DESIGN AND CONSTRUCTION OF TIME BASED SOLAR TRACKING SYSTEM

BY

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OCTOBER 2021

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A Research Project Submitted to the Department Of Electrical And Computer Engineering, Faculty Of Engineering and Technology, Kwara State University, Malete, in Partial Fulfilment of the Requirements for the Award Of Bachelors of Engineering Degree (B.Eng) Degree In Electrical And Computer Engineering

OCTOBER, 2021

DECLARATION

I hereby declare that this research project titled "**Design and Construction of Timed Based Solar Tracking System**" is my work and has not been submitted by any other person for any degree or qualification at any higher institution. I also declare that the information provided therein are mine and those that are not mine are properly acknowledged.

Suleiman Ajibola Suleiman

Name of Student

Signature and Date

CERTIFICATION

This is to certify that this project work titled "**DESIGN AND CONSTRUCTION OF TIME BASED SOLAR TRACKING SYSTEM**" was duly carried out by SULEIMAN AJIBOLA SULEIMAN, supervised and approved by me and it was found to be adequate in partial fulfilment of the requirement for the award of B.Eng. in Electrical and Computer Engineering of the faculty of Engineering and Technology, Kwara State University, Malete.

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DEDICATION

This project is dedicated to Almighty Allah for his infinite mercy, wisdom, knowledge and protection in my life. Also, with all my heart, I dedicate this report to my ever present and supportive parents, my wonderful family, friends and well-wishers for their full support and encouragement throughout this journey.

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I express my profound gratitude to numerous people and scholars who have contributed in several ways to ensure my success in the Kwara State University.

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To all my guys that never hide update no matter how small you are much appreciated.

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ABSTRACT

Solar power is the fastest growing means of renewable energy production with grid connected solar capacity increasing on average by 60% annually from 2004 to 2009 according to the National Center for Policy Analysis in the United States. In 2011, the International Energy Agency emphasized the development of affordable, inexhaustible and clean solar energy technologies will have huge longer-term benefits. This new solar technologies will increase countries' energy security through reliance on an indigenous, inexhaustible, and mostly import-independent resource, enhance sustainability, reduce pollution, lower the costs of mitigating global warming, and keep fossil fuel prices lower. Effectively harnessing solar irradiation incident to the solar panel is one of the major problems in utilizing solar power. To maximize the power of solar systems we need to keep the solar panel aligned with the sun, the design of an efficient solar tracking system based on Real Time Clock (RTC) using microcontroller is described. The proposed tracking system is a low cost, high accuracy, more efficient with low power consumption.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Renewable energy resources will be an increasingly important part of power generation in the new millennium. Besides assisting in the reduction of emission of greenhouse gases, they add the much- needed flexibility to the energy resource mix by decreasing the dependence on fossil fuels. The sun is the prime source of energy, directly or indirectly, which is also the fuel for most renewable systems (Das et al., 2015). Among all renewable systems Solar energy, radiant light and heat from the sun, has been harnessed by humans since ancient times using a range of ever-evolving technologies. Solar energy technologies include solar heating, solar photovoltaic's, concentrated solar power and solar architecture, which can make considerable contributions to solving some of the most urgent problems the world now faces (*World Energy Consumption - Wikipedia*, n.d.).The world population is increasing by the day, so also is the energy demand. In Nigeria for instance, it has been observed that the current energy demand in the country far exceeds the supply which results to a situation often termed "epileptic power supply". According to the Nigeria energy commission, the recent crash in the prices of crude oil and the instability experienced in most of the regions where this resource is produced is evident to the fact that these energy sources are not reliable.

Besides, it is common knowledge that these resources are exhaustible and hence, un-sustainable. Ironically, most countries of the world still depend on this unsustainable energy sources to meet their energy needs. The conversion principle of solar light into Electricity, called Photo-Voltaic (PV) conversion, is not very new, but the efficiency improvement of the PV conversion equipment is still one of top priorities for many academic and/or industrial research groups all over the world. Among the proposed solutions for improving the efficiency of PV conversion, we can mention solar tracking, the optimization of solar cell configuration and geometry, new materials and technologies etc (Anusha & Reddy, 2013). A Solar tracker is a system or device that orients various photovoltaic and solar thermal panels toward the sun. It ensures that the direct beam from the sun is incident normal to the surface of the panels at all times (Udoakah & Chukwu, 2018). Installing a solar tracker to a solar system proves to be more efficient than a stationary solar system in terms of power generation. In recent times one of the solar tracking methods is the use phototransistors for the solar tracking. The problem with a design like this is that phototransistors have a narrow range of sensitivity, once they have been set up in a circuit under set bias conditions. It was because of this fact that solar cells themselves were chosen to be the sensing devices (Anusha & Reddy, 2013). They provide an excellent mechanism in light intensity detection because they are sensitive to varying light and provide a near-linear voltage range that can be used to an advantage in determining the present declination or angle to the sun. As a result, a simple RTC based control system is proposed, with the natural positioning of the sun with respect to time has been implemented as an algorithm to control the solar PV by controlling the DC stepper motor.

1.2 MOTIVATON

A study on people in underprivileged cities of developing countries and how they could benefit from the use of a solar distributed generation system done by (Udoakah & Chukwu, 2018) assessed possible means to provide an efficient solar distributed generation system using a scaled down single-axis solar tracker. The tracker aligned with the light source by 1.5 degrees with calculated energy gain of 48.982% compared to an immobile solar panel. This study presents a good analysis because it considered the affordability of solar electricity but without detailed technicalities in the design which could be improved upon. Trackers add to the efficiency of the system, reducing its size and the cost per Kilowatts hour ampere (KWH.A). The design is going to extract maximum power from the sun by tracking it using a single axis solar panel. This is possible if solar panel is perpendicular to the intensity of light coming from the sun.

In conclusion, the tracking system presented has the following advantages: The tracking system is not constrained by the geographical location of installation of the solar panel since it is designed for searching the maximum solar irradiance in the whole azimuth and tilt angle (except hardware limitations) during day times; namely, the angle of elevation does not need to be adjusted periodically (Oner, 2006). The design system is a low–cost time based solar tracking system using a PIC microcontroller that is compatible and reliable. The components are relatively affordable in order to use this system domestically as well as commercially to get great efficiency. The design system is highly efficient and economical reliable in terms of the electrical energy output as compared to the other system (Kalhoro et al., 2019)

1.3 **PROBLEM STATEMENT**

Harnessing of solar radiation is one of the fundamental problems in the generation of solar energy. The generation efficiency of photovoltaic based generating units has mainly been affected by the amount of solar radiation incident on photovoltaic panels (Sharma et al., 2020). Solar radiation magnitude incident on panels depends on two important factors, direction and tilt angle of panels. The optimal tilt angle of the panel varies accordingly to the position of the sun with respect to the earth. It varies on a daily, monthly, and yearly basis. In order to collect the greatest amount of energy from the sun, solar panels must be aligned orthogonally to the sun. For this purpose, a time based solar tracking technique based on micro-controller is being implemented and tested in this study.

1.4 **AIM AND OBJECTIVES**

1.4.1 **Aim**

This aim of this project is to design and construct a single axis time based solar tracking system using PIC16F877A microcontroller and a Real time clock (RTC) DS3231.

1.4.2 Objectives

The objectives of this project includes

1. Design of a time based solar tracking circuits and algorithm
2. Implementing the design in a simulation software
3. Construct the circuit implemented in a printed board (PCB)
4. Test for functionality of the circuit and analyze the result.

1.5 METHODOLOGY

The system comprises of the real time clock module (RTC) DS3231, the 16*2 Liquid crystal display (LCD), the stepper motor (28BYJ-48 - 5V), the stepper motor driver ULN2003 and the PIC16f877a microcontroller. The programming of the microcontroller is done with MPLAB X IDE and the simulation of the circuit is with proteous 8 professional. The solar panel is connected to the stepper motor and ULN2003 is used to control the stepper motor this is because a stepper motor cannot be directly interfaced with the microcontroller. A 5-volts (v) supply is used to provide power supply power to the microcontroller. The real time clock DS3231 is used to give real time information to the microcontroller, finally the liquid crystal display is used to display the time and other important information and parameters of the system. The positional direction of the sun with respect to time has been measured and implemented as an algorithm in the controller. Then, the controller in the chip delivers an output, the corresponding PWM signals, to drive the stepping motors. Thus, the directions of the single dimensional solar platform can be tuned to achieve optimal energy respectively.

1.6 SIGNIFICANCE OF THE PROJECT

Without doubt, solar electricity has continued to prove successful in addressing the predicted future energy needs. Different researches estimate that covering 0.16% of the land on earth with 10% efficient solar conversion systems would provide 20 TW of power (Udoakah & Chukwu, 2018), nearly twice the world’s consumption rate of fossil energy. This proves the potential of solar energy which in turn points out the necessity of maximizing the captured solar irradiation by the provision of solar tracking mechanism.

1.7 SCOPE OF THE PROJECT

This project will focus on the use PIC16F877A microcontroller to read the real time value produced by the Real Time Clock module DS3231 and compare it with the tabular values stored, if it matches with those values the corresponding positional values will be sent to the PWM generator which will make the stepper motor to operate to rotate solar panel to an angle orthogonal to the direction of the sun. By tuning solar platform, the optimal efficiency of generating power will be achieved. The panel is connected to the DC motor and is controlled by the microcontroller. The output voltage of the panel will be read through the ADC channel of the controller and the converted digital voltage values are sent to the Liquid crystal display LCD to display the analog values for observation.

1.8 PROJECT ORGANIZATION

This project report is broken down into five chapters. The first chapter was mainly for introduction of the project, I discussed about the problem statement, the several objectives and aims of this research, the scope of work and the report outline. Chapter two reviewed related previous works and it shed light on the definition of some important terms related to this study. The methodology adopted in achieving the research aim and objectives was discussed in the third chapter; this chapter also provides details of the progress of the project. Result analysis and solution discussion were done in the fourth chapter. All discussion in chapter four is concentrating on the results and overall performance of the time based solar tracking system. And chapter five discussed the challenges, limitations, conclusion and recommendation for additional work.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

The purpose of this chapter is to review existing literature both the past and present. Research began by reviewing journals, magazines, books, and internet sites in the field of solar tracking systems. In this chapter, the background theory of the time based solar tracking system is discussed and the several terms associated with this tracking method will also be reviewed and discussed.

2.2 THEORETICAL BACKGROUND

2.2.1 Solar Energy

Solar energy is the term used for the heat and light which the sunlight contains. Sunlight reaches to earth in the form of photons. Photons are energy packets that contain light in it. Solar energy is considered as a renewable energy source because it does not destroy our eco system and is present naturally in the environment (Das et al., 2015). The solar revolution of the last two decades has made solar energy an increasingly powerful force in the energy arena. Solar Panels use arrays of solar photovoltaic cells to convert photons into usable electricity. With solar panels, we are provided with clean, renewable energy from the sun.

Energy from the sun is caused from thermonuclear explosions deep within the sun. These explosions fuse atoms of hydrogen into atoms of helium. A tremendous amount of energy is released during the thermonuclear reaction and the sun releases that energy as radiation. This radiation travels through space at the speed of light, and solar panels can make practical use of it. Our sun generates an enormous amount of energy, and potentially, had we the technology to harvest that sunlight with solar arrays across the solar system; we could harvest huge amounts of energy (Ferreira et al., 2018). Many are familiar with so-called photovoltaic cells, or solar panels, found on things like spacecraft, rooftops, and handheld calculators. The cells are made of semiconductor materials like those found in computer chips. When sunlight hits the cells, it knocks electrons loose from their atoms. As the electrons flow through the cell, they generate electricity. On a much larger scale, solar-thermal power plants employ various techniques to concentrate the sun's energy as a heat source. The heat is then used to boil water to drive a steam turbine that generates electricity in much the same fashion as coal and nuclear power plants, supplying electricity for thousands of people (*Solar Power Information and Facts*, n.d.). The Earth receives 174,000 terawatts (TW) of incoming solar radiation at the upper atmosphere. Approximately 30% is reflected back to space while the rest is absorbed by clouds, oceans and land masses. The spectrum of solar light at the Earth's surface is mostly spread across the visible and near-infrared ranges with a small part in the near ultraviolet. Most of the world's population lives in areas with solar radiation levels of 150300 watts/m², or 3.5-7.0 kWh/m² per day. The total solar energy absorbed by Earth's atmosphere, oceans and land masses is approximately 3,850,000 EJ per year. In 2002, this was more energy in one hour than the world used in one year (*Synopsyreport for Solar Vacuum Cleaner | Vacuum Cleaner | Solar Energy*, n.d.). Fig 2.1 shows the average daily radiation on earth.

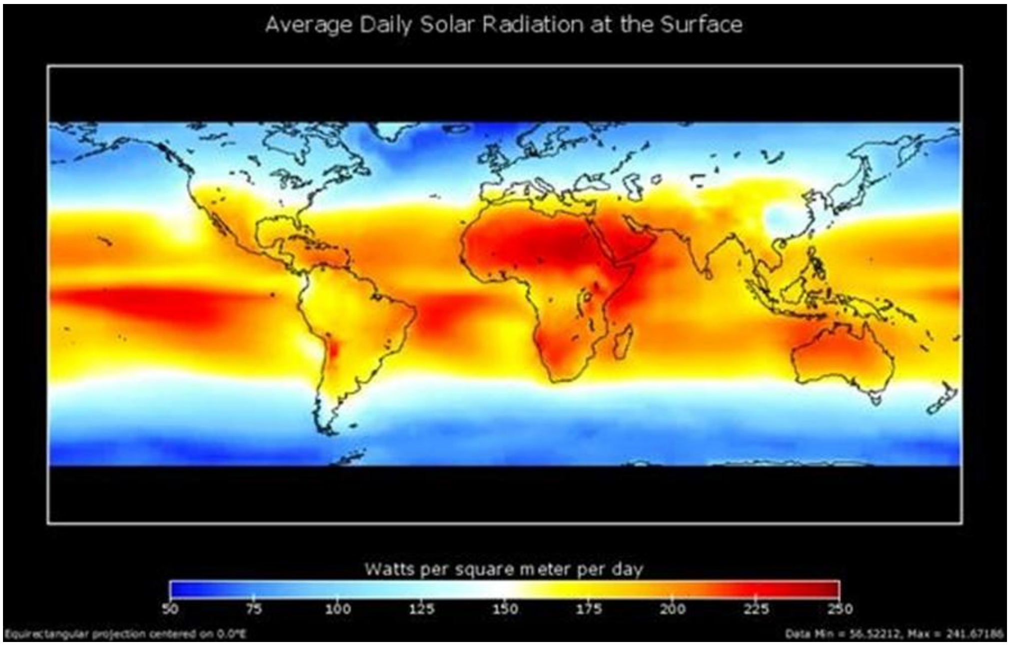

Fig 2. 1 Average daily solar radiation

2.2.2 **Electricity from Solar Power**

Solar power is the form of energy that helps in generation of electricity from the sunrays. There are many methods to generate electric current using sunlight but the most common methods are photovoltaic and concentrated solar power. Photovoltaic contains an array of solar cells which are pressed in solar panels. These solar panels are protected and framed by a glass sheet. This sheet does not allow any impurities to pass in. Hence only sunrays can make their way in. These solar panels are made up of conductive materials like impure silicon and copper indium mostly. These conductors help and support the flow of electrons, thus the heat present on the solar panels is able to generate direct electric current (Das et al., 2015). This electric current cannot support the electrical devices. Therefore it is converted to alternative current by using inverter and battery. Photovoltaic energy is growing rapidly and it is so far the only rapidly progressing renewable energy technology. Concentrating solar power (CSP) systems work on the principle of converging the sunlight form many kilometers to single focal point (Sneineh & Salah, 2019). The concentrated energy stored in this form is converted to thermal energy which is utilized to support photovoltaic cell.

The solar energy stored by CSP is also helpful in running steam turbines.

2.2.3 **Types of Solar Energy System**

Solar energy systems are of many types dependent upon their use. These include concentrating solar power systems, parabolic dishes, sunlight Stirling dishes, updraft towers, photovoltaic and solar ponds. All these systems are used to generate electricity in an economical and environment friendly manner. Photovoltaic solar panels are also used to heat water. The steam produced in this process is used for running the industrial machinery. Concentrating solar systems uses lenses, tracking system and glass to convert the sunlight into single beam. The heat stored in this way is used to support the conventional power houses. Parabolic dishes are another system which is used save solar energy. These parabolic antennas work on the mechanism of tracking

through single axis. Stirling solar dish systems contain a parabolic reflector that gathers the light to single focal point onto as a receiver. The updraft solar systems work by running wind turbines connected to it. These wind turbines produce electricity which is stored in the form of direct current in collectors at one end. Solar ponds were constituted to perform an experiment over the layers of salt present in red sea (Das et al., 2015). The heat from the sun is stored into the lower bed of salt. This heat is then used to heat water in collectors.

2.2.4 **Advantages of solar energy**

The importance and advantages of solar energy and its uses were not even declined in prehistoric times. Sunlight helps plants to generate food for them during the process of photosynthesis. Solar power energy free of cost energy source helped people store their food for longer when refrigerators were not in use (Haider, 2019), people used it for killing germs in clothes and most importantly this useful star provides us vitamin D to support healthy growth of our bones. Nowadays the practices of using solar energy are changing as it has been identified as an inexpensive way to produce electricity.

2.2.5 **Solar Energy Storage**

Producing electricity from sun is also termed as a renewable solar energy source. Renewable energy source refers to all those energy sources other than traditional bio fuels. Solar energy is of many uses. When the process of generating electricity was under consideration, the major challenge was to store solar energy to be used later in night, storms and rains (*Solar Power Information and Facts*, n.d.). Hence useful devices like solar panels, solar heating systems and solar cells supported this immense challenge. Solar energy can be used unless we have sun. Hence all the solar power applications can help us utilize solar energy rays to produce electricity for supporting personal, domestic and industrial applications. Now it is possible to store solar energy in batteries which are attached to the solar powers panels. The electricity generated through solar energy process can be used with or without traditional utility grids. Another experiment carried at the red sea demonstrated that solar energy can also be stored in the beds of salt to support solar heating systems (Das et al., 2015).

2.2.6 **Solar panel**

A solar panel is a set of solar photovoltaic modules electrically connected and mounted on a supporting structure. A photovoltaic module is a packaged, connected assembly of solar cells. The solar module can be used as a component of a larger photovoltaic system to generate and supply electricity in commercial and residential applications. Each module is rated by its DC output power under standard test Condit.

Solar modules use light energy (photons) from the sun to generate electricity through the photovoltaic effect. The majority of modules use wafer-based crystalline silicon cells or thin-film cells based on cadmium telluride or silicon. The structural (load carrying) member of a module can either be the top layer or the back layer. Cells must also be protected from mechanical damage and moisture. Most solar modules are rigid, but semi-flexible ones are available, based on thin film cells. Fig 2.2 shows of pictorial description of a typical solar panel.

