



**UNIVERSITI TEKNIKAL MALAYSIA MELAKA (UTeM)**

**MOTOR CONTROLLER FOR  
SOLAR ENERGY OPTIMUM ACQUISITION**

Thesis submitted in accordance with the partial requirements of the  
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Bachelor of Manufacturing Engineering (Robotic and Automation)

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## **ABSTRACT**

This project presents the design and implementation of a prototyped for motor controller for solar energy optimum acquisition. This prototype can be divided into two major parts: the mechanical parts and electrical parts. Mechanical parts consist of bearings, motor shaft, vertical tower, holding block and base plate. The electrical parts include the charge controller, battery, photovoltaic panel, logic comparator and other electrical components. The combination of both mechanical and electrical parts is known as Balance-of-System. There are four modules in this design, which are sensor module, logic comparator module, signal output module and battery charging module. The photo sensor in the sensor module use to detect the light source and the signal will send to logic comparator module to examine the light condition. And the signal output module analyses the signal to rotate the solar panel. Lastly, the battery-charging module will activate as soon as the light hits on the panel. Two relays used in this system with each relay control only one direction for the motor rotation besides used to regulate the flow rate of electricity from the photovoltaic module to the battery and the load. From this initiative, simple power generation via photovoltaic technology can be utilized. With environment in mind, this small step will be significant milestone for the gradual change towards renewable energy resources.

# CHAPTER 1

## INTRODUCTION

### 1.1 Background

The increasing global warming, the emission of gases that harm the environment and shortage of fossils are some of the issues, which are raised by the government and the World Wide Greenpeace. The shortage of fossils causes the oil price to increase and therefore add up the burden for the consumer. The thinning ozone layers due to harmful gases emission from the factories and the fuel burning; the dilution of glacier due to global warming will increase the sea level and floods to country like Bangladesh and India. Beside that, the fuel shortage and increasing of electricity bill bring affect to the developer and manufacturer. Both of these factors will increase the production cost and also the transportation cost. Therefore it will end up with the costly product and consumer can afford to buy it.

Realizing these crises will hinder the development and progress of a nation, there are many drastic actions and planning taken by the politician and researchers to overcome this problem. One of the solutions is seek for alternative energy for the future consumption. Among the many types of renewable energies, solar energy is considered promising as it is comparatively more evenly distributed geographically.

A branch of solar energy research that has received worldwide attention is photovoltaic. Solar technology has advanced rapidly in recent years as a direct benefit from the current development and advancement made in IC technology. Photovoltaic has shown its potential in cost reduction and better conversion efficiency. It is believed that photovoltaic system will become the primary future energy supplier.

Photovoltaic comprises the technology to convert sunlight directly into electricity. The term “photo” means light and “voltaic,” electricity. A photovoltaic cell, also known as “solar cell,” is a semiconductor device that generates electricity when light falls on it (Mah, 1998).

## **1.2 Problem Statement**

The current problem faced in the photovoltaic system is that solar energy supplied may not always be sufficient to power the embedded system. Solar panels and energy storage elements, such as batteries have different voltage-current characteristics, which must be matched to each other as well as the energy requirements of the system to maximize harvesting efficiency. Furthermore, battery non-idealities such as self-discharge and round-trip efficiency, directly affect energy usage and storage decisions. The ability of the system to modulate its power consumption by selectively deactivating its sub-components also impacts the overall power management architecture. Beside that, most of the solar panel system is static and cannot rotate and therefore cannot obtain optimum acquisition from the sun. This is because the solar panel is fixed at one location therefore it cannot track and aligned toward the sun movement and direction. And for most the designs which is rotate-able, it is not able to get optimum energy from the sun, meaning the system just collect the sun energy without comparing which direction can collect highest data.

Therefore, based on the problems that have been highlighted, a new design is essential to overcome the problems.

### **1.3 Scope**

The scope of the project is to make a prototype of a solar energy harvester that is capable to convert optimum solar energy from the sun using photovoltaic panel. This project will focus on the efficiency of the photovoltaic panel, which is controlled by the direct current (DC) motor. The logic comparator will remotely control this motor controller so that the photovoltaic will act as a sun tracker. A comparator will be used to compare the voltage so that when there is any changes in the voltage gain from the photovoltaic panel, the direct current motor will rotate the photovoltaic panel and align it to the direction of the sun, and stop the photovoltaic panel at the position where the comparator succeed in comparing and locating the direction with the highest value of sunlight. This process will repeat whenever this value is changing.

