# PIC Based Automatic Solar Radiation Tracker

**A Thesis**

***Submitted in the partial fulfillment of the requirement for the award of degree of***

**Master of Engineering**
**in**
**(Electronics Instrumentation & Control Engineering)**
**To**

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## Declaration

I hereby declare that the report entitled "PIC based Automatic Solar Radiation Tracker" is an authentic record of my own work carried out as requirements for the award of degree of M.E. (Electronic Instrumentation & Control) at Thapar University, Patiala, under the guidance of Mr. Mandeep Singh, Assistant Professor during January to June 2008.

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# Abstract

The following document details the research and development of an Automatic Solar radiation tracker. Fossil fuels are a relatively short-term energy source; consequently, the uses of alternative sources such as solar energy are becoming more wide spread. To make solar energy more viable, the efficiency of solar array systems must be maximized. A feasible approach to maximizing the efficiency of solar array systems is sun tracking. Proposed in this report is a system that controls the movement of a solar array so that it is constantly aligned towards the direction of the sun.

Solar modules are devices that cleanly convert sunlight into electricity and offer a practical solution to the problem of power generation in remote areas. The solar tracker designed and constructed in this project offers a reliable and affordable method of aligning a solar module with the sun in order to maximize its energy output.

Automatic Sun Tracking System is a hybrid hardware/software prototype, which automatically provides best alignment of solar panel with the sun, to get maximum output (electricity).

# Table of Contents

| Contents | Page No. |
|---|---|

# List of Figures

# List of Tables

| Tables | Page No. |
|---|---|

# List of Abbreviations

| | |
|---|---|
| **H/W** | **Hardware** |
| **A/D** | **Analog to Digital** |
| **MPP** | **Maximum Power Point** |
| **Cu** | **Copper** |
| **PV** | **Photovoltaic** |
| **UK** | **United Kingdom** |
| **TACS** | **Solar Tracking and Control System** |
| **LED** | **Light Emitting Diode** |
| **LCD** | **Liquid Crystal Display** |
| **DC** | **Direct Current** |
| **PC** | **Personal Computer** |
| **MPPT** | **Maximum Power Point Tracking** |
| **PWM** | **Pulse Width Modulation** |
| **ADP** | **Adaptive Step-Perturbation** |
| **P&O** | **Perturbation and Observation** |
| **PLC** | **Programmable Logic Control** |
| **WLED** | **White Light Emitting Diode** |
| **PCB** | **Printed Circuit Board** |
| **TTL** | **Transistor Transistor Logic** |
| **EMF** | **Electromotive Force** |
| **PIC** | **Programmable Interface Controller** |
| **RPM** | **Revolution per Minute** |
| **PRF** | **Pulse Repetition Frequency** |

| | |
|---|---|
| **VR** | **Variable Reluctance** |
| **PM** | **Permanent Magnet** |
| **HB** | **Hybrid** |
| **CPU** | **Central Processing Unit** |
| **RAM** | **Random Access Memory** |
| **I/O** | **Input /Output** |
| **MCLR** | **Master Clear (reset) Input** |
| **OSC1** | **Oscillator** |
| **CLK** | **Clock** |
| **EEPROM** | **Electrically Erasable Programmable Read Only Memory** |
| **USART** | **Universal Asynchronous Receiver Transmitter** |
| **ADC** | **Analog to Digital Convertor** |
| **IDE** | **Integrated Development Environment** |
| **ANSI** | **American National Standard Institute** |
| **HEX** | **Hexadecimal** |
| **ASCII** | **American Standard Code for Information Interchange** |
| **Mcl** | **Macro Command Language** |
| **CAN** | **Controller Area Network** |
| **SPI** | **Serial Peripheral Interface** |
| **CMOS** | **Complementary Metal Oxide Semiconductor** |

# Organization of the Thesis

This thesis consists of six chapters. The first chapter discusses theory regarding sun tracking, focuses on various methods and types of trackers. This incorporates a review of relevant literature in the field of sun tracking. The second chapter is based on stepper motor, in which types of stepper motor are briefed and its working is discussed in detail. The next chapter deals with hardware and embedded software and a detail study of the PIC microcontroller, mikroC instructions used in this thesis. Fourth chapter explains the control scheme used while forming a solution to the problem and the design considerations undertaken in this process. Fifth chapter gives an analysis of the design and data obtained during testing with discussions. Sixth chapter concludes the report by discussing the effectiveness of the tracking system. It also suggests some further research areas and future design proposals.

# CHAPTER 1

# Introduction to Sun Tracking

## 1.1 Background

As the range of applications for solar energy increases, so does the need for improved materials and methods used to harness this power source. There are several factors that affect the efficiency of the collection process. Major influences on overall efficiency include solar cell efficiency, intensity of source radiation and storage techniques. The materials used in solar cell manufacturing limit the efficiency of a solar cell. This makes it particularly difficult to make considerable improvements in the performance of the cell, and hence restricts the efficiency of the overall collection process. Therefore, the most attainable method of improving the performance of solar power collection is to increase the mean intensity of radiation received from the source. There are three major approaches for maximizing power extraction in medium and large scale systems. They are sun tracking, maximum power point (MPP) tracking or both.

## 1.2 Need of Sun Tracker

Each day, the sun rises in the east, moves across the sky, and sets in the west. Whenever the sun is shining on us, it is sending energy in our direction. We can feel the heat from the sun, and we can see objects that are illuminated by the light from the sun as it moves across the sky. However, if we could get a solar cell to turn and look at the sun all day, then it would be receiving the maximum amount of sunlight possible and converting it into the more useful energy form electricity.

If we are located in the tropics, we see that the sun appears to follow a path that is nearly directly overhead. However, for locations north or south of the tropics (e.g., latitudes greater than 23.5 degrees), the sun never reaches a position that is directly overhead. Instead, it follows a path across the southern or the northern part of the sky.

## 1.3 Objective of Work

If we could configure a solar cell so that it faces the sun continually as it moves across the sky from east to west, we could get the most electrical energy possible. One way to do this, of course, is by hand. However, keeping a solar cell facing the sun throughout the day is not a very efficient use of a person's time. Going outside to a solar cell every hour to turn it toward the sun might be possible, but this would still not be an efficient method. A photo sensor is employed to control the solar cell tracking system. For example, if the photo sensor is not aligned with sun rays, then it could turn on the motor until it is once again aligned. If the motor is attached to the frame holding the solar cell, then the solar cell could be moved to face the sun. As long as the photo sensor is in alignment with the sun, nothing happens. However, when the sun moves across the sky and is not in proper alignment with the photo sensor, then a motor moves the frame until the photo sensor is in the sun once more. This could have the effect of keeping the solar cell facing the sun as it moves across the required human attention. So we need a tracking system that would automatically keep the solar cell facing the sun throughout the day. We have to build an automated system of our own, using a single motor. The system includes a frame on which a solar cell could be mounted. The frame is to move so that it faces the sun as it travels across the sky during the day. The frame could be driven by an electric motor that turns on and off in response to the movement of the sky. Here in this thesis work, panel itself work as a sensor.

## 1.4 Solar Energy

One of the most important problems facing the world today is the energy problem. This problem is resulted from the increase of demand for electrical energy and high cost of fuel. The solution was in finding another renewable energy sources such as solar energy, wind energy, potential energy...etc. Nowadays, solar energy has been widely used in our life, and it's expected to grow up in the next years.

Solar energy has many advantages:

1. Need no fuel
2. Has no moving parts to wear out
3. Non-polluting & quick responding
4. Adaptable for on-site installation

5. Easy maintenance
6. Can be integrated with other renewable energy sources
7. Simple & efficient

Tracking systems try to collect the largest amount of solar radiation and convert it into usable form of electrical energy (DC voltage) and store this energy into batteries for different types of applications. The sun tracking systems can collect more energy than what a fixed panel system collects.

## 1.5 Introduction to Sun Tracker

**Figure 1.1: Solar Panel**

A Solar tracker is a device for orienting a solar photovoltaic panel or concentrating solar reflector or lens toward the sun. The sun's position in the sky varies both with the seasons (elevation) and time of day as the sun moves across the sky. Solar powered equipment works best when pointed at or near the sun, so a solar tracker can increase the effectiveness of such equipment over any fixed position, at the cost of additional system complexity. There are many types of solar trackers, of varying costs, sophistication, and performance. One well-known type of solar tracker is the heliostat, a movable mirror that reflects the moving sun to a fixed location, but many other approaches are used as well.

The required accuracy of the solar tracker depends on the application. Concentrators, especially in solar cell applications, require a high degree of accuracy to ensure that the concentrated sunlight is directed precisely to the powered device, which is at (or near) the focal point of the reflector or lens. Typically concentrator systems will not work at all without tracking, so at least single-axis tracking is mandatory.

Non-concentrating applications require less accuracy, and many work without any tracking at all. However tracking can substantially improve the amount of power produced by a system. The use of trackers in non-concentrating applications is usually an engineering decision based on economics. Compared to photovoltaics, trackers can be relatively inexpensive. This makes them especially effective for photovoltaic systems using high-efficiency panels.

For low-temperature solar thermal applications, trackers are not usually used, owing to the relatively high expense of trackers compared to adding more collector area and the more restricted solar angles required for winter performance, which influence the average year-round system capacity. Some solar trackers may operate most effectively with seasonal position adjustment and most will need inspection and lubrication on an annual basis.

## 1.6 Tracking Techniques

There are several forms of tracking currently available; these vary mainly in the method of implementing the designs. The two general forms of tracking used are fixed control algorithms and dynamic tracking. The inherent difference between the two methods is the manner in which the path of the sun is determined. In the fixed control algorithm systems, the path of the sun is determined by referencing an algorithm that calculates the position of the sun for each time period. That is, the control system does not actively find the sun's position but works it out given the current time, day, month, and year. The dynamic tracking system, on the other hand, actively searches for the sun's position at any time of day (or night).Common to both forms of tracking is the control system. This system consists of some method of direction control, such as DC motors, stepper motors, and servo motors, which are directed by a control circuit, either digital or analog.

## 1.7 Relevance of Solar Trackers

For people living in remote communities, often in third world countries, access to grid-connected electricity is not always possible. Often the nearest utility is a long distance from homes and the cost of developing the infrastructure that would allow for access to the grid is prohibitive. Remote communities in third world countries are of course not the only ones that suffer this dilemma. Australia is a large country with many farmers and communities that are remote from the local grid and in these cases alternative sources of electrical power must be obtained.

## 1.8 Equivalent Circuit of a Solar Cell

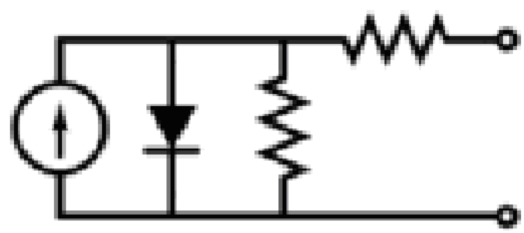

**Figure 1.2: Equivalent Circuit of Solar Cell**

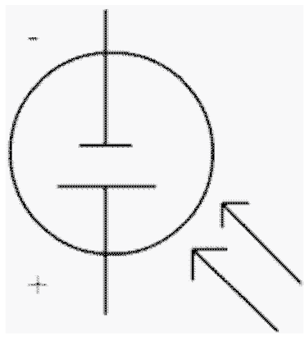


**Figure 1.3: The Schematic Symbol of Solar Cell**

To understand the electronic behaviour of a solar cell, it is useful to create a model which is electrically equivalent, and is based on discrete electrical components whose behaviour is well known. An ideal solar cell may be modelled by a current source in parallel with a diode. In practice no solar cell is ideal, so a shunt resistance and a series resistance component are added to the model. The result is the "equivalent circuit of a solar cell" as shown above. The other figure is the schematic representation of a solar cell for use in circuit diagrams.

## 1.9 Materials and Efficiency

Various materials have been investigated for solar cells. There are two main criteria - efficiency and cost. Efficiency is a ratio of the electric power output to the light power input. Ideally, near the equator at noon on a clear day; the solar radiation is approximately 1000 W/m$^2$. So a 10% efficient module of 1 square meter can power a 100 W light bulb. Costs and efficiencies of the materials vary greatly. By far the most common material for solar cells (and all other semiconductor devices) is crystalline silicon. Crystalline silicon solar cells come in three primary categories:

- **Single crystal or monocrystalline wafers**. Most commercial monocrystalline cells have efficiencies on the order of 14%; the sun power cells have high efficiencies around 20%. Single crystal cells tend to be expensive, and because they are cut from cylindrical ingots, they cannot completely cover a module without a substantial waste of refined silicon. Most monocrystalline panels have uncovered gaps at the corners of four cells.
- **Poly or multi crystalline** made from cast ingots - large crucibles of molten silicon carefully cooled and solidified. These cells are cheaper than single crystal cells, but also somewhat less efficient. However, they can easily be formed into square shapes that cover a greater fraction of a panel than monocrystalline cells, and this compensates for their lower efficiencies.
- **Ribbon silicon** formed by drawing flat thin films from molten silicon and has a multi crystalline structure. These cells are typically the least efficient, but there is a cost savings since there is very little silicon waste and this approach does not require sawing from ingots.

These technologies are wafer based manufacturing. In other words, in each of the above approaches, self supporting wafers of approximate 300 micro metres thick are fabricated and then soldered together to form a module.

Thin film approaches are module based. The entire module substrate is coated with the desired layers and a laser scribe is then used to delineate individual cells. Two main thin film approaches are amorphous silicon and CIS:

- **Amorphous silicon films** are fabricated using chemical vapor deposition techniques, typically plasma enhanced (PE-CVD). These cells have low efficiencies around 8%.
- **CIS** stands for general chalcogenide films of Cu. While these films can achieve 11% efficiency, their costs are still too high.

## 1.10 Photovoltaic Cell

A solar electric module (also known as a 'panel') is made up of many PV cells that are wired together in a series to achieve the desired voltage. The thin wires on the front of the module pick up the free electrons from the PV cell.

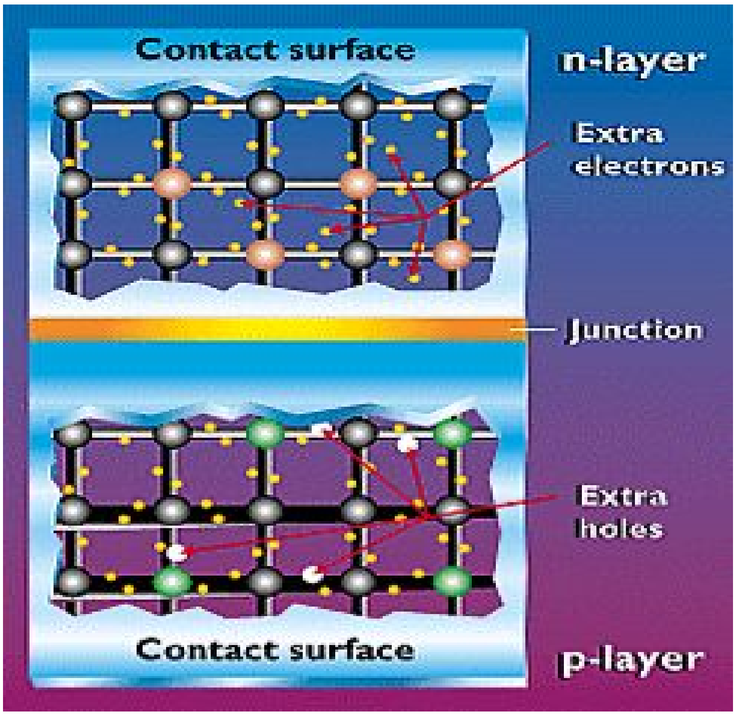


**Figure 1.4: Photovoltaic Cell**

- A solar cell or a photovoltaic cell, converts sunlight directly into electricity at the atomic level by absorbing light and releasing electrons. This behaviour is a demonstration of the photoelectric effect, a property of certain materials that produce small amounts of electric current when exposed to light.
- A typical solar cell has two slightly different layers of silicon in contact with each other. When the sun shines on these layers, it causes electrons to move across the junction between the layers, creating an electric current.

- The top silicon layer in a solar cell is very thin. It includes as a deliberate impurity some atoms of an element that has more electrons than silicon, such as phosphorus. These impurity atoms are called *donors*, because they can donate or release their extra electrons into the silicon layer as free electrons.
- The bottom silicon layer in a solar cell is much thicker than the top layer. It has as an impurity some atoms of an element such as boron that has fewer electrons than silicon atoms. These impurity atoms are called *acceptors*, because relative to the silicon atoms they have "holes" where electrons can be accepted.
- At the junction where these two layers come together, the donors next to the junction give up their electrons, which migrate across the junction to the adjacent acceptors. This gives the top layer with the donors a net positive charge (because they gave up their excess electrons), and the bottom layer a net negative charge (because the acceptors have their "holes" filled with the excess electrons).
- When light shines on the layers, atoms in the bottom layer absorb the light and release electrons in accordance with the photoelectric effect. These electrons then migrate to the positively charged top layer. This movement of electrons creates the electrical current from a solar cell that can flow through a circuit with contacts at the two layers.
- During the central part of the day, the output of the solar cell will be at or near its maximum because the sunlight is arriving at a more direct angle. At the beginning and at the end of the day, the output will fall off regardless of the orientation of the solar cell, mainly because the sunlight has to travel obliquely through the atmosphere at these times, arriving at a low angle. This decreases the intensity of the sunlight.
- Due to the designing, a solar cell will develop a voltage that is fairly constant. However, the higher the intensity of the sunlight falling on the cell, the more electrical current is produced. This is why a voltmeter connected to a solar cell will have just about the same reading from midmorning to mid afternoon, while a motor connected to the solar cell will run faster during the middle of the day, when the output current is a maximum.