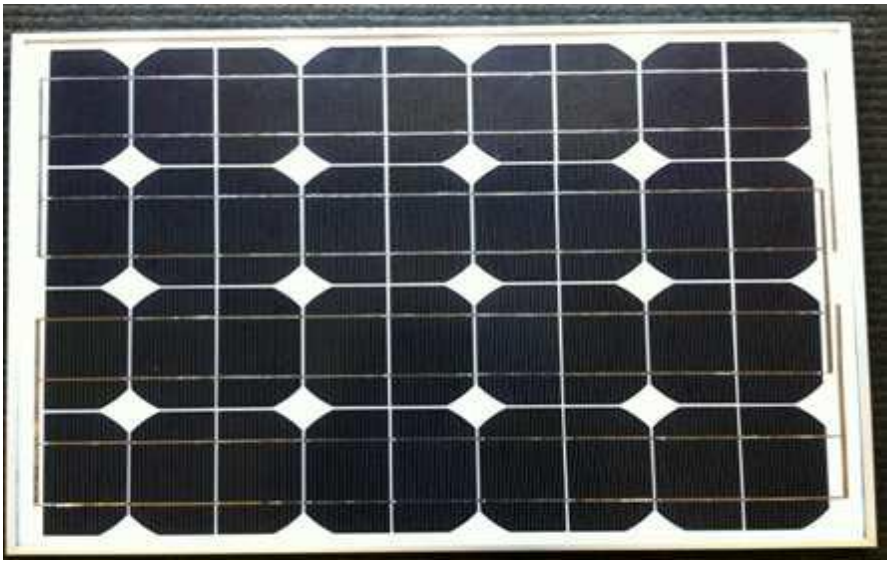

Fig 2. 2 Solar Panel

Solar cells are described as being photovoltaic irrespective of whether the source is sunlight or an artificial light. They are used as a photo-detector, detecting light or other electromagnetic radiation near the visible range, or measuring light intensity. When several solar panels are working together, they can be termed as a solar array. This is illustrated in the following Fig 2.3.

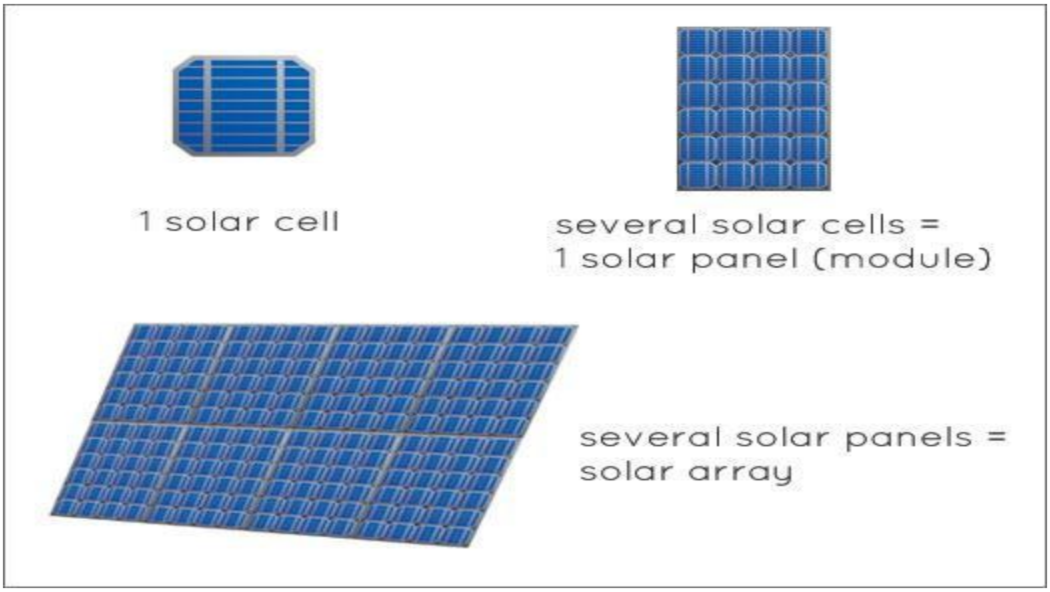

Fig 2. 3 Solar array

2.2.7 **Principle of photovoltaic cell**

Photovoltaic (PV) system is well recognized and widely utilized to convert the solar energy for electric power applications. It can generate direct current (DC) electricity without environmental impact and emission by way of solar radiation. The DC power is converted to AC power with an inverter, to power local loads or fed back to the utility. Being a semiconductor device, the PV systems are suitable for most operation at a lower maintenance costs. A diagrammatical representation of the photovoltaic conversion process is shown in Fig 2.4

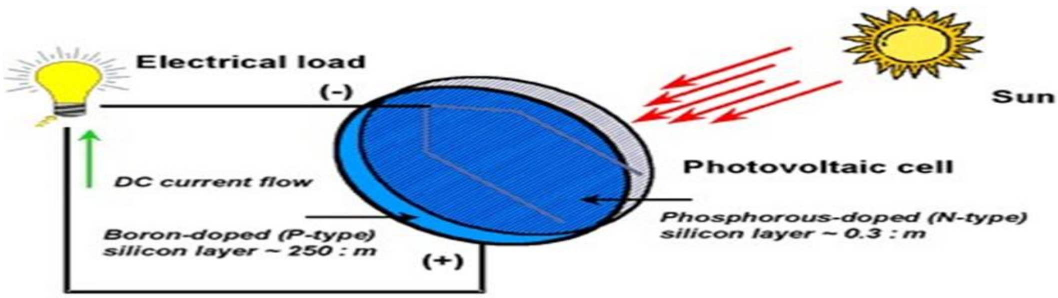

Fig 2. 4 Principles of photovoltaic cell

A typical silicon PV cell is composed of a thin wafer consisting of an ultra-thin layer of phosphorus-doped (N-type) silicon on top of a thicker layer of boron-doped (P-type) silicon. An electrical field is created near the top surface of the cell where these two materials are in contact, called the P-N junction. When sunlight strikes the surface of a PV cell, this electrical field provides momentum and direction to light-stimulated electrons, resulting in a flow of current when the solar cell is connected to an electrical load regardless of size, a typical silicon PV cell produces about 0.5 – 0.6 volt DC under open-circuit, no-load conditions. The current (and power) output of a PV cell depends on its efficiency and size (surface area), and is proportional to the intensity of sunlight striking the surface of the cell. For example, under peak sunlight conditions, a typical commercial PV cell with a surface area of 160 cm2 (~25 in2) will produce about 2 watts peak power. If the sunlight intensity were 40 percent of peak, this cell would produce about 0.8 watts (Udoakah & Chukwu, 2018).

2.2.8 **Tracking Technique**

There are several forms of tracking currently available, these vary mainly in the 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 (Johnson-hoyte et al., 2013). The dynamic tracking system, on the other hand, actively searches for the sun's position at any time of day or night. Control system is common for both tracking techniques. 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. Various methods have been implemented and used to track the position of the sun.

The simplest of all uses an LDR – a Light Dependent Resistor to detect light intensity changes on the surface of the resistor. Other methods, such as that published by (Anusha & Reddy, 2013), use two phototransistors covered with a small plate to act as a shield to sunlight as shown in Fig 2.5

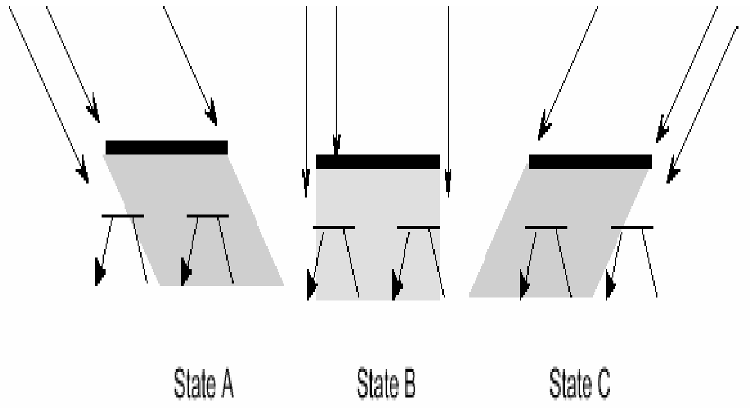

Fig 2. 5 Principle of operation of LDR

When morning arrives, the tracker is in state A from the previous day. The left phototransistor is turned on, causing a signal to turn the motor continuously until the shadow from the plate returns the tracker to state B. As the day slowly progresses, state C is reached shortly, turning on the right phototransistor. The motor turns until state B is reached again, and the cycle continues until the end of the day or until the minimum detectable light level is reached.

2.2.9 **Types of Solar Collector**

Different types of solar collector and their location (latitude) require different types of tracking mechanism. Solar collectors may be

I. Non-concentrating flat-panels, usually photovoltaic or hot-water

II. Concentrating systems of a variety of types.

Solar collector mounting systems may be fixed (manually aligned) or tracking. Tracking systems may be configured as:

2.2.9.1 Fixed mount

Domestic and small-scale commercial photovoltaic and hot-water panels are usually fixed, often flush-mounted on an appropriately facing pitched roof. Advantages of fixed mount systems (i.e. factors tending to indicate against trackers) include the following Mechanical simplicity and hence lower installation and ongoing maintenance costs .Wind-loading it is easier and cheaper to provision a sturdy mount (Johnson-hoyte et al., 2013); all mounts other than fixed flush-mounted panels must be carefully designed having regard to their wind loading due to their greater exposure.

2.2.9.2 Fixed collector or moving mirror

Many collectors cannot be moved, for example high-temperature collectors where the energy is recovered as hot liquid or gas (e.g. steam). Other examples include direct heating and lighting of buildings and fixed in-built solar cookers, such as Schaffer reflectors (Das et al., 2015). In such cases it is necessary to employ a moving mirror so that, regardless of where the Sun is positioned in the sky, the Sun's rays are redirected onto the collector. Due to the complicated motion of the Sun across the sky, and the level of precision required to correctly aim the Sun's rays onto the target, a heliostat mirror generally employs a dual axis tracking system, with at least one axis mechanized. In different applications, mirrors may be flat or concave.

2.2.10 **Single Axis Trackers**

The axis of rotation of single axis trackers is typically aligned along a true North meridian. It is possible to align them in any cardinal direction with advanced Single axis trackers have one degree of freedom that acts as an axis of rotation tracking algorithms. There are several common implementations of single axis trackers. These include horizontal single axis trackers (HSAT), vertical single axis trackers (VSAT), tilted single axis trackers (TSAT) and polar aligned single axis trackers (PSAT). The orientation of the module with respect to the tracker axis is important when modeling performance (Anusha & Reddy, 2013). The pictorial representation of a model of a single axis tracker is given in Fig 2.6

Fig 2. 6 Single axis tracker

2.2.10.1 Horizontal Single Axis Tracker (HSAT)

The axis of rotation for horizontal single axis tracker is horizontal with respect to the ground. The posts at either end of the axis of rotation of a horizontal single axis tracker can be shared between trackers to lower the installation cost (Anusha & Reddy, 2013). Field layouts with horizontal single axis trackers are very flexible. The simple geometry means that keeping the entire axis of rotation parallel to one another is all that is required for appropriately positioning the trackers with respect to one another. Appropriate spacing can maximize the ratio of energy production to cost, this being dependent upon local terrain and shading conditions and the time-of-day value of the energy produced. Backtracking is one means of computing the disposition of panels. Horizontal Trackers typically have the face of the module oriented parallel to the axis of rotation. As a module tracks, it sweeps a cylinder that is rotationally symmetric around the axis of rotation. A picture of a horizontal tracker is given in Fig 2.7. Several manufacturers can deliver single axis horizontal trackers. 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.

Fig 2. 7 Horizontal single axis trackers

2.2.10.2 Tilted Single Axis Tracker (TSAT)

All trackers with axes of rotation between horizontal and vertical are considered tilted single axis trackers. Tracker tilt angles are often limited to reduce the wind profile and decrease the elevated end’s height off the ground. Field layouts must consider shading to avoid unnecessary losses and to optimize land utilization. With backtracking, they can be packed without shading perpendicular to their axis of rotation at any density. However, the packing parallel to their axis of rotation is limited by the tilt angle and the latitude. Tilted single axis trackers typically have the face of the module oriented parallel to the axis of rotation. As a module tracks, it sweeps a cylinder that is rotationally symmetric around the axis of rotation. A pictorial representation of the tilted axis is shown in Fig 2.8

Fig 2. 8 Tilted Single Axis Tracker

2.2.10.3 Polar Aligned Single Axis Trackers (PASAT)

One scientifically interesting variation of a tilted single axis tracker is a polar aligned single axis tracker (PASAT). In this particular implementation of a Tilted Single Axis Tracker the tilt angle is equal to the latitude of the installation. This aligns the tracker axis of rotation with the earth's axis of rotation. These are rarely deployed because of their high wind profile.

2.2.11 Solar Position and Photovoltaic Module Tilt Angle

The positions of the Sun can be unambiguously determined for every place on the planet based on two angles: solar elevation (or height) α and solar azimuth γ. Some algorithms define the solar elevation as the angle between the center of the Sun and the horizon as seen from the viewer's position. The solar azimuth describes the angle between the geographic north and the vertical circle through the center of the Sun (south Hemisphere). (Ferreira et al., 2018)

In addition to the viewers' geographic location, solar elevation and solar azimuth are relative to the date and time of the day. The angle between the center of the Sun and the celestial equator, the solar declination δ, which changes over the course of a year between +23˚ 26.50` ≤ δ ≤ 23˚ -26.50` plays the biggest role. Fig 2.9 represents the Sun celestial sphere and coordinates relative to an observer on earth (south hemisphere).

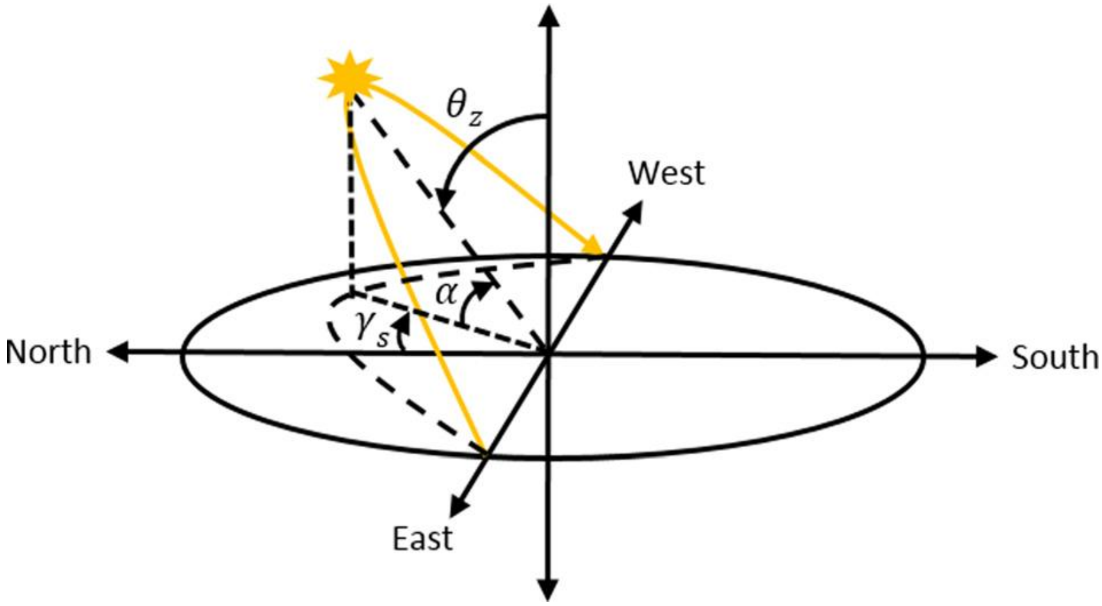

Fig 2. 9 Angles for the position of the sun southern hemisphere

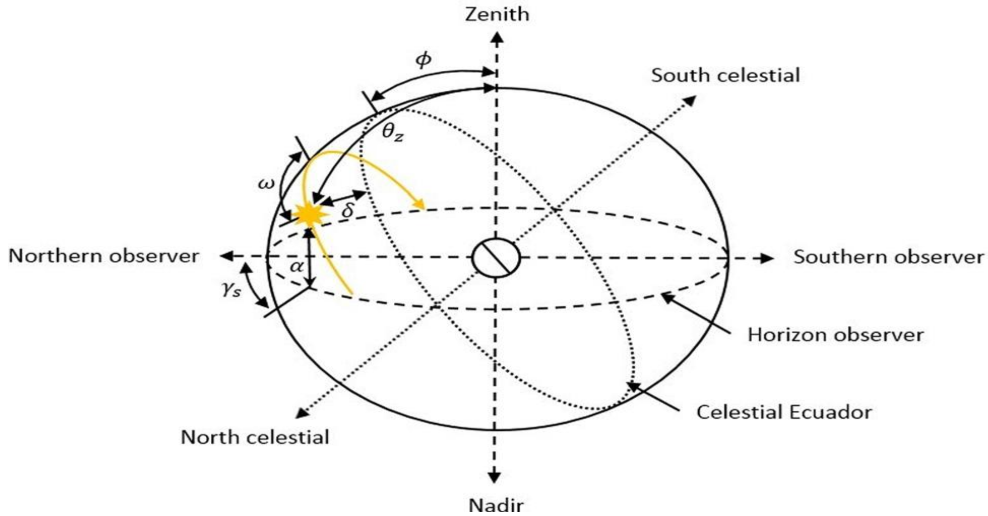

Fig 2. 10 Sun celestial sphere and coordinates relative to an observer in the southern hemisphere

The vertical vector (normal) of a place (observer) on earth intersects the celestial sphere in two points, called zenith and nadir. The angle formed by this line with the celestial equator plane is called geographic latitude ϕ. The horizon of the observer is the great circle on the celestial sphere whose plane passes through the center of the earth, normal to a line connecting the center of the earth and the zenith. The zenith angle, referred to as ϕ_z, is the angle between the local zenith and the line between the observer and the Sun. The solar elevation a (or height) is the angular height of the Sun above the celestial horizon of the observer, which is the complement of the zenith angle. The solar azimuth angle $\gamma_{s,}$ which varies within the range 0±180 deg, is the angle (on-site zenith) between the observer meridian plane and the maximum circle plane passing through the zenith and the Sun. The hour angle ψ is the angle measured at the celestial pole between the meridian of the observer and the meridian of the Sun, which is 0 deg at noon (solar time) and increases 15 deg per hour afterward.

The geographical position determines the relationship between the Sun and a horizontal surface, as expressed by

$$\mathrm{Cos}\phi = \sin\delta\sin\phi + \cos\delta\cos\phi\cos\psi$$

$$\mathrm{Cos}\gamma s = (\sin\alpha\sin\phi - \sin\phi)/(\cos\alpha\cos\phi)$$

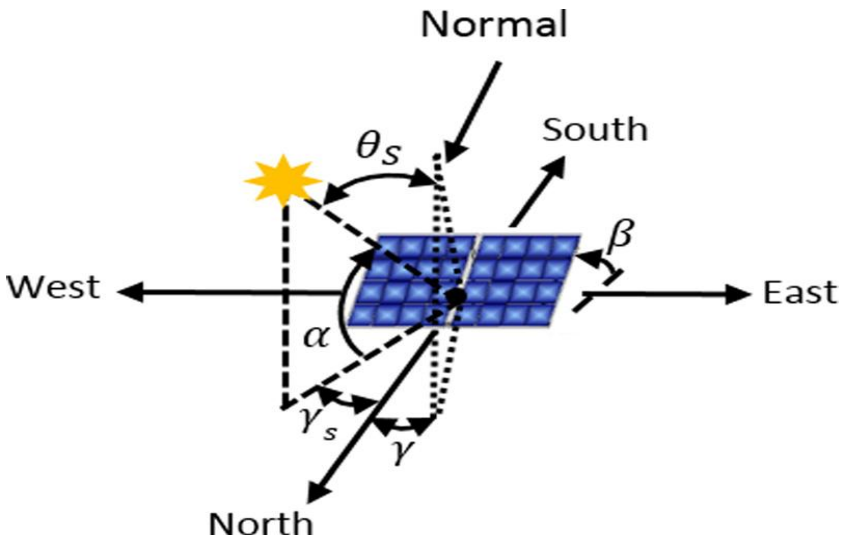

Fig 2. 11 Different angles for the sun's position on a tilted surface

Photovoltaic applications require the determination of the sun's position and its relationship with the solar panel tilt angle. The orientation of this tilted surface may be described by the tilt angle β regarding the observer's horizon and the azimuth angle of the inclined surface γ, which is the distance, regarding local meridian, the normal projection of the solar azimuth angle γs on the horizontal surface of the horizon observer, as represented in Fig 2.11 (Ferreira et al., 2018). ϕ_s represents the angle of incidence in Fig 2.11, formed by the normal on the tilted surface regarding the solar elevation angle α ϕ_s can be expressed as

$$\mathrm{Cos}\,\phi s = \cos\beta\cos\phi z - \sin\beta\sin\phi z\cos(\gamma s - \gamma)$$

Any reliable solar tracking strategy must be able to track the Sun at the right angle, even in the presence of clouds. A myriad of Solar tracking algorithms have already been proposed as complements to photovoltaic systems, as well as various open-source codes and solar astronomical algorithms and solar tracking software (Ferreira et al., 2018).