### **1.4 Objectives**

The aim of this project is to design and implement a motor controller for a photovoltaic system in order to get optimum acquisition of solar energy. Throughout this project, the following objectives will be achieved:

- a) To design a photovoltaic system that is controlled by a motor controller and always aligned towards the direction of the sun.
- b) To design a photovoltaic system that is able to gain optimum solar energy acquisition.

## **1.5 A Brief History of Solar Energy**

As we know, Malaysia is a sunshine country and it has abundant supply of solar power. Therefore we should make use of this natural energy and apply it to our daily life. There are many ways we can use to produce solar energy nowadays. The sun that is the main source for solar energy provides electricity which can be applied in our daily life. The energy gained from the sun can be used at homes, businesses, and industries. The solar energy (electricity) is produced when photons (particles of light) strike the surface of a photovoltaic panel. The electricity produced from the solar panel will be saved into a battery for further application.

Photovoltaic solar power is one of the most promising renewable energy sources in the world. This is because solar energy is environmental friendly and it does not require much maintenance. Solar energy does not cause pollution either air pollution or sound pollution. A very important characteristic of photovoltaic power generation is that it does not require a large-scale installation to operate, as different from conventional power generation stations. Power generators can be installed at anywhere using area that is already developed, and allowing individual users to generate their own power, quietly and safely (Smith, 1995).

Since hundreds of years ago, the ancient Greeks and Romans had been using the sun's capacity to light and heat indoor spaces. The Greek philosopher Socrates wrote, "In houses that look toward the south, the sun penetrates the portico in winter." With these sentences, the Romans advanced the art by covering south facing building openings with glass or mica to hold in the heat of the winter sun (Southface, 2005).

Auguste Mouchout did the inventor of the first active solar motor. Seeing the fossil fuels powering the Industrial Revolution in the 19th century, he knew that the coal will undoubtedly be used up one day and the industry will no longer find in Europe due to the fast growing and prodigious expansion of the industry. Worry that the industry will gone due to the short of fossil fuels, Mouchout developed a steam

engine powered entirely by the sun in 1861. But its high costs coupled with the falling price of English coal doomed his invention to become a footnote in energy history (Southface, 2005).

Nevertheless, solar energy continued to intrigue and attract European scientists through the 19th century. Scientists developed large cone-shaped collectors that could boil ammonia to perform work like locomotion and refrigeration. In the United States, Swedish-born John Ericsson managed to design the “parabolic trough collector,” a technology which functions more than a hundred years later on the same basic design. Ericsson is best known for having conceived the USS Monitor, the armored ship integral to the U.S. Civil War (Smith, 1995).

Albert Einstein was awarded the 1921 Nobel Prize in physics for his research on the photoelectric effect—a phenomenon central to the generation of electricity through solar cells. Due to this award, it boost backed the solar power research even though interest in a solar-powered civilization almost gone in the early 20<sup>th</sup> century. After some years, William Grylls Adams had discovered that when light was shined upon selenium, the material shed electrons, thereby creating electricity.

In 1953, Bell Laboratories scientists Gerald Pearson, Daryl Chapin and Calvin Fuller developed the first silicon solar cell that capable of generating a measurable electric current. The New York Times reported the discovery as “the beginning of a new era, leading eventually to the realization of harnessing the almost limitless energy of the sun for the uses of civilization.”

In 1956, solar photovoltaic cells were far from economically practical. The “Space Race” of the 1950s and 60s gave modest opportunity for progress in solar, as satellites and crafts used solar paneling for electricity.

The hope in the 1970s was that through massive investment in subsidies and research, solar photovoltaic costs could drop precipitously and eventually becomes

competitive with fossil fuels. By the 1990s, the reality was that costs of solar energy had dropped as predicted, but costs of fossil fuels had also dropped.