## 1.11 Photovoltaic Module

Photovoltaic (PV) modules are devices that cleanly convert sunlight into electricity and offer a practical solution to the problem of power generation in remote areas. They are especially useful in situations where the demand for electrical power is relatively low and can be catered for using a low number of modules. Running lights, a refrigerator and a television in a small home or the powering of water pumps on a remote farming property are examples of tasks that a small array of solar modules can cope with. It has high purchase cost and to keep the number of modules required to a minimum, it is important that the modules produce as much electricity during the hours that they are exposed to sunlight as possible.

The solar tracker that has been designed and constructed in this project optimizes the power output of PV modules by making sure that they are pointed towards the sun at all times during the day. The tracker could be implemented in any situation where solar modules are used. It would be especially effective in situations where only a small number of modules are required and where efficiency is of a great importance.

Analysis has shown that by using this solar tracker an efficiency increase of about 8% when compared to fixed panels can be obtained.

## 1.12 Solar Tracker Fundamentals

A solar tracker is a device that is used to align a single P.V module or an array of modules with the sun. Although trackers are not a necessary part of a P.V system, their implementation can dramatically improve a systems power output by keeping the sun in focus throughout the day. Efficiency is particularly improved in the morning and afternoon hours where a fixed panel will be facing well away from the suns rays. P.V modules are expensive and in most cases the cost of the modules themselves will outweigh the cost of the tracker system. Additionally a well designed system which utilizes a tracker will need fewer panels due to increased efficiency, resulting in a reduction of initial implementation costs.

## 1.13 Overview of Current Tracker Drive Types

Solar trackers can be divided into three main types depending on the type of drive and sensing or positioning system that they incorporate. Passive trackers use the sun's radiation to heat gases that move the tracker across the sky. Active trackers use electric or hydraulic drives and some type of gearing or actuator to move the tracker. Open loop trackers use no sensing but instead determine the position of the sun through pre-recorded data for a particular site.

### 1.13.1 Gas Trackers (Passive Trackers)

Passive trackers use a compressed gas fluid as a means of tilting the panel. A canister on the sun side of the tracker is heated causing gas pressure to increase and liquid to be pushed from one side of the tracker to the other. This affects the balance of the tracker and caused it to tilt. This system is very reliable and needs little maintenance. Although reliable and almost maintenance free, the passive gas tracker will very rarely point the solar modules directly towards the sun. This is due to the fact that temperature varies from day to day and the system can not take into account this variable. Overcast days are also a problem when the sun appears and disappears behind clouds causing the gas in the liquid in the holding cylinders to expand and contract resulting in erratic movement of the device. Passive trackers are however an effective and relatively low cost way of increasing the power output of a solar array.

The tracker begins the day facing west. As the sun rises in the east, it heats the unshaded west-side canister, forcing liquid into the shaded east-side canister. The liquid that is forced into the east side canister changes the balance of the tracker and it swings to the east. It can take over an hour to accomplish the move from west to east. The heating of the liquid is controlled by the aluminium shadow plates. When one canister is exposed to the sun more than the other, its vapour pressure increases, tracker and caused it to tilt. This system is very reliable and needs little maintenance. Although reliable and almost maintenance free, the passive gas tracker will very rarely point the solar modules directly towards the sun. This is due to the fact that temperature varies from day to day and the system can not take into account this variable. Overcast days are also a problem when the sun appears and disappears behind clouds causing the gas in the liquid in the holding cylinders to expand and contract resulting in erratic movement of the device. Passive trackers are however an effective and relatively low cost way of increasing the power output of a solar array.

### 1.13.2 Active Trackers

Active trackers measure the light intensity from the sun to determine where the solar modules should be pointing. Light sensors are positioned on the tracker at various locations or in specially shaped holders. If the sun is not facing the tracker directly there will be a difference in light intensity on one light sensor compared to another and this difference can be used to determine in which direction the tracker has to tilt in order to be facing the sun.

### 1.13.3 Open Loop Trackers

Open loop trackers determine the position of the sun using computer controlled algorithms or simple timing systems.

**1.13.3.1 Timed Trackers –** These use a timer to move the tracker across the sky. Incremental movement throughout the day keeps the solar modules facing the general direction of the sun. Trackers of this type can utilize one or two axes depending on their application. The main disadvantage of timed systems is that their movement does not take into account the seasonal variation in sun position. Unless measures are taken to adjust the tracker position seasonally, there will be a noticeable difference in efficiency depending on the season.

**1.13.3.2 Altitude / Azimuth Trackers** use astronomical data or sun position algorithms to determine the position of the sun for any given time and location. Tracker location, date and time are used by a micro controller to fix the position of the sun. Once the position has been calculated, the modules are moved using servo motors and there position measured by encoders built into the tracker frame.

## 1.14 Types of Solar Trackers

There are many different types of solar tracker which can be grouped into single axis and double axis models.

### 1.14.1 Single Axis Trackers:

**Figure 1.5: Single Axis Solar Tracker**

Single axis solar trackers can either have a horizontal or a vertical axle. The horizontal type is used in tropical regions where the sun gets very high at noon, but the days are short. The vertical type is used in high latitudes (such as in UK) where the sun does not get very high, but summer days can be very long.
These have a manually adjustable tilt angle of 0 - 45 °and automatic tracking of the sun from East to West. They use the PV modules themselves as light sensor to avoid unnecessary tracking movement and for reliability. At night the trackers take up a horizontal position.

### 1.14.2 Dual Axis Trackers

**Figure 1.6: Double Axis Tracker**

Double axis solar trackers have both a horizontal and a vertical axle and so can track the Sun's apparent motion exactly anywhere in the world. This type of system is used to control astronomical telescopes, and so there is plenty of software available to automatically predict and track the motion of the sun across the sky.

Dual axis trackers track the sun both East to West and North to South for added power output (approx 40% gain) and convenience.

## 1.15 Tracker Mount Types

Solar trackers may be active or passive and may be single axis or dual axis. Single axis trackers usually use a polar mount for maximum solar efficiency. Single axis trackers will usually have a manual elevation (axis tilt) adjustment on a second axis which is adjusted on regular intervals throughout the year. There are two types of dual axis trackers, polar and altitude-azimuth.

### 1.15.1 Polar

Polar trackers have one axis aligned close to the axis of the rotation of the earth,hence the name polar .By this,only high accuracy astronomical telescope mounts rotate on an axis parallel to the earth's axis .For solar trackers ,so called "polar"trackers have their axis aligned perpendicular to the 'ecliptic"(an imaginary disc containing the apparent path of the sun).

**Figure 1.7: Polar Mount**

Simple solar trackers are manually adjusted to compensate for the shift of the ecliptic through the seasons. Adjustment is usually at least twice a year at the equinoxes; once to establish a position for autmn and winter , and a second adjustment for spring and summer .Such trackers are also referred to as "single axis" because only one drive mechanism is needed for daily operation. This reduces the cost and allows the use of passive tracking methods.

### 1.15.2 Horizontal Axle

**Figure 1.8: Horizontal Axle Mount**

Single axis horizontal trackers may be oriented by either passive or active mechanisms .In these, a long horizontal tube is supported on bearings mounted upon pylons or frames .The axis of the tube is on a north-south line. Panels are mounted upon the tube , and the tube will rotate on its axis to track the apparent motion of the sun through the day. Since these do not tilt toward the equator they are not especially effective during winter midday(unless located near the equator),but add a substantial amount of productivity during the spring and summer seasons when the solar path is high in the sky. These devices are less effective at higher latitudes .The principal advantage is the inherent robustness of the supporting structure and the simplicity of the mechanism. Since the panels are horizontal, they can be compactly placed on the axle tube without danger of self-shading and are also readily accessible for cleaning. For active mechanisms, a single control and motor may be used to actuate multiple rows of panels.

### 1.15.3 Vertical Axle

A single axis tracker may be constructed that pivots only about a verticle axle , with the panels either vertical or at a fixed elevation angle. Such trackers are suitable for high latitudes, where the apparent solar path is not especially high ,but which leads to long days in summer, with the sun travelling through a long arc. This method has been used in the construction of a cylindrical house in austria (latitude above 45 degrees north )that rotates in its entirety to track the sun, with vertical panels mounted on one side of the building .

**Figure 1.9: Vertical Axle Mount**

The solar panels rotate independently, allowing control of the natural heating from the sun.

### 1.15.4 Altitude Azimuth

**Two –axis mount**

**Figure 1.10: Two Axis Mount**

Point focus parabolic dish with sterling system. The horizontally rotating azimuth table mounts the vertical frames on each side which hold the elevation triunions for the dish and its integral engine/generator mount.

Restricted to active trackers, this mount is also becoming popular as a large telescope mount owing to its structural simplicity and compact dimensions .One axis is a vertical pivot shaft or horizontal ring mount that allows the device to be swung to a compass point. The second axis is a horizontal elevation pivot mounted upon the azimuth platform. By using combinations of the two axis, any location in the upward hemisphere may be pointed. Such systems may be operated under computer control according to the expected solar orientation, or may use a tracking sensor to control motor drives that orient the panels toward the sun. This type of mount is also used to orient parabolic reflectors that mount a sterling engine to produce electricity at the device.

## 1.16 Multi Mirror Reflective Units

This device uses multiple mirrors in a horizontal plane to reflect sunlight upward to a high temperature photovoltaic or other system requiring concentrated solar power. Structural problems and expense are greatly reduced since the mirrors are not significantly exposed to wind loads. Through the employment of a patented mechanism, only two drive systems are required for each device. It is especially suited for use on flat roofs and at lower latitude because of the configuration of the device.

## 1.17 Module Orientation

The orientation of your solar tracking system (the compass direction that system faces and the angle at which it tilt down from the horizontal) will affect performance. Often, the best location for a solar tracking system is a south-facing roof, but roofs that face east or west may be acceptable. Flat roofs also work for solar systems because the solar tracking modules can be mounted on racks tilted toward the south at the optimal angle. The optimal orientation for solar tracking modules is facing due south and tilted up about $45^{\circ}$ from the horizontal.

## 1.18 Literature Survey

**Daniel A. Pritchard** had given the design, development, and evaluation of a microcomputer-based solar tracking and control system (TACS) in 1983. It was capable of maintaining the peak power position of a photovoltaic (PV) array by adjusting the load on the array for maximum efficiency and changed the position of the array relative to the sun. At large PV array system installations, inverters were used to convert the dc electrical output to ac for power grid compatibility. Adjustment of the inverter or load for maximum array output was one function performed by the tracking and control system. Another important function of the system was the tracking of the sun, often a necessity for concentrating arrays. The TACS also minimized several other problems associated with conventional shadow-band sun trackers such as their susceptibility to dust and dirt that might cause drift in solar alignment. It also minimized effects of structural war page or sag to which large arrays might be subjected during the day. Array positioning was controlled by Q single-board computer used with a specially designed input output board. An orderly method of stepped movements and the finding of new peak power points was implemented. This maximum power positioning concept was tested using a small two-axis tracking concentrator array. A real-time profile of the TACS activity was produced and the data analysis showed a deviation in maximum power of less than 1% during the day after accounting for other variations [Daniel A. Pritchard, 1983].

**Ashok Kumar Saxena and V. Dutta** had designed a versatile microprocessor based controller for solar tracking in 1990 .Controller had the capability of acquiring photovoltaic and metereological data from a photovoltaic system and controlled the battery /load. These features were useful in autonomous PV systems that were installed for system control as well as monitoring in remote areas .Solar tracking was achieved in both open loop as well as closed loop modes. The controller was totally automatic and did not require any operator interference unless needed [Ashok Kumar Saxena and V.Dutta, 1990].

**A. Konar and A.K. Mandal** had given a microprocessor based automatic position control scheme in 1991. They had designed for controlling the azimuth angle of an optimally tilted photovoltaic flat type solar panel or a cylindrical parabolic reflector to get the illuminating surface appropriately positioned for the collection of maximum solar irradiance. The proposed system resulted in saving of energy .It was designed as a pseudo tracker in which step tracking scheme had been used to keep the motor idle to save energy . The tracking system was not constrained by the geographical location of installation of the solar panel since it was designed for searching the MSI in the whole azimuth angle of 360" during the locking cycle. Temporal variations in environmental parameters caused by fog, rain etc., at a distance from the location where panel was mounted, did not affect proper direction finding [A. Konar and A.K Mandal, 1991]

**A. Zeroual et al.** had designed an automatic sun-tracker system for optimum solar energy collection in 1997. They used electro-optical sensors for sun finding and a microprocessor controller unit for data processing and for control of the mechanical drive system. This system allowed solar energy collectors to follow the sun position for optimum efficiency. It had a modular structure which facilitates its application to different systems without great modifications. The system had been applied to control a water heating parabolic solar system for domestic uses. Many parameters had been controlled for system security such as temperature, pressure and wind velocity. The system had been tested for a long period in variable illumination. The result showed that it operated satisfactorily with high accuracy [A.Zeroual et al., 1997].

**F. Huang et al.** had designed a microcontroller based automatic sun tracker combined with a new solar energy conversion unit in 1998 .The automatic sun tracker was implemented with a dc motor and a dc motor controller. The solar energy conversion unit consisted of an array of solar panels, a step-up chopper, a single-phase inverter, an ac mains power source and a microcontroller based control unit. High efficiency was achieved through the automatic sun tracker and the MPP detector. In this system, the MPP detection and the power conversion were realized by using the same hardware circuit. In the existed MPP detectors, the detection of the MPP was achieved by using analog computing, comparing, and holding. In contrast to the existed ones, in the new system, the MPP was detected by software which was embedded in a microcontroller [F. Huang et al., 1998].

**Hasan A. Yousef** had given the design and Implementation of a fuzzy logic computer controlled sun tracking system to enhance the power output of photo-voltaic (PV) solar panels in 1999. The tracking system was driven by two permanent magnet DC motors to provide motion of the PV panels in two axes. A PC-based fuzzy logic control algorithm utilizing the knowledge of the system behaviour was designed in order to achieve the control objectives because the control of the dual axis tracking system was not an easy task due to nonlinear dynamics and unavailability of the model parameters. The implementation of such a controller was realized by building an interfacing card consisting of sensor data acquisition, motor driving circuits, signal conditioning circuits and serial communication with the PC. The developed fuzzy logic controller algorithm had a simple structure, in fact it was of P-type like controller [ Hasan A. Yousef , 1999].

**Chee-Yee Chong et al.** had given the process architectures for track fusion in 2000. They used the concept of multiple targets tracking because it had shown that tracking with multiple sensors can provide better performance than using a single sensor. One approach to multiple targets tracking with multiple sensors was to first perform single sensor tracking and then fused the tracks from the different sensors. Two processing architectures for track fusion were presented: sensor to sensor track fusion, and sensor to system track fusion. They presented different approaches for fusing track state estimates, and compared their performance through theoretical analysis and simulations [Chee-Yee Chong et al., 2000].

**Eftichios Koutroulis et al.** had given the microcontroller based photovoltaic maximum power point tracking control system in 2001. Maximum power point tracking (MPPT) was used in photovoltaic (PV) systems to maximize the photovoltaic array output power, irrespective of the temperature and irradiation conditions and of the load electrical characteristics. A new MPPT system had developed, consisting of a Buck-type dc/dc converter, which was controlled by a microcontroller-based unit. The PV array output power delivered to a load was maximized using MPPT control systems, which consisted of a power conditioner to interface the PV output to the load, and a control unit, which drove the power conditioner such that it extracted the maximum power from a PV array. It was used to directly control the dc/dc converter, thus reducing the complexity of the system. The resulting system had high-efficiency, lower-cost [ Eftichios Koutroulis et al. , 2001].

**Yeong Chau Kuo et al.** proposed a novel maximum power point tracking (MPPT) controller for a photovoltaic (PV) energy conversion system in 2001. They used the slope of power versus voltage of a PV array, the proposed MPPT controller allowed the conversion system to track the maximum power point very rapidly. As opposed to conventional two-stage designs, a single stage configuration was implemented, resulted in size and weight reduction and increased efficiency. The proposed system acted as a solar generator on sunny days, in addition to working as an active power line conditioner on rainy days. Finally, computer simulations and experimental results demonstrated the superior performance of the proposed technique [Yeong Chau Kuo et al., 2001]

**K. K. Tse et al.** had presented a novel technique for efficiently extracting maximum power from photovoltaic (PV) panels in 2002. The power conversion stage, which was connected between a PV panel and a load or bus, was a SEPIC or converter or their derived circuits operated in discontinuous inductor–current or capacitor– voltage mode. Method of locating the maximum power point (MPP) was based on injecting a small-signal sinusoidal perturbation into the switching frequency and compared the ac component and the average value of the panel terminal voltage. Apart from not requiring any sophisticated digital computation of the panel power, the proposed technique did not approximate the panel characteristics and could even locate the MPP under wide insolation conditions. They had verified tracking capability experimentally with a 10 W solar panel under a controlled experimental setup [K.K.Tse et al., 2002].

**Henry Shu-Hung Chung et al**. had given a novel technique for efficiently extracting the maximum output power from a solar panel under varying meteorological conditions in 2003. The methodology was based on connecting a pulse-width-modulated (PWM) dc/dc SEPIC or converter between a solar panel and a load or battery bus. The converter was operated in discontinuous capacitor voltage mode whilst its input current was continuous. By modulated a small-signal sinusoidal perturbation into the duty cycle of the main switch and compared the maximum variation in the input voltage and the voltage stress of the main switch, the maximum power point (MPP) of the panel could be located. The nominal duty cycle of the main switch in the converter was adjusted to a value, so that the input resistance of the converter was equal to the equivalent output resistance of the solar panel at the MPP. This approach ensured maximum power transfer under all conditions without using microprocessors for calculation. Detailed mathematical derivations of the MPP tracking technique were included. The tracking capability of the proposed technique had been verified experimentally with a 10-W solar panel at different insolation (incident solar radiation) levels and under large-signal insolation level changes [Henry Shu-Hung Shung et al., 2003].