2.2.12 **Active solar tracking systems (ASTS)**

ASTS are mechanisms capable of changing the position of solar power systems to increase the uptake of energy by orienting the systems perpendicularly to solar rays. Typically, the ASTS include several components, such as transmission mechanical drive subsystems, electric motors, sun position sensors, solar position algorithms, control units and limit switches. The objectives of the ASTS are to achieve high precision solar tracking, robustness against disturbances, high stability, soft control signals and ease of implementation. Furthermore, the energy consumption of the solar tracker should be 2%

to 3% of the increased energy in a solar power generation system (Fuentes-Morales et al., 2020). (Fuentes-Morales et al., 2020) Presented the comparison of the main construction parameters of ASTS. One of the main differences is the Solar tracking precision, which increases the conversion efficiency of solar energy into thermal or electrical energy. Commonly, the minimum Solar tracking precision required is established by means of the acceptance angle of the concentration system, usually defined as the off-tracking angle at which power generation decreases below 90% .The more accurate the solar tracking, the greater the efficiency of the solar power generation systems (Fuentes-Morales et al., 2020).

2.3 **REVIEW OF RELATED WORK**

The design and construction done by (Anusha & Reddy, 2013) made use of LPC2148 development board with built in ADC and RS232 features. A 6V, 300mA solar panel is fixed to the rotor of the DC motor. Communication between controller and Personal Computer (PC) was established by (Anusha & Reddy, 2013) through serial communication using RS232 to record the output voltage. The recorded output voltage from the panel is stored in the data base for analyses. The tracking results obtained by (Anusha & Reddy, 2013) are compared with fixed solar system results. From the results, it is observed that the performance of the tracking system is 40% more efficient than a fixed solar system. The solar energy is captured from the sun with fixed system means without tracking can be taken for six days.

The work in (Ferreira et al., 2018) involved the use of the Raspberry PI3 collects the sensor data and processes the information to make decisions. (Ferreira et al., 2018) also used an analog digital converter (ADC) once Raspberry PI3 has digital inputs and outputs (GPIO). In this work the ADC MCP3008 converter was chosen. The camera used in this project was the PICAM, which was connected to the platform by a specific CSI port. Stress simulation was performed with the structural analysis by finite elements in the CATIA V5 software. In order to calculate the force to be applied in each photovoltaic module, the maximum wind speed was chosen according to ABNT NBR 6123.

(Ferreira et al., 2018) showed that preliminary results for the tested algorithms were measured from a prototype integrated to a photovoltaic module. An increase of up to 38% was calculated for the local-solar-time-driven system compared to the fixed, reference PV module.

Investigation of potential system benefits of simple tracking solar system using an Arduino MEGA 2560, stepper motor and light sensors reading series of values was carried out by (Udoakah & Chukwu, 2018).

The DC motor selected for this work is a bipolar stepper motor, NEMA 17 variant. It is chosen because it provides just sufficient torque to support the mechanics of the design efficiently. The program for the design in (Udoakah & Chukwu, 2018) is written with the Arduino IDE in C programming language and uploaded to the microcontroller via a USB serial port. The operation of the designed solar tracker is achieved by using a MEGA2560 microcontroller which compares the ADC values which is proportional to light intensity illuminated onto the LDRs in each sensor module. The microcontroller has ADC pins to convert analog values to digital values. Each LDR circuit produces analog voltage which is proportional to light intensity. Comparing the values of the LDRs helps in detecting which is under shadow and then send +5V pulse to the motor driver that powers the motor to tilt the necessary axis till about equal amount of light is received.

After the testing and simulation of the prototype (Udoakah & Chukwu, 2018)came to the conclusion that as time increases towards noon, the difference in the energy yields decreases and is approximately equal around noon and continues to increase in difference towards sunset.

A study carried out by (Das et al., 2015) discusses a similar tracking system using photodiode as sensors. Two photodiode sensing the position of the panel and two photodiode to sense the mirror position for boosting voltage drop between the two sensors of the panel, the signal obtained will go to the microcontroller which calculates the ADC value. The relationship between radiant sun light and electrical power generated can be demonstrated with the aid of measuring equipment called photovoltaic Trainer. A major drawback of the this project is the fact that the photodiodes used as the tracking device is subject to bias due to weather conditions. Furthermore, (Das et al., 2015) came to the conclusion that the efficiency of solar panel is 9% using the tracking technique discussed above. The paper has presented a novel and a simple control implementation of a Sun tracker that employed to follow the Sun and produce electricity.

A paper published by (Sharma et al., 2020) proposed strategies for the effective harnessing of available solar energy for electricity generation. This paper focused it research on radiation models these

Radiations models are simulated mostly through MATLAB programming and the tilt angle has been optimized. The radiation data needed for the models are generally taken from National Aeronautics and space administration (NASA) website or local meteorological department of the past years. For the data acquisition system SOLAX real time monitoring portal was used to display the micro-inverter's data on the computer from anywhere through the internet. The electrical parameters output such as voltage, current, and power of the panel were monitored in real time from the system. The sampled data of PV panels of every 10 minutes came into the inverters and can be monitored on the portal. The real time data of PV panel generation and load power at different angles were displayed on the portal. Regression method simulation results are used for the validation of these real time data experimental results. Thus the paper was able to generate a correlation between obtaining optimum tilt angle and reduction in the carbon dioxide produced in an environment. It is concluded that the proposed optimally placed solar panel of capacity 5 kW can help in reducing carbon dioxide emission in the range of 27.55 kg to 32.8 kg in a year. If there is large solar PV plant installed with optimal tilt. A major drawback of the work is the fact that different mathematical analysis has to be computed for different geographical areas and different time of the year.

(Krishna Kumar & Subramaniam, 2018) In his work designed a dual axis solar tracking system and divided the system into two main parts; the mechanical design part and the electronic control unit. In this solar tracking system, the mechanical design part consists of stepper motor, gear wheel, screw, bearing, bolt and base stand. There are two stepper motors used to rotate the concentrator in order to follow the sun. One of these motor is used to rotate the concentrator in azimuth direction, which is consists of two gear wheels. The entire electronic control unit (ECU) is including sensor unit, control unit and measurement unit. Various parameters such as time and position are senses by sensor unit and send the signal to the control unit. After receiving the signal from the sensor unit, the control unit controls the stepper motor direction (clock and anti-clock wise direction) by sending appropriate signals to the driver unit. The driver unit receives the electrical signal from the control unit and adjusts the direction of the stepper motor which is connected with the gear wheel. After aligning the concentrator to the sun's position, the temperature sensor at the receiver point senses the focused solar radiation temperature and converts it to electrical signal. Then it will send to the measurement unit in order to display the obtained temperature. The performance of the proposed system was studied and report taken for the month of February and March 2017. The solar tracking mechanism was tested from morning 10.00 AM to 3.00 PM and the temperature were recorded. The result shows that the real time clock based solar tracking system has 75% more average thermal gain when compared to fixed solar tracking system. A major drawback of the project is the need to use additional correctional software to control the mechanical errors detected during the testing stage.

The work done by (León et al., 2014) involves the use of a semi-passive solar tracking concentrator (SPSTC) whose configuration requires a minimal mechanical effort and reduced movement for sun tracking is proposed. It mainly consists of a micro-heliostat array, a Fresnel lens and a receiver. The array tracks the position of the sun to reflect the sun's rays toward the Fresnel lens, which remains horizontal, reducing wind loads over the whole system. The receiver, located on the lens focus, remains stationary, releasing its weight on the sun tracking system and thus reducing the energy required for movement. The SPSTC's kinematics for both altitude and azimuth tracking on 25°39'15'' N latitude is analyzed. An optimum fixed array's tilt of 49.054° was found to maximize the effective Fresnel lens area by reducing blocking and shading, both caused by the position of the array above the lens. It is observed from this project that a solar concentrator function that raises the complexity and cost of the system. For precise orientation throughout the day and year, a complex electro-mechanical system capable of adapting to latitude changes and environmental conditions is required.

In an effort to improve the efficiency of PV cells (Sohu, 2019) designed a Field Programmable Gate Array (FPGA) that works on the solar tracking control system. The mechanism of whole design keeps the solar panel in horizontal rotation in order to get maximum energy from the sun during the day. The mechanical assemble of prototype solar cell is manufactured to change the position of panel from 180 degree East to West.

Also the design involved the use of electronic circuit, which has quality for sensing the sunlight as well as controlling the servo motor. The tracking system is operated by using the software Altera Quartus-II. The process is gone through the programming and loaded into Altera DE2 FPGA board and tested successfully in the laboratory. This system has more energy concentration and has more improvement factor rather than using fixed solar panel system. During the analysis of the results obtained it was inferred that FPGA is assigned for sun tracking system paths about 24 hours and rotates the motor to the sun direction from this. Time achieves optimistic solar irradiance throughout the complete cycle. Hence the designed system can reach extra lights and energy concentration than conventional fixed solar panel and can improve overall efficiency. The major characteristic of this design over traditional, single chip designs (such as the 8051 or PIC device) is that traditional chips cannot write VHDL. If old devices and discrete machines were chosen for the task, outside logic circuits were necessary to gadget the controller which would increase complexity in overall implementation. Moreover, in such case, the control system is difficult to correct or troubleshoot, in cases of error and may be unreliable due to lenience of components, environmental and aging effects

A study carried was out by (Barrera-erreyes et al., 2020) during the first half of 2017 in the city of Riobamba, Ecuador, with the objective of implementing a two-axis solar tracking system controlled by a fuzzy logic algorithm, optimizing energy collection with respect to fixed orientation solar panels.

Diffuse control was performed from the Lab VIEW platform. A prototype was built to verify the hypothesis that a solar panel located on a two-axis solar tracker uses solar energy better than one in a fixed orientation. A solar cell was assembled and incidence readings were taken, then the non-parametric Mann-Whitney U test was performed. Therefore, the difference in brightness will be captured or acquired by the fuzzy logic algorithm; this will cause a servo motor to actuate and act on the inclination of the panel by rotating it until the luminous intensity is equal in all the sensors. Fuzzy logic was used in this work since it allows tracking sunlight throughout the day regardless of the time of year and the geographic location of the panel. On the other hand, another control system would need to have equations that describe the solar movement for a specific location and date. The control logic was done with LabVIEW program of National Instruments. The results obtained led to the following conclusions: a two-axis solar tracking system with fuzzy control was designed and implemented, which makes the best use of solar radiation. The two-axis solar panel prototype allowed validating the fuzzy control algorithm for a two-axis solar tracker.

Through the measurements of the incident energy captured on a fixed plate system and a two-axis system, it is that a two-axis solar tracking system with fuzzy logic allows capturing more solar radiation during the day.

Although more energy is produced in this system, a higher amount of energy a higher amount of energy is also consumed by the consumption of the motors, but this is much lower than the energy gained by the system as a whole, due to the fact that the motors are low power and the materials used in the construction of the tracker, are light.

The work done by (Kalhoro et al., 2019) involves the use of bi–facial solar system model provides an effective measurement of power. The solar radiation such as global, diffuse and direct irradiation is fallen on the design solar system. The basic blocks diagram consisting of Solar PV Panel, light dependent resistor (LDR), raspberry pi, relay module, analog to digital converter (ADC), power supply, and battery. These models are representing the principal climate phenomena to attain solar electricity. The output power of the proposed design system which is highly dependent on the Global Horizontal Irradiation (GHI) as well as Global Tilted Irradiation (GTI). The power of the system depends upon solar irradiation received by the surface of photovoltaic modules and the GHI is the sums of the direct and diffuse solar radiation [kWh/m2]. The GHI is considered as a climate reference as it is an important parameter to check for the solar PV installation. The power capabilities of the proposed design system had been experimentally tested with two 40W solar panels at different rotations of the time frame under standard test conditions.

A summary of all the literature that has been reviewed with their strength and weakness as well as the methodology is given in Table 2.1

Table 2. 1 Table of review of related past work

Name(s) of Authors	**Topic**	**Method Used**	**Strengths**	**Weaknesses**
(Anusha & Reddy, 2013)	Design and Development of Real Time Clock based efficient Solar Tracking System	This design made use of LPC2148 development board with built in ADC and RS232 features. A 6V, 300mA solar panel is fixed to the rotor of the DC motor.	Communication between controller and Personal Computer (PC) was established through serial communication using RS232 to record the output voltage. The recorded output voltage from the panel is stored in the data base for analyses.	In this project the supply to the microcontroller was dependent on the connection to the nearby computer system.

Name(s) of Authors	**Topic**	**Method Used**	**Strengths**	**Weaknesses**
(Ferreira et al., 2018)	A solar tracking system based on local solar time integrated to photovoltaic systems	The work involved the use of raspberry PI3 as the microcontroller, an external ADC MP3008 for analog to digital conversion and PICAM is used as a tracking mechanism	This paper focused on the use of IoT as a platform for service for solar tracking strategy.	The tracking mechanism used is connected to a CSI port which microcontroller selective.
(Udoakah & Chukwu, 2018)	Design and Implementation of a Dual Axis Solar Tracker Using Arduino Microcontroller	This work made use Arduino MEGA 2560, stepper motor and light sensors as a tracking mechanism.	The project made use of a NEMA17 stepper motor which has high torque capabilities and also micro stepping function can be performed by means of a code.	This project made use of four LDR sensors as its tracking mechanism which is subject to weather bias as it does not provide efficient tracking in cloudy conditions.

Name(s) of Authors	Topic	Method Used	Strengths	Weaknesses
(Das et al., 2015)	Automatic Solar Tracking System with Mirror Booster	Two photodiode are used to sense the position of the panel and two photodiode to sense the mirror position for boosting voltage drop between the two sensors of the panel, the signal obtained will go to the microcontroller which calculates the ADC value	. The relationship between radiant sun light and electrical power generated can be demonstrated with the aid of measuring equipment called photovoltaic Trainer.	A major drawback of the this project is the fact that the photodiodes used as the tracking device is subject to bias due to weather conditions.

Name(s) of Authors	**Topic**	**Method Used**	**Strengths**	**Weaknesses**
(Sharma et al., 2020)	Optimal Tilt Angle Determination for PV Panels Using Real Time Data Acquisition	This paper focused it research on radiation models these radiations models are simulated mostly through MATLAB programming	For the data acquisition system SOLAX real time monitoring portal was used to display the micro-inverter's data on the computer from anywhere through the internet	A major drawback of the work is the fact that different mathematical analysis has to be computed for different geographical areas and different time of the year.

Name(s) of Authors	Topic	Method Used	Strengths	Weaknesses
(Krishna Kumar & Subramaniam, 2018)	Real time clock based energy efficient automatic dual axis solar tracking system	In this solar tracking system, the mechanical design part consists of stepper motor, gear wheel, screw, bearing, bolt and base stand. There are two stepper motors used to rotate the concentrator in order to follow the sun.	After aligning the concentrator to the sun's position, the temperature sensor at the receiver point senses the focused solar radiation temperature and converts it to electrical signal. Then it will send to the measurement unit in order to display the obtained temperature	A weakness observed in the project is the need to use additional correctional software to control the mechanical errors detected during the testing stage.

Name(s) of Authors	**Topic**	**Method Used**	**Strengths**	**Weaknesses**
(León et al., 2014)	Semi-passive solar tracking concentrator	This system mainly consists of a micro-heliostat array, a Fresnel lens and a receiver. The array tracks the position of the sun to reflect the sun's rays toward the Fresnel lens, which remains horizontal, reducing wind loads over the whole system.	The use of a semi-passive solar tracking concentrator (SPSTC) allows kinematics for both altitude and azimuth tracking on latitude to be analyzed	For precise orientation throughout the day and year, a complex electro-mechanical system capable of adapting to latitude changes and environmental conditions is required.

Name(s) of Authors	**Topic**	**Method Used**	**Strengths**	**Weaknesses**
(Sohu, 2019)	2019 2nd International Conference on Computing, Mathematics and Engineering Technologies (iCoMET)	The system designed is a Field Programmable Gate Array (FPGA) that works on the solar tracking control system. The mechanism of whole design keeps the solar panel in horizontal rotation in order to get maximum energy from the sun during the day.	A major advantage of this design over traditional, single chip designs (such as the 8051 or PIC device) is that traditional chips cannot write VHDL. If old devices and discrete machines were chosen for the task, outside logic circuits were necessary to gadget the controller which would increase complexity in overall implementation.	The control system is difficult to correct or troubleshoot in cases of error and may be unreliable due to lenience of components, environmental and aging effects

Name(s) of Authors	**Topic**	**Method Used**	**Strengths**	**Weaknesses**
(Barrera-erreyes et al., 2020)	Fuzzy logic algorithm for solar tracking system	The paper focused on the use of fuzzy logic algorithm to capture the difference in brightness and this will cause a servo motor to actuate and act on the inclination of the panel by rotating it until the luminous intensity is equal in all the sensors.	Through the measurements of the incident energy captured on a fixed plate system and a two-axis system, it is that a two-axis solar tracking system with fuzzy logic allows capturing more solar radiation during the day.	Although more energy is produced in this system, a higher amount of energy a higher amount of energy is also consumed by the consumption of the motors
(Kalhoro et al., 2019)	An Economical And Relatively Efficient Implementation of the Real–Time Solar	The basic blocks diagram consisting of Solar PV Panel, light dependent	This system involved the use of bi–facial solar system model provides an effective	The power of the system depends upon solar irradiation received by the surface of

	Tracking System	resistor (LDR), raspberry pi, relay module, analog to digital converter (ADC), power supply, and battery.	measurement of power.	photovoltaic modules and the GHI is the sums of the direct and diffuse solar radiation

2.4 **SUMMARY**

This chapter was grouped into three phases. The first phase was for the purpose of introduction. The second section discussed about the principles of photovoltaic cells and solar tracking, several terms and definitions under it as well as the importance of solar tracking a means of improving the efficiency of photovoltaic cells. The third section gave a comprehensive review of past works that are related to this study as well as the strength, weakness and the methods adopted in each review.

CHAPTER THREE

METHODOLOGY

3.1 **INTRODUCTION**

This chapter discusses the method used for the execution of this project, how it was done and what are the ingredients and tools behind solving the problem discussed earlier in chapter one. The relevant information needed to execute this project has been gathered in the literature review in the previous chapter. This chapter will cover the design analysis, software implementation, tracking algorithm, the control unit, the tracking and sensory unit, and the display unit.