However, huge photovoltaic market growth in Japan and Germany from the 1990s to the present has reenergized the solar industry. In 2002 Japan installed 25,000 solar rooftops. Such large PV orders are creating economies of scale, thus steadily lowering costs. Meanwhile, solar thermal water heating is an increasingly cost-effective means of lowering gas and electricity demand. From here we can see that technologies have changed and improved for decades. Still, the basics of solar thermal and photovoltaic have remained the same (Southface, 2005).

## **CHAPTER 2**

### **LITERATURE REVIEW**

#### **2.1 Photovoltaic System**

A photovoltaic panel is not able to convert the solar energy to electricity by itself. It needs to connect with other components so that it can start to collect the solar energy from the sun and then convert it to electricity for others application (Treble,1991). The basic components needed in a photovoltaic system are divided into three categories:

- a) Structure and installation
- b) Power conditioning and control system
- c) Storage batteries

For structure and installation categories, the components will include photovoltaic panel, comparator, mechanical part and all the part needed to complete the design structure. And for the power conditioning and control systems, it is more on electrical devices such as microcontroller, PCB board, wires, relay and so on. Lastly, for the storage batteries, battery is used for storing the converted solar energy gained from the photovoltaic system. This electricity will store in the battery for further application (Charles Smith,1995). The components of a balance-of-system will be discussed in depth in this chapter.

## **2.2 The Photovoltaic Panel**

There are many types of photovoltaic panels in the market, but this photovoltaic system can be categorized into three major types; which are the stand-alone, utility-interactive system and bi-modal systems. The first operate independent of the utility grid and includes hybrid systems. The second is connected to the grid while the third has an ability to function like the first two but not simultaneously, in a book by author Jenny Nelson in year 2003, entitled “The Physics of Solar Cell”.

In other definition given by Richard D. Dorf, Editor-In-Chef of “The Engineering Handbook”, solar power system are usually classified by technology- solar thermal and photovoltaic systems principal types. Photovoltaic usually use the energy in sunlight directly to produce electricity; in solar thermal power systems, the sun heats the transfer medium such oil.

A photovoltaic system consists of solar cell electrically connected to each other in support structure to form a module. Modules are designed to supply electricity at the certain voltage, at 12 Volts. The current produced is directly dependent on how much light strikes the module. In general, larger area of a module or array will produce more electricity. Photovoltaic modules and array can be connected in both series and parallel to produce any required voltage and current. A solar photovoltaic energy conversion is a one step conversion progress which generates electrical energy from light energy. The effectiveness of a photovoltaic device depends upon the choice of light absorbing materials and the way in which they are connected to the external circuit (Dorf et al, 1996).

### **2.2.1 Cell Types**

Two major types of photovoltaic (PV) systems are available in the marketplace today, which is flat plate and concentrators. Flat plate systems build the PV modules on a rigid and flat surface to capture sunlight while concentrator systems use lenses to concentrate sunlight on the PV cells and increase the cell power output. If we compare both systems, flat plate systems are less complicated but employ a larger number of cells while the concentrator systems use smaller areas of cells but require more sophisticated and expensive tracking systems. Concentrator systems do not work under cloudy conditions because it unable to focus diffuses sunlight. The efficiency of commercial devices is usually around 15%. (Mah, 1998)

PV cells are made of semiconductor materials. The major types of materials are crystalline and thin films, which vary from each other in terms of light absorption efficiency, energy conversion efficiency, manufacturing technology and cost of production. In this section we will discuss the characteristics, advantages and limitations of these two major types of cell materials (Garg & Prakash, 1997).

#### **2.2.1.1 Crystalline Materials**

##### **a) Single-Crystal silicon**

Single-crystal silicon cells are the most common in the photovoltaic industry. The main technique for producing single-crystal silicon is the Czochralski (CZ) method. High-purity polycrystalline is melted in a quartz crucible. A single-crystal silicon seed is dipped into this molten mass of polycrystalline. As the seed is pulled slowly from the melt, a single-crystal ingot is formed. The ingots are then sawed into thin wafers about 200-400 micrometers thick. The thin wafers are then polished, doped, coated, interconnected and

assembled into modules and arrays. Single-crystal silicon has a uniform molecular structure.

Compared to non-crystalline materials, its high uniformity results in higher energy conversion efficiency where the ratio of electric power produced by the cell to the amount of available sunlight power. The conversion efficiency for single-silicon commercial modules ranges between 15-20%. Not only are they energy efficient, single-silicon modules are highly reliable for outdoor power applications (Adolf et al, 1998).

