timers	ECCP	EUSART	SSP	Interrupt	Pull-up	Basic
RA0	19	AN0/ULPWU	C1IN+	—	—	—	—	IOC	Y	ICSPDAT
RA1	18	AN1/VREF	C12IN0-	—	—	—	—	IOC	Y	ICSPCLK
RA2	17	AN2	C1OUT	T0CKI	—	—	—	IOC/INT	Y	
RA3	4	—	—	—	—	—	—	IOC	Y[(1)]	$\overline{MCLR}$/VPP
RA4	3	AN3	—	$\overline{T1G}$	—	—	—	IOC	Y	OSC2/CLKOUT
RA5	2	—	—	T1CKI	—	—	—	IOC	Y	OSC1/CLKIN
RB4	13	AN10	—	—	—	—	SDI/SDA	IOC	Y	—
RB5	12	AN11	—	—	—	RX/DT	—	IOC	Y	—
RB6	11	—	—	—	—		SCL/SCK	IOC	Y	—
RB7	10	—	—	—	—	TX/CK	—	IOC	Y	—
RC0	16	AN4	C2IN+	—	—	—	—	—	—	—
RC1	15	AN5	C12IN1-	—	—	—	—	—	—	—
RC2	14	AN6	C12IN2-	—	P1D	—	—	—	—	—
RC3	7	AN7	C12IN3-	—	P1C	—	—	—	—	—
RC4	6	—	C2OUT	—	P1B	—	—	—	—	—
RC5	5	—	—	—	CCP1/P1A	—	—	—	—	—
RC6	8	AN8	—	—	—	—	$\overline{SS}$	—	—	—
RC7	9	AN9	—	—	—	—	SDO	—	—	—
—	1	—	—	—	—	—	—	—	—	VDD
—	20	—	—	—	—	—	—	—	—	VSS

Note 1: Pull-up activated only with external $\overline{MCLR}$ configuration.

PIC16F690 Pin Diagram (QFN)

20-pin QFN



Note 1: CCP1/P1A, P1B, P1C and P1D are available on PIC16F685/PIC16F690 only.

2: SS, SDO, SDI/SDA and SCL/SCK are available on PIC16F677/PIC16F687/PIC16F689/PIC16F690 only.

3: RX/DT and TX/CK are available on PIC16F687/PIC16F689/PIC16F690 only.