**Z.G. Piao et al.** proposed a 150W solar tracking system in 2003. In solar tracking system, they used DC motors, special motors like stepper motors, servo motors, real time actuators, to operate moving parts. DC motors were normally used to operate solar tracking system but it was highly expensive to maintain and repair. The system was designed as the normal line of the solar cell always moved parallel to the ray of the sun. Designed like this one could minimize the cosign loss of the system [Z.G. Piao et al., 2003].

**A. A.Khalil et al.** had presented experimental investigation of a sun tracking system in 2004. This Tracking system tried to collect the largest amount of solar radiation and converted it into usable form of electrical energy (DC voltage) and stored this energy into batteries for different types of applications. The sun tracking systems could collect more energy than what a fixed panel system collected. Therefore, the proposed system was easy to implement and efficient. The sun tracking system was an efficient system for solar energy collection [A.A. Khalil et al., 2004].

**Kimiyoshi Kohayashi et al.** had given a Novel Optimum Operating Point Tracker of the Solar Cell Power Supply System in 2004. They proposed the dc-dc converter applied the new optimum operating point tracker of the solar array using the pn-junction diodes detector. A Simple and inexpensive optimum operating point tracker had been developed, in which the forward voltage drop of the pn-junction diodes was used as a reference voltage to track the optimum operating voltage. The detection error voltage of the proposed optimum operating tracker of the solar array was within

2.5% and the detection error power was estimated to be negligibly small. The temperature dispersion at the front-side and back-side surfaces of the solar array was within 4degree, and the optimum operating point tracker was achieved by detecting the back-side surface temperature of the solar array with the pn-junction diodes detector. They proposed a new optimum operating point tracker of the solar cell power supply system, in which inexpensive pn-junction diodes were used to generate the reference voltage of the operating point of the solar array. Using this method, the high degree of the solar array optimum point tracking performance could be obtained, even when the light intensity and environmental temperature of the solar array were varied [Kimiyoshi Kohayashi et al., 2004].

**S. Armstrong et al.** had investigated the effectiveness of maximum power point tracking (MPPT) and proposed a quantitative measure of MPPT efficiency in 2005. Used a vector methodology to track the direction and path of the sun throughout the day, the optimal solar tracking angle and angle of incidence of the sun's rays were derived. The solar array's output power was monitored, under sunny sky conditions, with and without the use of maximum power point tracking in order to study the difference in efficiencies and to quantify the benefits of maximum power point tracking. He presented results for the efficiency of MPPT under fixed horizontal solar panel conditions and optimal solar tracking. It had been shown that solar panel east-west tracking combined with maximum power point tracking provided optimum amount of available energy at any time [S. Armstrong et al., 2005]

**S. Shanmugam et al**. had given the tracking of the sun for solar paraboloidal dish concentrators in 2005. Paraboloidal dish concentrators need tracking the sun in the east-west and north-south direction continuously throughout the year but they explained the method of intermittent tracking of the sun in the north-south direction with no tracking in the east-west direction for less energy yield. The frequency of tracking in the north-south direction was determined by the relationship between the variation in solar altitude angle and the size of the absorber in the paraboloidal dish concentrator. A computer program in visual basic was written to enable the detailed calculations of data for the analysis [S.Shanmugam et al., 2005].

**Rong-Jong Wai et al.** had given grid connected photovoltaic (PV) generation system with an adaptive step-perturbation (ASP) method and an active sun tracking scheme in 2006. The ASP method was proposed to achieve the objective of maximum power point tracking (MPPT), and the active sun tracking scheme without any light sensors was investigated to make PV plates to face the sun directly for capturing the maximum irradiation and promoting the system efficiency. The realization of the ASP method provided faster tracking response with 3s settling time and had overcome the oscillation problem in the conventional perturbation and observation (P&O) method for reducing extra power losses. Moreover, the implementation of the active sun tracking scheme on the basis of the open-circuit voltage of PV modules was to improve the generation efficiency of the fixed installation PV array, and to save the cost of the conventional sun tracker with light sensors [Rong -Jong Wai et al, 2006].

**Ross McCluney et al.** presented a new approach to beam day lighting with an active tracking system in 2006 which was capable of illuminating a 1000 square foot area with no glare or localized overheating and with relatively uniform illumination over the course of most of the daylit hours in the day. For good performance at low solar elevation angles, a one-axis tracking system was employed, along with a patent-pending optical system to accommodate changes in solar elevation throughout the day. The design included a glazed collection head on the roof, which redirected incident beam sunlight downward into a reflective light shaft through the ceiling below. A ceiling luminaire distributed this light flux across a diffusely-reflecting white ceiling and into the space below that [Ross McCluney et al., 2006].

**Cemil Sungur** had given the electromechanical control system of a photovoltaic (PV) panel tracking the sun on the axis it moved along according to its azimuth angle in 2007. In this system, Programmable Logic Controls (PLC) was used instead of photosensors which were widely used for tracking the sun. The azimuth angle of the sun from sunrise to sunset times was calculated for each day of the year at 37.6 degrees latitude in the Northern hemisphere, the location of the city where the experiment was conducted. According to this azimuth angle, the required analog signal was taken from the PLC analog module and sent to the actuator motor, which controlled the position of the panel to ensure that the rays fell vertically on the panel. After the mechanical control system of the system was started, the performance measurements of the solar panel were carried out. For this, the necessary measurements were implemented when the solar panel was in a fixed position. Afterwards, the panel was moved on a single axis according to the azimuth angle and the necessary measurements were performed. The values obtained from the measurements were compared and the necessary evaluations were conducted [Cemil Sungur, 2007].

**Omar Aliman et al.** proposed different technique of sun tracking method which was explored to make the construction of the sun tracking with many element mirrors cost effective while maintained a precise sun tracking in 2007. In this new technique, they introduced a new rotational axis to the sun tracking frame, the slave mirrors of the same column or the same row could be arranged to share the same driving device. As it applied a single stage collector replaced conventional double stages structure, the new technique had significantly benefits use in high temperature and high concentration solar energy applications. Meanwhile, the stationary or fixed target (receiver) offered more convenient working environment for various applications. Large and heavy solar powered Stirling Engine could be placed at the stationary location. On the other hand, advantage offered by the new technique, the optical alignment was reasonably easier and less time consuming [Omar Aliman et al., 2007].

**Theerawut Jinayim et al.** proposed an efficient low power consumption tracking solar cells for white LED-based lighting system in 2007. In this system, they used the dc power generated by fixed solar cells module to energize white LED light sources that were operated by directly connected white LED with current limitation resistors, resulted in much more power consumption. They presented the use of white LED as a general lighting application powered by tracking solar cells module and used pulse to apply the electrical power to the white LED. This system resulted in high efficiency power conversion, low power consumption, and long light of the white LED. They considered the solar tracking system and applied for lighting application based on WLED that use Pulse Width Modulation (PWM) technique for WLED circuit driver. It had shown that maximum charging time for tracking system was more than fixed module, so the utilization efficiency of solar cell module was considerably increased. The concept and control principle of directly connected white LED circuit driver with current limitation resistors had low efficiency because most of energy was lost as heat at each resistor. Compared to Pulse Width Modulation (PWM), the average output value was controlled by duty cycle of input pulse. [Theerawut Jinayim et al., 2007]

# CHAPTER 2

# Stepper Motor

## 2.1 Introduction to Stepper Motor

The stepper motor is an electromagnetic device that converts digital pulses into mechanical shaft rotation. The shaft or spindle of a stepper motor rotates in discrete step increments when electrical command pulses are applied to it in the proper sequence. The sequence of the applied pulses is directly related to the direction of motor shafts rotation. The speed of the motor shafts rotation is directly related to the frequency of the input pulses and the length of rotation is directly related to the number of input pulses applied. Many advantages are achieved using this kind of motors, such as higher simplicity, since no brushes or contacts are present, low cost, high reliability, high torque at low speeds, and high accuracy of motion. Many systems with stepper motors need to control the acceleration/ deceleration when changing the speed.

**Figure 2.1: Stepper motor**

## 2.2 Bipolar v/s. Unipolar Stepper Motors

The two common types of stepper motors are the bipolar motor and the unipolar motor. The bipolar and unipolar motors are similar, except that the unipolar has a center tap on each winding. The bipolar motor needs current to be driven in both directions through the windings, and a full bridge driver is needed .The center tap on the unipolar motor allows a simpler driving circuit, limiting the current flow to one direction. The main drawback with the unipolar motor is the limited capability to energize all windings at any time, resulting in a lower torque compared to the bipolar motor. The unipolar stepper motor can be used as a bipolar motor by disconnecting the center tap.

In unipolar there are 5 wires.One common wire and four wires to which power supply has to be given in a serial order to make it drive. Bipolar  can have 6 wires and a pair of wires are given supply at a time to drive it in steps.

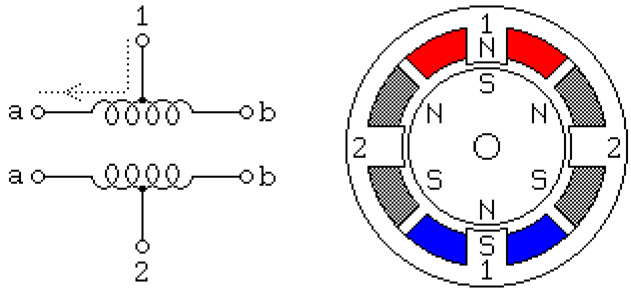


**Figure 2.2: A 2- phase (winding) unipolar Stepper Schematic.**

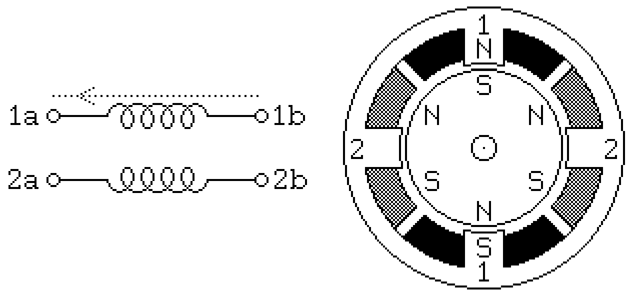


**Figure 2.3: A two phase (winding) bipolar stepper motor.**

## 2.3 Stepper Motor Connection Diagram

The wires from the Logic PCB connector to the stepper motor are as follows


**Figure 2.4:  PCB Connector**

The ULN2003 / MC1413 is a 7-bit 50V 500mA TTL-input NPN darlington driver. This is more than adequate to control a four phase unipolar stepper motor such as the KP4M4-001.

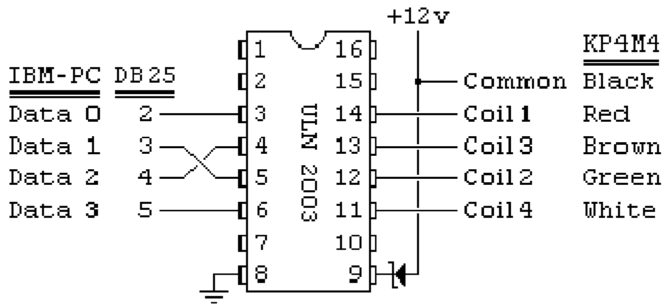


**Figure 2.5: ULN 2003**

It is recommended to connect a 12v zener diode between the power supply and $V_{DD}$ (Pin 9) on the chip, to absorb reverse (or "back") EMF from the magnetic field collapsing when motor coils are switched off.

## 2.4 Driving a Stepper Motor:

1) **Identify the wire** : Common and windings

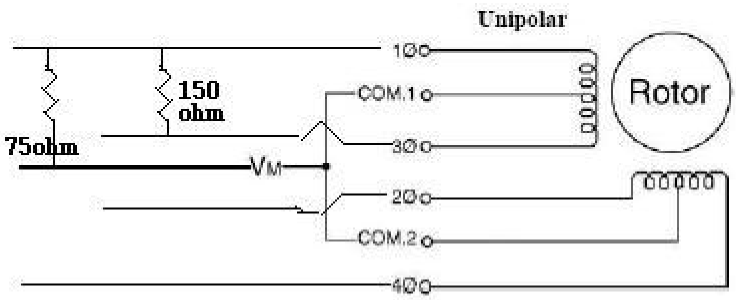


**Figure 2.6: Connection to Identify the common winding**

It has been seen that out of the five wires two are grouped as common. The other four are the windings that have to give supply to. Major crux here is to identify the common line. Just take the multimeter and check the resistance between the wires.Hold one wire a common and it must bear a resistance of 75 ohms with all the other wires then that is the common wire.

## 2.5 Connection of the Circuit:

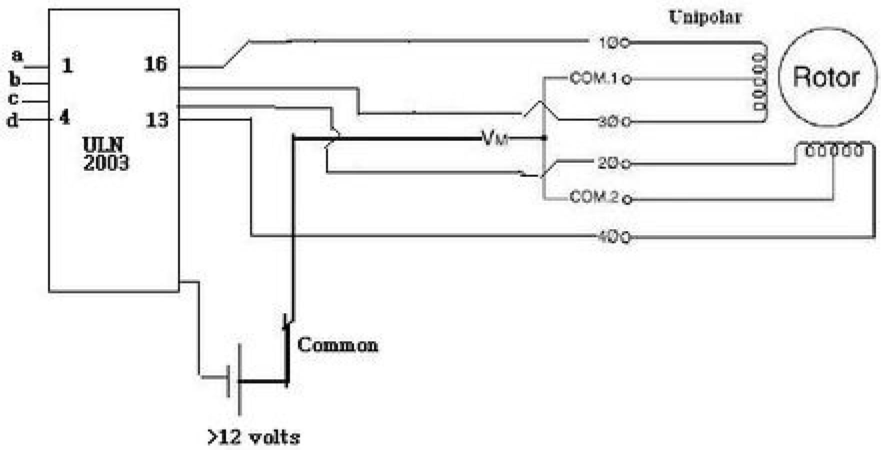


**Figure 2.7: Connection of ULN with motor**

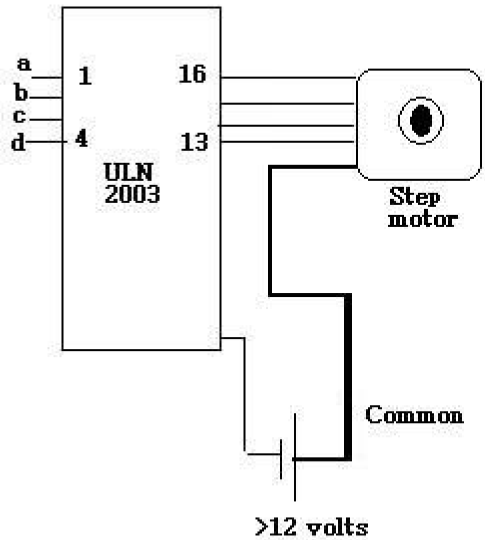


**Figure2.8: Compact design**

Use Microcontroller PIC16F877A to give +5v supply to pins a,b,c,d one by one that's:

a=5v,b=0,c=0,d=0

a=0,b=5v,c=0,d=0

a=0,b=0,c=5v,d=0

a=0,b=0,c=0,d=5v

Then the motor will run.

## 2.6 Unipolar Stepper Motor:

In the construction of unipolar stepper motor there are four coils. One end of each coil is tide together and it gives common terminal which is always connected with positive terminal of supply. The other ends of each coil are given for interface. Specific colour code may also be given. Like in this motor orange is first coil (L1), brown is second (L2), yellow is third (L3), black is fourth (L4) and red for common terminal.

By means of controlling a stepper motor operation we can

- Increase or decrease the RPM (speed) of it
- Increase or decrease number of revolutions of it
- Change its direction means rotate it clockwise or anticlockwise

To vary the RPM of motor we have to vary the PRF (Pulse Repetition Frequency). Number of applied pulses will vary number of rotations and last to change direction we have to change pulse sequence.

So, all these three things just depend on applied pulses. Now there are three different modes to rotate this motor

1. Single coil excitation
2. Double coil excitation
3. Half step excitation

| **Single coil excitation** | | **Double coil excitation** | | **Half step excitation** | |
|---|---|---|---|---|---|
| **Clockwise** | **Anticlockwise** | **Clockwise** | **Anticlockwise** | **Clockwise** | **Anticlockwise** |
| L4 L3 L2L1 | L4 L3 L2 L1 | L4 L3 L2L1 | L4 L3 L2 L1 | L4 L3 L2L1 | L4 L3 L2 L1 |
| 0 0 0 1 | 0 0 0 1 | 0 0 1 1 | 0 0 1 1 | 0001 | 0001 |
| 0 0 1 0 | 1 0 0 0 | 0 1 1 0 | 1 0 0 1 | 0011 | 0011 |
| 0 1 0 0 | 0 1 0 0 | 1 1 0 0 | 1 1 0 0 | 0010 | 1000 |
| 1 0 0 0 | 0 0 1 0 | 1 0 0 1 | 0 1 1 0 | 0110 | 1001 |
| | | | | 0100 | 0100 |
| | | | | 1100 | 1100 |
| | | | | 1000 | 0010 |
| | | | | 1001 | 0110 |

**Table 2.1: Sequence of giving pulses to motor**

In half step excitation mode motor will rotate at half the specified given step resolution. Means if step resolution is 1.8 degree then in this mode it will be 0.9 degree. Step resolution means on receiving on 1 pulse motor will rotate that much degree. If step resolution is 1.8 degree then it will take 200 pulses for motor to compete 1 revolution (360 degree).