3.2 **DESIGN ANALYSIS**

The project is broadly divided into two hardware design and software design. The hardware is the physical part of the system while the software consists of the codes written for the interaction of the microcontroller with the peripherals and also to control the operation of the microcontroller. The block diagram of the time based solar tracking system is given in Fig 3.1

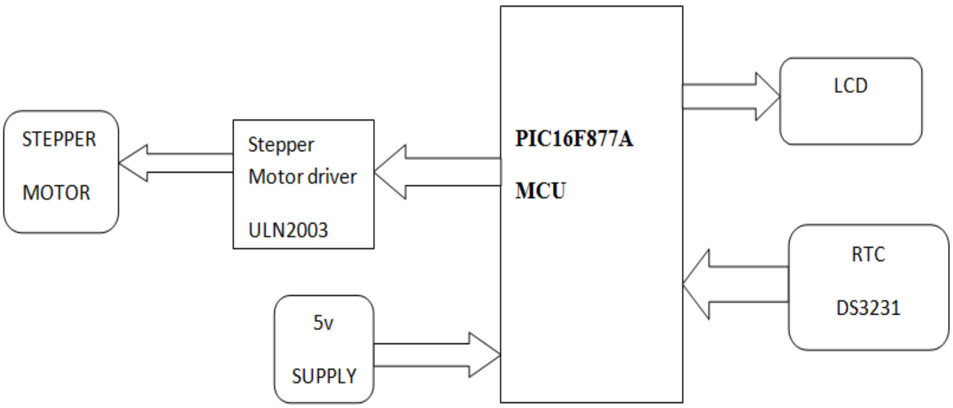

Fig 3. 1 Block diagram of the time based solar tracking system

The system comprises of the real time clock module(RTC) DS3231, the 16*2 Liquid crystal display(LCD), the stepper motor, the stepper motor driver ULN2003 and the PIC16f877a microcontroller. The solar panel is connected to the stepper motor and ULN2003 is used to control the stepper motor this is because a stepper motor cannot be directly interfaced with the microcontroller. A 5-volts (v) supply is used to provide power supply power to the microcontroller. The real time clock DS3231 is used to give real time information to the microcontroller, finally the liquid crystal display is used to display the time and other important information and parameters of the system.

3.3 **TRACKING AND SENSORY UNIT**

This unit is the mechanical framework that carries the payload which will be oriented at optimum position against the sun. The payloads could be photovoltaic panels, reflectors, Collectors, lenses or other optical devices (Udoakah & Chukwu, 2018). This will be achieved via comparing the inputs from the real time clock. The solar panel is attached to a stepper motor shaft; the motor rotation results in the tilting of the angle at which the solar panel is inclined. The tracking and sensory unit comprises of solar panel, the real time clock , the stepper motor, the stepper motor driver.

3.3.1 **Solar Panel**

Solar panels collect clean renewable energy in the form of sunlight and convert that light into electricity which can then be used to provide power for electrical loads. Solar panels are comprised of several individual solar cells which are themselves composed of layers of silicon, phosphorous (which provides the negative charge), and boron (which provides the positive charge). Solar panels absorb the photons and in doing so initiate an electric current. The resulting energy generated from photons striking the surface of the solar panel allows electrons to be knocked out of their atomic orbits and released into the electric field generated by the solar cells which then pull these free electrons into a directional current. This entire process is known as the PhotovoltaicEffect(Prowler,2014).

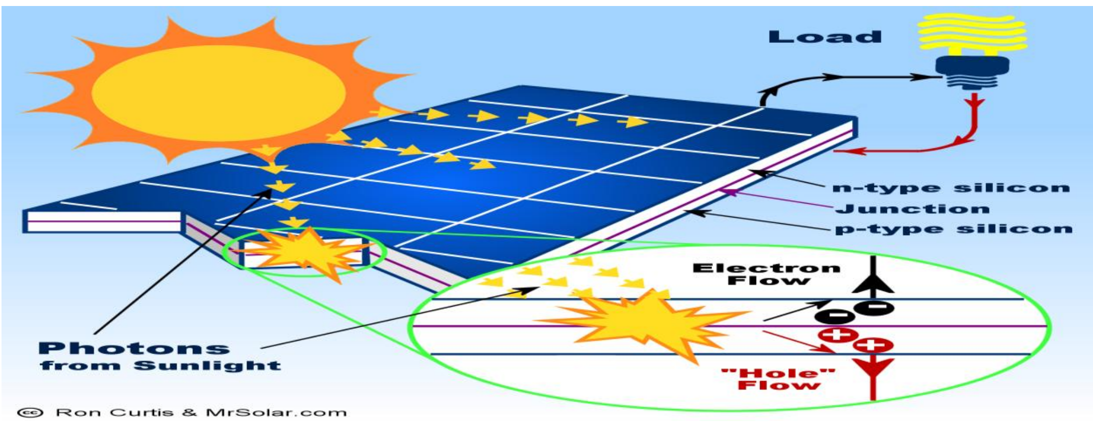

Fig 3. 2 Solar panel working principle

The specifications of the solar panel used are summarized in Table 3.1

Table 3. 1 Solar Panel Specifications

S/No	Features	Description
1	Dimensions(mm)	225 by 190
2	Output Tolerance	±5%
3	Maximum Power Pmax (W)	5
4	Current at Pmax (A)	0.29
5	Voltage at Pmax (V)	17.5
6	Short circuit Current (A)	0.32
7	Open Circuit Voltage (V)	22.05

3.3.2 **Real Time Clock (DS3231)**

The DS3231 is a low-cost, extremely accurate I2C real-time clock (RTC) with an integrated temperature compensated crystal oscillator (TCXO) and crystal. The device incorporates a battery input, and maintains accurate timekeeping when main power to the device is interrupted. The integration of the crystal resonator enhances the long-term accuracy of the device as well as reduces the piece-part count in a manufacturing line. The DS3231 is available in commercial and industrial temperature ranges, and is offered in a 16-pin, 300-mil SO package. The RTC maintains seconds, minutes, hours, day, date, month, and year information. The date at the end of the month is automatically adjusted for months with fewer than 31 days, including corrections for leap year. The clock operates in either the 24-hour or 12-hour format with an AM/PM indicator. Two programmable time-of-day alarms and a programmable square-wave output are provided. Address and data are transferred serially through an I2C bidirectional bus(Prowler, 2014). A precision temperature-compensated voltage reference and comparator circuit monitors the status of VCC to detect power failures, to provide a reset output, and to automatically switch to the backup supply when necessary. Additionally, the RST pin is monitored as a pushbutton input for generating a microprocessor reset. The operating circuit of the RTC is given in Fig 3.3

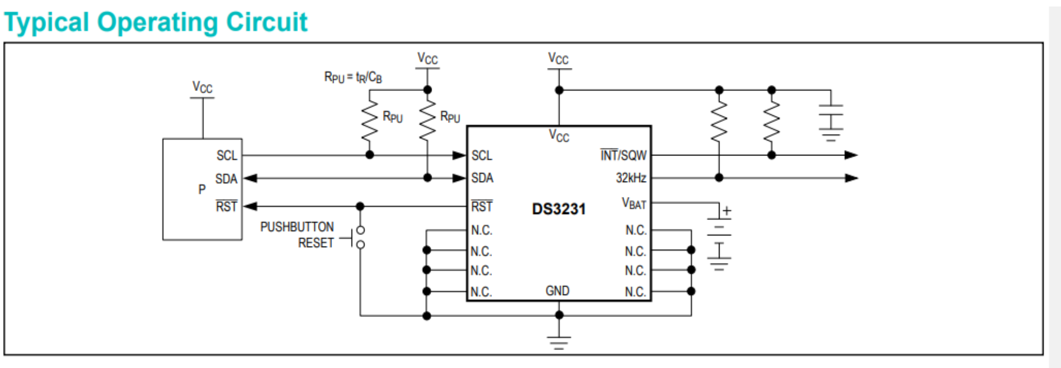

Fig 3. 3 Typical Operating Circuit Of DS3231

The Circuit diagram for PIC Microcontroller based Digital Clock is given in Fig 3.4. As told earlier the DS3231 works with the help of I2C communication so it will have a Serial Clock (SCL) and a Serial Data (SDA) pin which has to be connected to the I2C pins on our PIC which is the pin 18(SCL) and pin 23 (SDA). A pull up resistor of value 4.7k is used to keep the bus at high state when idle. The circuit diagram of the RTC interfaced with the microcontroller is given in Fig 3.4

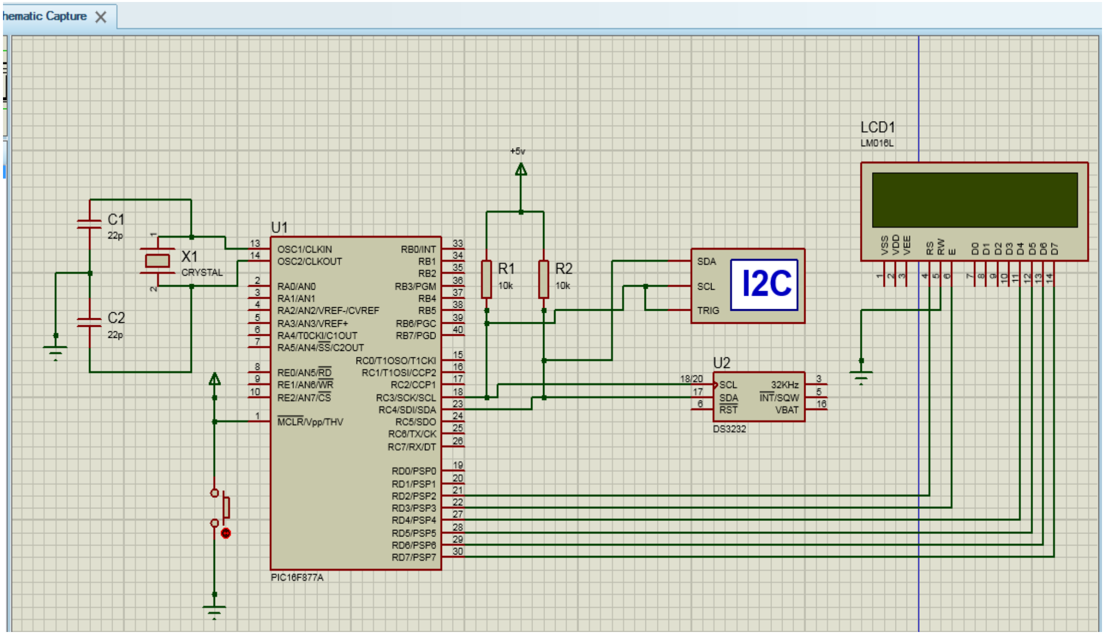

Fig 3. 4 DS3231 Connection Circuit

By default when the RTC module was purchased the correct time and date will not be set in it, so we have to set it through our program. So we declare variable for each data and feed in the real world time and date as shown in Fig 3.5

```
/*Set the current value of date and time below*/
int sec = 00;
int min = 55;
int hour = 10;
int date = 06;
int month = 05;
int year = 18;
/*Time and Date Set*/
```

Fig 3. 5 Setting the time and date

The RTC module communicates with the help of I2C protocol so to enable the I2C communication our PIC microcontroller. Most devices including the DS3231 modules have an I2C operating frequency of 100 KHz to start the I2C communication with a frequency of 100 KHz as shown in Fig 3.6

```
I2C_Initialize(100); //Initialize I2C Master with 100KHz clock
```

Fig 3. 6 Initializing I2C procedure

The variables are of integer data type, to convert them to individual characters so that it can display them on the LCD screen. The modulus operator is used to get the once digit and divide the variable by 10 to get the tens digit. The same is done for all the variables. The algorithm for initializing the display is given in Fig 3.7

```
//Split the into char to display on lcd
 char sec_0 = sec%10;
 char sec_1 = (sec/10);
 char min_0 = min%10;
 char min_1 = min/10;
 char hour_0 = hour%10;
 char hour_1 = hour/10;
 char date_0 = date%10;
 char date_1 = date/10;
 char month_0 = month%10;
 char month_1 = month/10;
 char year_0 = year%10;
 char year_1 = year/10;
```

Fig 3. 7 Initializing the Display

3.3.3 28BYJ-48 - 5V Stepper Motor

The DC motor selected for this work is a bipolar stepper motor, 28BYJ-48 variant. It is chosen because it provides just sufficient torque to support the mechanics of the design efficiently. Fig 3.8 shows a picture of the stepper motor.

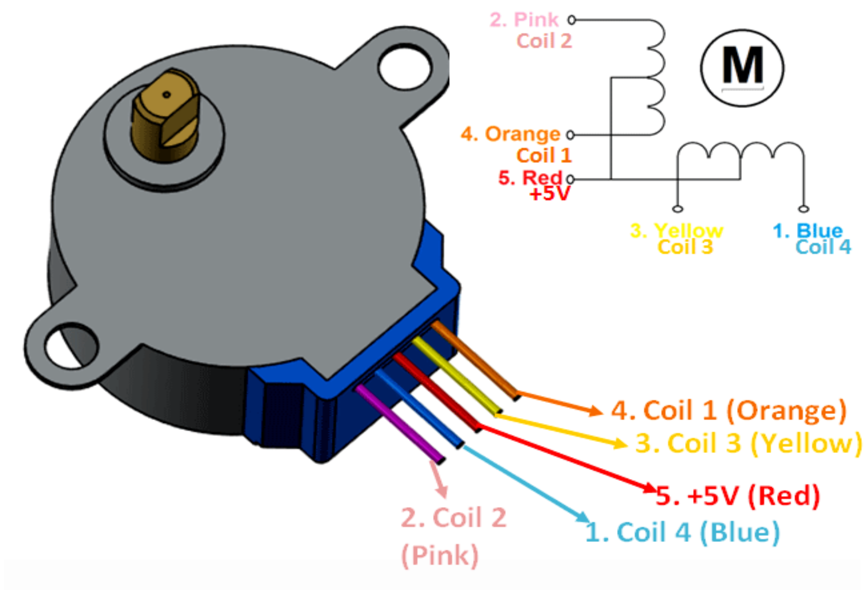

Fig 3. 8 28BYJ-48 Stepper Motor

The specification of this variant of stepper motor is given in Fig 3.9

Rated voltage :	5VDC
Number of Phase	4
Speed Variation Ratio	1/64
Stride Angle	5.625°/64
Frequency	100Hz
DC resistance	50Ω±7%(25℃)
Idle In-traction Frequency	> 600Hz
Idle Out-traction Frequency	> 1000Hz
In-traction Torque	>34.3mN.m(120Hz)
Self-positioning Torque	>34.3mN.m
Friction torque	600-1200 gf.cm
Pull in torque	300 gf.cm
Insulated resistance	>10MΩ(500V)
Insulated electricity power	600VAC/1mA/1s
Insulation grade	A
Rise in Temperature	<40K(120Hz)
Noise	<35dB(120Hz,No load,10cm)
Model	28BYJ-48 – 5V

Fig 3. 9 Stepper motor Specification

These stepper motors consume high current and hence a driver IC like the ULN2003 is mandatory. To know how to make this motor rotate the coil diagram shown in Fig 3.10 must be given adequate consideration.

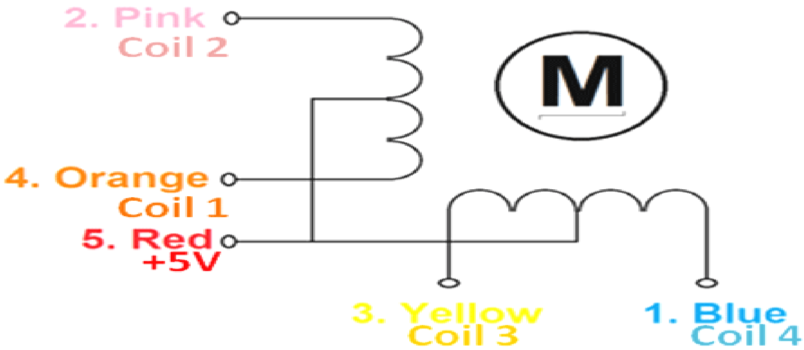

Fig 3. 10 Coil Diagram of the stepper motor

As we can see from Fig 3.10 there are four coils in the motor and one end of all the coil is tied to +5V (Red) and the other ends (Orange, Pink, Yellow and Blue) are taken out as wires. The Red wire is always provided with a constant +5V supply and this +5V will be across (energize) the coil only if the other end of the coil is grounded. A stepper motor can be made to rotate only if the coils are energized (grounded) in a logical sequence. This logical sequence can be programmed using a microcontroller or by designing a digital circuit. The sequence in which each coil should be triggered is shown in the table below. Here “1” represent the coil is held at +5V, since both the ends of coil is at +5V (red and other end) the coil will not be energized. Similarly “0” represents the coil is held to ground, now one end will be +5V and the other one is grounded so the coil will be energized (*28BYJ-48 Stepper Motor Pinout Wiring, Specifications, Uses Guide & Datasheet*, n.d.). There are three major ways to drive the stepper motor the full drive, half drive and wave drive.

3.3.3.1 Full drive mode

If two stator electromagnets are energized at a time, the motor will run at full torque referred as full-drive sequence mode. This allows the stepper motor to move in steps four times. Table 3.2 represents the sequence in full drive mode

Table 3. 2 Full drive mode

Step	Blue	Pink	Yellow	Orange
1	1	1	0	0
2	0	1	1	0
3	0	0	1	1
4	1	0	0	1

3.3.3.2 Half drive mode

When alternatively one and two phases are energized, the motor will run in half drive mode. It's used to increase the angular resolution. Drawback is less torque produced in this movement. Table 3.3 represents the sequence in half drive mode

Table 3. 3 Half drive mode

Step	Blue	Pink	Yellow	Orange
1	1	0	0	0
2	1	1	0	0
3	0	1	0	0
4	0	1	1	0
5	0	0	1	1
6	0	0	0	1
7	1	0	0	1
8	1	0	0	0

3.3.3.3 Wave drive mode

In this mode, one stator electromagnet is turned on. Its follows 4 steps same as Full-drive mode. It consumes low power with low torque (*Interfacing Stepper Motor with PIC Microcontroller (PIC16F877A)*, n.d.). Table 3.4 represents the sequence in wave drive mode

Step	**Blue**	**Pink**	**Yellow**	**Orange**
1	1	0	0	0
2	0	1	0	0
3	0	0	1	0
4	0	0	0	1

3.3.4 **ULN2003 stepper motor driver**

ULN 2003 is a high-voltage; high-current Darlington arrays each containing seven open collector Darlington pairs with common emitters. Each channel is rated at 500 mA and can withstand peak currents of 600 mA. Suppression diodes are included for inductive load driving and the inputs are pinned opposite the outputs to simplify board layout. The versions interface to all common logic families: ULN2001 (general purpose, DTL, TTL, PMOS, CMOS); ULN2002 (14 - 25 V PMOS); ULN2003 (5 V TTL, CMOS); ULN2004 (6 - 15 V CMOS, PMOS). These versatile devices are useful for driving a wide range of loads including solenoids, relay DC motors, LED display filament lamps, thermal print heads and high-power buffers. The circuit diagram for the ULN2003 is given in Fig 3.11

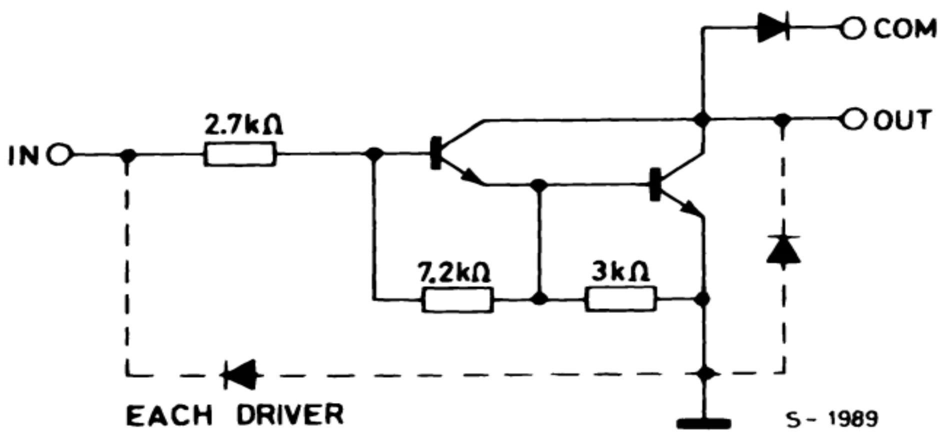

Fig 3. 11 ULN2003 Circuit Diagram

The ULN2003 has been established to have high current handling capabilities; Table 3.5 provides a summary of information on the ratings of the stepper motor drivers

Table 3. 4 Maximum rating of ULN2003

Symbol	Parameter	Value	Unit
V_O	Output voltage	50	V
V_I	Input voltage (for ULN2002A/D - 2003A/D - 2004A/D)	30	V
I_C	Continuous collector current	500	mA
I_B	Continuous base current	25	mA
I_F	Clamping diode continuous current	350	mA
V_R	Clamping diode reverse voltage	50	V
T_A	Operating ambient temperature range	- 40 to 85	°C
T_{STG}	Storage temperature range	- 55 to 150	°C
T_J	Junction temperature	150	°C
ESD	Electrostatic discharge rating - HBM	2	kV

The pin configuration of the ULN2003 is given in Fig 3.12 including how the common and the ground terminals are connected to the individual pin.