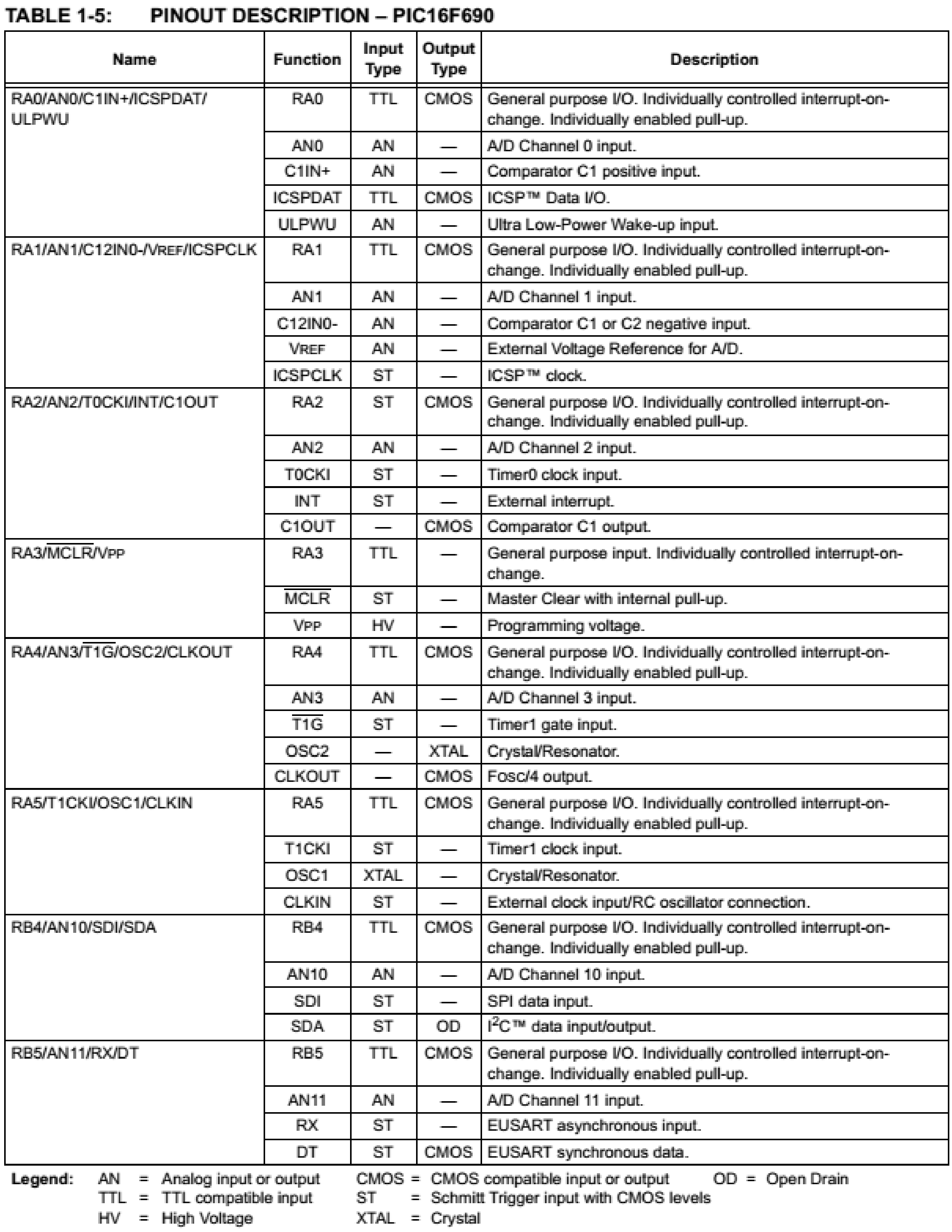


TABLE 1-5: PINOUT DESCRIPTION – PIC16F690

Name	Function	Input Type	Output Type	Description
RA0/AN0/C1IN+/ICSPDAT/ ULPWU	RA0	TTL	CMOS	General purpose I/O. Individually controlled interrupt-on-change. Individually enabled pull-up.
	AN0	AN	—	A/D Channel 0 input.
	C1IN+	AN	—	Comparator C1 positive input.
	ICSPDAT	TTL	CMOS	ICSP™ Data I/O.
	ULPWU	AN	—	Ultra Low-Power Wake-up input.
RA1/AN1/C12IN0-/VREF/ICSPCLK	RA1	TTL	CMOS	General purpose I/O. Individually controlled interrupt-on-change. Individually enabled pull-up.
	AN1	AN	—	A/D Channel 1 input.
	C12IN0-	AN	—	Comparator C1 or C2 negative input.
	VREF	AN	—	External Voltage Reference for A/D.
	ICSPCLK	ST	—	ICSP™ clock.
RA2/AN2/T0CKI/INT/C1OUT	RA2	ST	CMOS	General purpose I/O. Individually controlled interrupt-on-change. Individually enabled pull-up.
	AN2	AN	—	A/D Channel 2 input.
	T0CKI	ST	—	Timer0 clock input.
	INT	ST	—	External interrupt.
	C1OUT	—	CMOS	Comparator C1 output.
RA3/$\overline{\text{MCLR}}$/VPP	RA3	TTL	—	General purpose input. Individually controlled interrupt-on-change.
	$\overline{\text{MCLR}}$	ST	—	Master Clear with internal pull-up.
	VPP	HV	—	Programming voltage.
RA4/AN3/$\overline{\text{T1G}}$/OSC2/CLKOUT	RA4	TTL	CMOS	General purpose I/O. Individually controlled interrupt-on-change. Individually enabled pull-up.
	AN3	AN	—	A/D Channel 3 input.
	$\overline{\text{T1G}}$	ST	—	Timer1 gate input.
	OSC2	—	XTAL	Crystal/Resonator.
	CLKOUT	—	CMOS	Fosc/4 output.
RA5/T1CKI/OSC1/CLKIN	RA5	TTL	CMOS	General purpose I/O. Individually controlled interrupt-on-change. Individually enabled pull-up.
	T1CKI	ST	—	Timer1 clock input.
	OSC1	XTAL	—	Crystal/Resonator.
	CLKIN	ST	—	External clock input/RC oscillator connection.
RB4/AN10/SDI/SDA	RB4	TTL	CMOS	General purpose I/O. Individually controlled interrupt-on-change. Individually enabled pull-up.
	AN10	AN	—	A/D Channel 10 input.
	SDI	ST	—	SPI data input.
	SDA	ST	OD	I^2C™ data input/output.
RB5/AN11/RX/DT	RB5	TTL	CMOS	General purpose I/O. Individually controlled interrupt-on-change. Individually enabled pull-up.
	AN11	AN	—	A/D Channel 11 input.
	RX	ST	—	EUSART asynchronous input.
	DT	ST	CMOS	EUSART synchronous data.