Specification of the stepper motor:

Max rated current per coil: 0.75 Ampere, unipolar, 6 wires

The motors rotation has several direct relationships to these applied input pulses. The sequence of the applied pulses is directly related to the direction of motor shafts rotation. The speed of the motor shafts rotation is directly related to the frequency of the input pulses and the length of rotation is directly related to the number of input pulses applied.

## 2.7 Stepper Motor Advantages and Disadvantages

Advantages:

1. The rotation angle of the motor is proportional to the input pulse.
2. The motor has full torque at standstill (if the windings are energized)
3. Precise positioning and repeatability of movement since good stepper motors have an accuracy of 3 – 5% of a step and this error is non cumulative from one step to the next.
4. Excellent response to starting/ stopping/reversing.
5. Very reliable since there are no contact brushes in the motor. Therefore, the life of the motor is simply dependant on the life of the bearing.
6. The motors response to digital input pulses provides open-loop control, making the motor simpler and less costly to control.
7. It is possible to achieve very low speed synchronous rotation with a load that is directly coupled to the shaft.
8. A wide range of rotational speeds can be realized as the speed is proportional to the frequency of the input pulses.

Disadvantages:

1. Resonances can occur if not properly controlled.
2. Not easy to operate at extremely high speeds.

## 2.8 Open Loop Operation

One of the most significant advantages of a stepper motor is its ability to be accurately controlled in an open loop system. Open loop control means no feedback information about position is needed. This type of control eliminates the need for expensive sensing and feedback devices such as optical encoders. Position of stepper motor is known simply by keeping track of the input step pulses.

## 2.9 Stepper Motor Types

There are three basic stepper motor types. They are:

- Variable-reluctance
- Permanent-magnet
- Hybrid

### 2.9.1 Variable-reluctance (VR)

This type of stepper motor has been around for a long time. It is probably the easiest to understand from a structural point of view. This type of motor consists of a soft iron multi-toothed rotor and a wound stator. When the stator windings are energized with DC current the poles become magnetized. Rotation occurs when the rotor teeth are attracted to the energized stator poles.

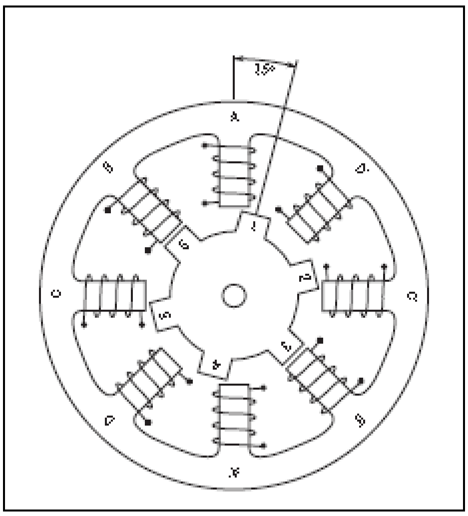


**Figure 2.9: Cross section of a variable reluctance motor.**

### 2.9.2 Permanent Magnet (PM)

Often referred to as a “tin can” or “canstock” motor the permanent magnet step motor is a low cost and low resolution type motor with typical step angles of 7.5° to 15°. (48 – 24 steps/revolution) PM motors as the motor name implies have permanent magnets added to the motor structure. The rotor no longer has teeth as with the VR motor. Instead the rotor is magnetized with alternating north and south poles situated in a straight line parallel to the rotor shaft. These magnetized rotor poles provide an increased magnetic flux intensity and because of this the PM motor exhibits improved torque characteristics when compared with the VR type.

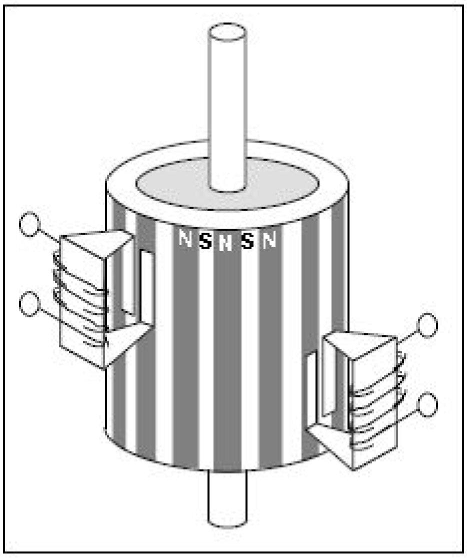


**Figure 2.10: Principle of a PM type stepper motor.**

### 2.9.3 Hybrid (HB)

The hybrid stepper motor is more expensive than the PM stepper motor but provides better performance with respect to step resolution, torque and speed. Typical step angles for the hybrid stepper motor, range from 3.6° to 0.9° (100 – 400 steps per revolution). The hybrid stepper motor combines the best features of both the PM and VR type stepper motors. The rotor is multi-toothed like the VR motor and contains an axially magnetized concentric magnet around its shaft. The teeth on the rotor provide an even better path which helps guide the magnetic flux to preferred locations in the airgap. This further increases the detent, holding and dynamic torque characteristics of the motor when compared with both the VR and PM types.

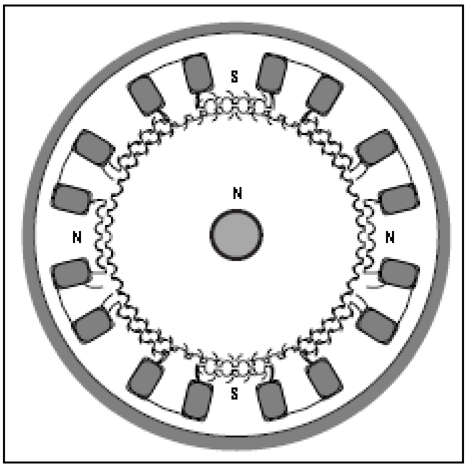


**Figure 2.11: Cross section of hybrid stepper motor.**

## 2.10 Applications of Stepper Motor

A stepper motor can be a good choice whenever controlled movement is required. They can be used to advantage in applications where you need to control rotation angle, speed, position and synchronism. Because of the inherent advantages listed previously, stepper motors have found their place in many different applications. Some of these include printers, plotters, high end office equipment, hard disk drives, medical equipment, fax machines, automotive and many more.

## 2.11 The Rotating Magnetic Field

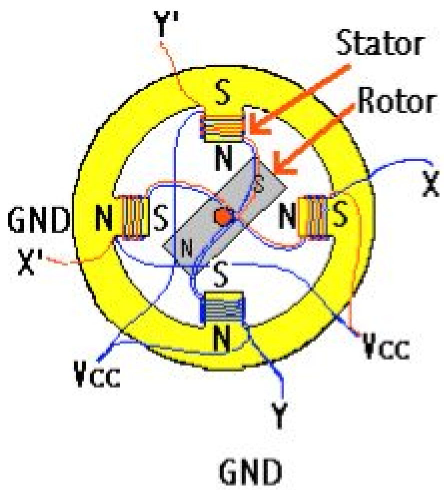


**Figure 2.12: Magnetic field rotation in Stepper Motor**

When a phase winding of a stepper motor is energized with current a magnetic flux is developed in the stator. The direction of this flux is determined by the "Right Hand Rule" which states:

“If the coil is grasped in the right hand with the fingers pointing in the direction of the current in the winding (the thumb is extended at a 90° angle to the fingers), then the thumb will point in the direction of the magnetic field. The rotor then aligns itself so that the flux opposition is minimized. In this case the motor would rotate clockwise so that its south pole aligns with the north pole of the stator and its north pole aligns with the south pole of stator. To get the motor to rotate we must provide a sequence of energizing the stator windings in such a fashion that provides a rotating magnetic flux field which the rotor follows due to magnetic attraction.

## 2.12 Torque Generation

The torque produced by a stepper motor depends on several factors:

- The step rate
- The drive current in the windings
- The drive design or type

In a stepper motor a torque is developed when the magnetic fluxes of the rotor and stator are displaced from each other. The stator is made up of a high permeability magnetic material. The presence of this high permeability material causes the magnetic flux to be confined for the most part to the paths defined by the stator structure in the same fashion that currents are confined to the conductors of an electronic circuit. This serves to concentrate the flux at the stator poles. The torque output produced by the motor is proportional to the intensity of the magnetic flux generated when the winding is energized.

The basic relationship which defines the intensity of the magnetic flux is defined by:

$H = (N * i) / l$

Where:

N = Number of winding turns

i = Current

H = Magnetic field intensity

l = Magnetic flux path length

This relationship shows that the magnetic flux intensity and consequently the torque is proportional to the number of winding turns and the current and inversely proportional to the length of the magnetic flux path. It has been seen that the same frame size stepper motor could have very different torque output capabilities simply by changing the winding parameters.

## 2.13 Phases, Poles and Stepping Angles

Usually stepper motors have two phases, but three- and five-phase motors also exist. A bipolar motor with two phases has one winding/phase and a unipolar motor has one winding, with a center tap per phase. Sometimes the unipolar stepper motor is referred to as a “four phase motor”, even though it has only two phases. Motors that have two separate windings per phase also exist—these can be driven in either bipolar or unipolar mode. A pole can be defined as one of the regions in a magnetized body where the magnetic flux density is concentrated. Both the rotor and the stator of a step motor have poles.

In reality several more poles are added to both the rotor and stator structure in order to increase the number of steps per revolution of the motor, or in other words to provide a smaller basic (full step) stepping angle. The permanent magnet stepper motor contains an equal number of rotor and stator pole pairs. Typically the PM motor has 12 pole pairs. The stator has 12 pole pairs per phase. The hybrid type stepper motor has a rotor with teeth. The rotor is split into two parts, separated by a permanent magnet making half of the teeth south poles and half north poles. The number of pole pairs is equal to the number of teeth on one of the rotor halves. The stator of a hybrid motor also has teeth to build up a higher number of equivalent poles (smaller pole pitch, number of equivalent poles = 360/teeth pitch) compared to the main poles, on which the winding coils are wound. It is the relationship between the number of rotor poles and the equivalent stator poles, and the number the number of phases that determines the full-step angle of a stepper motor.

**Step Angle :** The angle with which the stepper motor turns for a single pulse if supply to one wire or a pair is called step angle.

$$Stepangle = \frac{360}{N_{Ph} * Ph} = \frac{360}{N}$$

$N_{Ph}$ = Number of equivalent poles per

Phase = number of rotor poles

Ph = Number of phases

N = Total number of poles for all phases together

If the rotor and stator tooth pitch is unequal, a more-complicated relationship exist

# CHAPTER 3

# Hardware and Embedded Software

## 3.1 PIC Microcontroller

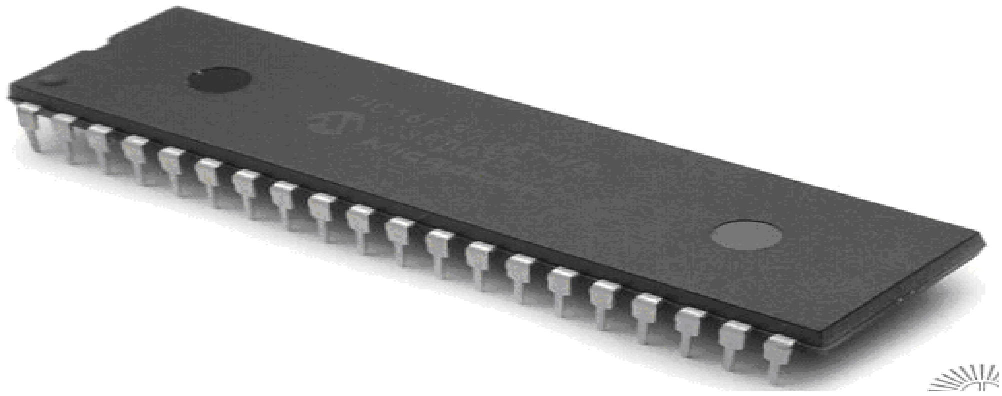

**Figure3.1: PIC 16F877A Microcontroller**

PIC is a family of Harvard architecture microcontrollers made by microchip technology, derived from the PIC1640 originally developed by general instrument's microelectronics divison. The name PIC initially referred to "Programmable interface controller", but shortly thereafter was renamed as "programmable intelligent computer". PIC is popular due to their low cost ,wide availability ,large user base, extensive collection of application notes ,availability of low cost or free development tools and serial programming (and re-programming with flash memory) capability.

## 3.2 Core Architecture of 8-bit CPUs

The PIC architecture is distinctively minimalist .It is characterized by the following features:

1. Separate code and data spaces(Harvard architecture)
2. A small number fixed length instructions.
3. Most instructions are simple cycle execution (4 clock cycles) with single delay cycles upon branches and skips.
4. A single accumulator (W), the use of which (as source operand) is implied (i.e is not encoded in the opcode).
5. All RAM location function as registers as both source and/or destination of math and other functions.

6. A hardware stack for storing return addresses.
7. A fairly small amount of addressable data space (typically 256 bytes),extended through banking
8. Data space mapped CPU, port and peripheral registers
9. The program counter is also mapped into the data space and writable (this is used to implement indirect) unlike most other CPU's ,there is no distinction 'memory" and "register" space because the RAM serves the job of both memory and registers and the RAM is usually just referred to as the register file or simply as the registers.

## 3.3 Architecture of the PIC microcontroller

**Harvard architecture**

Harvard architecture is newer concept than Von-Neumann's. It rose out of the need to speed up the work of the microcontroller. In Harvard architecture, data bus and address bus are separate .Thus a greater flow of data is possible through the central processing unit ,and of course ,a greater speed of work .Separating a program from data memory makes it further possible for instructions not to have to be 8-bit words. PIC 16F877 uses 14 bits for instructions which allows for all instructions to be one word instructions. It is also typical for Harvard architecture to have fewer instructions to be one word instructions. It is also typical for Harvard architecture to have fewer instructions than Von Neumann's and to have instructions to be executed in one cycle. The major advantage with this architecture is that while an instruction is being executed the next can be fetched .The execution speed is doubled .We find this architecture in PIC16F877A.

PIC uses Harvard architecture, so the size of an instruction can be different from the size of the data.

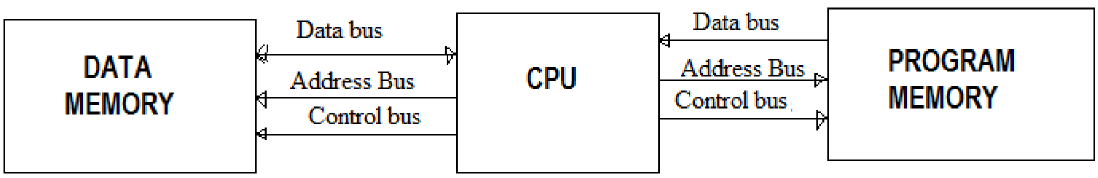


**Figure3.2: Harvard Architecture**

PIC 16F877A is one of the most commonly used microcontrollers especially in automotive ,industrial ,appliances and consumer applications .PIC16F877A is at the upper end of the mid range series of the microcontrollers developed by microchip Inc. It can be reprogrammed and erased upto 10,000 times .Therefore it is very good for new product development phase.

## 3.4 PIC16F877A pin Layout

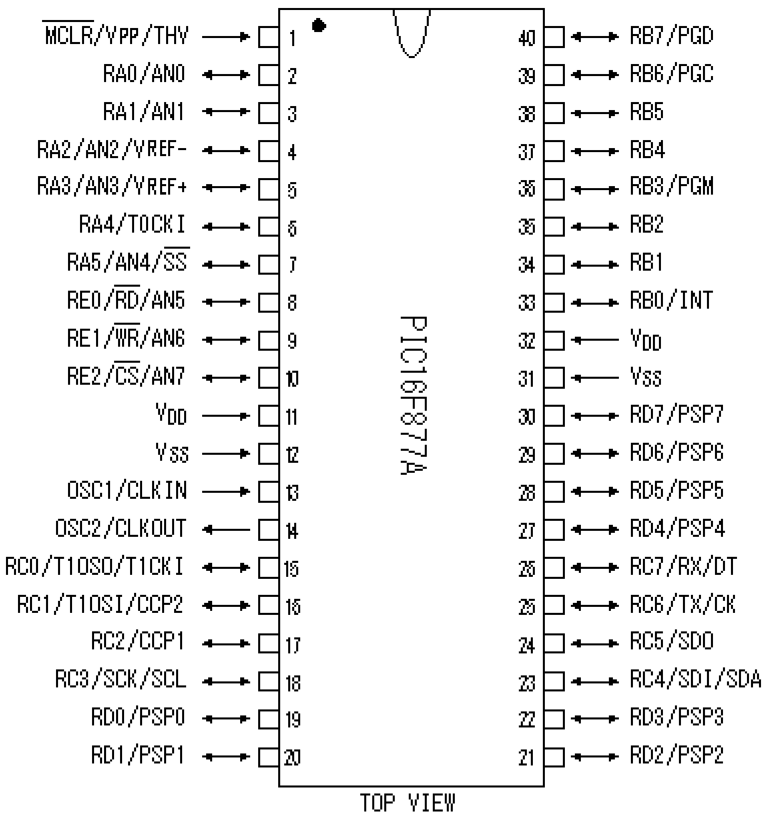


**Figure 3.3: Pin Diagram**

## I/O Pins

There are 40 pins on PIC 16F877A. Most of them can be used as an I/O pin. Others are for specific functions.