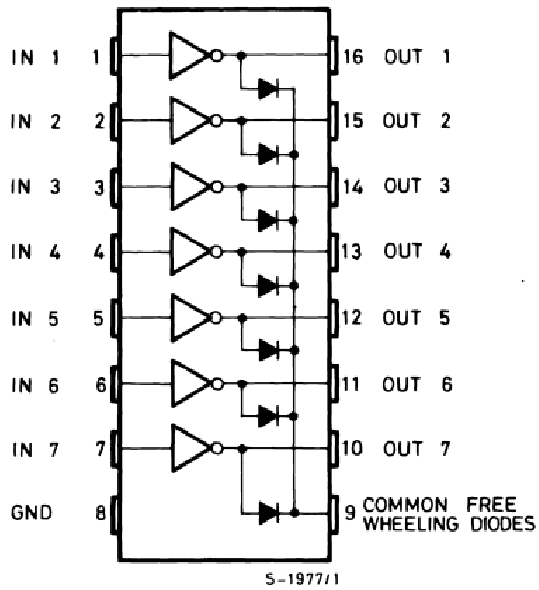

Fig 3. 12 Pin connections of ULN2003

The circuit diagram for the interface will include the combination of the motor driver and the stepper motor itself. Also, the general input and output pins of the microcontroller serves as the point of connection to the stepper motor driver and does not require the use of additional module.

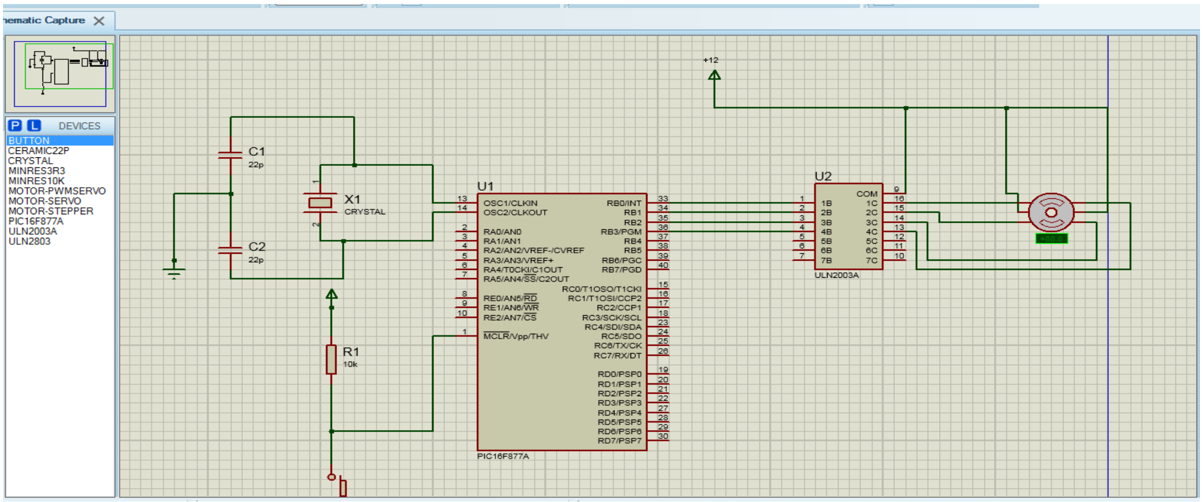

Fig 3. 13 Stepper motor interface with PIC16F877a

The selection of the mode of operation of the stepper motor is done via the code and the block of code used to select between the wave, full and half drive mode is given in Fig 3.14

```
#define _XTAL_FREQ 200000000 //Crystal Frequency, used in delay

#define speed 1 // Speed Range 10 to 1 10 = lowest , 1 = highest

#define steps 250 // how much step it will take

#define clockwise 0 // clockwise direction macro

#define anti_clockwise 1 // anti clockwise direction macro

Void full_drive(char direction)

Void half_drive(char direction)

Void wave_drive(char direction)
```

Fig 3. 14 Algorithm for the mode of operation of the stepper motor

3.4 **THE POWER SUPPLY UNIT**

The power supply unit is responsible for supplying a regulated 5V DC and unregulated12V DC supply to the entire circuit. The power supply unit used in this design is a simple 12VDC power adapter delivering 2A current. However, the energy from the system could be used to power the motor driver and the control unit. The schematic explanation of the power supply unit is given in Fig 3.15

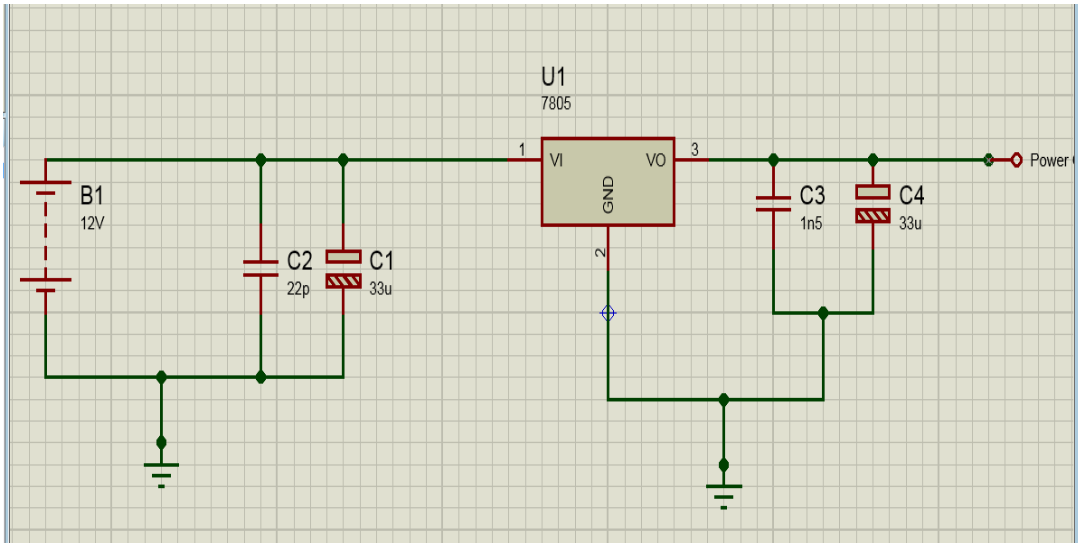

Fig 3. 15 Power Supply circuitry

The 12 volts lithium battery supplies the unregulated DC voltage and this serves as input to the voltage regulator. The voltage regulator performs the basic function of outputting a constant voltage of 5 volts from the input from the 12 volts battery. The function of the capacitor is to perform the basic filtering function.

3.4.1 **Lithium Battery**

Lithium batteries are widely used in portable consumer electronic devices. The term "lithium battery" refers to a family of different lithium-metal chemistries, comprising many types of cathodes and electrolytes but all with metallic lithium as the anode. The battery requires from 0.15 to 0.3 kg of lithium per kWh. As designed these primary systems use a charged cathode, that being an electro-active material with crystallographic vacancies that are filled gradually during discharge (*Lithium Battery - Wikipedia*, n.d.).

Lithium batteries find application in many long-life, critical devices, such as pacemakers and other implantable electronic medical devices. These devices use specialized lithium-iodide batteries designed to last 15 or more years. But for other, less critical applications such as in toys, the lithium battery may actually outlast the device. In such cases, an expensive lithium battery may not be cost-effective.

Lithium batteries can be used in place of ordinary alkaline cells in many devices, such as clocks and cameras. Although they are more costly, lithium cells will provide much longer life, thereby minimizing battery replacement. However, attention must be given to the higher voltage developed by the lithium cells before using them as a drop-in replacement in devices that normally use ordinary zinc cells.

Table 3. 5 Battery specification

Lithium Battery type	**12V – 100Ah Lithium Ion Battery**
Nominal capacity	100Ah
Nominal battery voltage	12V DC
Operation voltage discharge	9.2V DC
Operation voltage charge	15V DC
Cell voltage min cut-off	2.3V DC
Continuous discharge current	100 A

Chemistry(Components)	LiFeYPO4
Dimensions (W x H x D)	192x274x301 mm
Watt hours	1320 Wh

The picture of the Lithium battery used in the implementation of the protoype is given in Fig 3.16

Fig 3. 16 12V lithium battery

The voltage regulator is used to maintain a steady voltage of 5VDC at the output irrespective of voltage fluctuation at the input. Voltage regulators (VRs) keep the voltages from a power supply within a range that is compatible with the other electrical components. While voltage regulators are most commonly used for DC/DC power conversion, some can perform AC/AC or AC/DC power conversion as well. The type of voltage regulator used is a fixed type of the KA 78XX series. The specification of the regulator used is given in Table 3.7

Table 3. 6 Voltage Regulator Specifications

Parameter	**Minimum**	**Typical**	**Maximum**	**Unit**
Model type		KA 7805		
Output Voltage	4.8	5.0	5.2	Volts(V)
Input Voltage	8 to 25		100	Volts(V)
Ripple Rejection	62	78		Decibels(Db)
Output Resistance		0.017		Ohms(Ω)
Short circuit output current		750		Milliamps(mA)
Peak Output Current		2.2		Ampere(A)
Internal Reference Voltage		3		Volts (V)

The minimum input voltage is given as:

$$Vmin = Vout + Vref.$$

V_{min} = Minimum input Voltage

V_{out} = Maximum output Voltage

V_{ref} = Reference Voltage

For a 5V regulator, V_{min} = 5 + 3 = 8 V

Note, for a regulator to operate, the input voltage must be higher than the rated output voltage.

The picture of the regulator used in the implementation of the prototype is given in Fig 3.17

Fig 3. 17 Voltage Regulator

3.4.2 **Capacitors**

Capacitors are two-terminal electrical component separated by a dielectric (insulator) and are used for storing electric charges. An ideal capacitor is characterized by a single constant value. Capacitance is measured in farads. The capacitor used is rated 1000uF, 25V. This was chosen because capacitor voltage must be greater than circuit voltage. The **primary** purpose of **capacitors** is to store electrostatic energy in an electric field and where possible, to supply this energy to the circuit. To prevent a dangerous failure of the circuit, they allow the AC to move but block the flow of DC. The pictorial representation of the electrolytic and ceramic capacitors used in the design and construction of the prototype is given in Fig 3.18

Fig 3. 18 Electrolytic and Ceramic Capacitors

3.5 **Control Unit**

The processing unit performs the overall control and decision-making function. This decision is based on set of instructions stored in the memory. It takes in series of inputs from the various sensors: real time clock, solar cell and gives output commands to the motor driver which enables the motor to move to align the solar panel perpendicular to the sun. The microprocessor used in this design is the PIC16F877A microcontroller. This microcontroller is a reduced instruction set computer (RISC) that has a watchdog timer (WDT) with its own on chip RC- Oscillator for reliable operation. It is based on complementary metal oxide semiconductor (CMOS) technology it has a wide range of operating voltage usually from 3.3v to 5.5v and available for industrial and commercial applications.

3.5.1 **PIC16F877A Microcontroller**

The PIC microcontroller PIC16f877a is one of the most renowned microcontrollers in the industry. This microcontroller is very convenient to use, the coding or programming of this controller is also easier. One of the main advantages is that it can be write-erase as many times as possible because it uses FLASH memory technology. It has a total number of 40 pins and there are 33 pins for input and output. PIC16F877A is used in many PIC microcontroller projects. PIC16F877A also have much application in digital electronics circuits. It is used in remote sensors, security and safety devices, home automation and many industrial instruments. The PIC16F877A is shown in Fig 3.19. An EEPROM is also featured in it which makes it possible to store some of the information permanently like transmitter codes and receiver frequencies and some other related data. The cost of this controller is low and its handling is also easy. It is flexible and can be used in areas where microcontrollers have never been used before as in microprocessor applications and timer functions etc. Some of the main features of the microcontroller are explained in details below

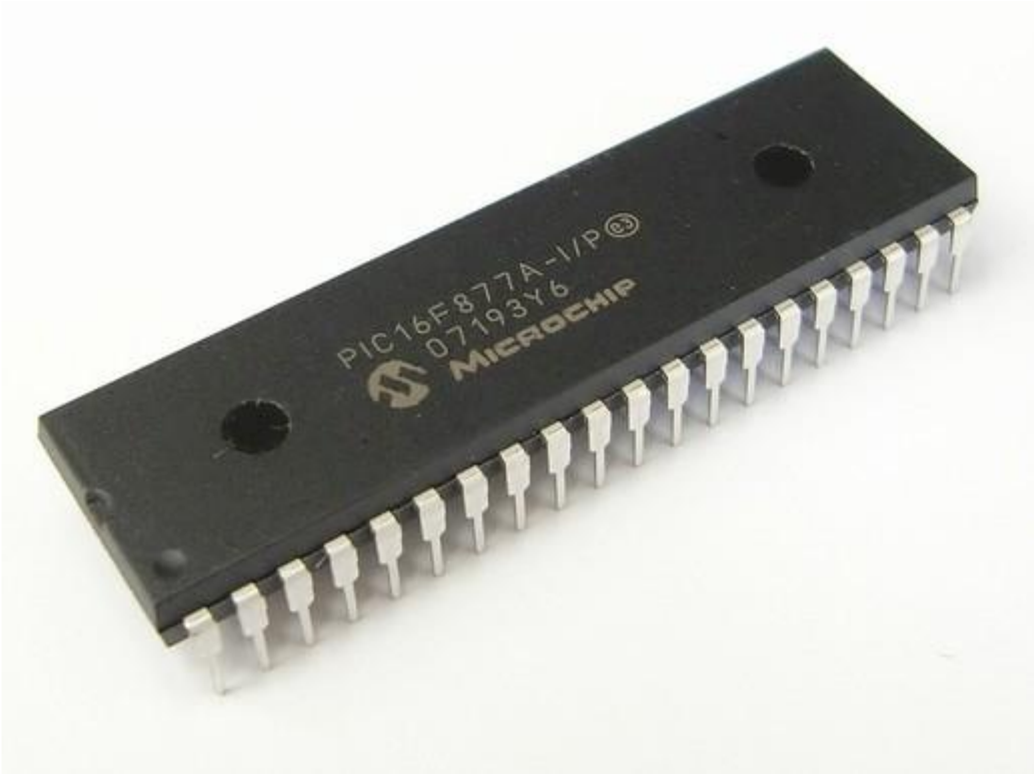

Fig 3. 19 PIC16F877A Microcontroller

3.5.1.1 Analog to digital converter module

It has 8 bit ADC module which consists of 8 channels. We can use 8 analog sensors with this microcontroller.

3.5.1.2 Timers

It provides three timers timer0, timer1 and timer2. All these timers can be used either in timer mode or in counter mode. These timers are used to generate delays, pulse width modulation, counting external events and timer interrupts. TIMER0 is a 8 bit timer and it can operate with internal or external clock frequency. When we use Timer0 in timer mode, we usually operate it with internal frequency and in counter mode; we trigger it with external clock source. Similarly, TIMER1 is a 16-bit timer and it can also operate in both modes. TIMER2 is also of 8-bit. It is used with PWM as a time base for CCP module.

3.5.1.3 EEPROM

It also has built-in electrically erasable read only memory 256 x 8 bytes which can used to store data permanently even if the microcontroller is switched off, data will remain there. This particular feature is important to the design and construction time based solar tracking system as it is used to store the predetermined values of the position of the sun at different times of the day.

3.5.1.4 PWM modules

It also provides 2 CCP modules. CCP stands for capture compare PWM modules. We can easily generate two PWM signals with this microcontroller. The maximum resolution it supports is 10 bits.

3.5.1.5 Serial or UART communication pins

It supports one UART channel. UART pins are used for serial communication between digital devices. RC7 pin is a transmitter or RX pin which is pin number 26. RC6 is a receiver or Tx pin which is pin number 25.

3.5.1.6 I2C Communication

PIC16F877A also support I2C communication and its has one module for I2C communication. Pin#18/RC3 and 23/RC4 are **SCL** and **SDA** pins respectively. SCL is a serial clock line and SDA is serial data line.

3.5.1.7 Interrupts

Interrupts have wonderful applications in embedded systems field. If you don't know about interrupts, I suggest you to get complete understanding about them, you will not get command on embedded programming them. PIC16F877A microcontroller provides 8 types of interrupts namely; External interrupts, timer interrupts, PORT state change interrupts, UART interrupt, I2C, PWM interrupts.

3.5.1.8 Watchdog timer

WDT is an on chip separate oscillator which runs freely. It is a separate oscillator from OSC1/CLKI. WDT will also work even if the device is in sleep mode. It is used to wake up device from sleep mode and also used to generate watchdog timer reset.

3.5.1.9 Sleep mode

PIC16F877A also provide sleep mode operation. In this mode, device operates at very low power. All peripherals draws minimum amount of current. Wake up from sleep mode from interrupts resources like timer1 interrupt, UART interrupt, EEPROM write completion operation and many others. A summary of the key features of the 16F87XX Family is given in Fig 3.20

Key Features	PIC16F873A	PIC16F874A	PIC16F876A	PIC16F877A
Operating Frequency	DC – 20 MHz	DC – 20 MHz	DC – 20 MHz	DC – 20 MHz
Resets (and Delays)	POR, BOR (PWRT, OST)	POR, BOR (PWRT, OST)	POR, BOR (PWRT, OST)	POR, BOR (PWRT, OST)
Flash Program Memory (14-bit words)	4K	4K	8K	8K
Data Memory (bytes)	192	192	368	368
EEPROM Data Memory (bytes)	128	128	256	256
Interrupts	14	15	14	15
I/O Ports	Ports A, B, C	Ports A, B, C, D, E	Ports A, B, C	Ports A, B, C, D, E
Timers	3	3	3	3
Capture/Compare/PWM modules	2	2	2	2
Serial Communications	MSSP, USART	MSSP, USART	MSSP, USART	MSSP, USART
Parallel Communications	—	PSP	—	PSP
10-bit Analog-to-Digital Module	5 input channels	8 input channels	5 input channels	8 input channels
Analog Comparators	2	2	2	2
Instruction Set	35 Instructions	35 Instructions	35 Instructions	35 Instructions
Packages	28-pin PDIP 28-pin SOIC 28-pin SSOP 28-pin QFN	40-pin PDIP 44-pin PLCC 44-pin TQFP 44-pin QFN	28-pin PDIP 28-pin SOIC 28-pin SSOP 28-pin QFN	40-pin PDIP 44-pin PLCC 44-pin TQFP 44-pin QFN

Fig 3. 20 Features of PIC16f877A

3.5.2 Pin Configuration and description of PIC16F877a microcontroller

There are 40 pins of this microcontroller IC. It consists of two 8 bit and one 16 bit timer. Capture and compare modules, serial ports, parallel ports and five input/output ports are also present in it. This figure 3.21 shows the pin out diagram of PIC16F877A.