Legend:
AN = Analog input or output
TTL = TTL compatible input
HV = High Voltage
CMOS = CMOS compatible input or output
ST = Schmitt Trigger input with CMOS levels
XTAL = Crystal
OD = Open Drain

TABLE 1-5: PINOUT DESCRIPTION – PIC16F690 (CONTINUED)

Name	Function	Input Type	Output Type	Description
RB6/SCK/SCL	RB6	TTL	CMOS	General purpose I/O. Individually controlled interrupt-on-change. Individually enabled pull-up.
	SCK	ST	CMOS	SPI clock.
	SCL	ST	OD	I^{2}C™ clock.
RB7/TX/CK	RB7	TTL	CMOS	General purpose I/O. Individually controlled interrupt-on-change. Individually enabled pull-up.
	TX	—	CMOS	EUSART asynchronous output.
	CK	ST	CMOS	EUSART synchronous clock.
RC0/AN4/C2IN+	RC0	ST	CMOS	General purpose I/O.
	AN4	AN	—	A/D Channel 4 input.
	C2IN+	AN	—	Comparator C2 positive input.
RC1/AN5/C12IN1-	RC1	ST	CMOS	General purpose I/O.
	AN5	AN	—	A/D Channel 5 input.
	C12IN1-	AN	—	Comparator C1 or C2 negative input.
RC2/AN6/C12IN2-/P1D	RC2	ST	CMOS	General purpose I/O.
	AN6	AN	—	A/D Channel 6 input.
	C12IN2-	AN	—	Comparator C1 or C2 negative input.
	P1D	—	CMOS	PWM output.
RC3/AN7/C12IN3-/P1C	RC3	ST	CMOS	General purpose I/O.
	AN7	AN	—	A/D Channel 7 input.
	C12IN3-	AN	—	Comparator C1 or C2 negative input.
	P1C	—	CMOS	PWM output.
RC4/C2OUT/P1B	RC4	ST	CMOS	General purpose I/O.
	C2OUT	—	CMOS	Comparator C2 output.
	P1B	—	CMOS	PWM output.
RC5/CCP1/P1A	RC5	ST	CMOS	General purpose I/O.
	CCP1	ST	CMOS	Capture/Compare input.
	P1A	ST	CMOS	PWM output.
RC6/AN8/$\overline{\text{SS}}$	RC6	ST	CMOS	General purpose I/O.
	AN8	AN	—	A/D Channel 8 input.
	$\overline{\text{SS}}$	ST	—	Slave Select input.
RC7/AN9/SDO	RC7	ST	CMOS	General purpose I/O.
	AN9	AN	—	A/D Channel 9 input.
	SDO	—	CMOS	SPI data output.
VSS	VSS	Power	—	Ground reference.
VDD	VDD	Power	—	Positive supply.

Legend: AN = Analog input or output CMOS = CMOS compatible input or output OD = Open Drain
TTL = TTL compatible input ST = Schmitt Trigger input with CMOS levels
HV = High Voltage XTAL = Crystal

PIC16F690 BLOCK DIAGRAM