## $V_{SS}$ and $V_{DD}$

These are power supply pins .$V_{DD}$ is the positive supply and $V_{SS}$ is the negative supply or 0V.The maximum supply voltage that you can use is 6V and the minimum is 2V.

## MCLR

Master clear (reset) input. This pin is an active low to the device. This pin is used to erase the memory locations inside the PIC (i.e. when we want to re-program it).In normal use it is connected to the positive supply rail.

## OSC1/CLK IN and OSC2/CLKOUT

These are oscillator crystal input and output. These pins are where we connect an external clock, so that the microcontroller has some kind of timing. These are connected to crystal or resonator in crystal oscillator mode.

## 3.5 Features of PIC 16F877A

| | |
|---|---|
| FLASH Program Memory (14-bit word) | 8K Words |
| Data Memory (RAM) | 368 Bytes |
| Data Memory (EEPROM) | 256 Bytes |
| Interrupts | 14 |
| I/O Ports | Ports A, B, C, D, E |
| Timers | 3 |
| Capture/Compare/PWM Modules | 2 |
| Serial Communications | MSSP, USART |
| Package | 40 Pin DIP |
| A/D Channels | 8(10 Bit) |

**Table 3.1 Key features of PIC**

## 3.6 Introduction to ADC

The analog-to-digital (A/D) converter module can have up to eight analog inputs for a device. The analog input charges a sample and hold capacitor. The output of the sample and hold capacitor is the input into the converter. The converter then generates a digital result of this analog level via successive approximation. This A/D conversion, of the analog input signal, results in a corresponding 10-bit digital number. The analog reference voltages (positive and negative supply) are software selectable to either the device's supply voltages (AVDD, AVss) or the voltage level on the AN3/VREF+ and AN2/VREFpins. The A/D converter has a unique feature of being able to operate while the device is in SLEEP mode.

The A/D module has four registers. These registers are:

• A/D Result High Register (ADRESH)

• A/D Result Low Register (ADRESL)

• A/D Control Register0 (ADCON0)

• A/D Control Register1 (ADCON1)

The ADCON0 register, shown in Figure, controls the operation of the A/D module. TheADCON1 register, shown in Figure, configures the functions of the port pins. The port pins can be configured as analog inputs (AN3 and AN2 can also be the voltage references) or as digital.

## 3.7 Control Register

**ADCON0 Register**

| R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | U-0 | R/W-0 |
|---|---|---|---|---|---|---|---|
| ADCS1 | ADCS0 | CHS2 | CHS1 | CHS0 | GO/DONE | ____ | ADON |
| bit 7 | | | | | | | bit 0 |

**Figure3.4: ADCON register**

bit 7-6 **ADCS1:ADCS0**: A/D Conversion Clock Select bits

00 = FOSC/2

01 = FOSC/8

10 = FOSC/32

11 = FRC (clock derived from the internal A/D RC oscillator)

bit 5-3 **CHS2:CHS0**: Analog Channel Select bits

000 = channel 0, (AN0)

001 = channel 1, (AN1)

010 = channel 2, (AN2)

011 = channel 3, (AN3)

100 = channel 4, (AN4)

101 = channel 5, (AN5)

110 = channel 6, (AN6)

111 = channel 7, (AN7)

Note: For devices that do not implement the full 8 A/D channels, the unimplemented selections are reserved. It is recommended not to select any unimplemented channel.

bit 2 **GO/DONE**: A/D Conversion Status bit

When ADON = 1

1 A/D conversion in progress (setting this bit starts the A/D conversion which is automatically cleared by hardware when the A/D conversion is complete)

0 A/D conversion not in progress

bit 1 **Unimplemented**: Read as '0'

bit 0 **ADON**: A/D On bit

1 A/D converter module is powered up

0 A/D converter module is shut off and consumes no operating current

R Readable bit

W Writable bit

U Unimplemented Bit, read as ‘0’ –n = Value at POR reset.

## 3.8 Analog to Digital Converter Module

The Analog-to-Digital (A/D) Converter module has five inputs for the 28-pin devices and eight for the 40/44-pin devices. The conversion of an analog input signal results in a corresponding 10-bit digital number. The A/D module has high and low-voltage reference input that is software selectable to some combination of VDD, VSS, RA2 or RA3. The A/D converter has a unique feature of being able to operate while the device is in Sleep mode. To operate in Sleep, the A/D clock must be derived from the A/D’s internal RC oscillator.

The ADCON0 register controls the operation of the A/D module. The ADCON1 register configures the functions of the port pins. The port pins can be configured as analog inputs (RA3 can also be the voltage reference) or as digital I/O.

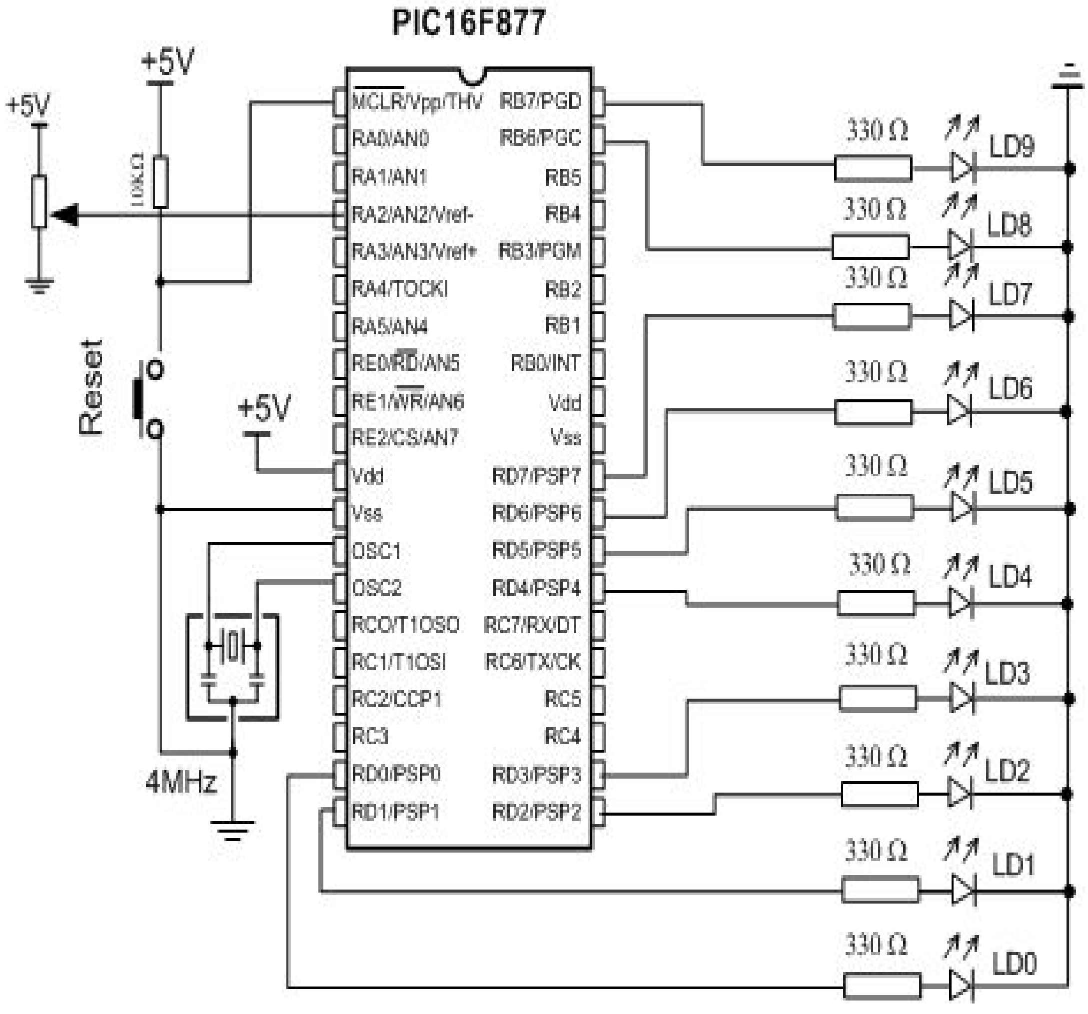


**Figure 3.5: ADC HW connection**

## 3.9 Introduction to mikroC

MikroC is a powerful, feature rich development tool for PIC micros. It is designed to provide the customer with the easiest possible solution for developing applications for embedded systems, without compromising performance or control. MikroC provides a successful match featuring highly advanced IDE, ANSI compliant compiler, broad set of hardware libraries, comprehensive documentation, and plenty of ready-to-run examples.

PIC and C fit together well: PIC is the most popular 8-bit chip in the world, used in a wide variety of applications, and C, prized for its efficiency, is the natural choice for developing embedded systems. It develops applications quickly and easily with the world's most intuitive C compiler for PIC Microcontrollers (families PIC12, PIC16, and PIC18). Highly sophisticated IDE provides the power which is needed with the simplicity of a windows based point-and-click environment. With useful implemented tools, many practical code examples, broad set of built-in routines, and a comprehensive Help, mikroC makes a fast and reliable tool.

MikroC allows developing and deploying complex applications:

- Write C source code using the highly advanced Code Editor.
- Use the included MikroC libraries to dramatically speed up the development: data acquisition, memory, displays, conversions, communications…
- Monitor program structure, variables, and functions in the Code Explorer.
- Generate commented, human-readable assembly, and standard HEX compatible with all programmers.
- Inspect program flow and debug executable logic with the integrated Debugger. Get detailed reports and graphs on code statistics, assembly listing, calling tree…

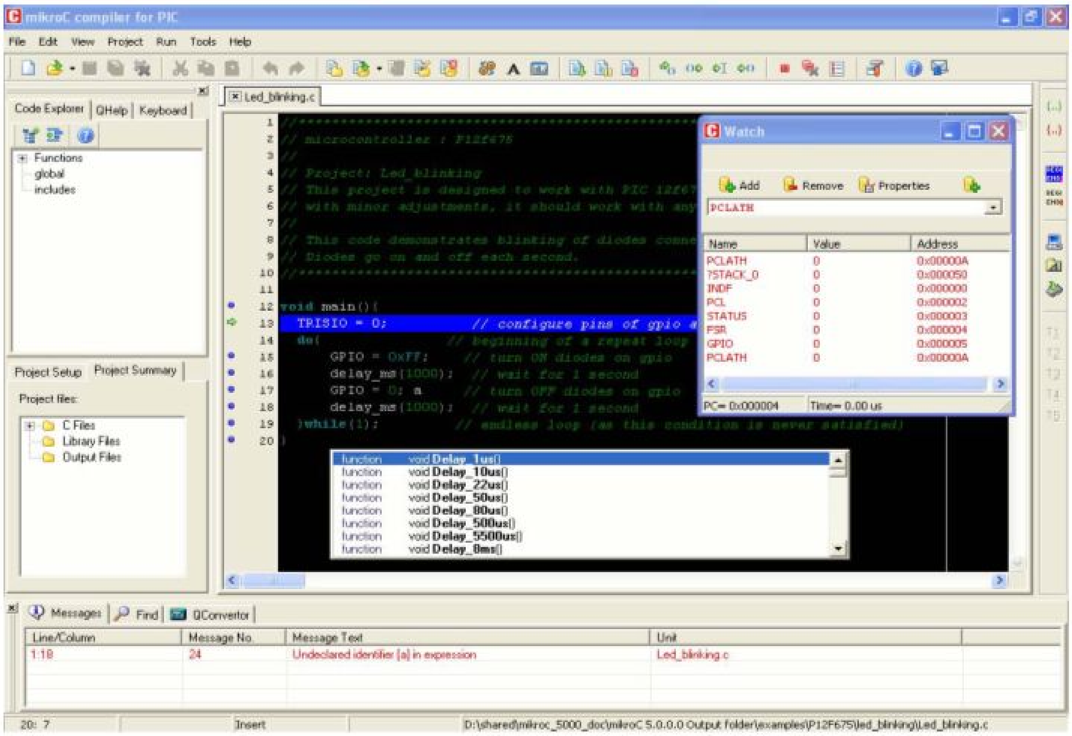


**Figure 3.6: MikroC window**

## 3.10 MikroC IDE

MikroC IDE has seven different parts through which we can make the projects. These are Code Editor, Code Explorer, Debugger, Error window, Statistics, Integrated tools, keyboard shortcuts.

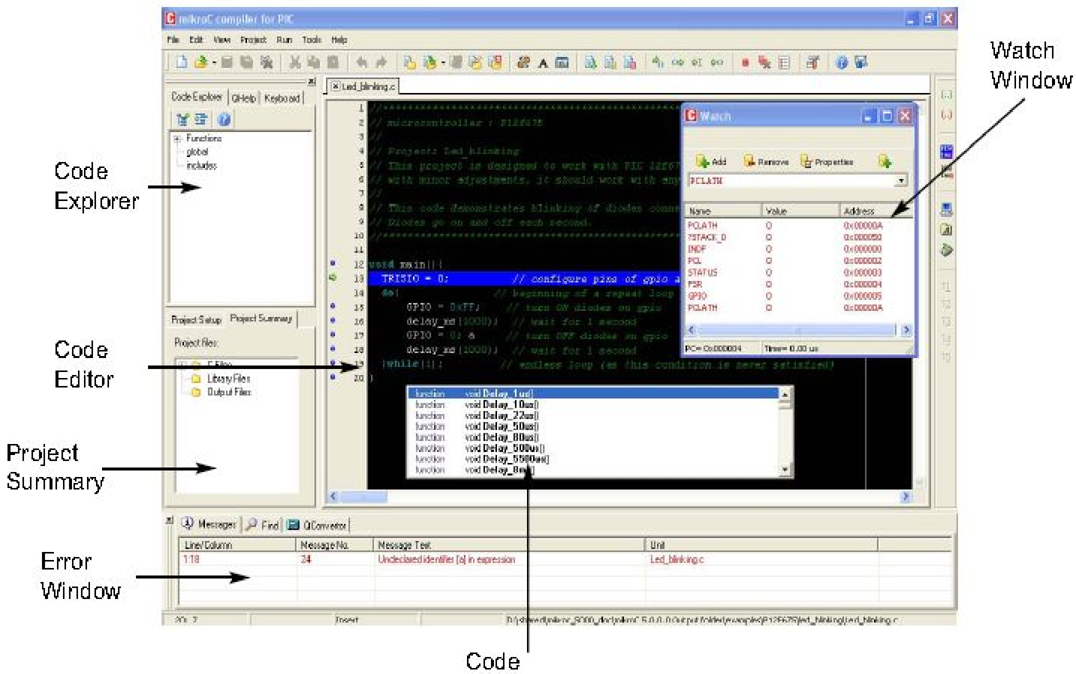


**Figure 3.7: Various parts of mikroC IDE**

### 3.10.1 Code Editor

The Code Editor is an advanced text editor fashioned to satisfy the needs of professionals. General code editing is same as working with any standard text-editor, including familiar Copy, Paste, and Undo actions, common for Windows environment. Advanced editor features include: Adjustable Syntax Highlighting, Code Assistant, Parameter Assistant, Code Templates (Auto Complete), Auto Correct for common types, Bookmarks and Go to Line.

Customize these options from the Editor Settings dialog. To access the settings, choose Tools > Options from the drop-down menu, or click the Tools icon.

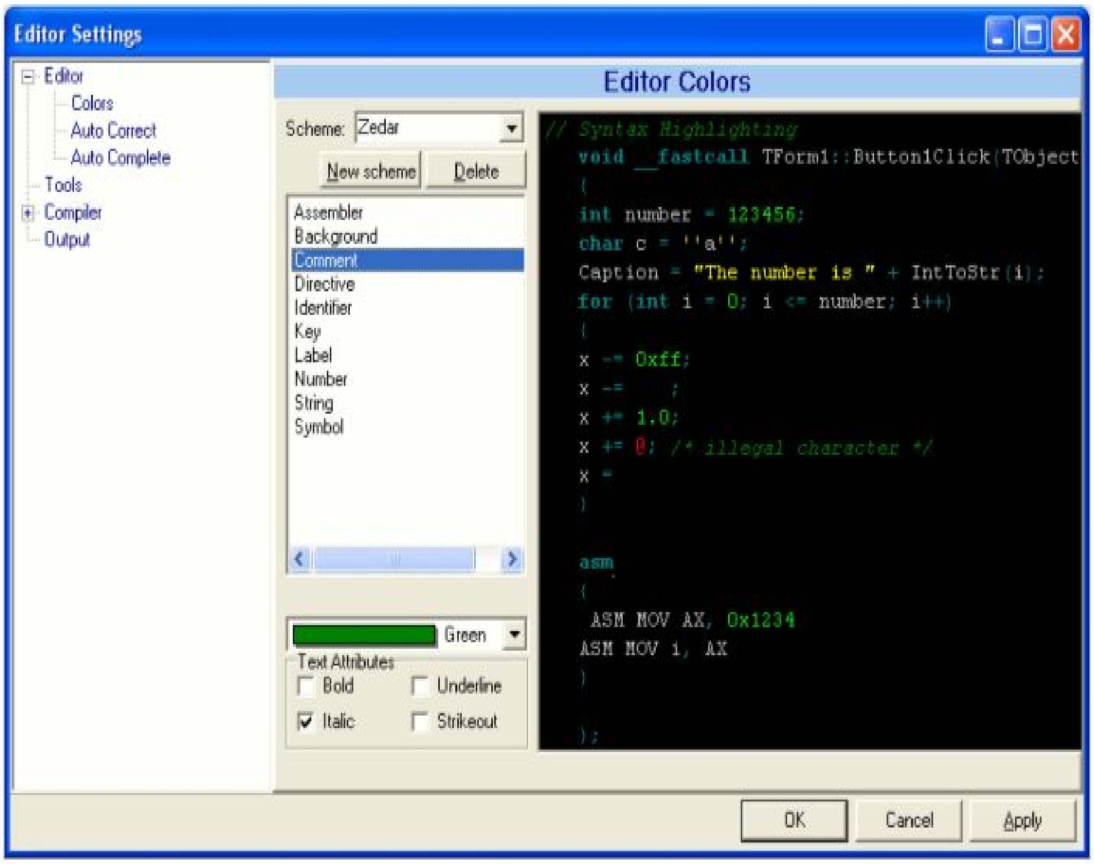


**Figure 3.8: Code editor**

### 3.10.2 Code Explorer

The Code Explorer is placed to the left of the main window by default, and gives a clear view of every declared item in the source code. It is possible to jump to a declaration of any item by clicking it, or by clicking the Find Declaration icon. To expand or collapse tree view in Code Explorer, use the Collapse/Expand all icon. Also, two more tabs are available in Code Explorer. Q Help Tab lists all the available built-in and library functions, for a quick reference. Double-clicking a routine in QHelp Tab opens the relevant Help topic. Keyboard Tab lists all the available Collapse/Expand keyboard shortcuts in mikroC.

