ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

SCHOOL OF ELECTRICAL ENGINEERING AND COMPUTING

DESIGN AND IMPLEMENTATION OF SOLAR PV SYSTEM WITH MICROCONTROLLER BASED SINGLE AXIS TRACKING SYSTEM

(CASE STUDY: ADAMA POLYTECHNIC COLLEGE ADMINISTRATION OFFICES)

A THESIS SUBMITTED TO ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY, DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTERS OF SCIENCE IN INDUSTRIAL AUTOMATION AND CONTROL TECHNOLOGY MANAGEMENT

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DECLARATION

We, Roman Ayalew, Bacha Wake and Taddele Gashaw hereby declare that this thesis entitled design and implementation of solar PV system with microcontroller based single axis tracking system for Adama Polytechnic College Administration Offices is entirely our own work and to our knowledge it has not been done or presented by other person. The result of our own work carried out under the supervision of Dr. Tafesse Asrat

We swear that all the materials used have been properly referenced.

Candidates Name	Signature	Date
Roman Ayalew	________________	____________
Bacha Wake	________________	____________
Taddele Gashaw	________________	____________

CERTIFICATE

The thesis design and implementation of solar PV system with microcontroller based single axis tracking system for Adama Polytechnic College Administration Offices by Roman Ayalew, Bacha Wake and Taddele Gashaw have been carried out under my supervision and that this work has not been submitted elsewhere for a degree. This thesis has been submitted for examination with my approval as a University Advisor.

Advisor Name: Dr. Tafesse Asrat

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ACRONYMS AND ABBREVIATIONS

AC	Alternating Current
ADC	Analog-to-Digital Converter
AGM	Absorbed Glass Mat
AH	Ampere Hour
AMD	Advanced Micro Device
ANSI	American National Standard Institute
APC	Adama Polytechnic College
ASCII	American Standard Code for Information Interchange.
ASTM	Standard Spectrum
ASTU	Adama science and Technology University
BOS	Balance of System equipment
CCDs	Charge Couple Devices
CCW	Counter Clockwise
CIS/CIGS	Copper Indium Gallium Selenide
CISC	Complex Instruction Set Computer.
CMOS	Complementary Metal-Oxide Semiconductor
CPU	Central Processing Unit
CRT	Cathode Ray Tube
CSP	Concentrating Solar Power
CV	Constant Voltage
CW	Clockwise
DC	Direct Current
DoD	Depth of Discharge
DTL	Diode-Transistor Logic
EEPROM	Electrical Erasable programmable only memory
EMF	Electro Motive Force
FLA	Flooded Lead Acid batteries
GIZ	German Society for International cooperation
GTA	Green Technology for Africa

IDE	Integrated Development Environment
ISIS	Intelligent Schematic Input System
ISP	In system Programme
LCD	Liquid Crystal Display
LDR	Light Dependent Resistor
MATLAB	Matrix Laboratory
MCLR	Master Clear Reset
MPP	Maximum Power Point
MPPT	Maximum Power Point Trackers
OPC	Organic Photovoltaic Cells
PCB	Printed Circuit Board
PIC	Peripheral Interface Controller
PMOS	p-channel Metal-Oxide-Semiconductor field-effect transistor
PS	Power Supply
PV	Photovoltaic
PWM	Pulse-Width Modulated
RAM	Read Access Memory
RISC	Reduced Instruction Set Computer
ROM	Read Only Memory
SAPS	Stand Alone Power System
SPI	Serial Peripheral Interface
STC	Standard Test Conditions
TL	Transistor Logic
TVET	Technical, Vocational Education and Training
UK	United Kingdom
USART	Universal Synchronous asynchronous Receiver Transmitter

ABSTRACT

This thesis deals about the design and implementation of solar PV system with microcontroller based single axis tracking system. Solar modules are devices that cleanly convert sunlight into electricity and offer a practical solution to the problem of power generation. Solar energy is one form of the renewable energy which is very abundant in regions close to the equator like Ethiopia. Single axis solar tracking system is the project that has used PIC16F877A Microcontroller as a brain to control the whole system because this microcontroller is low cost and easily available in the local market. The light dependent resistor has been used to sense the intensity of light and sent the data to the microcontroller. The stepper motor, with low cost and closed loop position control system has rotated the solar panel. Moving the solar panel in the direction of sun can increase the solar energy harvesting from the solar cell and controller process this information and controls the movement of solar panel attached to stepper motor with driver ULN2003. Proteus 8.0 Professional has been used to design overall circuit diagram and to prepare PCB of the project respectively. The microcontroller has been programmed using powerful embedded C language. The project also displays the direction of rotation of stepper motor on LCD display unit. The optimum solar energy extracted by using this design has been inverted to AC and supplied to the college administration offices to facilitate its training programs. We have taken AC electrical loads / appliances which have existed in the administrative offices and have also calculated the total daily energy demand by using Microsoft Excel to determine PV panels, charge controllers, storage battery, power inverters and cable size.