About half of the manufacturing cost comes from wafering, a time-consuming and costly batch process in which ingots are cut into thin wafers with a thickness no less than 200 micrometers thick. If the wafers are too thin, the entire wafer will break in wafering and subsequent processing (Mah, 1998).

## **b) Polycrystalline silicon**

To reduce the cost, these cells are now often made from multi or polycrystalline silicon. As opposed to extracting a single crystal from silicon bath, these cells are formed by pouring hot, liquid silicon into molds or casts. Once cooled, and hardened, the silicon blocks are sliced in a similar fashion to the single crystal described above.

Compare to single crystalline cells, polycrystalline cells are less expensive to produce because their manufacturing process does not require many careful hours of rotating silicon material, less strict growth requirements and sawing process is not needed

The energy conversion for the polycrystalline is between 10 to 14% and is less than single crystalline cells. This is because of the grain boundaries in the structure hinder the flow of electrons and reduce the power output of cell.

However polycrystalline silicon material is stronger and can be cut into one-third the thickness of single-crystal silicon material (Boyle & Godfrey, 1996).

### **c) Gallium Arsenide (GaAs)**

This photovoltaic panel is made from a mixture of two elements: gallium (Ga) and arsenic (As). GaAs has a crystal structure similar to silicon. An advantage of GaAs is that it has high level of light absorptivity. To absorb the same amount of sunlight, GaAs requires only a layer of few micrometers thick while crystalline silicon requires a wafer of about 200-300 micrometers thick. Also, GaAs has much higher energy conversion efficiency than crystal silicon, reaching about 25 to 30%.

GaAs mostly apply in space applications due to its strong resistance radiation damage and high cell efficiency. The biggest drawback of GaAs PV cells is the high cost of the single-crystal substrate that GaAs is grown on. Therefore it is most often used in concentrator systems where only a small area of GaAs cells is needed and the prices are rather expensive (Boyle & Godfrey, 1996).

#### **2.2.1.2 Thin Film Materials**

In a thin-film PV cell, a thin semiconductor layer of PV materials is deposited on low-cost supporting layer such as glass, metal or plastic foil. Since thin-film materials have higher light absorption ability than crystalline materials, the deposited layer of PV materials is extremely thin. Thinner layers of material yield significant cost saving. Also, the deposition techniques in which PV materials are sprayed directly onto glass or metal substrate are cheaper. Therefore the manufacturing process is faster, using up less energy and mass production can be made. However, the energy conversion efficiency for a thin film PV cells are low due to non-single crystal structure. Therefore it required larger array areas and increasing area-related costs such as mountings (Zweibel & Ken, 1995).

### **a) Amorphous Silicon (A-Si)**

Amorphous silicon cells (A-Si), a type of thin film technology, are already used in many PV modules. Amorphous silicon cells are composed of randomly arranged atoms, having no predictable crystal structure. A significant advantage of A-Si is its high light absorptivity, about 40 times higher than that of single-crystal silicon. Therefore only a thin layer of A-Si is sufficient for making PV cells. Also, A-Si can be deposited on various low-cost substrates, including steel, glass and plastic, and the manufacturing process requires lower temperatures and thus less energy, making it less expensive to produce.

Despite the promising economic advantages, A-Si still has two major roadblocks to overcome. One is the low cell energy conversion efficiency, ranging between 5-9% due to lacks ordered structure and inherent photovoltaic properties of crystalline silicon and the other is the outdoor reliability problem in which the efficiency degrades within a few months of exposure to sunlight, losing about 10 to 15%.

### **b) Cadmium Telluride (CdTe)**

Cadmium telluride (CdTe) is a very promising material for thin film solar cells. It can either be p-type or n-type, has a high absorption coefficient and bears good electrical transport properties. Theoretical, CdTe cells have maximum efficiency close to 25%. Practically, efficiencies approaching 15 % have been achieved in laboratory while module efficiencies register approximately 10%. (Zweibel & Ken, 1995).