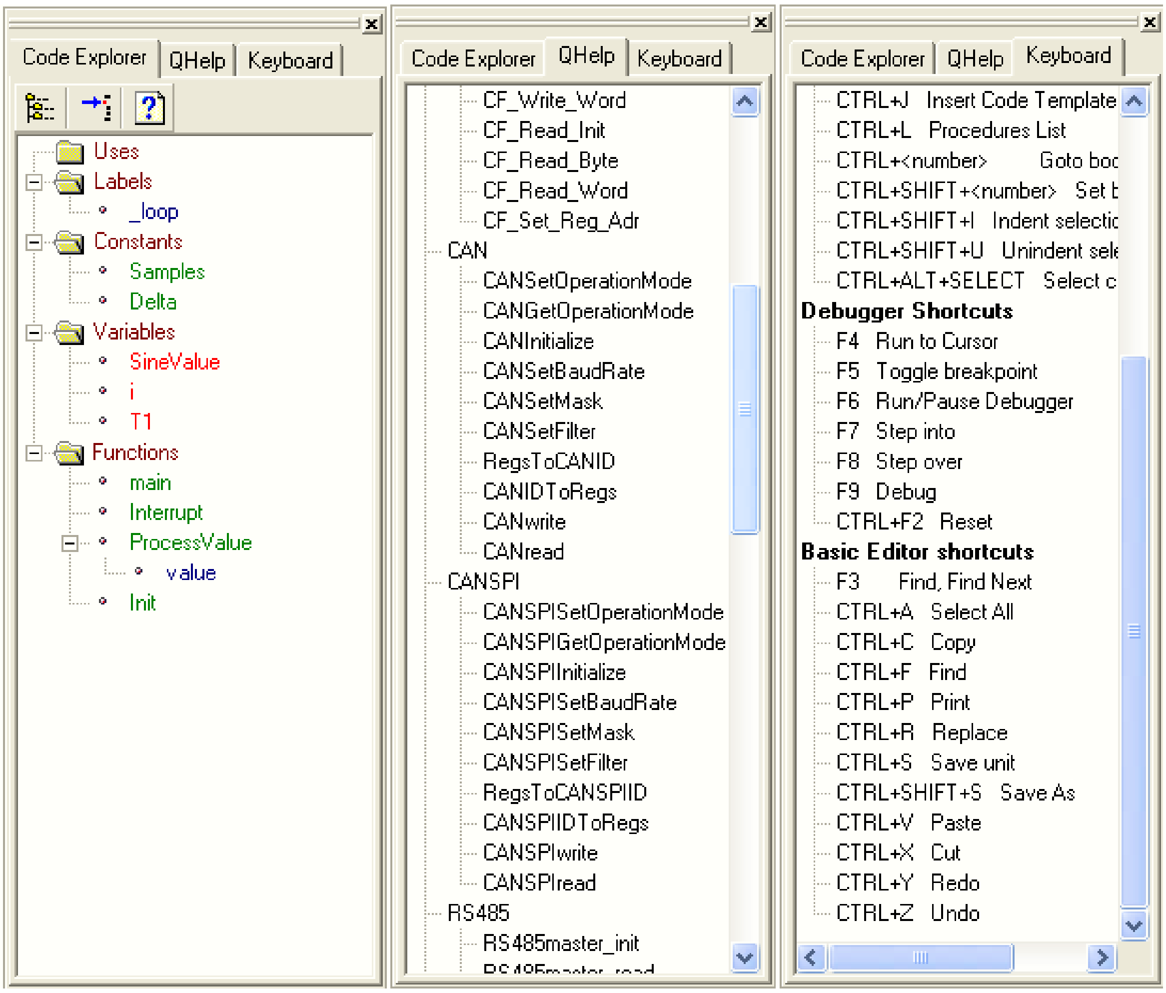


**Figure 3.9: Code Explorer**

### 3.10.3 Debugger

The source-level Debugger is an integral component of mikroC development environment. It is designed to simulate operations of Microchip Technology's PIC micros and to assist users in debugging software written for these devices. Start Debugger -The Debugger simulates program flow and execution of instruction lines, but does not fully emulate PIC device behavior: it does not update timers, interrupt flags, etc. After successfully compiled project, we can run the Debugger by selecting Run > Debug from the drop-down menu, or by clicking the Debug Icon. Starting the Debugger makes more options available: Step Into, Step Over, Run to Cursor, etc. Line that is to be executed is color highlighted. Debug [F9] -Start the Debugger. Run/Pause Debugger [F6].

### 3.10.4 Error Window

In case the errors are encountered during compiling, the compiler will report and won't generate a hex file. The Error Window will be prompted at the bottom of the main window by default. The Error Window is located under the message tab, and displays location and type of errors compiler has encountered.

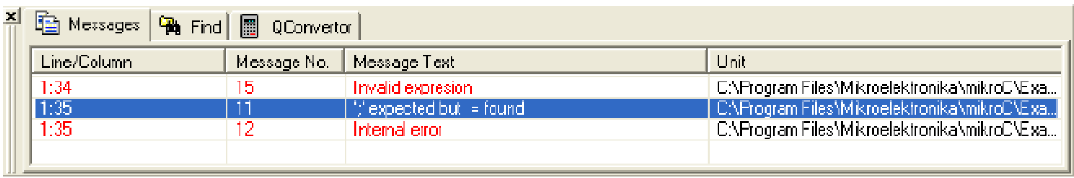


**Figure3.10: Error window**

The compiler also reports warnings, but these do not affect the output; only errors interfere with generation of hex.

### 3.10.5 Statistics

After successful compilation, review statistics of the code. Select Project > View Statistics from the drop-down menu, or click the Statistics icon. There are six tab windows: one of them is Memory Usage Window that Provides overview of RAM and ROM memory usage in form of histogram. Procedures (Graph) Window Displays functions in form of histogram, according to their memory allotment.

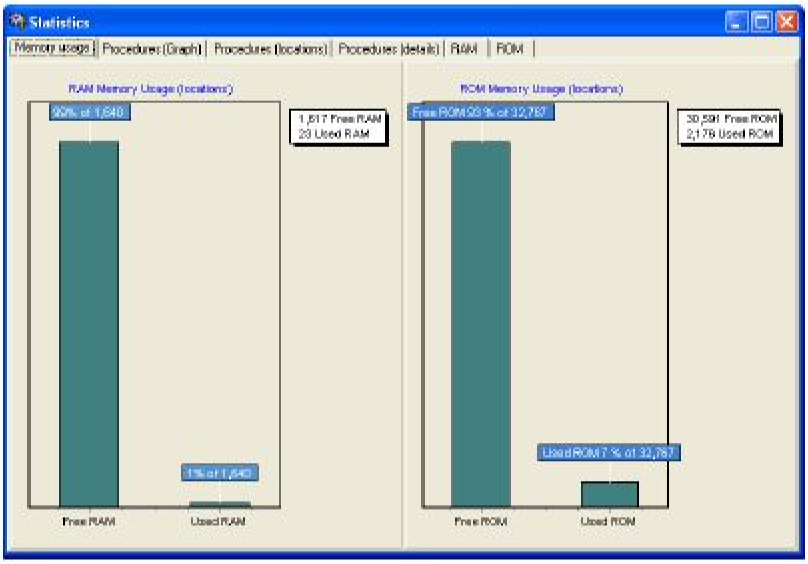


**Figure3.11: Memory usage window**

### 3.10.6 Integrated tools

These contain 4 integrated tools.

1. USART Terminal - mikroC includes the USART (Universal Synchronous asynchronous Receiver Transmitter) communication terminal for RS232 communication. We can launch it from the drop-down menu Tools > Terminal or by clicking the Terminal icon.
2. ASCII Chart - The ASCII Chart is a handy tool, particularly useful when working with LCD display. Launch it from the drop-down menu Tools > ASCII chart.
3. 7 Segment Display Decoder -The 7seg Display Decoder is a convenient visual panel which returns decimal/hex value for any viable combination to display on 7seg. Click on the parts of 7 segment image to get the desired value in the edit boxes. It can be launched from the drop-down menu Tools > 7 Segment display.
4. EEPROM Editor -EEPROM Editor allows user to easily manage EEPROM of PIC microcontroller.

### 3.10.7 Keyboard Shortcuts

Below is the complete list of keyboard shortcuts available in mikroC IDE. Keyboard shortcuts in Code Explorer window can be viewed, tab Keyboard.

### 3.10.7.1 IDE Shortcuts

| | |
|---|---|
| F1 | Help |
| CTRL+N | New Unit |
| CTRL+O | Open |
| CTRL+F9 | Compile |
| CTRL+F11 | Code Explorer on/off |
| CTRL+SHIFT+F5 | View breakpoints |

**Table3.2 IDE Shortcuts**

### 3.10.7.2 Basic Editor Shortcuts

| | |
|---|---|
| F3 | Find, Find Next |
| CTRL+A | Select All |
| CTRL+C | Copy |
| CTRL+F | Find |
| CTRL+P | Print |
| CTRL+R | Replace |
| CTRL+S | Save unit |
| CTRL+SHIFT+S | Save As |
| CTRL+V | Paste |
| CTRL+X | Cut |
| CTRL+Y | Redo |
| CTRL+Z | Undo |

**Table 3.3 Basic Editor Shortcuts**

### 3.10.7.3 Advanced Editor Shortcuts

| | |
|---|---|
| CTRL+SPACE | Code Assistant |
| CTRL+SHIFT+SPACE | Parameters Assistant |
| CTRL+D | Find declaration |
| CTRL+G | Goto line |
| CTRL+J | Insert Code Template |
| CTRL+<number> | Goto bookmark |
| CTRL+SHIFT+<number> | Set bookmark |
| CTRL+SHIFT+I | Indent selection |
| CTRL+SHIFT+U | Unindent selection |
| CTRL+ALT+SELECT | Select columns |

**Table 3.4 Advanced editor Shortcuts**

### 3.10.7.4 Debugger Shortcuts

| | |
|---|---|
| F4 | Run to Cursor |
| F5 | Toggle breakpoint |
| F6 | Run/Pause Debugger |
| F7 | Step into |
| F8 | Step over |
| F9 | Debug |
| CTRL+F2 | Reset |

**Table 3.5 Debugger Shortcuts**

## 3.11 Building Application

Creating applications in mikro C is easy and intuitive. Project Wizard allows to set up the project in just few clicks: name the application, select chip, set flags, and get going. MikroC allows distributing the projects in as many files as we find appropriate. We can then share mikro C compiled Libraries (.mcl files) with other .mcl developers without disclosing the source code. The best part is that bundles created by mikro Pascal or mikro Basic can be used.

## 3.12 MikroC language Reference

C offers unmatched power and flexibility in programming microcontrollers. MikroC adds even more power with an array of libraries, specialized for PIC hardware modules and communications. Along with the specifics of programming PIC microcontrollers, this can help to learn and recollect C syntax.

## 3.13 Mikro C libraries

MikroC provides a number of built-in and library routines which help to develop the application faster and easier. Libraries for ADC, CAN, USART, SPI, I2C, 1-Wire, LCD, PWM, RS485, numeric formatting, bit manipulation, and many other are included along with practical, ready-to-use code examples.

# CHAPTER 4
# Control Strategy

## 4.1 Problem Statement

In remote areas the sun is a cheap source of electricity because instead of hydraulic generators it uses solar cells to produce electricity. While the output of solar cells depends on the intensity of sunlight and the angle of incidence, it means to get maximum efficiency; the solar panels must remain in front of sun during the whole day. But due to rotation of earth those panels can't maintain their position always in front of sun. This problem results in decrease of their efficiency. Thus to get a constant output, an automated system is required which should be capable to constantly rotate the solar panel to receive maximum solar energy. The Automatic Solar Radiation Tracking System is one of the proven methods to get around this problem.

## 4.2 Proposed area of Research

Unlike other designs, this tracker utilizes the solar module itself as a sensor to determine which part of the sky will deliver the most power to the load. Sun position is determined by measuring the in circuit current of the solar module during the "sky scanning" phase of the trackers movement. The point of travel, which gives the highest in circuit current, is logged in the trackers microcontroller and this point is then targeted. Using the Photovoltaic module itself as the sensors means that there are no other external sensors required and therefore the cost and complexity of the device are lowered. After careful consideration of the forms of tracking available and the methods of implementing each, it has been decided that the preferred tracking system is built around a microcontroller based dynamic tracking system using stepper motors for alignment.

## 4.3 Definition of Research Project

The objective of this thesis is to design an Automatic solar radiation tracker. The concise definition of this system is to design and develop a prototype of microcontroller controlled solar array that actively tracks the sun so that maximum power is received by the array at all time of the day.

## 4.4 Problem Solution

Polycrystalline photovoltaic module is used in this system and it is designed to track the maximum sunlight by stepping motor that is commanded by PIC microcontroller to get the maximum energy out of it. The energy received by the solar panel depends on the atmospheric conditions too. For example, when outside is cloudy, the solar energy received goes down to 10% from its initial value; in this situation it is not advisable to move the solar panel. The algorithm presented by us can foresee such a situation in which the program hibernate control action till the sun reappears.

## 4.5 Block Diagram of the hardware design:

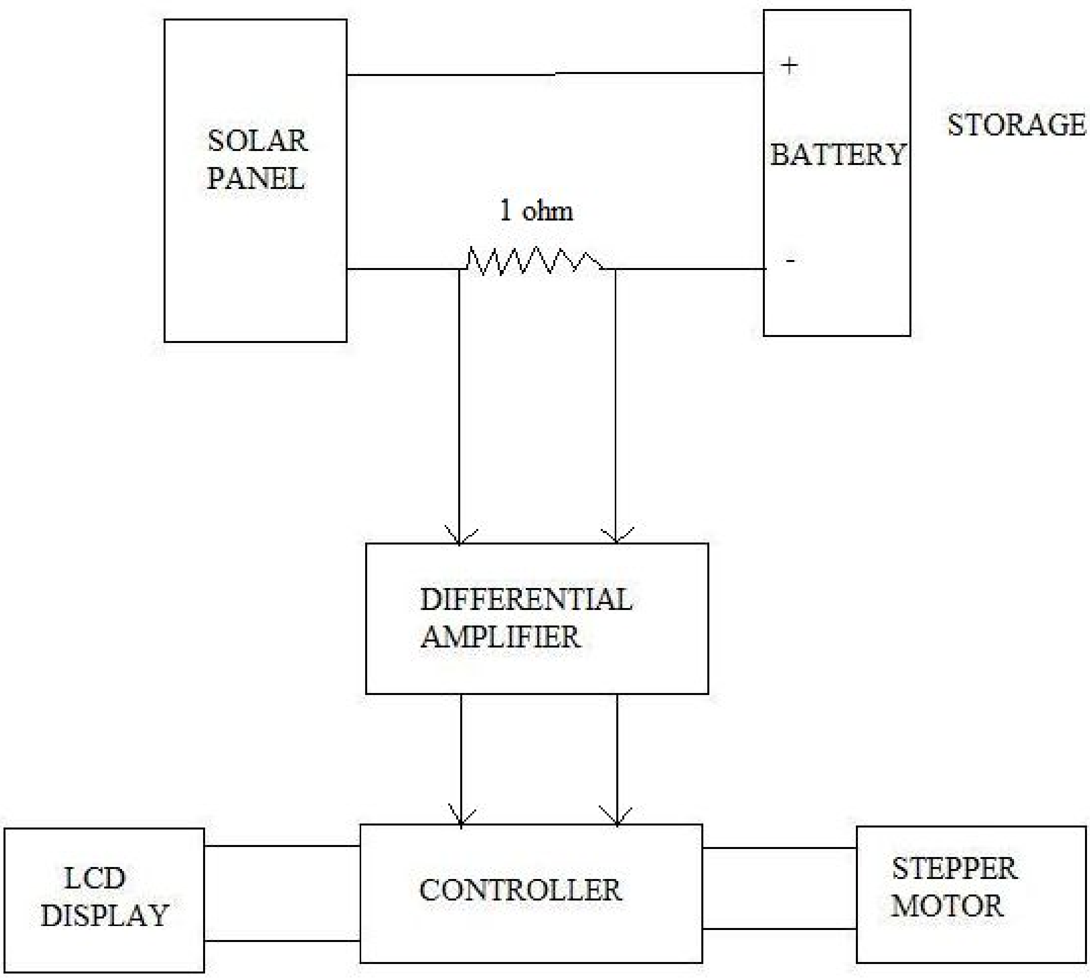


**Figure 4.1: Block diagram**

## 4.6 LCD

LCD is used in our proposed scheme to display the values of in-circuit current. For simulation purpose, we can use LCD in a 4-bit Mode. For that, we require only four data lines to be connected to the four port pins of PIC and three control signals to control the data flow and display.