Key words: - *Solar panel, microcontroller, stepper motor, motor driver light dependent resistor, sun tracking system, liquid crystal display, charge controller, storage battery, power inverters. Cable size*

CHAPTER ONE

1. INTRODUCTION

1.1. Motivation

Most administration offices and training classes in Adama Polytechnic College consume alternating current electrical power supplied from Ethiopian electric utility south east region retail business office for its electrical loads such as: lighting, computers, refrigerators, receivers, data recording purpose, color television, training purpose and printing and other works. In the college, offices are obligatory to do their day- to -day activities such as secretarial service, lighting, communication, recording data, training and others by using alternating current power which is frequently interrupting unlimited times per day causing negative impacts on the effectiveness of its training programs.

Thus, solar electrification is a vital step for improving and facilitating the administration works and training programmes in the college and crucial for the country's overall renewable energy utilization. Enormous benefits can be achieved in office works, data recording, core processing, and training purpose for industrial automation and control technology trainees.

The thesis work mainly depends on design and implementation of solar PV system with microcontroller based single axis tracking system to extract electric power from the renewable energy sources collecting maximum solar energy from the sun. Tracking the sun radiation is very necessary to avoid the problem of air pollution from different fossil fuel and to solve the problem of power interruption occurred from Ethiopian electric utility south east region retail business office many times per day that affects different activities in the administration office of Adama Polytechnic College.

This project has been designed and implemented based on the necessary data gathered from different responsible organizations such as Ethiopian electric utility south east region retail business office, National Meteorological Agency Adama Branch Directorate and Adama Polytechnic College administration offices. Based on the maximum power demand required per day and peak sun hour gathered , we have designed the system and selected the standard photovoltaic cell, storage battery, charge controller, and inverter and by using different software. We have also designed the hardware system and prepared the prototype for showing its functionality.

1.2. Background of the Study

As we know, sun is one of the most important components in this world. Without sun, it is impossible for a human or living creature to live in this world. Humans nowadays feel uncomforted about the global warming situation. Even this kind of situation bring a lot of negative perception, they should have to think it through the positive way. One of the ways to reduce the global warming is to reduce the utilizing of electrical voltage obtained from fossil fuel and change to a natural voltage source like wind, rain, tides, sunlight [3]. So, the engineers try to create a new device that can convert the natural energy to an electrical energy like solar panel for sunlight energy, wind turbines for wind energy, water turbines for hydroelectric power energy, etc. The problem that still exists now is the device that invests by an engineer. For example, the solar panel that many of the users use is only in a one way direction. If the sun located at the direction that is not perpendicular to the solar panel, the power that can be generated is low compare to when the sun located exactly perpendicular to the solar panel [26]. The sun rotates from east to west but the highest power that can be generating by the solar panel is when location of sun is perpendicular to the solar panel. So the power that can be used in the night day is quite short [10].

A solar electric system contains common basic parts such as: solar modules to generate electricity from available sunlight, rechargeable batteries needed to store electricity for later use at night and during inadequate sunshine periods; control circuit which in this case is PIC microcontroller based will be used for switching load, and finally electrical appliances [21]. A solar panel which is located at the top of the pole converts sunlight into electrical power. A charge controller regulates the voltage coming from the solar panel. The regulated power obtained is used to charge a battery. During daytime, (DC) electrical appliance can use voltage direct from solar panel. At the same time, the battery can be charged and to be used at night and during inadequate sunshine periods [15].

Normal/fixed solar panels have a full day efficiency of about 45-50%. It has been estimated that the use of a tracking system/an automatic, over a fixed system, can increase the power output by 30% - 60% [23]. This thesis is an attempt to come up with an inexpensive tracking system so that it can be used extensively. Also it needs to be robust so that the entire device can be left alone in remote areas, without requiring further repairing. This thesis helps for power generation by setting the equipment to get maximum sunlight automatically and uses two Light dependent resistor sensors in two directions (East and west) to sense the direction of maximum intensity of light. The Light Dependent Resistors used to sense the intensity of light and send the data to the microcontroller [23]. This system detects the maximum intensity of light. When there is decrease in intensity of light, this system automatically changes its direction using a stepper motor to get a maximum intensity of light and it uses a PIC 16F877A Microcontroller as a brain to operate this system and a stepper motor to rotate the solar panel [20].