### **c) Copper Indium Diselenide (CuInSe<sub>2</sub>, or CIS)**

Copper indium diselenide (CIS) is chosen as PV substances due to its high absorption coefficient and potentially in expensive preparation. Thin films of CIS were introduced in 1970's and the combined with cadmium sulphide (CdS) film to form solar cell. This PV type is very promising because the materials used are neither toxic nor difficult to obtain, with the exception of indium. Because of this insufficiency, large scale productions are not quite possible. CIS layers can be produced by different techniques, one common method being the thermal evaporation of each element simultaneously onto common substrate, which yields the high efficiency. Unlike the A-Si cells, the CIS cells have good long term outdoor reliability, which efficiencies from 7% to 10% (Zweibel & Ken, 1995).

#### **2.2.1.3 Organic Materials**

Beside that, there are alternative way to replace the current semiconductor photovoltaic which is using organic photovoltaic (PV) composed of carbon-based dyes and polymers. The reason of using organic photovoltaic is because the materials used is light, bend without breaking, and are showing rapidly improving efficiencies. Although their ability to convert photons into electricity must improve, the vision of solar plastics is moving rapidly toward realization. The main component of the organic material is using Gratzel cells, a form of organic PV. Gratzel cells mimic photosynthesis: light-sensitive organic dyes dissolved in an electrolyte absorb light and transfer energized electrons to titania nanocrystals sintered to an electrode-coated substrate (Konarka, 2004).

Table 2.1 Criteria for Choice of material for PV cells (Garg & Prakash,1997)

Property	Criteria
Band gap of smaller band-gap material	Band gap near 1.4eV to maximize absorption of solar radiation, while minimizing diode current that limits Voc, direct optical absorption so that carriers re generated close to the junction. Long minority-carrier diffusion length.
Band gap of larger band-gap material	As large as possible while material maintaining low series resistance.
Conductivity types	Smaller band gap material should usually be p-type because of longer electron diffusion length.
Electron affinities	Material should be chosen so that no potential spike occurs at the junction for the minority photo excited carriers.
Diffusion voltage	As large as possible since the maximum value Voc is proportional to the diffusion voltage.
Lattice mismatch	As little mismatch in lattice constant between the two materials as possible
Deposition methods	Suitable deposition method for thin-film formation and control should be available.
Material availability	Supplies of the material should be sufficient to allow large-area cell production.
Material cost	Cost of the material should be competitive with alternative systems.
Material toxicity	Material should be nontoxic, or control of the toxicity should be possible
Cell stability and lifetime	Cell must have an operating life time sufficient to pay back economic and energy costs required to produce it.
Electrical contacts	It should be possible to form low-resistance electrical contacts to both n-and p-type materials.

### 2.2.2 How Does Solar Cells Work

In a photovoltaic cell, there are two layers of silicon. Both are doped or lightly mixed with a certain element. Typically, one side is doped with boron and the other with arsenic. Because of the way each element bonds to the silicon, the layer containing boron, called the *n-type layer*, has a surplus of free electrons. The other side, the *p-type layer*, has a deficit of electrons. These deficits are called *holes*. The p-type layer and n-type layer are pressed closely against each other and linked by a wire connected to an external load. This creates a circuit in the solar cell (Anissimov, 2006).

When sunlight of the right energy level hits the n-type layer, which is on top of the solar cell, it excites some of the free electrons, which break loose from their natural state and flow across the boundary between the layers to create a current. Normally both layers are pressed directly with each other's so that current flows through the p-layer into the wire and flow to the load. Normally the current produce is DC current, therefore an inverter needed to convert the DC current to AC current for household appliances. After flowing through the load, the current continues back into the n-layer, which is lacking in electrons in some areas due to the current. A current is generated without any mechanical input (Garg & Prakash,1997).

For protection, the top layer of the solar cell is covered with a glass plate affixed with transparent resin. The entire setup is called a series of p-n junction diode (Anissimov, 2006).

The material used to make a PV can be grouped into 3 categories, which are conductor, insulator and semiconductor. And the most important parts are semiconductor layers, because this is where the electron current is created. There are three, four or five electron in the outer shell and these electrons can be only freed if some additional energy is supplied. The conductivity of a semiconductor can be changed by orders of magnitude by introducing new foreign elements called dopants (Garg & Prakash,1997).