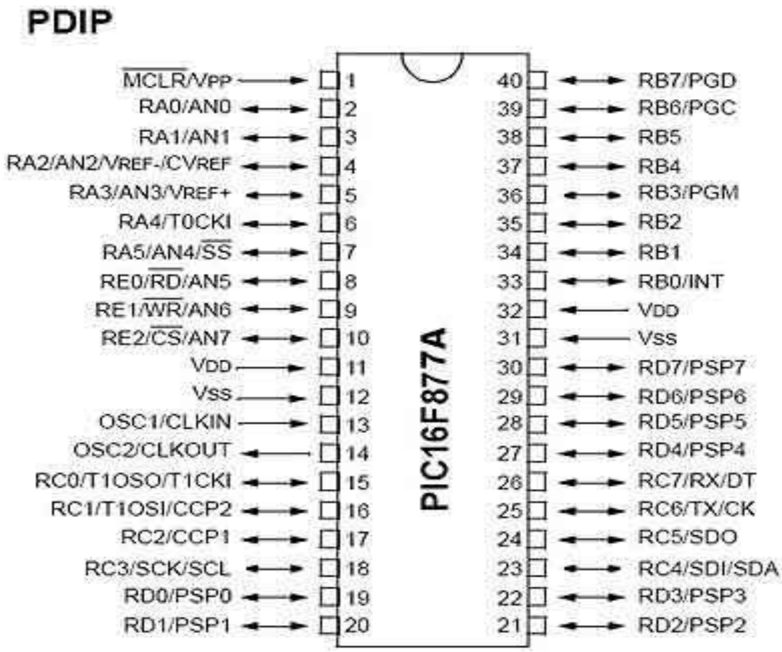

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Fig 3. 21 Pin Configuration

3.5.2.1 Pin 1 MCLR:

The first pin is the master clear pin of this IC. It resets the microcontroller and is active low, meaning that it should constantly be given a voltage of 5V and if 0 V are given then the controller is reset. Resetting the controller will bring it back to the first line of the program that has been burned into the IC.

A push button and a resistor is connected to the pin. The pin is already being supplied by constant 5V. When we want to reset the IC we just have to push the button which will bring the MCLR pin to 0 potential thereby resetting the controller. The circuit for implementation of the MCLR is shown in Fig 3.22

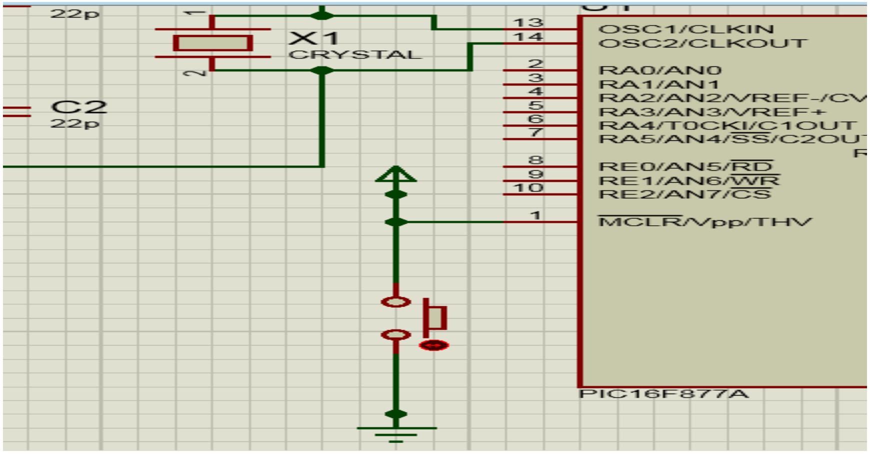

Fig 3. 22 MCLR circuit

3.5.2.2 Pin 2 RA0/AN0: PORTA consists of 6 pins, from pin 2 to pin 7, all of these are bidirectional input/output pins. Pin 2 is the first pin of this port. This pin can also be used as an analog pin AN0. It is built in analog to digital converter

3.5.2.3 Pin 8 RE0/RD/AN5: PORTE starts from pin 8 to pin 10 and this is also a bidirectional input output port. It can be the analog input 5 or for parallel slave port can act as a 'read control' pin which will be active low.

3.5.2.4 Pin 9 RE1/WR/AN6: It can be the analog input 6. And for the parallel slave port it can act as the 'write control' which will be active low.

3.5.2.5 Pin 10 RE2/CS/A7: It can be the analog input 7, or for the parallel slave port it can act as the 'control select' which will also be active low just like read and write control pins.

3.5.2.6 Pin 11 and 32 VDD: These two pins are the positive supply for the input/output and logic pins. Both of them should be connected to 5V.

3.5.2.7 Pin 12 and 31 VSS: These pins are the ground reference for input/output and logic pins. They should be connected to 0 potential.

3.5.2.8 Pin 13 OSC1/CLKIN: This is the oscillator input or the external clock input pin.

3.5.2.9 Pin 14 OSC2/CLKOUT: This is the oscillator output pin. A crystal resonator is connected between pin 13 and 14 to provide external clock to the microcontroller. ¼ of the frequency of OSC1 is outputted by OSC2 in case of RC mode. This indicates the instruction cycle rate. The connection of the external oscillator to the microcontroller using the OS1 and OS2 pins is shown in Fig 3.23

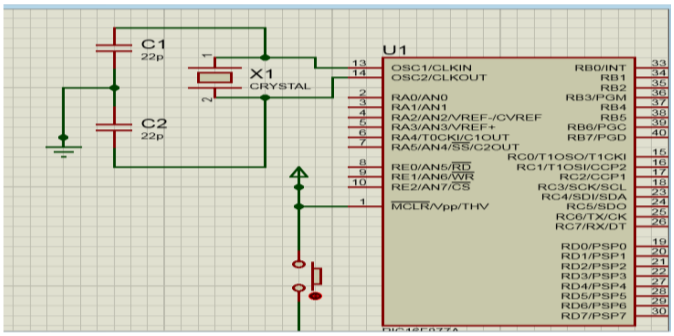

Fig 3. 23 Oscillator Connection

3.6 **Display Unit**

The display unit outputs two main values: The real time clock value and the tilt angle of the solar panel. The 16x2 LCD is the choice display used. It is a very basic module commonly used in various devices and circuits. These modules are preferred over seven segments and other multi segment LEDs. The reasons being: LCDs are economical; easily programmable; have no limitation of displaying special & even custom characters (unlike in seven segments), animations and so on.

3.6.1 **Liquid Crystal Display 16x2 LCD**

A liquid-crystal display (LCD) is a device that uses the light-modulating properties of Liquid crystals. Liquid crystals do not emit light directly, instead using a backlights or reflector to produce images in color or monochrome. LCDs are available to display arbitrary images (as in a general-purpose computer display) or fixed images with low information content, which can be displayed or hidden, such as preset words, digits, and seven segment displays, as in a digital clock. They use the same basic technology, except that arbitrary images are made up of a large number of small, while other displays have larger elements. A picture of a typical LCD is shown in Fig 3.24.

LCDs are used in a wide range of applications including LCD televisions, computer monitors, instrument panels, aircraft cockpit displays and indoor and outdoor signage. Small LCD screens are common in portable consumer devices such as digital cameras, watches, calculators, and mobile telephones including smart phones LCD screens are also used on products such as DVD players, video game devices and LCD screens have replaced heavy, bulky (CRT) displays in nearly all applications. LCD screens are available in a wider range of screen sizes than CRT and with LCD screens available in sizes ranging from tiny to very large. The LCD screen is more energy-efficient and can be disposed of more safely than a CRT can.

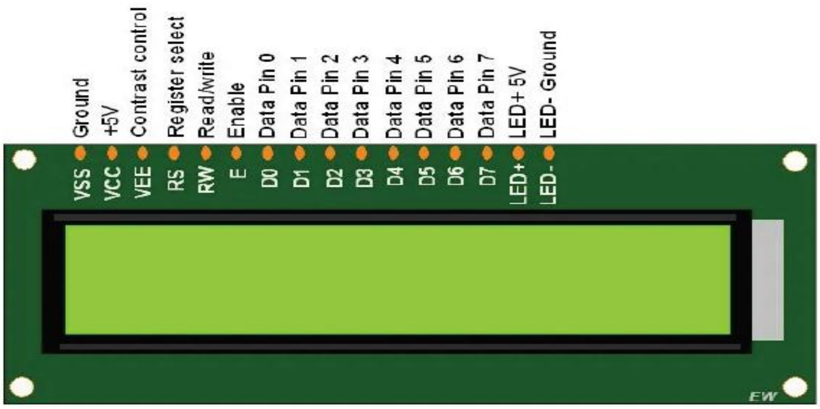

Fig 3. 24 16x2 LCD Display

3.6.2 Interfacing 16x2 LCD with PIC16f877a microcontroller

There are two ways to interface the LCD diver (controller) IC. You can use the full bus width (8-Bits) for data or alternatively you can use a 4-Bit interface for a reduced pin count needed to control the LCD. Specifically low pin count MCUs need to operate in the 4-Bit mode. The 4 bit mode is used for the design and implementation of this project as it saves the number of pin used because it works in the principle of multiplexing of data lines. The specifications and features of the LCD is given in Table 3.8

Table 3. 7 LCD specifications

LCD Pin No.	LCD Pin Name	MCU Pin Name	MCU Pin No.
1	Ground	Ground	12
2	VCC	+5V	11
3	VEE	Ground	12
4	Register Select	RD2	21
5	Read/Write	Ground	12
6	Enable	RD3	22
7	Data Bit 0	NC	-
8	Data Bit 1	NC	-
9	Data Bit 2	NC	-
10	Data Bit 3	NC	-

11	Data Bit 4	RD4	27
12	Data Bit 5	RD5	28
13	Data Bit 6	RD6	29
14	Data Bit 7	RD7	30
15	LED Positive	+5V	11
16	LED Negative	Ground	12

PORTE of the microcontroller is connected to the lower bit of the liquid crystal display and the information is multiplexed so as to reduce the number of pins utilized in the microcontroller. The circuit shown in Fig 3.25 shows the process of interfacing with PIC microcontroller

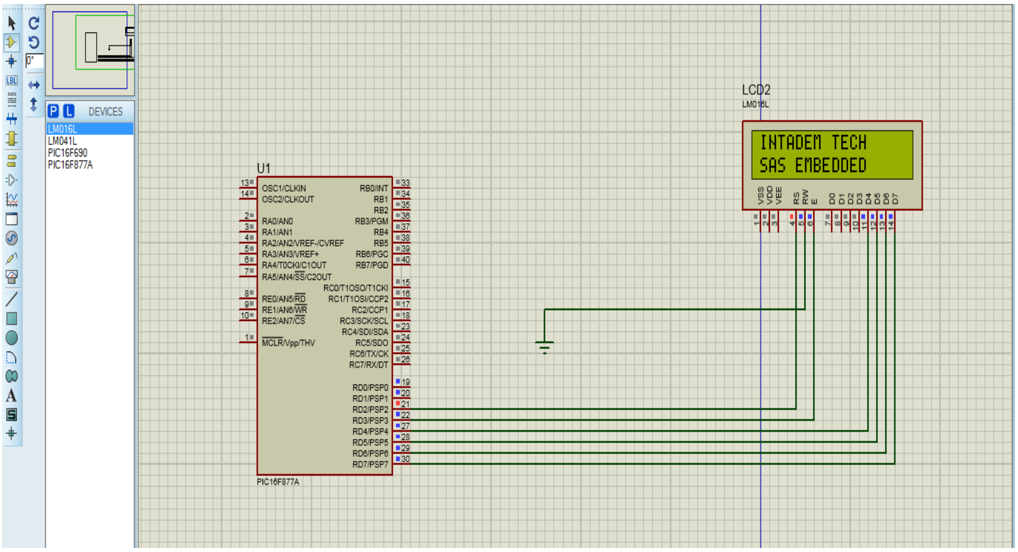

Fig 3. 25 LCD circuit diagram

3.7 **Tracking Algorithm**

The tracking algorithm involves storing the parameters of the sun in the EEPROM of the microcontroller. The information stored provides the basis for controlling the actuator. The solar parameters that are considered in the tracking algorithm include the solar altitude angle, zenith angle, azimuth angle. The details on the various parameters are discussed below

3.7.1 **Solar Altitude**

Solar altitude (ϕ_s) is the angle of the sun relative to the Earth's horizon, and is measured in degrees. A diagrammatical illustration of the solar altitude is given in Fig 3.26. The altitude is zero at sunrise and sunset, and can reach a maximum of 90 degrees (directly overhead) at noon at latitudes near the equator. The solar altitude varies based on time of the day, the change of time throughout the year, the latitude on earth.

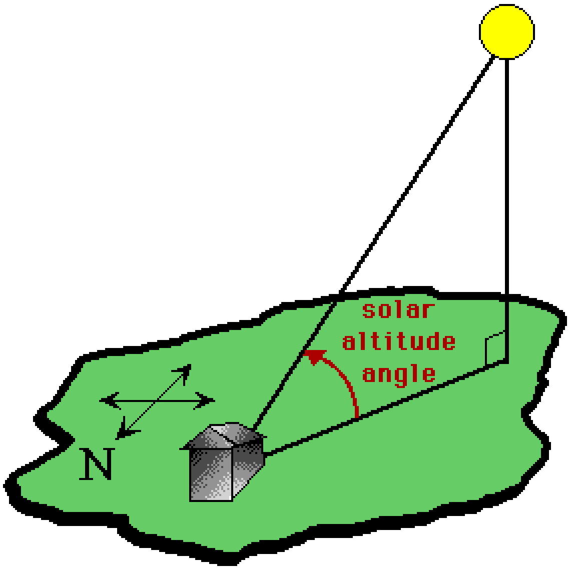

Fig 3. 26 Solar altitude

3.7.2 **Zenith Angle**

The zenith angle is the angle between the sun and the vertical as shown in Fig 3.27. The zenith angle is similar to the elevation angle but it is measured from the vertical rather than from the horizontal, thus making the zenith angle. Mathematically the zenith angle can be expressed as

$$\boldsymbol{\gamma z} = \mathbf{90^{\circ}} - \phi s$$

γ_z = Zenithal Angle

ϕ_s = Solar altitude

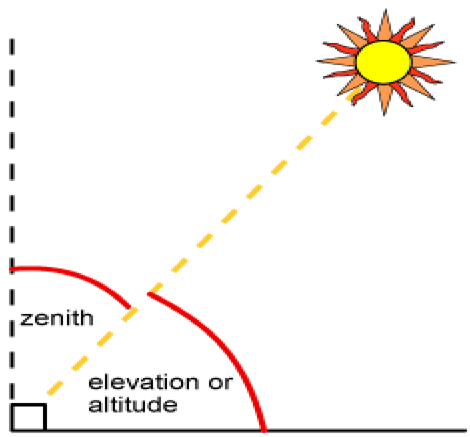

Fig 3. 27 Zenith Angle

3.7.3 **Azimuth Angle**

The azimuth angle (ψ) is the compass direction from which the sunlight is coming. The diagrammatical illustration of the azimuth angle is shown in Fig 3.28. At solar noon, the sun is always directly south in the northern hemisphere and directly north in the southern hemisphere. The azimuth angle varies throughout the day as shown in Fig 3.28. At the equinoxes, the sun rises directly east and sets directly west regardless of the latitude, thus making the azimuth angles 90° at sunrise and 270° at sunset. In general however, the azimuth angle varies with the latitude and time of year.

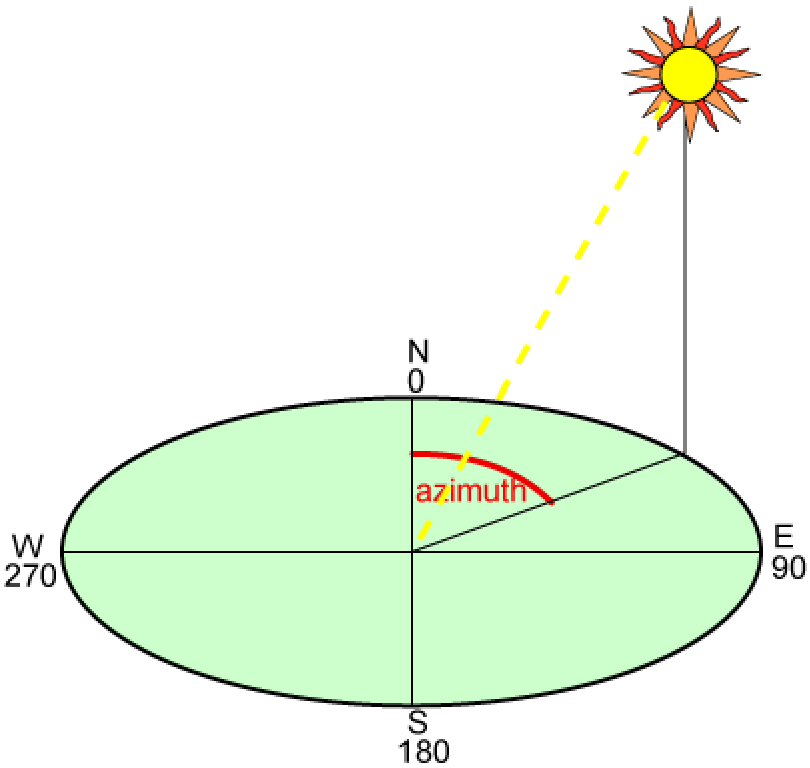

Fig 3. 28 Solar Azimuth

3.7.4 **Tracking Method**

The zenithal angle is chosen as the reference angle which the microcontroller moves the stepper motor, hence the solar panel so as to track the position of the sun. It has already been established that zenithal angle varies with respect to the latitude, time of the day and season of the year. The information programmed in the microcontroller is with respect to Malete community in Moro local government area kwara state with longitude 4.4820812˚ and latitude 8.734276˚. The tracking angle about the polar-axis is equal to the sun's hour angle and the tracking angle about the perpendicular axis is dependent on the declination angle. The tracking velocity is almost constant at 15 degrees per hour and therefore the control system is easy to be designed. The accuracy of the tilt-roll tracking system relies strongly upon how well the roll-axis can be aligned in parallel with the polar-axis, which is also latitude dependant(Chong & Wong, 2009). The information about solar parameter with respect to the stipulated geographical location is obtained using the kesian.casio calculator. The kesian.casio algorithm provides information on the solar elevation, zenith angles and azimuth angles for 24 hours.