In Ethiopia, there is a lot of shortage of electricity that the government looking forward to produce energy from other available resources. A 2011 study by German society for international cooperation (GIZ) shows that Ethiopia has a huge solar power potential, especially in the western and eastern low lands, which receive a high density of irradiation (insolation). Ethiopia's solar market is still at an early development stage with an estimated installed capacity of just 5MW. Demand is especially high in grid-off areas which constitute 80% of the country according to the GIZ study, GTA notes [11]. Solar energy is one of the important ways to produce electricity other than traditional way of producing electricity. It is a onetime project which benefits future. Our project work is suitable to be used for street light, traffic light, in educational institute like Technical Vocational and Educational Training Institutions, households and others that want to save their budget for a long term electrical energy cost as well as to keep environment clean and green.

Adama Polytechnic College (APC) was established in 1947 in Oromia Regional State (ORS) of Adama City. This college is one of the governmental Technical Vocational and Educational Training Institutions found in the Adama City Administration. Currently, the college is not being using any types of solar panels. To this reason, our ultimate goal is to design solar PV system with microcontroller based single axis tracking system and to implement with a relatively low cost for producing maximum energy output for electrical powered applications, to avoid unnecessary power interruptions frequently happening in the college by the supplier authority namely; Ethiopian electric utility south east region retail business office, and as a training purpose for the trainers who are taking industrial automation and control technology management (Level-V).

Based on the current problems observed in the college, we have gathered necessary data which were required power demand for the administrative office of APC was 78969.6Watt-Hour/Day. The number of solar panels and the desired wattage is 190 modules and 300 Watt respectively. For 300w, we have selected 12V, 200AH size of battery and total numbers of batteries are 42 for the total capacity of 8226AH. We have selected 1500W size of the power inverter with the total of 17165W; we have needed a total number of 12 inverters. Finally, we have selected the size of charge controller as 20A with the total number of 107 for the total of 2120 A to control the entirely required power demand.

Therefore, our project particularly “design and implementation of solar PV system with microcontroller based single axis tracking system for Adama Polytechnic College Administration Offices” has been used to increase the optimum energy sustainability without any power interruption of administration offices works by effectively and efficiently tracking of the maximum sun radiation.

1.3. Statement of the Problem

As we have seen, there are no any types of solar panels (fixed or automatic sun trackers) in Adama Polytechnic College to obtain the optimum amount of sunlight throughout the day to achieve the balance between power consumption and power production which is a bigger challenge in the administration office to precede the offices duties .In addition to this, there is unnecessary power interruptions happening many times per day in the college from Ethiopian electric utility south east region retail business office resulting in decreasing the effectiveness and efficiency of administrative office works which directly affects the training processes for the achievement of the vision, missions as well as objectives of the TVET programs generally for the country, particularly for the college community.

Thus, to get sustainable and optimum energy output, an automated system was required which should be capable to constantly rotate the solar panel to sun’s direction to receive maximum solar energy. So, the project that we have developed here is called “Design and Implementation of Solar PV system with Microcontroller Based Single Axis Tracking System for Adama Polytechnic College Administration Offices” that has been used to solve the existing energy supply problems in college.

1.4. Objectives of the Study

1.4.1. General objective of the study

The main objective of this thesis was to Design and Implementation of Solar PV system with Microcontroller Based Single Axis Tracking System for Adama Polytechnic College Administration Offices to utilize the maximum solar energy supply, and to minimize unnecessary power interruptions frequently happening in the college due to the problems of supplier authority namely; Ethiopian electric utility south east region retail business office.

1.4.2. Specific objectives of the study

The specific objectives of the study include the following:-

- To design an automatic single axis solar tracker;
- To optimize power generation by solar panel using LDR sensors
- To determine energy demand per day; and
- To analyze and develop a prototype of automatic single axis solar tracking system to alternative current electrical powered appliances.

1.5. Significance of the Study

The use of solar power which is a reliable, free, low running /maintenance cost, cheap and environmental friendly sources of energy as well as no pollution of environment occur. This thesis is going to help for the growth of Ethiopian economy because right now the country is going through a lot of major issues, and electricity is one of them. Using automatic solar radiation tracker system increases the amount of solar energy which can be received by the solar energy collector and improves the energy output of electricity which is generated.