### **2.2.3 Photovoltaic Efficiency**

The amount of energy produced by a PV device depends not only on available solar energy but also on how well the device, or solar cell, converts sunlight to useful electrical energy. This is called solar cell efficiency. It is defined as the amount of electricity produced divided by the sunlight energy striking the PV device. The important factor involved in the calculation of efficiency for various types of cell is radiation of sun or known as irradiance (solar radiation intensity), in a book by author Thomas Markvart in year 2000, entitled “Solar Electricity “.

Solar cells do not operate at the theoretical maximum efficiency because of several limitations, out of which some are avoidable but others are intrinsic to the cell. Some of the limitations can be independently tackled while the others are interrelated. The following factors limit the efficiency of a photovoltaic solar energy conversion device:-

- a) Reflection losses at the top surfaces
- b) Shading due to charge collection grid at the top surface
- c) Incomplete absorption of photon energy due to limited cell thickness
- d) Collection loss
- e) Voltage factor loss
- f) Curve or fill factor loss
- g) Series and shunt resistance loss

#### **2.2.4 Design Requirements for Photovoltaic Modules**

The manufacture of PV modules must follow the standard to produce modules that fulfill market requirement of high efficiency and low-cost. A module consists of one or more solar cells that are placed between transparent and moisture-proof backing glasses to protect it from damaging.

Modules must be designed for reliable and maintenance-free operation for many years in the environment condition for which they are intended. The current target is

a lifetime of 30 years. To keep operational temperatures as low as possible and thereby maximize performance, the module should be designed to absorb the maximum solar energy and take full advantage of radioactive, convective and conductive cooling. The module must be strong and rigid enough to support the fragile cells, before during and after installation in the array.

It should be able to withstand wind-induced vibrations and take loads imposed by high winds, rain, snow and ice. The module should be easy to mount, interconnect and replace. Mountings, terminals and connectors should be non-corrosive. Equally important, production costs must be kept as low as possible. Since the cost of the materials is proportional to the area of the module, the cell-packing factor, example the ration of cell area to total area, should be as high as is consistent with adequate spacing. Obviously, square or rectangular cells are better than circular ones this respect. The conversion efficiency of the most commercial crystalline silicon cells is at present between 12% and 15% (Treble, 1991).

As yet, there is no consensus on the optimum size of module, although most nowadays are in the 30W to 50W range. Small modules are cheaper to replace and have advantages in automated manufacture and testing but large ones (100W to 150W) yield higher module efficiency because there is proportional less frame area, need simpler support structures and require less on-site labors. Pre-assembled panels of small modules may prove to be best compromise (Treble, 1991).

## **2.3 Battery**

### **2.3.1 Types of Battery and Storage System**

Before we can decide which types of battery to be used in the PV system, we should understand types of battery available in the market and study their specification and characteristic so that the battery used is suitable and applicable with the PV panel and the designed prototype. This is because the battery should be able to withstand several charge and discharge cycle and a low self-discharge rate and provide back-up power source so that it able to operate to the whole system such as motor during periods of low solar irradiance and night (Garg & Prakash,1997).

There are many types of battery in the market, a certain battery may be designed for small size and long runtime, but this pack has a limited cycle life. Another battery may be built for durability but is big and bulky. A third pack may have high energy density and long durability but this version is too expensive for the consumer. There are many types of energy storage systems we can used and it can be classified according to the form in which the energy is stored (Allison et al, 1975).

Below is a summary of the strength, limitations of battery energy, density service life, load characteristics, maintenance requirements, self-discharge and operational costs for all the battery available in market.

#### **2.3.1.1 Nickel-Cadmium**

This battery has moderate energy density. Nickel-cadmium is used where long life, high discharge rate and extended temperature range is important. Main applications are two-way radios, biomedical equipment and power tools. Nickel-cadmium contains toxic metals.

#### **2.3.1.2 Nickel-Metal-Hydride**

It has a higher energy density compared to nickel-cadmium at the expense of reduced cycle life. There are no toxic metals. Applications include mobile phones and laptop computers.

### **2.3.1.3 Lead-Acid**

The most economical and able to provide larger power applications where weight is of little concern are lead-acid battery. Lead-acid is the preferred choice for hospital equipment, wheelchairs, emergency lighting and UPS systems.