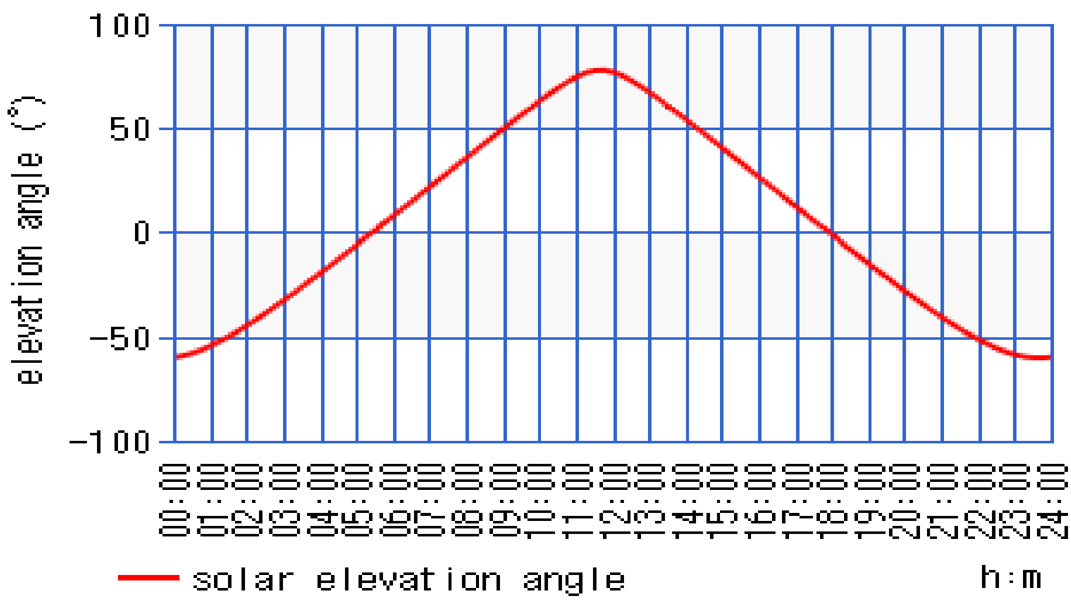

Fig 3. 29 Solar altitiude in Malete Community

The initial orientation of the solar panel with is at a zenith angle of 90 degrees. Thus as the solar elevation changes the, the azimuth angle also changes. At mid day when the solar altitude is at 90 degrees the zenithal orientation of the solar panel will be at 0 degree. The different zenithal, azimuth and elevation information with respect to the malete community provided by kesian.casio calculator is given in Table 3.9

Table 3. 8 Solar Parameters

Time	Solar Altitude Angle	Azimuth angle	Zenith Angle
06:00 A.M	8.10	70.03	81.9
07:00 A.M	22.01	70.99	67.99
08:00 A.M	36.00	70.55	54.00
09:00 A.M	49.88	67.91	40.12
10:00 A.M	63.27	60.32	26.73
11:00 A.M	74.68	36.69	15.32
12:00 P.M	76.86	337.82	13.24
1:00 P.M	67.00	304.07	23.00
2:00 P.M	53.92	293.66	36.09
3:00 P.M	40.14	290.01	49.86
4:00 P.M	26.17	289.05	63.83
5:00 P.M	12.21	289.64	77.79
6:00 P.M	-1.11	291.46	91.11

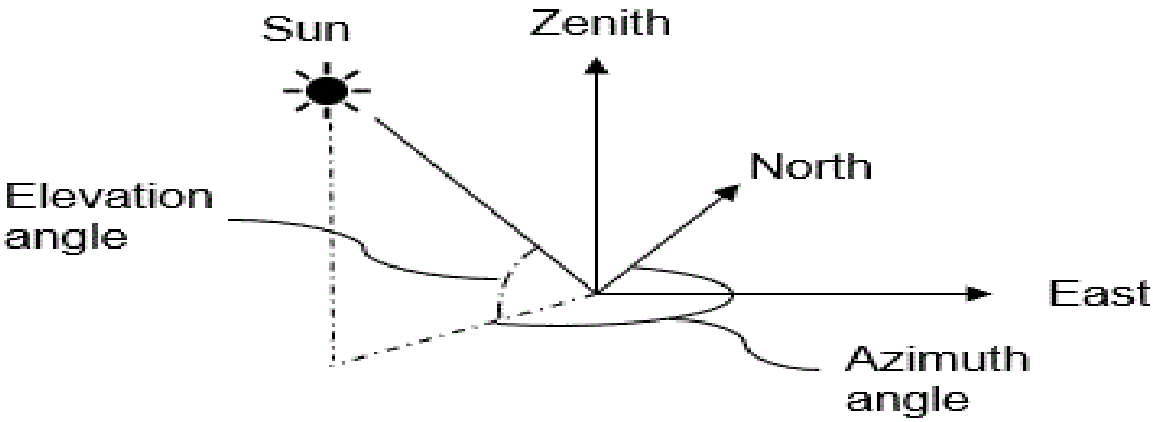

Fig 3. 30 Tracking angles

From the information in Table 3.9 the real time clock module provides the microcontroller with the timing in which the microcontroller moves the stepper motor appropriately for the solar tracking operation. The Fig 3.30 shows the various tracking angle.

3.8 **Principle of Operation**

The complete circuit diagram of the design and construction of time based solar tracking system is shown in Fig 3.31. This design prototype can be implemented to improve the radiation efficiency of solar tracking systems.

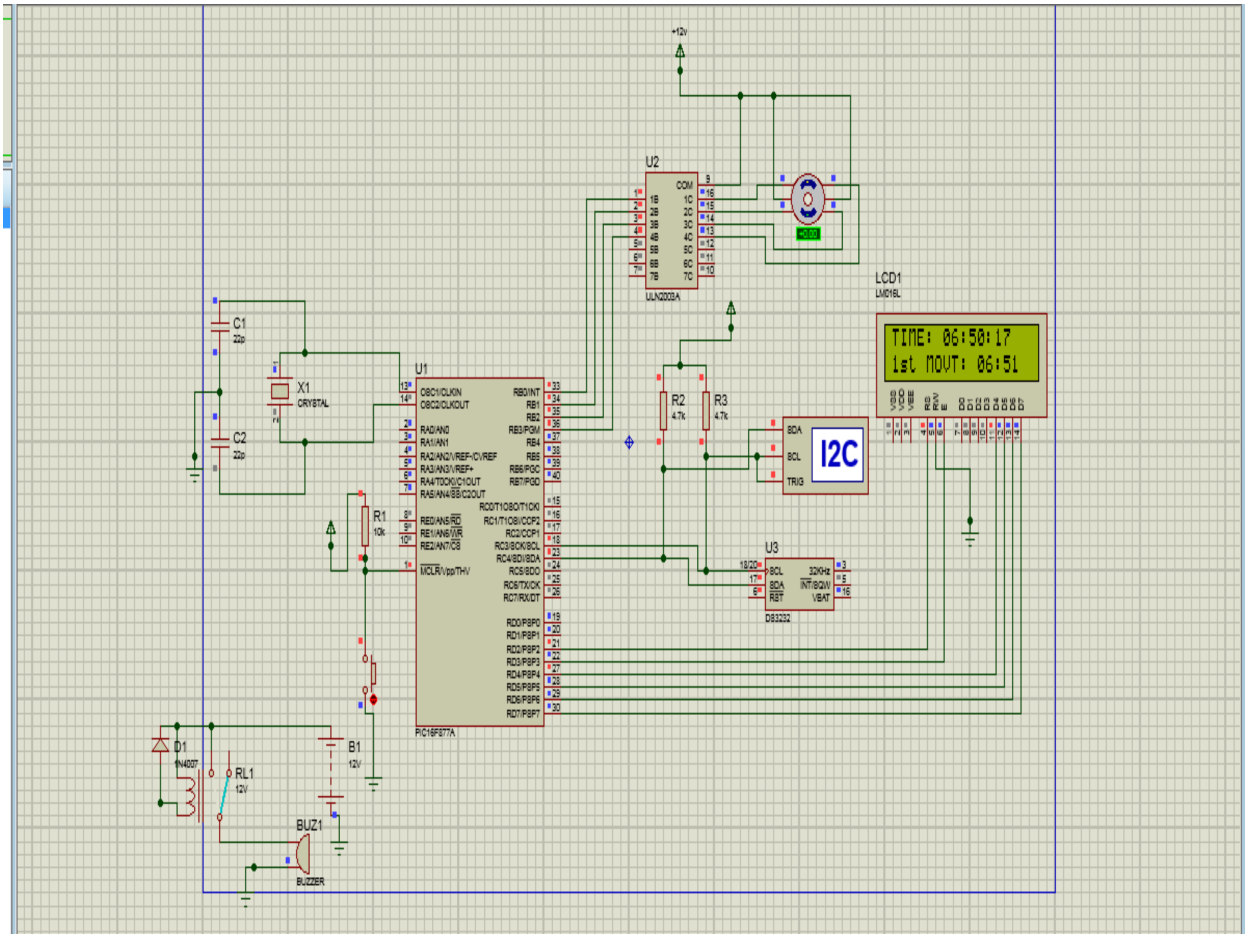

Fig 3. 31 Complete circuit diagram

The power supply is given to the tracking system from external battery.7805 voltage regulator converts this incoming power supply into 5 volts in order to provide supply to other components in the system. The program to the PIC16F877a micro controller is given through ISP pins using the PICKit 3 programmer. Based on the operation of the Real time clock RTC, the number of tilts of the panel will be set in the software using the interrupt controller module and the RTC is used to keep track of the tilt. Real Time, Tilt time settings are displayed on LCD which is connected to Port E of the micro controller. In this project design, we use 8 tilts for tracking purpose and 9th tilt for bringing the panel back to the initial position. The RTC continuously runs and sends a high output to the microcontroller at our prescribed tilt time. Then microcontroller sends a high output to the ULN2003 stepper motor driver which drives the motors connected to the panel. The panel rotation or tilt angles will be initially fixed in the program that is given to the microcontroller. The output of solar panel is connected in a way which amplifies the signal and gives it to the ADC which is connected to the port A of the microcontroller. Voltage generated by the panel as per the individual tilt time is displayed on LCD.

3.9 **Software Implementation**

The program for the design is written with the MPLAB X IDE in C programming language and uploaded to the microcontroller via a PICKit 3 programmer. The compiler used in the programming was the xc8 compiler as it provides vast information of the map file and list file of the microcontroller.

3.10 **Flow Chart**

The operation of the system starts by initializing the different peripheral modules attached to the system. After the initialization the microcontroller begins to read data from the real time clock RTC and if the data matches the pre stored set of information in the EEPROM then a pulse width modulated signal is generated to drive the stepper motor. After the movement the information obtained from the panel is sent to the liquid crystal display to obtain the parameters. In a situation where data does not match the microcontroller continues to read information from the EEPROM. The sequence is shown in Fig 3.32

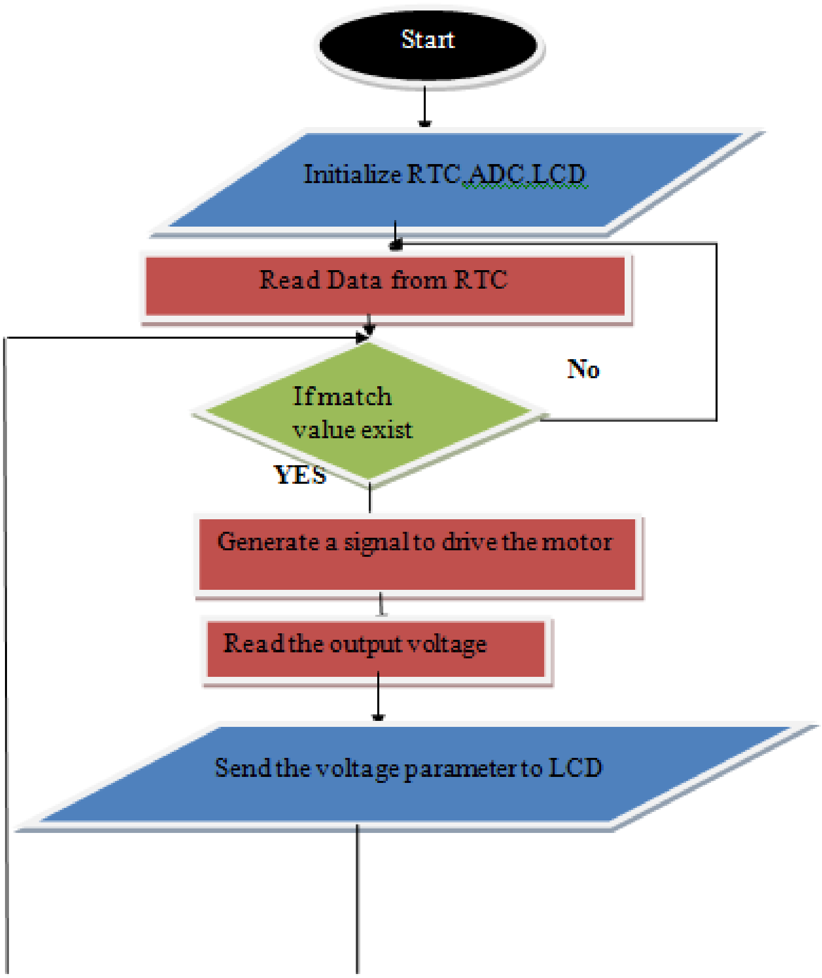

Fig 3. 32 Flow chart of the prototype

3.11 SUMMARY

This chapter provides adequate information on how the project was constructed. It also gives the specifications of each components and the tracking algorithm of the projects.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

The actual construction of the prototype is discussed in this chapter. The implementation of the design can be categorized into various hardware units with each unit consisting of various group of components connected together for overall efficient performance of the system. The results obtained from the constructed prototype are also discussed in this chapter.

Detailed description of the results were shown by employing the use of tables, calculations, charts, images and graphs where necessary to ensure the proper understanding of this project for readers. Also, the methods to combat the issues encountered were proposed.

4.2 CONSTRUCTION

The building of the time based solar tracking system involves basically five stages. The five stages are:

- Programming stage
- Simulation stage
- Bread boarding/prototype troubleshooting
- Printed circuit board design stage

- Prototype construction stage

4.2.1 **Programming stage**

The programming of the microcontroller and other peripheral devices was done using a peripheral interface controller (PIC) optimized integrated development environment named MPLAB X IDE. The programming of the microcontroller is based on the C and C++ programming language. MPLAB X IDE is an expandable, highly configurable software program that incorporates powerful tools to help to discover, configure, develop, debug and qualify embedded designs for most of Microchip's microcontrollers and digital signal controllers.

The system's control algorithm is implemented in embedded C language. The C program which was embedded within the microcontroller controls every operation of the system. Without it, the whole system would be nothing but a box of electronic component with no use. The MPLAB X IDE workspace is shown in Fig 4.1

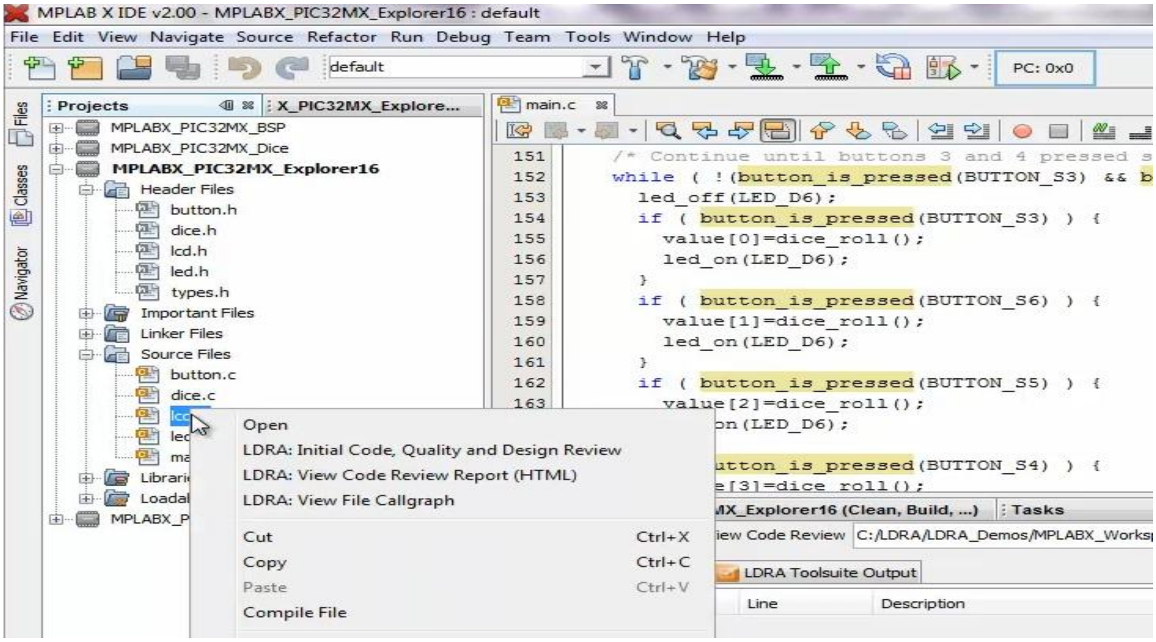

Fig 4. 1 MPLAB workbench

4.2.2 Simulation stage

Design of this project was done on Proteus v7.7 software shown in Fig 4.2. Designing of circuits in Proteus is easy in that it uses a drag and drop mechanism in designing. Proteus as a simulation software allows the import of written programs from program source file into programmable integrated circuits within as library. The program for the microcontroller PIC16F877A was written in C language and compiled with the XC8 compiler program, after which it was simulated on Proteus electronic workbench being programmed into the microcontroller. Proteus is a virtual system modeling and circuit simulation application and the simulations gave an idea of how the code would function in the hardware but the final inference could only come from testing the code on the hardware it was programmed for. However, all errors discovered on Proteus were corrected until the code worked perfectly as expected on the virtual circuit. When placed in the hardware, several anomalies were observed in the behavior of the system, and the program was refined until its interaction with the rest of the hardware was stabilized.

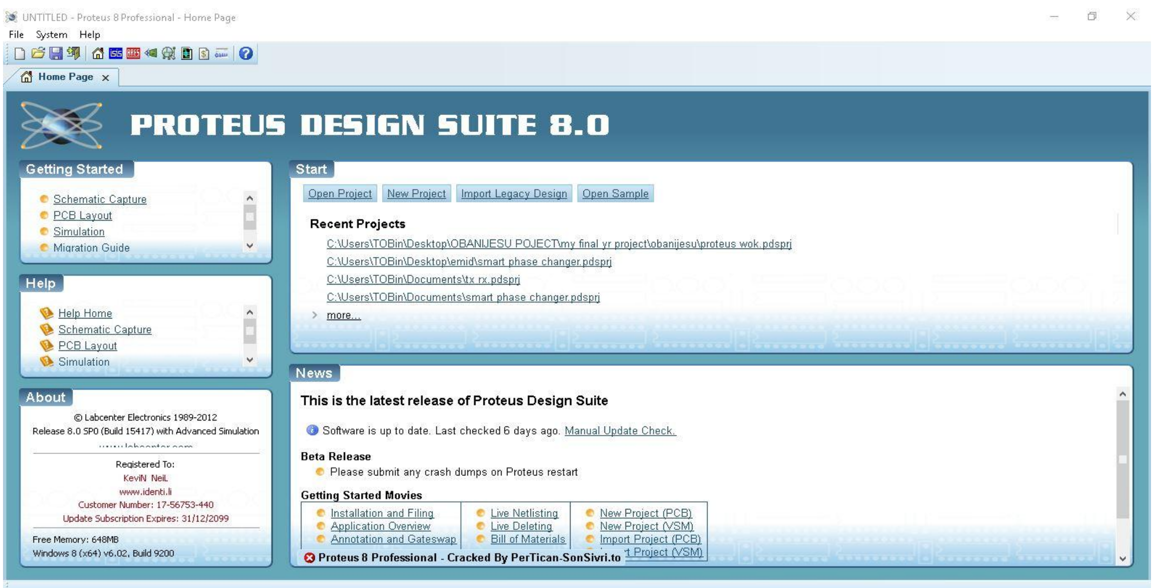

Fig 4. 2 Proteus workbench

4.2.3 Bread boarding and prototype troubleshooting

After the completion of the system design and successful simulations were made, the hardware components were assembled on a bread board for real time analysis and trouble shooting. This is necessary because designs simulation sometimes exhibits certain amount of discrepancies when tested in real life. So to ensure 100% system-control, it is very important to first breadboard the same deign before constructed using a Vero board or printed circuit board.