The major significances of the study are as follows:

- Provides a solution for energy saving and to achieve balanced between consumption and generation of power;
- It increases solar panel output and maximizes the efficiency of the panel;
- Avoids unnecessary power interruptions frequently happening in the college from Ethiopian electric utility south east region retail business office.
- Helps as training purpose for industrial automation and control technology level-v trainees in Adama Polytechnic College administration offices ; and
- It can also be the spring board for the researchers who will be interested to do the related research works in the future.

1.6. Scope of the Project

The scope of this thesis has been focused to design and implementation of solar PV system with microcontroller based single axis tracking system for Adama Polytechnic College Administration Offices.

Therefore, this thesis prototype covers the scope as follows:-

- Using PIC 16F877A microcontroller;
- Using stepper motor ;
- Using two sensors (LDRs) being located in east and west directions to detect and compare the solar intensity of light;
- Designing solar PV system; and
- Supplying inverted AC power to Adama Polytechnic College for its administration offices.

1.7. Limitation of the Study

Since as it is new technology to our country ,very few studies (almost no) had conducted by Ethiopian scholars concerning the field (automatic solar tracking using microcontroller), getting information is very hard. Moreover, electronic components required for the project are not easily accessible so that we had to find alternatives; in the course of finding the best alternatives we have faced considerable time and financial constraints. There is also luck of budget allocated by the college to implement the real project in the college.

1.8. Methodology Overview

Step by step procedures have been followed during the progress of this thesis to accomplish the task successfully. Thus, methodology for this system is the fundamental and decisive part to design and implementation of solar PV system with microcontroller based single axis tracking system. The followed method includes the followings:

Data Collection: - Data collection has been conducted by using methods such as interview, desk study and observation. The necessary data for the existing daily power requirement in terms of Watt-Hour/Day of Adama Polytechnic College Administration Office is obtained from different sites Ethiopian electric utility south east region retail business office, APC and National Meteorological Agency Adama Branch Directorate. These data which is the more essential for the study include; the power rating of the lamps , type of lamp used, computers, printer, refrigerator, color television, Receiver, and cooling fun, the voltage rating, solar irradiance/ insolation, temperature , latitude and longitude (sun angle), are collected so as to determine the output in the design and implementation of the system.

Load Estimation: - to design solar PV panel with its accessories for micro controller based single axis solar tracking system design, necessary data have been gathered and calculated. Thus, primary electric loads for the Adama Polytechnic College Administrative Offices were estimated by observing and recording the electrical equipment's and their ratings from nameplate data that currently exists in the administration offices. For this purpose Microsoft-Excel software tool has been used.

Analysis Method:-depending on the data collected and information gathered, the hardware have been designed by using micro C PRO software and Proteus 8.0 Professional (ISIS) for the implementation of microcontroller based single axis solar tracking system. Micro C PRO compiler have been used to compile the source code written in C program language and also Microsoft Office Excel for the design of PV, charge controller, inverter, battery size and MATLAB for modeling circuit.

Simulation, observation and drawing conclusion: Finally, all the simulation results which are in line with the objective were recorded, interpreted. Conclusions and recommendations are made based on the results obtained from analysis.

1.9. Organization of the Study

This study consists of five chapters. The first chapter is an introduction part and discusses about the overview of thesis, statements of the problem and its magnitude, objective of the research-general and specific objectives, significance of the study, scope of the project, limitation of the study, methodology overview. Chapter two refers the review of related literature, literature survey and it contains a detailed description of solar tracking system. It explains about the concept of renewable energy, solar energy, solar tracking system, the application of this system and the involved hardware components in this project. Chapter three includes the thesis methodology and it explains how the project is organized and the flow of process in completing this thesis. Also this topic discusses the methodology of the system, circuit design, and software design. Chapter four is about findings and analysis and it contains detailed description about hardware development. It explains more detail about the electronic component that had been used and the method used to develop hardware. This chapter includes the software methodology of model and simulation. This discuses more about the software that had been used to design programming for the whole project and the software that had been used to design a Printed Circuit Board (PCB). Chapter five consists of more about discussion/conclusion and recommendation. It summarizes and concludes the whole project and gives future recommendations to make the project perfect and improve its quality. Finally, references of the sources cited in the thesis, and appendices containing any other relevant material used for the study and sample of the programming codes are attached at the end of the paper.

CHAPTER TWO

2. REVIEW OF LITERATURE

2.1. General Overview

In recent years, quite a good deal of attention has been paid to research and development in various fields of energy e.g. fossil fuels, nuclear energy, solar energy and etc. In particular, quite a lot of work has been done in solar energy in the developed countries while the less under developing ones, most of which have an abundant supply of solar energy are still striving to follow suit [9].