LCD Pin Diagram:

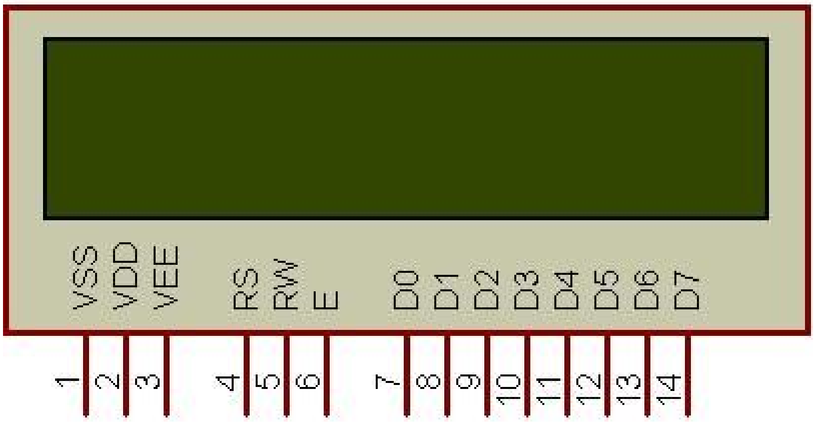


**Figure 4.2: LCD Pin Diagram**

Data can be displayed using following instructions:

**Lcd_Config**

Prototype – void Lcd_Config(unsigned short *port, unsigned short RS, unsigned short EN, unsigned short WR, unsigned short D7, unsigned short D6, unsigned short D5, unsigned short D4).

Description - Initializes LCD at port with pin settings you specify: parameters RS, EN, WR and D7. D4 need to be a combination of values 0–7 (e.g. 3, 6, 0, 7, 2, 1, 4).

**Lcd_Init**

Prototype – void Lcd _ Init (unsigned short *port)

Description- Initializes LCD at port with default pin settings

D7 → port.7

D6 → port.6

D5 → port.5

D4 → port.4

E → port.3

RS → port.2

Example - Lcd_Init (&PORTB);

RW → port.0

**Lcd_Out**

Prototype- void Lcd_Out_Cp(char *text);

Description - Prints text on LCD at specified row and column (parameters row and col). Both string variables and literals can be passed as text.

**Lcd_Out_Cp**

Prototype- void Lcd _Out_Cp(char *text);

Description - Prints text on LCD at current cursor position. Both string variables and literals can be passed as text.

**Lcd_Chr**

Prototype – void Lcd_Chr (unsigned short row, unsigned short col, char character);

Description - Prints character on LCD at specified row and column (parameters row and col). Both variables and literals can be passed as character.

**Lcd_Chr_Cp**

Prototype – void Lcd_Chr_Cp(char character);

Description - Prints character on LCD at current cursor position. Both variables and literals can be passed as character.

**Lcd_Cmd**

Prototype – void Lcd_Cmd(unsigned short command);

Description - Sends command to LCD. You can pass one of the predefined constants to the function. The complete list of available commands is below.

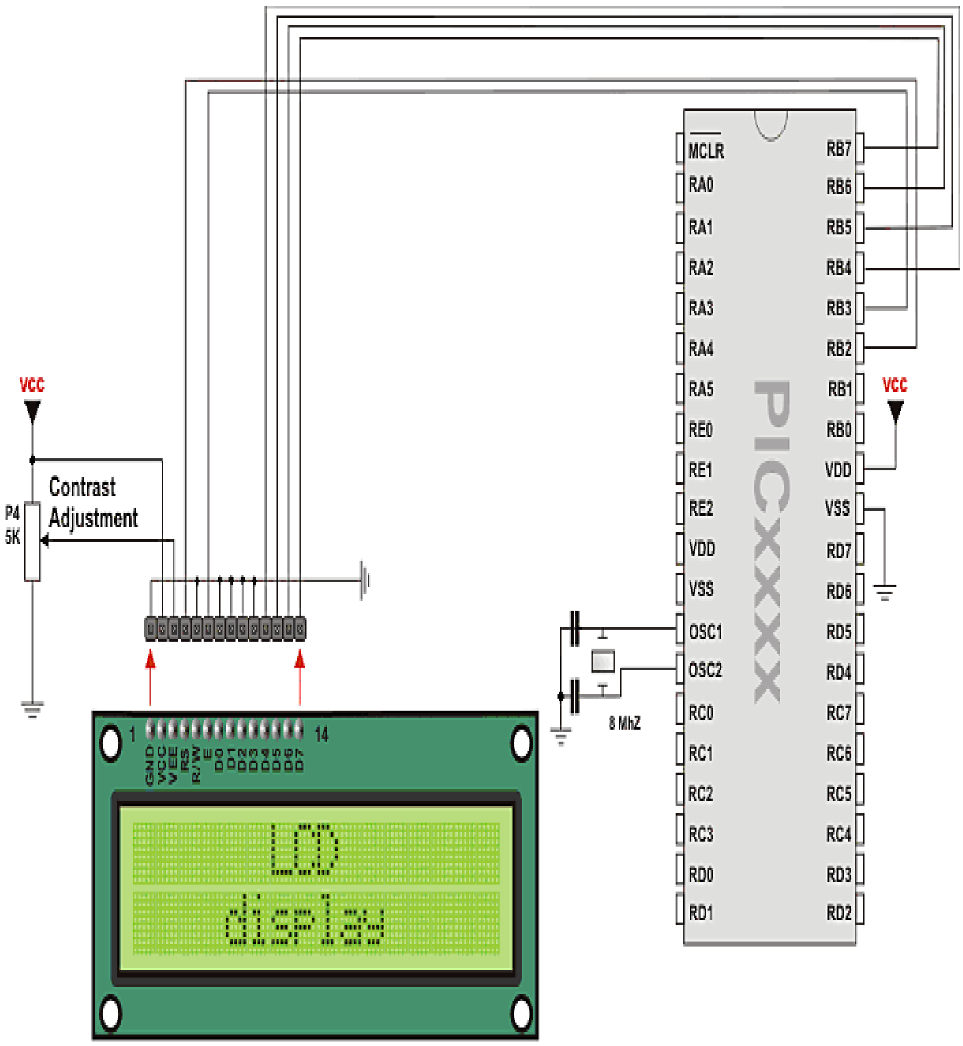


**Figure 4.3: LCD H/W Connection**

## 4.7 Circuit Diagram:

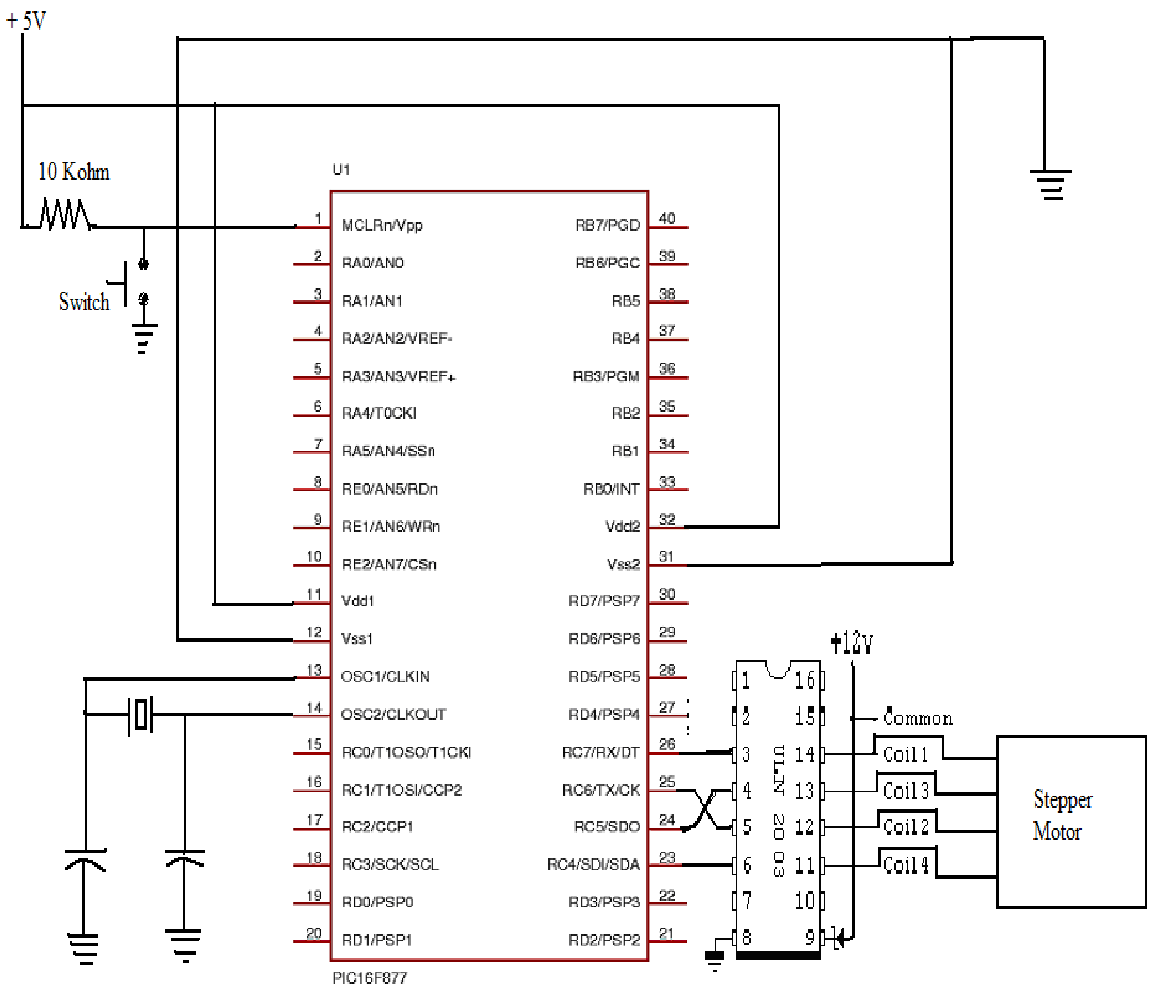


**Figure 4.4: Circuit Diagram**

| Pin Name | Pin No. | Description | Application |
|---|---|---|---|
| $V_{DD}$ | 11,32 | Positive Supply (+5V) | Positive Supply to chip |
| $V_{SS}$ | 12,31 | Ground Reference | Ground Reference |
| OSC | 13,14 | For Oscillator or resonator | Connected to Resonator 8MHz with 22pF |
| MCLR | 1 | Reset Input | Always connected to +5V |

**Table 4.1 Description of Pins used in Circuit.**

## 4.8 PIC Circuit

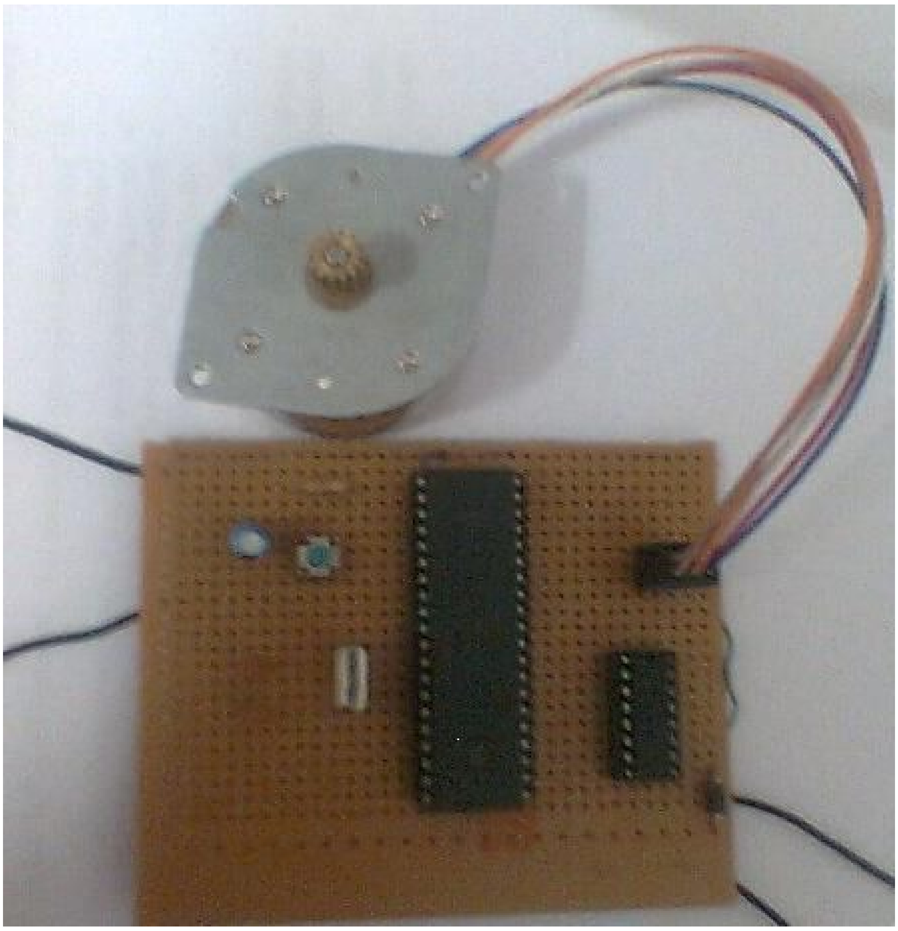

**Figure 4.5: PCB made for the proposed scheme.**

## 4.9 PIC 16f877A Circuit Components

- One reset button
- Crystal oscillator
- Capacitors
- Resistance
- ULN

**Reset button:**

Reset button is connected to MCLR (pin 1) of PIC16f877A with a pull up resistance of 10KΩ. One leg of reset button is connected to +VCC through resistance and alternate opposite leg is connected to the ground.

**Crystal oscillator:**

Crystal oscillator of 8MHz is connected to the (13-14) pin of PIC.27pf capacitor with one leg grounded is connected to leg of oscillator.

## 4.10 ULN

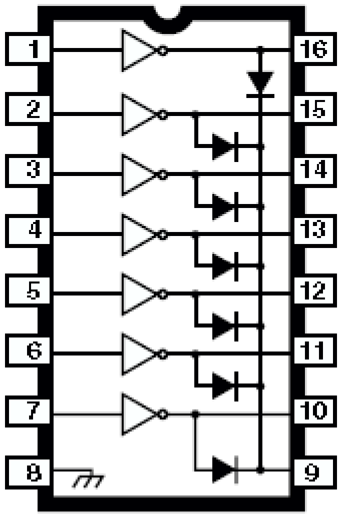


**Figure 4.6: ULN 2003**

The ULN2003 is a monolithic high voltage and high current Darlington transistor arrays. It consists of seven NPN Darlington pairs that feature high-voltage outputs with common-cathode clamp diode for switching inductive loads. The collector-current rating of a single Darlington pair is 500mA. The Darlington pairs may be paralleled for higher current capability. Applications include relay drivers, hammer drivers, lamp drivers, display drivers (LED gas discharge),line drivers, and logic buffers. The ULN2003 has a 2.7kW series base resistor for each Darlington pair for operation directly with TTL or 5V CMOS devices.

## 4.11 Key Features of ULN:

- Seven darlingtons per package
- Output current 500mA per driver (600mA peak)
- Output voltage 50 V
- Integrated suppression diodes for inductive loads
- Outputs can be paralleled for higher current
- TTL/CMOS/PMOS/DTL Compatible inputs
- Inputs pinned opposite outputs to simplify layout.

## 4.12 Control algorithm:

1. Measure in circuit current.
2. If current is <dark value (It indicates onset of night) the tracker resets itself to reset position (extreme east) and sleeps for 10 hours, then it goes to step1.
3. If current <threshold value (minimal daylight current), wait for 15 minutes and go to step 1.
4. Turn panel forward by $15^{\circ}$and measure current again after a pause of 1 minute. If current increases, continue with rotation. If it decreases, then revert back by $15^{\circ}$. If it remains constant, stop rotating, wait for 15 minutes and go to step 1.

Using PIC 16F877A, in circuit current is being monitored as and when indicated in above algorithm and depend on the control strategy command is given to stepper motor to turn forward to backward .The monitored current is displayed on LCD panel .

Here we use small stepper motor just for making the working model. We can use big motor of higher rating with proper gear arrangement to give automatic rotation to tracker.

# CHAPTER 5
# Results and Discussions

## 5.1 Description of the Circuit Used for Analysis:

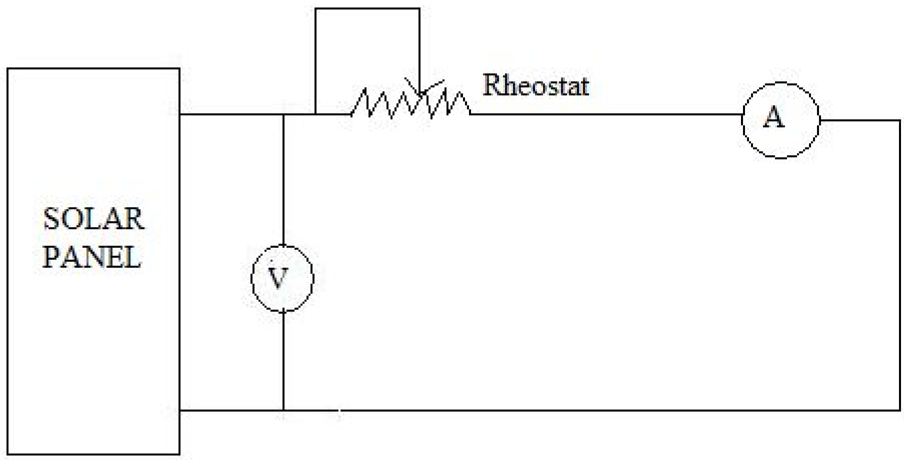


**Figure 5.1: Circuit Diagram**

The tracking capability of the proposed technique had been verified experimentally with a 10-W solar panel at different rotations of Tracker. Solar panel of 10 W was connected with rheostat varying from 0-200 ohms which was in series with an ammeter. Tracker was connected in parallel to the voltmeter (0-50V). Here we have simulated 15V battery by keeping closed circuit voltage constant. Current was being monitored at various angles of tracker as the sun moved from east to west. The Tracker was moved manually but with the help of proper gearing and motor, we can actually rotate the panel and made it automatic.