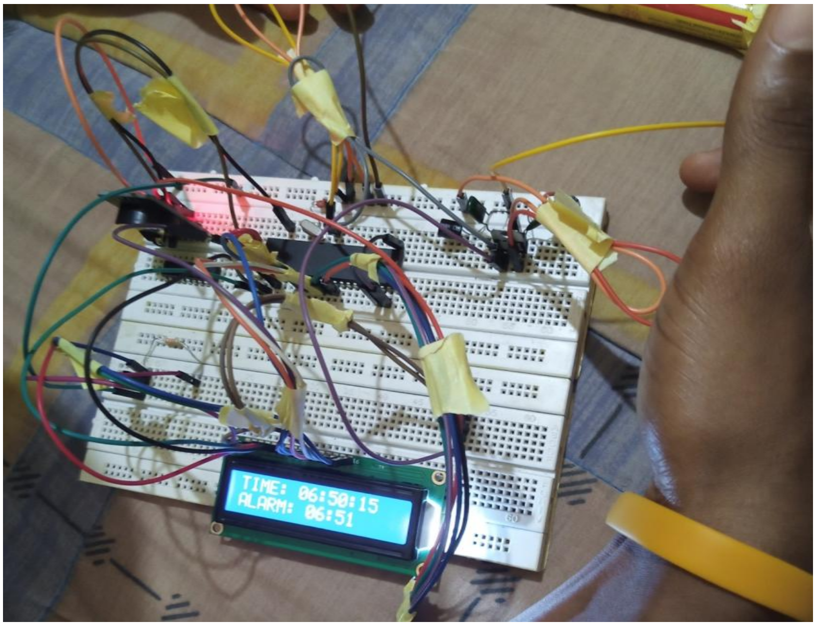

Fig 4. 3 Breadboard circuit

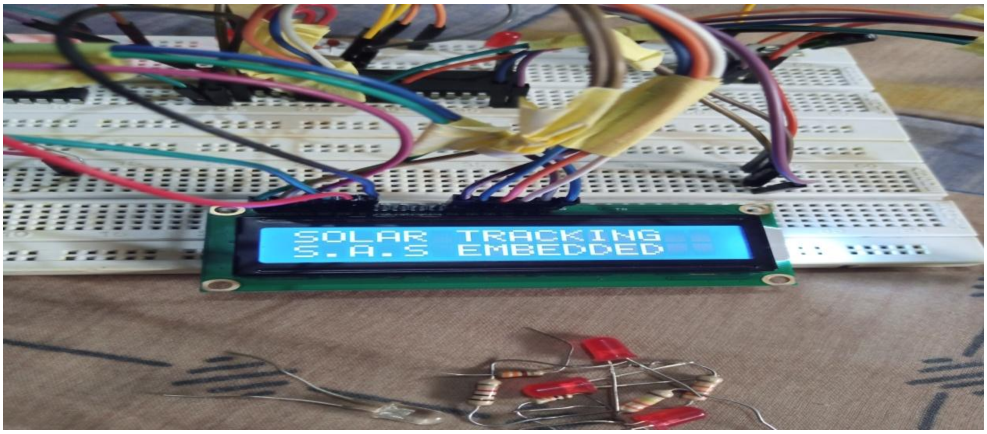

Fig 4. 4 LCD Troubleshooting

Fig 4.3 and Fig 4.4 shows the assemblages of the components on the breadboard to verify the correct operation of the circuit in order make sure the performance is within the specified parameters.

4.2.4 Printed circuit board design and construction stage

The actual translation of the circuit of the time based solar tracking system to a printed circuit board pattern is carried out using EasyEDA PCB software. First the circuit was compiled and check for errors before the transfer to a PCB layout for onward processing as a PCB file. On the layout the different component foot points were carefully placed on a dimension of (80x 100mm).The output of the EasyEDA is shown in Fig 4.5. The placement was done to ensure the shortest possible distance between related components. An electrical rules violation check (ERC) was performed on the design and the placed footprints before processing with the routing. The entire component electrical connection was then auto routed using the routing component of EasyEDA PCB software. The actual implementation of the PCB design was achieved using the tonner.

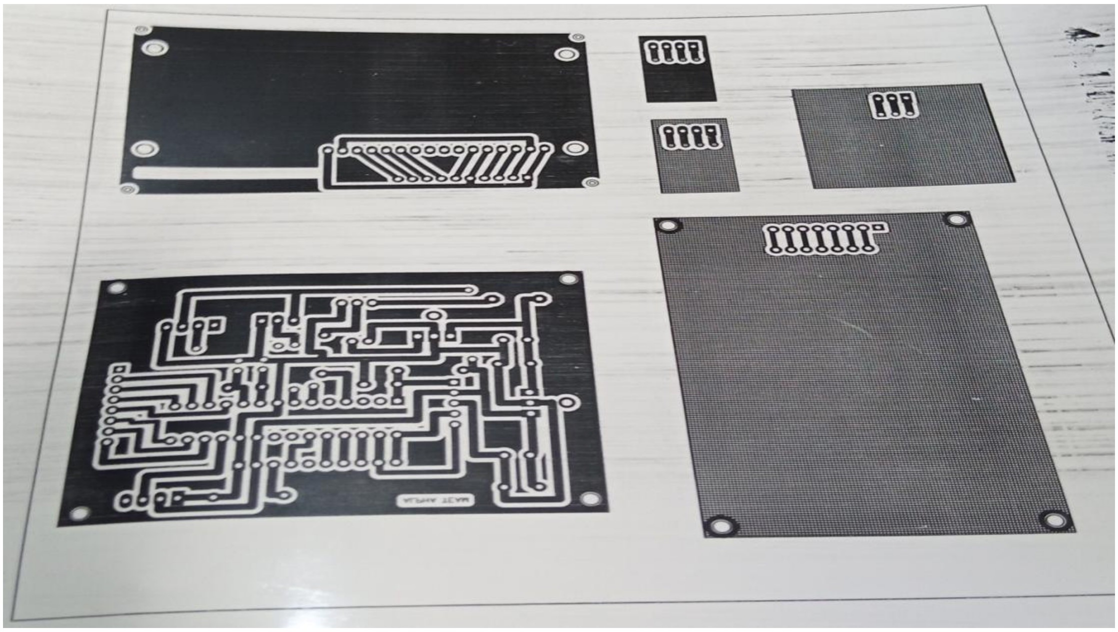

Fig 4. 5 PCB layout from EasyDA

4.2.5 **Prototype construction stage**

After testing and troubleshooting of the system has been made, the designed system is constructed on a PCB board. The layout obtained from the PCB software is transported using heating method and the printed circuit board is then etched using ferric chloride to map out the conductive surface of the circuitry. After the conductive surface of the system of the system has been established the PCB, holes for the attachment of circuit element is bore on the surface of the board. The images of the etched PCB circuit is shown in Fig 4.6

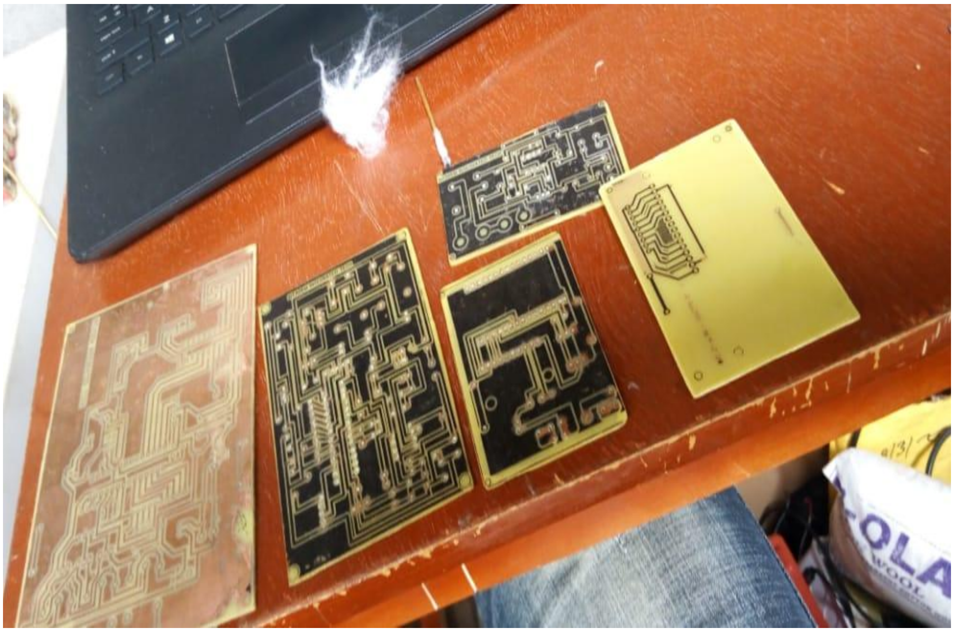

Fig 4. 6 The PCB circuit

The construction of the mechanical framework of the solar tracking system was implemented using the acrylic sheet. The construction process is shown in Fig 4.7

Fig 4. 7 Construction of the casing

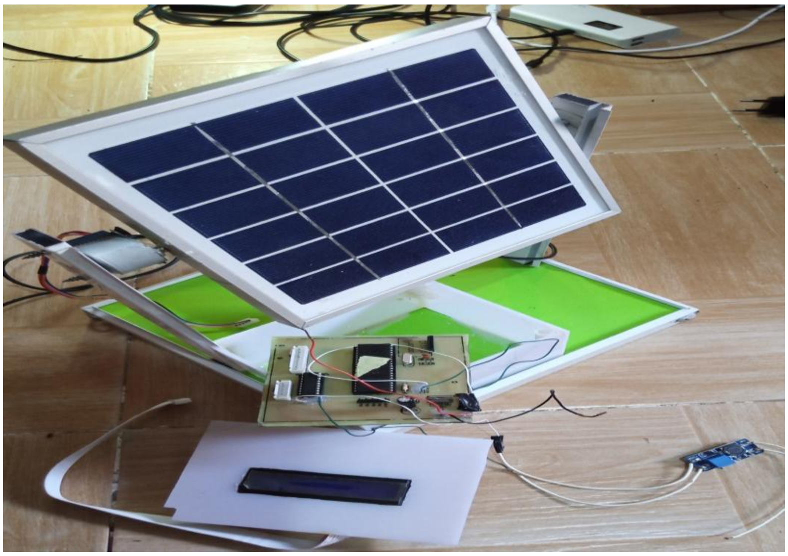

Fig 4. 8 Final construction stages

For the construction purpose, some materials were purchased to aid the process. These materials are listed below:

- Nose mask
- Soldering iron
- Lead sucker
- PCB board
- Jumper wires
- Lead coil
- Digital Multimeter
- Soldering stand

4.3 TESTING

After construction was completed, the system was put under series of test and results were obtained. Some of the test that was carried out on the system is discussed below

4.3.1 Continuity Test

It is a test done to determine whether a circuit is open or closed. A digital multi-meter was used to carry out this test. Its mode was set to the continuity and the probes were placed on the terminals under test. A buzzer comes on if the terminals are continuous. This implies that a closed circuit is continuous.

4.3.2 **Voltage Test**

This test was done to discover the voltage level at different points in the circuit. A multi-meter was used in carrying out this test. The voltage range of the multi-meter was set to suit the voltage to be measured. The red probe was place on the terminal and the black probe on the negative terminal.

4.3.3 **Current Test**

This test was done to ascertain the current demand of the circuit. It was done using a multimeter which was connected in series with circuit whose current demand is to be measured.

4.4 **RESULTS**

After the system has been successfully constructed and the verification of the circuit has been completed. The output voltage of the solar panel of the time based solar tracking system is obtained and the result is compared to that of a fixed solar panel. A summary of the series of result obtained is given Table 4.1, Table 4.2 and Table 4.3

Table 4. 1 Results obtained for June 23, 2021

Time	**Voltage of Fixed Solar Panel (volts)**	**Voltage of Solar Tracking Panel (volts)**
6:00 am	0.00	0.00
7:00 am	1.32	1.32
8:00 am	7.1	7.1 (Initial Position)
9:00 am	10.9	10.9
10:00 am	10.4	13.2 (First Tilt)
11:00 am	11.9	15.1
12:00 pm	12.2	16.9 (Second Tilt)
1:00 pm	12.1	16.8
2:00 pm	10.8	14.9 (Third Tilt)
3:00 pm	9.4	14.2
4:00 pm	7.3	12.8(Fourth Tilt)
5:00 pm	6.5	9.3
6:00 pm	1.5	3.2 (Reverse)

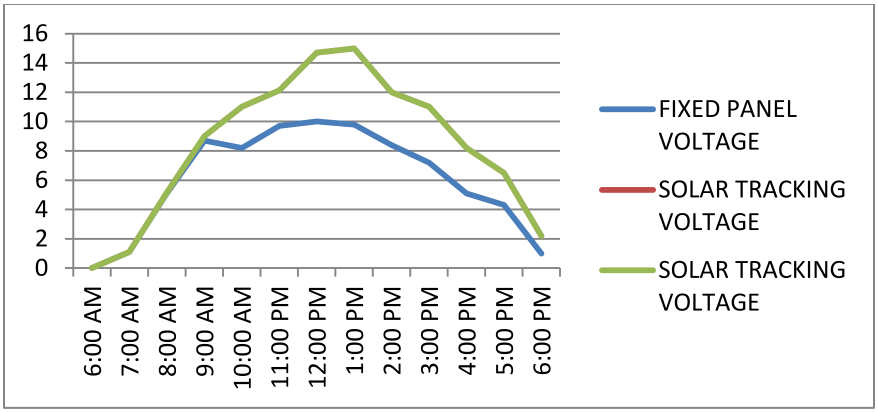

Fig 4. 9 Plot of the output

Table 4. 2 Results obtained for August 7, 2021

Time	**Voltage of Fixed Solar Panel (volts)**	**Voltage of Solar Tracking Panel (volts)**
6:00 am	0.00	0.00
7:00 am	1.10	1.11
8:00 am	5.10	5.13 (Initial Position)
9:00 am	8.70	9.00
10:00 am	8.20	11.02 (First Tilt)
11:00 am	9.70	12.12
12:00 pm	10.00	14.70 (Second Tilt)
1:00 pm	9.80	14.99
2:00 pm	8.40	12.7 (Third Tilt)
3:00 pm	7.20	12.00
4:00 pm	5.10	10.4(Fourth Tilt)
5:00 pm	4.30	7.10
6:00 pm	0.99	2.20(Reverse)

Fig 4. 10 Plot of the output

Table 4. 3 Results Obtained for August 30, 2021

Time	**Voltage of Fixed Solar Panel (volts)**	**Voltage of Solar Tracking Panel (volts)**
6:00 am	0.01	0.01
7:00 am	1.90	1.94
8:00 am	6.20	6.43 (Initial Position)
9:00 am	9.90	9.99
10:00 am	9.40	12.22 (First Tilt)
11:00 am	10.7	13.32
12:00 pm	11.01	15.07 (Second Tilt)
1:00 pm	12.10	16.59
2:00 pm	8.40	13.07 (Third Tilt)
3:00 pm	8.20	13.20
4:00 pm	6.21	11.24(Fourth Tilt)
5:00 pm	4.93	8.31
6:00 pm	1.99	3.01 (Reverse)

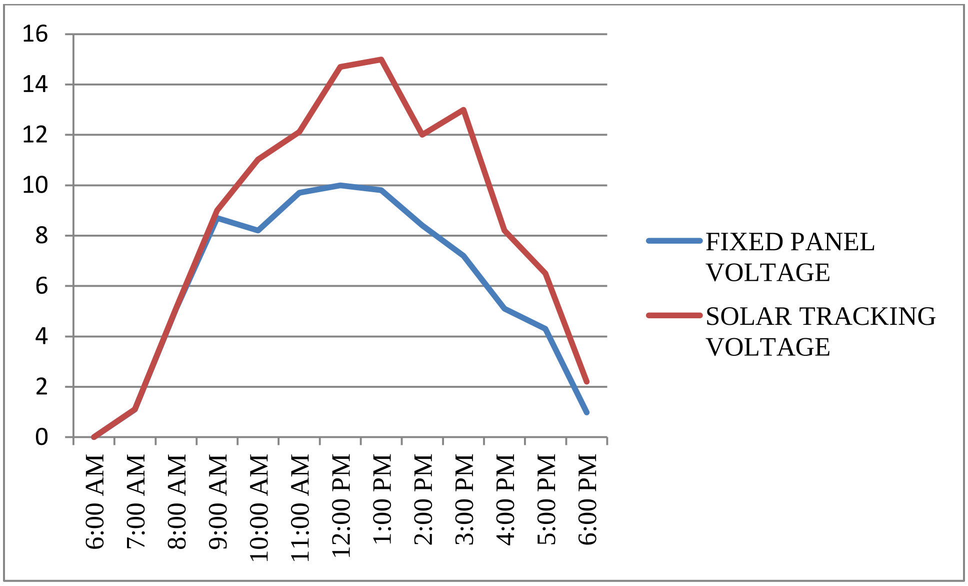

Fig 4. 11 Plot of the data output

4.5 DISCUSSIONS ON THE RESULTS

From the result it can be observed that the microcontroller sends signal to the stepper motor every two hours. This is done with the aid of the real time clock serving as the input sensor to the microcontroller. The plot of the various readings obtained. It can be observed from the plot that there is comparatively much energy yield in the tracking system than the fixed panel. Also, as time increases towards noon, the difference in the energy yield decreases and is approximately equal around noon and continues to increase in difference towards sunset.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSION

In this work, a solar tracking system has been designed and implemented with the result from the tests showing reasonable increase in the energy yield. The mechanicals were done with aluminum sheets and stepper motors were used as the actuators. A real time clock module DS3231 serves as the input to the microcontroller. The PIC16F877a microcontroller was used to control the movement of the solar panel. The decision-making of the microcontroller is based solely on available data collected by the real time clock module which makes the system intelligent and responsive to changes in the physical environment.

5.2 RECOMMENDATION

The recommended additions that can be made to this project in the future is to add a button that access the analog digital converter module of the microcontroller which will display the current voltage of the of the solar panel instead of using external multimeter when there is a need to measure the parameters of the solar panel.

Secondly, integration of internet of things (IoT) with the project such that the parameters can be measured virtually with the use of ESP module.

Finally, part of the output of the solar system can be used to charge the power supply hence the system completely independent.

5.3 **LIMITATION**

The prototype implemented is a single axis time based solar tracking system; hence a dual axis solar tracking system will be able to harness more energy from the sun

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APPENDIX

Source code

```
#pragma config FOSC = HS        // Oscillator Selection bits (HS oscillator)

#pragma config WDTE = OFF       // Watchdog Timer Enable bit (WDT disabled)

#pragma config PWRTE = ON       // Power-up Timer Enable bit (PWRT enabled)

#pragma config BOREN = ON       // Brown-out Reset Enable bit (BOR enabled)

#pragma config LVP = OFF        // Low-Voltage (Single-Supply) In-Circuit Serial Programming Enable bit (RB3 is digital I/O, HV on MCLR must be used for programming)

#pragma config CPD = OFF        // Data EEPROM Memory Code Protection bit (Data EEPROM code protection off)

#pragma config WRT = OFF        // Flash Program Memory Write Enable bits (Write protection off; all program memory may be written to by EECON control)

#pragma config CP = OFF         // Flash Program Memory Code Protection bit (Code protection off)


#define _XTAL_FREQ 20000000 //We are running on 20MHz crystal



#include <xc.h>

//Define the LCD pins

#define RS RD2

#define EN RD3

#define D4 RD4

#define D5 RD5

#define D6 RD6
```

```
#define D7 RD7



#include <stdio.h>
#include <stdlib.h>
#include "solar_i2c_header.h"
#include "solar_lcd.h"
 lcd_clear();
     lcd_clear();
    lcd_set_cursor(1,1);
    lcd_write_string("TIME: ");
    lcd_write_char(hour_1+ '0');
    lcd_write_char(hour_0+ '0');
    lcd_write_char(':');
    lcd_write_char(min_1+ '0');
    lcd_write_char(min_0+ '0');
    lcd_write_char(':');
    lcd_write_char(sec_1+ '0');
    lcd_write_char(sec_0+ '0');

    lcd_set_cursor(2,1);
    lcd_write_string("2nd MOVT: ");
    lcd_write_char(alarm_value[0]+ '0');
    lcd_write_char(alarm_value[1]+ '0');
```

```
lcd_write_char(':');
lcd_write_char(alarm_value[2]+ '0');
lcd_write_char(alarm_value[3]+ '0');
```