As a developing nation, Ethiopia is rapidly increasing its energy consumption and is short on energy supplies. Fortunately, Ethiopia is located in that part of the world where sun shines for maximum number of hours. It is, therefore, a matter of interest to assess the significance of solar energy and its utilization in different fields of applications. The utilization of the solar energy in Ethiopia will play an important role in the future [2]. Detailed information of the availability of solar radiation on the surface of the earth is essential in understanding many physical and biological processes. With the rapid increase in population and economic development, the problems of the energy crisis and global warming effects are today a cause for increasing concern. The utilization of renewable energy resources is the key solution to these problems. Solar energy is one of the primary sources of clean, abundant and inexhaustible energy that not only provides alternative energy resources, but also improves environmental pollution in the country [2], [3].

The most immediate and technologically attractive use of solar energy is through photovoltaic conversion. The PV cell converts the sunlight directly into direct current electricity by the photovoltaic effect [11]. A PV panel or module is a packaged interconnected assembly of PV cells. In order to maximize the power output from the PV panels, one needs to keep the panels in an optimum position perpendicular to the solar radiation during the day. As such, it is necessary to have it equipped with a sun tracker. Solar tracking is the most appropriate technology to enhance the electricity production of a PV system. To achieve a high degree of tracking accuracy, several approaches have been widely investigated.

Compared to a fixed panel, a sun tracker solar technology is a viable option to reduce pollution emissions and is a practical renewable energy source. A sun tracker solar technology can be applicable for the polytechnic college, because it can be multifunctional. The technology can be used both as an energy source and an educational tool to train people about renewable energy technologies and its applications. Particularly, microcontroller based single axis solar tracking system is our project design to harvest maximum solar energy to supply electrical power for Adama Polytechnic College Administration Offices and also used as training purpose for industrial automation and control technology management trainees in the college.

2.2. Solar

Ethiopia generates most of its electricity from renewable energy. The country began a large program to expand electricity supply in the 2010s from 2,000 MW to 10,000 MW. This was to be done mainly with renewable sources. Solar photovoltaic is being promoted to replace fuel-based lighting and off-grid electrical supply with a solar panel assembly plant opening in Addis Ababa in early 2013. The majority of the Ethiopia's population lives in rural areas and very few have access to electricity [26].

Ethiopia is thought to have about 5 MW of off-grid solar [2]. Almost all current solar power is used for telecommunications. Other uses include village well pumps, health care and school lighting. A current government initiative plans to bring solar power to 150,000 households by 2015. The first phase included 1 MW of panels. The first large installation of solar was a village grid of 10 kW in 1985, expanded to 30 kW in 1989. A solar panel assembly plant opened in Addis Ababa in early 2013 capable of making 20 MW of panel per year [11].

2.3. Solar Energy Conversion System

2.3.1 The Sun

The sun, the source of solar radiation, is a sphere of intensely hot gaseous matter with a diameter of about 1.39 x 109 m, a total mass of 1.99 x 1030 kg and on the average 1.50 x 1011 m away from the earth. An atomic reaction taking place in the inner active part of the sun makes the outer surface to have a temperature of 5800K [3]. Solar radiation in the form of radio magnetic wave emanates from this surface and propagates spherically in space. Some part of the radiation reaches the earth surface after atmospheric effect (reflection, refraction, absorption, scattering etc.). Such radiation is called diffused radiation. There is also some part of radiation that reaches the earth's surface without such atmospheric effect which is called direct radiation [3], [4], [20].

2.3.2 Energy from the Sun

Energy from the sun can be used in three ways. Hence, when we are talking about solar energy, it is important to distinguish between these three types as stated in [9].

Passive heat: This is heat that we receive from the sun naturally. This can be taken in to account in the design of buildings so that less additional heating is required.

Solar thermal: Where we use the sun's heat to provide hot water for homes or swimming pools (also heating systems).

Photovoltaic energy (PV): Uses energy from the sun to create electricity to run appliances and lighting. A photovoltaic system requires only daylight - not direct sunlight - to generate electricity. And this is the concern of this thesis.

2.3.3. Photovoltaic's

In short, Photovoltaic means (photo = light; voltaic = produces voltage) or PV systems convert light energy from the sun directly into DC electricity using semiconductor technology (figure 2-1 clarifies this fact).