### **2.3.1.4 Lithium-Ion**

This type of battery has fastest growing battery system and it offers high-energy density and low weight. Protection circuit is needed to limit voltage and current for safety reasons. Applications include notebook computers and cell phones.

### **2.3.1.5 Lithium-Ion-Polymer**

Similar to lithium-ion, this system enables slim geometry and simple packaging at the expense of higher cost per watt/hours. Main applications are cell phones.

### **2.3.1.6 Reusable Alkaline**

Its limited cycle life and low load current is compensated by long shelf life, making this battery ideal for portable entertainment devices and flashlights.

## **2.3.2 Lead-Acid Battery for the PV Systems**

Finding the ideal charge voltage limit is critical. Any voltage level is a compromise. A high voltage limit (above 2.40V/cell) produces good battery performance but shortens the service life due to grid corrosion on the positive plate. The corrosion is permanent. A low voltage (below 2.40V/cell) is safe if charged at a higher temperature but is subject to sulfating on the negative plate.

There are three types of lead-acid batteries that are widely used in solar electric systems. These batteries are flooded lead acid battery, absorbed glass mat sealed lead acid battery and gelled electrolyte sealed lead acid battery.

### **2.3.2.1 Flooded Lead Acid**

Flooded lead acid batteries have been used in the photovoltaic systems since decades ago. Nowadays, it is still used in the majority of standalone solar systems. This is because it rechargeable and the least cost per amp-hour of any of the choices. The only weaknesses are they require regular maintenance in the form of watering, equalizing charges and keeping the top and terminals clean. Some examples of flooded lead-acid batteries used in solar electric systems are 6 volt golf-cart batteries, 6 volt L-16's and 2 volt industrial cells for large systems.

### **2.3.2.2 Absorbed Glass Mat Sealed Lead Acid (AGM)**

AGM batteries are type of batteries with maintenance free and also the prices are getting cheaper due mass production. This makes them ideally suited for use in grid-tied solar systems with battery back up. Compare with flooded lead acid batteries, AGM do not need periodic watering, and emit no corrosive fumes, the electrolyte will not corrode and no equalization charging is required.

AGM's come in most popular battery sizes and are even available in large 2 volt cells for the ultimate in low maintenance large system storage. AGM batteries would last

for 10 years at 25°C (77°F), but it will only be good for 5 years if operated at 33°C (95°F).

### **2.3.2.3 Gelled Electrolyte Sealed Lead Acid**

The gelled electrolyte in these batteries is highly viscous and recombination of the gases generated while charging, occurs at a much slower rate. This means that they typically have to be charged slower than either flooded lead acid or AGM batteries. Therefore it is designed with a low over-voltage potential to prohibit the battery from reaching its gas-generating potential during charge. Excess charging would cause gassing and water depletion. And these batteries can never be charged to their full potential.

The gelled lead acid able to provide 200 to 300 discharge/charge cycles depending on the depth of discharge and operating temperature. The primary reason for its relatively short cycle life is grid corrosion of the positive electrode, depletion of the active material and expansion of the positive plates. These changes are most prevalent at higher operating temperatures.

The optimum operating temperature for the lead-acid battery is 25°C (77°F) which is coincides with the environmental temperatures in our country. The sealed lead-acid battery is rated at a 5-hour discharge or 0.2C. Some batteries are rated at a slow 20-hour discharge. Longer discharge times produce higher capacity readings. The lead-acid performs well on high load currents.

Lead acid is durable to weather resistance and provides dependable service. It is inexpensive and easy to manufacture. The self-discharge is among the lowest of rechargeable battery systems. It only required low maintenance requirement. Its capability of high discharge rates makes it as the best battery to be used in PV system.

## **2.4 Charge Controller**

The primary function of charge controller in a stand-alone PV system is to maintain the battery at highest possible state of charge while protecting it from overcharge by the module and loads. There are some PV systems can be effectively designed without the use of charge control. But for the system that has unpredictable loads, user intervention, and optimized battery storage, it must have a battery charge controller (James P. Dunlop, 1997). Important functions of battery charge controllers and systems controls are:

- a) Prevent battery overcharge
- b) To limit the energy supplied to the battery by the PV array when the battery becomes fully charged.
- c) Prevent battery over discharge
- d) To disconnect the battery from electrical loads when the battery reaches low stage of charge.
- e) Provide load control functions
- f) To automatically connect and disconnect an electrical load at specified time, for example operating a lighting load from sunset to sunrise.