## 5.2 Results

Voltage level had to be maintained at 15V. We kept the standard alignment of tracker at 45 degree. Then we moved the tracker with 15 degree steps in rotation with sun from east to west so that it could extract maximum amount of solar energy. At first, we measured open circuit voltage. For closed circuit, corresponding to constant voltage, we measured in-circuit current, resistance as well as angles at which tracker got to rotate. Consequently, we came to following results.

Results are tabulated as follows:

**Table 5.1 Variations of current with constant closed circuit voltage of 15V at 8.00a.m.**

| Open circuit voltage (volts) | Constant closed circuit voltage(volts) | Angle (in degrees) | Current at variable angle (Amperes) | Resistance (ohms) |
|---|---|---|---|---|
| 17.29 | 15 | +90 | 0.10 | 150 |
| 17.85 | 15 | +75 | 0.17 | 87.2 |
| 18.30 | 15 | +60 | 0.27 | 64.4 |
| 18.53 | 15 | +45 | 0.37 | 42.3 |
| 18.74 | 15 | +30 | 0.43 | 37.4 |
| 18.98 | 15 | +15 | 0.49 | 31.8 |
| 18.95 | 15 | 0 | 0.49 | 45.2 |
| 19.07 | 15 | -15 | 0.68 | 24.02 |
| 19.48 | 15 | -30 | 0.72 | 25.96 |
| 19.35 | 15 | -45 | 0.70 | 23.40 |
| 18.85 | 15 | -60 | 0.66 | 23.91 |
| 18.81 | 15 | -75 | 0.65 | 24.43 |
| 18.30 | 15 | -90 | 0.30 | 55.4 |

**Table 5.2 Variations of current with constant closed circuit voltage of 15V at 9.00a.m.**

| Open circuit voltage (volts) | Constant closed circuit voltage(volts) | Angle (in degrees) | Current at variable angle (amperes) | Resistance (ohms) |
|---|---|---|---|---|
| 18.05 | 15 | +90 | 0.24 | 63.7 |
| 18.40 | 15 | +75 | 0.35 | 44.4 |
| 18.71 | 15 | +60 | 0.44 | 35.4 |
| 18.63 | 15 | +45 | 0.52 | 39.4 |
| 18.16 | 15 | +30 | 0.31 | 53.5 |
| 18.60 | 15 | +15 | 0.63 | 25.76 |
| 19.08 | 15 | 0 | 0.71 | 23.25 |
| 19.17 | 15 | -15 | 0.72 | 24.63 |
| 19.12 | 15 | -30 | 0.69 | 25.11 |
| 19.01 | 15 | -45 | 0.70 | 22.80 |
| 18.89 | 15 | -60 | 0.65 | 25.55 |
| 18.76 | 15 | -75 | 0.60 | 25.10 |
| 18.58 | 15 | -90 | 0.53 | 28.4 |

**Table 5.3 Variations of current with constant voltage of 15V at 10.00a.m.**

| Open circuit voltage (volts) | Constant closed circuit voltage(volts) | Angle (in degrees) | Current at variable angle (amperes) | Resistance (ohms) |
|---|---|---|---|---|
| 17.95 | 15 | +90 | 0.35 | 45.2 |
| 18.09 | 15 | +75 | 0.41 | 37.9 |
| 18.20 | 15 | +60 | 0.47 | 35.4 |
| 18.31 | 15 | +45 | 0.54 | 28.8 |
| 18.40 | 15 | +30 | 0.59 | 28.7 |
| 18.56 | 15 | +15 | 0.63 | 25.52 |
| 18.74 | 15 | 0 | 0.65 | 25.20 |
| 18.64 | 15 | -15 | 0.68 | 23.08 |
| 18.57 | 15 | -30 | 0.66 | 23.17 |
| 18.56 | 15 | -45 | 0.64 | 33 |
| 18.56 | 15 | -60 | 0.61 | 32.5 |
| 18.44 | 15 | -75 | 0.57 | 26.86 |
| 18.35 | 15 | -90 | 0.53 | 29.08 |

**Table 5.4 Variations of current with constant voltage of 15V at 11.00a.m.**

| Open circuit voltage (volts) | Constant closed circuit voltage(volts) | Angle (in degrees) | Current at variable angle (amperes) | Resistance (ohms) |
|---|---|---|---|---|
| 18.35 | 15 | +90 | 0.50 | 34.7 |
| 18.44 | 15 | +75 | 0.54 | 30.40 |
| 18.46 | 15 | +60 | 0.56 | 27.67 |
| 18.42 | 15 | +45 | 0.59 | 27.55 |
| 18.51 | 15 | +30 | 0.61 | 27.82 |
| 18.18 | 15 | +15 | 0.54 | 39 |
| 18.74 | 15 | 0 | 0.64 | 25.07 |
| 18.66 | 15 | -15 | 0.64 | 24.72 |
| 18.60 | 15 | -30 | 0.61 | 25.22 |
| 18.52 | 15 | -45 | 0.58 | 28.99 |
| 18.41 | 15 | -60 | 0.56 | 42.4 |
| 18.33 | 15 | -75 | 0.53 | 28.6 |
| 18.24 | 15 | -90 | 0.50 | 31.7 |

**Table 5.5 Variations of current with constant voltage of 15V at 12 noon.**

| Open circuit voltage (volts) | Constant closed circuit voltage(volts) | Angle (in degrees) | Current at variable angle (amperes) | Resistance (ohms) |
|---|---|---|---|---|
| 18.58 | 15 | +90 | 0.59 | 26.44 |
| 18.58 | 15 | +75 | 0.55 | 38.6 |
| 18.57 | 15 | +60 | 0.57 | 29.4 |
| 18.27 | 15 | +45 | 0.48 | 33.7 |
| 18.27 | 15 | +30 | 0.49 | 31.8 |
| 18.68 | 15 | +15 | 0.59 | 29.6 |
| 18.80 | 15 | 0 | 0.59 | 33.1 |
| 18.68 | 15 | -15 | 0.55 | 34.4 |
| 18.53 | 15 | -30 | 0.50 | 34.6 |
| 18.42 | 15 | -45 | 0.44 | 34.8 |
| 18.38 | 15 | -60 | 0.38 | 42.1 |
| 18.22 | 15 | -75 | 0.39 | 40.6 |
| 18.11 | 15 | -90 | 0.39 | 40.1 |

**Table 5.6 Variations of current with constant voltage of 15V at 1.00p.m.**

| Open circuit voltage (volts) | Constant closed circuit voltage(volts) | Angle (in degrees) | Current at variable angle (amperes) | Resistance (ohms) |
|---|---|---|---|---|
| 18.78 | 15 | +90 | 0.54 | 28.4 |
| 18.79 | 15 | +75 | 0.55 | 28.3 |
| 18.75 | 15 | +60 | 0.56 | 27.8 |
| 18.69 | 15 | +45 | 0.58 | 26.62 |
| 18.66 | 15 | +30 | 0.59 | 25.63 |
| 18.67 | 15 | +15 | 0.60 | 25.57 |
| 18.81 | 15 | 0 | 0.60 | 25.62 |
| 18.59 | 15 | -15 | 0.44 | 40.9 |
| 18.52 | 15 | -30 | 0.40 | 43.8 |
| 18.42 | 15 | -45 | 0.35 | 48.6 |
| 18.28 | 15 | -60 | 0.30 | 54.8 |
| 18.36 | 15 | -75 | 0.29 | 57 |
| 18.32 | 15 | -90 | 0.28 | 57.9 |

**Table 5.7 Variations of current with constant voltage of 15V at 2.00p.m.**

| Open circuit voltage (volts) | Constant closed circuit voltage(volts) | Angle (in degrees) | Current at variable angle (amperes) | Resistance (ohms) |
|---|---|---|---|---|
| 18.08 | 15 | +90 | 0.44 | 38 |
| 18.54 | 15 | +75 | 0.58 | 35 |
| 18.41 | 15 | +60 | 0.57 | 29 |
| 18.49 | 15 | +45 | 0.58 | 28.95 |
| 18.62 | 15 | +30 | 0.62 | 28.3 |
| 18.67 | 15 | +15 | 0.63 | 27.33 |
| 18.74 | 15 | 0 | 0.64 | 24.07 |
| 18.74 | 15 | -15 | 0.62 | 33.8 |
| 18.50 | 15 | -30 | 0.56 | 26.46 |
| 18.45 | 15 | -45 | 0.50 | 31.4 |
| 18.31 | 15 | -60 | 0.44 | 40.6 |
| 18.24 | 15 | -75 | 0.39 | 44.8 |
| 18.13 | 15 | -90 | 0.33 | 46.7 |

**Table 5.8 Variations of current with constant voltage of 15V at 3.00p.m.**

| Open circuit voltage (volts) | Constant closed circuit voltage(volts) | Angle (in degrees) | Current at variable angle (amperes) | Resistance (ohms) |
|---|---|---|---|---|
| 18.39 | 15 | +90 | 0.43 | 37.2 |
| 18.52 | 15 | +75 | 0.51 | 32.1 |
| 18.62 | 15 | +60 | 0.56 | 30.2 |
| 18.65 | 15 | +45 | 0.61 | 27.06 |
| 18.64 | 15 | +30 | 0.62 | 27.90 |
| 18.49 | 15 | +15 | 0.61 | 30.5 |
| 18.83 | 15 | 0 | 0.63 | 26.43 |
| 18.54 | 15 | -15 | 0.58 | 30.8 |
| 18.65 | 15 | -30 | 0.53 | 33.1 |
| 18.47 | 15 | -45 | 0.45 | 39.4 |
| 18.29 | 15 | -60 | 0.35 | 50.3 |
| 17.98 | 15 | -75 | 0.26 | 62.8 |
| 17.58 | 15 | -90 | 0.16 | 92.6 |

**Table 5.9 Variations of current with constant voltage of 15V at 4.00p.m.**

| Open circuit voltage (volts) | Constant closed circuit voltage(volts) | Angle (in degrees) | Current at variable angle (amperes) | Resistance (ohms) |
|---|---|---|---|---|
| 18.16 | 15 | +90 | 0.27 | 59.4 |
| 18.46 | 15 | +75 | 0.32 | 49.0 |
| 18.69 | 15 | +60 | 0.45 | 37.2 |
| 18.86 | 15 | +45 | 0.54 | 32.3 |
| 18.96 | 15 | +30 | 0.57 | 30.2 |
| 19.23 | 15 | +15 | 0.60 | 28.26 |
| 19.12 | 15 | 0 | 0.59 | 30.2 |
| 18.89 | 15 | -15 | 0.51 | 31.8 |
| 18.79 | 15 | -30 | 0.47 | 35.3 |
| 18.59 | 15 | -45 | 0.39 | 41.2 |
| 18.21 | 15 | -60 | 0.29 | 61 |
| 17.87 | 15 | -75 | 0.15 | 106.7 |
| 16.80 | 15 | -90 | 0.11 | 180 |

**Table 5.10 Variations of current with constant voltage of 15V at 5.00p.m.**

| Open circuit voltage (volts) | Constant closed circuit voltage(volts) | Angle (in degrees) | Current at variable angle (amperes) | Resistance (ohms) |
|---|---|---|---|---|
| 17.01 | 15 | +90 | ----- | ----- |
| 17.70 | 15 | +75 | 0.10 | 150 |
| 18.02 | 15 | +60 | 0.22 | 71 |
| 18.26 | 15 | +45 | 0.30 | 60.3 |
| 18.97 | 15 | +30 | 0.52 | 28.8 |
| 18.47 | 15 | +15 | 0.46 | 40.1 |
| 18.43 | 15 | 0 | 0.40 | 43.7 |
| 18.33 | 15 | -15 | 0.51 | 35.8 |
| 18.65 | 15 | -30 | 0.48 | 34.2 |
| 18.43 | 15 | -45 | 0.45 | 41.7 |
| 18.19 | 15 | -60 | 0.39 | 44.6 |
| 17.74 | 15 | -75 | 0.31 | 59.7 |
| 17.58 | 15 | -90 | 0.20 | 85 |

**Table 5.11 Variations of current with constant voltage of 15V at 6.00p.m.**

| Open circuit voltage (volts) | Constant closed circuit voltage(volts) | Angle (in degrees) | Current at variable angle (amperes) | Resistance (ohms) |
|---|---|---|---|---|
| | 15 | +90 | ----- | ----- |
| 15.94 | 15 | +75 | ----- | ----- |
| 17.28 | 15 | +60 | 0.10 | 158 |
| 17.92 | 15 | +45 | 0.18 | 87 |
| 18.70 | 15 | +30 | 0.33 | 57.6 |
| 18.47 | 15 | +15 | 0.29 | 52.7 |
| 18.28 | 15 | 0 | 0.24 | 65.2 |
| 18.62 | 15 | -15 | 0.29 | 53.8 |
| 18.44 | 15 | -30 | 0.27 | 59.3 |
| 18.32 | 15 | -45 | 0.23 | 68.2 |
| 18.01 | 15 | -60 | 0.19 | 84.5 |
| 17.60 | 15 | -75 | 0.13 | 124 |
| 16.75 | 15 | -90 | ----- | ------- |

## 5.3 To Calculate the Enhancement by Employing Tracker

Here we have compared maximum current values at variable angles with maximum current values at fixed angles.

**Table 5.12 Comparison of Maximum Current between fixed and variable angle.**

| Time of day | Open circuit voltage(V) | Closed circuit voltage(V) | Current at fixed angle 0 degree(Amperes) | Variable Angle (degrees) for maximum current | Maximum current at variable angle (Amperes) |
|---|---|---|---|---|---|
| 8.00 A.M | 19.07 | 15 | 0.49 | -30 | 0.72 |
| 9.00 A.M | 19.08 | 15 | 0.71 | -15 | 0.72 |
| 10.00A.M | 18.74 | 15 | 0.65 | -15 | 0.68 |
| 11.00 A.M | 18.66 | 15 | 0.64 | 0 | 0.64 |
| 12.00 noon | 18.80 | 15 | 0.59 | 0 | 0.59 |
| 1:00 P.M | 18.78 | 15 | 0.60 | 0 | 0.60 |
| 2:00 P.M | 18.74 | 15 | 0.64 | 0 | 0.64 |
| 3:00 P.M | 18.54 | 15 | 0.63 | 0 | 0.63 |
| 4:00 P.M | 19.12 | 15 | 0.59 | +15 | 0.60 |
| 5:00 P.M | 18.97 | 15 | 0.40 | +30 | 0.52 |
| 6.00 P.M | 18.70 | 15 | 0.24 | +30 | 0.33 |
| Total | | | 6.18 | | 6.67 |

$$efficiency = \frac{(6.67 - 6.18)*100}{6.18} = 7.9\%$$

## 5.4 Discussions

Thus efficiency is increased around 8% on a clear sunny day. Range for analog to digital conversion is $2^{10}$ = 1024 bit. Maximum current is taken as 1Ampere. So current value is 1/1024 is approximately 1milli ampere. Thus minimum current value is 240 mA and maximum current value is 640 mA as shown above in table.

Threshold Value is 0.2Ampere i.e. 200 mA. When current value will be less than 200mA it will be overcast in sky. Tracker will stop working .It will be fixed in the same position.

Dark value which is less than threshold value is 0.05 Ampere i.e. 50mA. If current value will be less than 50mA, it means it is dark now. Tracker will turn itself off, turn to east and remain in that fixed position. Tracker will be off for 10 hours, remaining fixed in the same position so that when the sun will rise next day, it will catch the sun.

# CHAPTER 6

# Conclusion and Scope for Future Work

## 6.1 Conclusion

In this thesis, the sun tracking system was implemented which is based on PIC microcontroller. After examining the information obtained in the data analysis section, it can be said that the proposed sun tracking solar array system is a feasible method of maximizing the energy received from solar radiation. The controller circuit used to implement this system has been designed with a minimal number of components and has been integrated onto a single PCB for simple assembly. The use of stepper motors enables accurate tracking of the sun while keeping track of the array's current position in relation to its initial position.

The automatic solar radiation tracker is an efficient system for solar energy collection. It has been shown that the sun tracking systems can collect about 8% more energy than what a fixed panel system collects and thus high efficiency is achieved through this tracker.
8% increase in efficiency is not the most significant figure; it can be more prominent in concentrating type reflectors.

## 6.2 Scope for Future Work

To improve the sun tracking, a stand alone sun tracker can be designed using 18 series PIC microcontroller. In 18 series PIC microcontroller, data can be stored periodically in MMC card .We need not to do it manually (no need of rotation).
In this proposed area, we took 45 degree as standard alignment during results which had been taken in April, 2008. Alignment can be varied changing with season. Moreover, concentrating type collectors are more efficient than flat plate collectors. We can make use of that to increase efficiency.

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