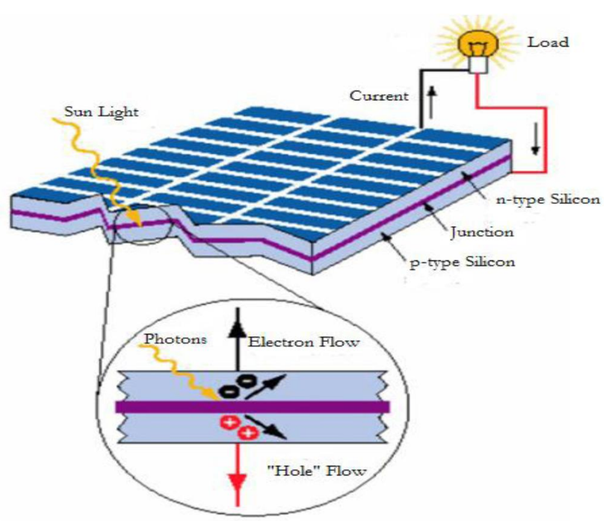

Figure 2- 1 Photovoltaic effect of solar cell [26]

The physics of PV cell is very similar to the classical p-n junction diode. Solar cells consist of two types of materials, often p-type silicon and n-type silicon. Light of certain wavelength is able to ionize the atoms in the silicon and the internal field produced by the junction separates some of the positive charge ("holes") from the negative charge (electrons) within the photovoltaic device [10]. These charge carriers (electron-ion pairs or electron-hole pairs in a solid semiconducting material) in the junction region create a potential gradient, get accelerated under the electric field and circulate as the current through an external circuit. The holes are swept into the positive or p-layer and the electrons are swept in to the negative or n-layer. Although these opposite charges are attracted to each other, most of them can only recombined by passing through an external circuit outside the material because of the internal potential energy barrier. Hence, if a circuit is made as is shown in the figure 2-1. Power can be produced from the cell under illumination, since the free electrons have to pass through the load to recombine with the holes [3].

The output power of a photovoltaic cell depends on the amount of light projected on the cell. Time of the day, season, panel position and orientation are also the factors behind the output power. The current-voltage and power-voltage characteristics of a photovoltaic cell are shown in Fig. 2.2 Photovoltaic cells are the smallest part of a solar panel. Solar panel gives maximum power output at the time when sun is directly aligned with the panel [11].

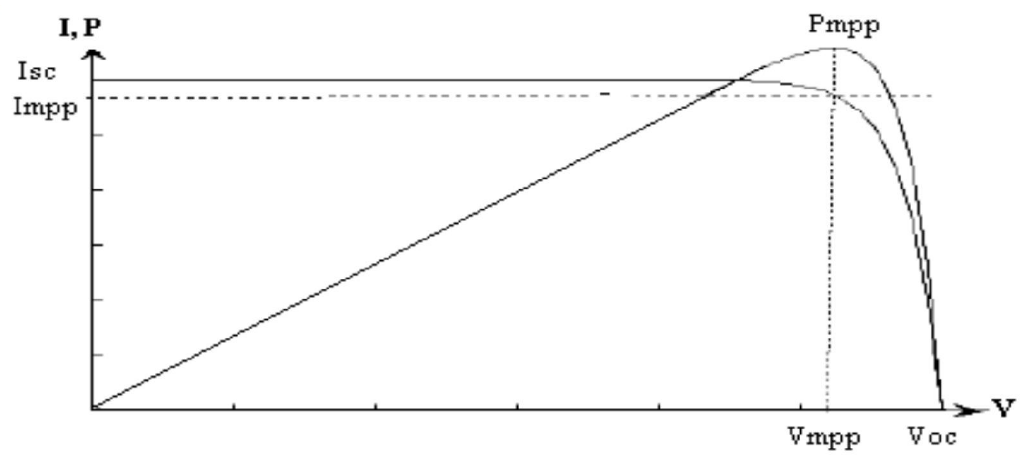

Figure 2-2 I-V and P-V characteristics of PV cell [11]

2.4. 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. Concentrating solar power (CSP) [2] systems work on the principle of converging the sunlight form many kilometers to single focal point. The concentrated energy stored in this form is converted to thermal energy which is utilized to support photovoltaic cell [9]. The solar energy stored by CSP is also helpful in running steam turbines. Solar energy systems are of many types dependent upon their use.

2.4.1. Storage of solar energy

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. Hence useful devices like solar panels, solar heating systems and solar cells supported this immense challenge. 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 [2], [4].

2.4.2. Advantages and disadvantages of solar electricity

Advantages of solar electricity

- Solar power is pollution free during use. Production end wastes and emissions are manageable using existing pollution controls
- Facilities can operate with little maintenance or intervention after initial setup.
- Once the initial capital cost of building a solar power plant has been spent, operating costs are extremely low compared to existing power technologies.