#### **2.4.1 Overcharge Protection**

When the solar panel is operating under good weather conditions, energy generated by the array often exceeds the electrical load demand. To prevent battery damage resulting from overcharge, a charge controller is used to protect the battery. The purpose of a charge controller is to supply power to the battery in a manner which fully recharges the battery without overcharging. Without charge controller, the current from the array will flow into a battery proportional to the irradiance, whether the battery needs charging or not. If the battery is fully charged, unregulated charging will cause the battery voltage to reach exceedingly high levels, causing severe gassing, electrolyte loss, internal heating and accelerated grid corrosion.

Charge regulation is most often accomplished by limiting the battery voltage to a maximum value, often referred to as the voltage regulation (VR) set point. Once the controller senses that the battery reaches the voltage regulation set point, the controller will either discontinue battery charging or begin to regulate (limit) the amount of current delivered to the battery.

### **2.4.2 Over-discharge Protection**

During periods of below average insulations or during periods of excessive electrical load usage, the battery produced by the PV may not sufficient enough to keep the battery fully recharged. When the battery is excessively discharged repeatedly, loss of a capacity and life will eventually occur. Therefore low voltage load disconnect (LVD) device connected between the battery and load is used to disconnect the systems loads once the battery reaches the allowable low voltage stage.

Precautions steps must be taken when selecting the low voltage load disconnect set point. This is because in PV systems, battery should not be completely discharged, as this will shorten its service life. Normally LVD values used in lead-acid batteries are between 11v and 11.5v, which corresponds to about 75-90% depth of discharge for most nominal 12v lead-acid batteries at discharges rates (James P. Dunlop, 1997).

## **2.5 Motor**

Motor is a machine or device that converts any form of energy into mechanical energy, or imparts motion. In constructing a robot, for example, motor plays an important role as to give movement to the robot. In general, motor operates with the effect of conductor with current and the permanent magnetic field. The conductor with current will produce magnetic field which will react with the magnetic field produces by the permanent magnet to make the motor rotate.

There are three basic types of motor, DC motor, servomotor and stepper motor.

## 2.5.1 DC Motor

The DC motor is a device that converts electrical energy into mechanical energy. The DC motor has a rotating armature in the form of an electromagnet. In order to flow through the armature so that the poles of the electromagnet push and pull against the permanent magnets on the outside of the motor, we used a commutator to reverse the direction of the electric current twice every cycle. As the poles of the armature electromagnet pass the poles of the permanent magnets, the commutator reverses the polarity of the armature electromagnet. During that instant of switching polarity, inertia keeps the classical motor going in the proper direction. (Mott, 2004).

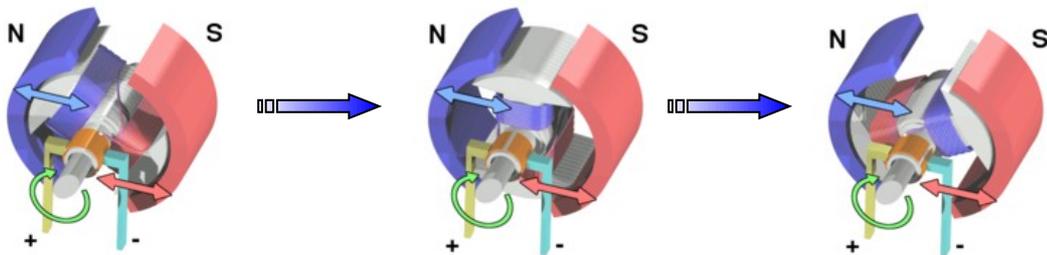


Figure 2.2 A simple DC motor (Wikipedia, 2006)

As shown in the figure above, when the coil is powered, a magnetic field is generated around the armature. The left side of the armature is pushed away from the left magnet and drawn toward the right, causing rotation. The armature continues to rotate. When the armature becomes horizontally aligned, the commutator reverses the direction of current through the coil, reversing the magnetic field. The process then repeats.