Disadvantages of solar electricity

- Solar electricity is almost always more expensive than electricity generated by other sources.
- Solar cells produce DC which must be converted to AC (using a grid tie inverter) when used in currently existing distribution grids. This incurs an energy loss of 4-12% [18].

2.5. Solar Panel

A solar panel (photovoltaic module or photovoltaic panel) is a packaged interconnected assembly of solar cells, also known as photovoltaic cells. The solar panel can be used as a component of a larger photovoltaic system to generate and supply electricity in commercial and residential applications [10], [11].

Most solar panels are rigid, but semi-flexible ones are available, based on thin-film cells. Electrical connections are made in series to achieve a desired output voltage and/or in parallel to provide a desired current capability. Separate diodes may be needed to avoid reverse currents, in case of partial or total shading, and at night. Solar cells become less efficient at higher temperatures and installers try to provide good ventilation behind solar panels. Some recent solar panel designs include concentrators in which light is focused by lenses or mirrors onto an array of smaller cells [6].

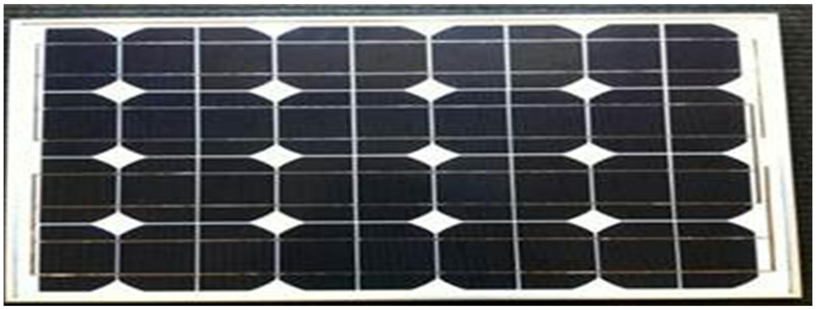

Figure 2- 3 Typical solar panel [6]

Advantage of solar panel

- Works according to sun direction
- Low cost and reliable circuit

Application of panel

- Educational institute
- Street light
- Solar water heater
- Offices

2.5.1. Major solar PV system components

Solar PV system includes different components that should be selected according to our system type, site location and applications. The major components for solar PV system are solar charge controller, inverter, battery bank, auxiliary energy sources and loads (appliances).

Typical System Components

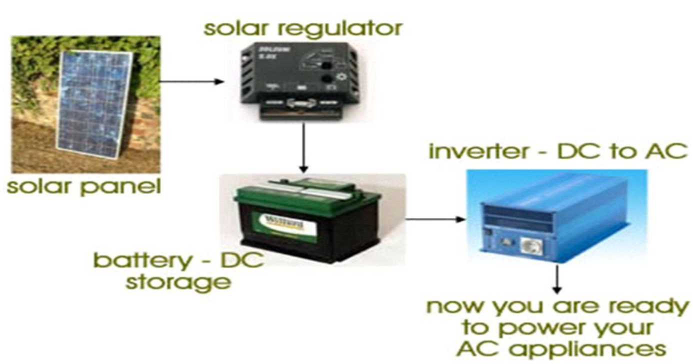

Figure 2-4 Major solar PV system components [3]

- **PV Array:** A PV Array is made up of PV modules, which are environmentally-sealed collections of PV Cells—the devices that convert sunlight to electricity.
- **Solar charge controller:** - regulates the voltage and current coming from the PV panels going to battery and prevents battery overcharging and prolongs the battery life.
- **Battery:** - stores energy for supplying to electrical appliances when there is a demand.
- **DC-AC inverter: -** This is the device that takes the dc power from the PV array and converts it into standard ac power used by the house appliances.
- **Balance of system equipment (BOS):-** BOS includes mounting systems and wiring systems used to integrate the solar modules into the structural and electrical systems of the home. The wiring systems include disconnects for the dc and ac sides of the inverter, ground-fault protection, and over current protection for the solar modules.
- **Load:** - are electrical appliances that connected to solar PV system such as lights, radio, TV, computer, refrigerator, etc.

2.5.2. Types of photovoltaic panels

a) Single-Crystalline PV

These are the oldest type of PV solar panel. They are also the most expensive type per panel. However, they are also the most efficient in terms of electricity generated per unit of surface area of panel (not the most cost-efficient!) [10].

- Single-crystalline efficiency = 10% to 12%
- Loss in efficiency over time = 0.25% to 0.5% per annum

b) Poly-Crystalline PV

Poly-crystalline panels are manufactured out of silicon, as are single-crystalline modules. However, poly-crystalline panels are made using a type of silicone with a different chemical structure, which is slightly cheaper to produce, at a very small loss in efficiency [10].

- Poly-crystalline efficiency = 10% to 11%
- Loss in efficiency over time = 0.25% to 0.5% per annum

c) String Ribbons

A new technique has recently started being used to create string ribbons solar modules. Whilst they are much cheaper to produce than single-crystalline or poly-crystalline, they are also quite a lot less efficient. This means that in order to generate the same amount of electricity, the typical string ribbon system is 30% larger in terms of surface area [10].

- String ribbons efficiency = 8% to 9%
- Loss in efficiency over time = 0.25% to 0.5% per annum

d) Thin-Film / Amorphous

Whilst mono and poly-crystalline solar panels are manufactured with molded silicone, thin-film solar panels use a thin film of silicone, which is sprayed over their base. This is also the newest solar panel technology available thin-film solar panels are also the least efficient solar panels, which is admittedly offset by their much lower price. On average, this means that a thin-film solar power system needs to be double the surface area of a mono-crystalline solar panel setup, in order to produce the same amount of electricity [10].

- Thin-Film efficiency = 5% to 7%
- Loss in efficiency over time = possibly 0.5% to 1% per annum, although untested (they're new!)

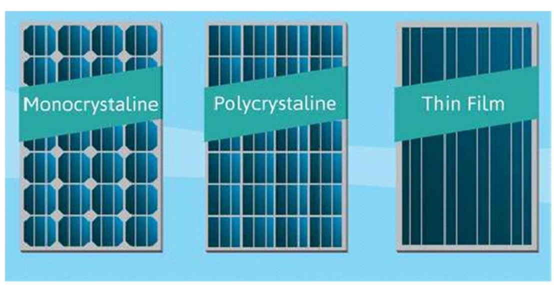

Figure 2- 5 Mono, Poly and Thin Film Panels [10]

2.5.3. Grid-Tied solar photovoltaic (PV) systems

If your building is already connected to the mains power network or a connection to the national grid would be easy and not too expensive to arrange, a Grid-Tied Solar Photovoltaic system is often the most cost effective PV System to install [23],[24].

Grid-Tied Solar Photovoltaic (PV) Equipment :-Solar PV Panels / PV Modules , A Grid-Tie Inverter , Cables & Accessories , Isolators , Mounting System , Monitor , Generation Meter.

2.5.4. Off-Grid solar photovoltaic (PV) systems

An Off-Grid Solar PV System is self-contained and uses batteries to store and release electricity when the Solar PV Panels aren't active such as at night. An Off-Grid PV solution is ideal for remote buildings, application specific functions such as for powering machinery, temporary solutions, and pumps, boats, pretty much anywhere where mains electricity isn't available or isn't needed [23].

Off-Grid Solar Photovoltaic (PV) Equipment are solar PV panels / PV modules ,power inverters , charge controller , cables & accessories , isolators monitor ,batteries.

2.6. Solar Trackers

A Solar tracker is a device used for orienting a solar photovoltaic panel or lens towards the sun by using the solar or light sensors connected with the machine (ex: stepper motor, servo motor, gas filled piston). Hence, the sun tracking systems can collect more energy than what a fixed panel system collects [4], [16], [17].

Need of solar tracker:-

- Increase solar panel output
- Maximum efficiency of the panel
- Maximize power per unit area
- Able to grasp the energy throughout the day

2.6.1. Comparison of fixed solar panel and solar tracker

Many of the solar panels had been positioned on a fixed surface such as a roof, ground and etc. As sun is a moving object, this approach is not the best method. One of the solutions is to actively track the sun using a sun tracking device to move the solar panel to follow the sun. With the sun always facing the panel, the maximum energy can be absorbed, as the panel is operating at their greatest efficiency [20].

Generally, the efficiency of single-axis tracking system over fixed mount, the average power values prove that the single-axis panel produces more power than that of the fixed mount. The power efficiency calculated for the singe-axis solar tracker is more than that of the fixed mount [23].

2.6.2. Tracker drive types

Solar trackers can be divided into three main types depending on the type of drive and sensing or positioning system that they incorporate such are passive tracker, active tracker and open loop tracker [23],[26].

a) Gas Trackers (Passive Trackers)

Passive trackers use a compressed gas fluid as a means of tilting the panel. This system is very reliable and needs little maintenance. Passive trackers are however an effective and relatively low cost way of increasing the power output of a solar array [23].

b) Active Trackers

Active trackers measure the light intensity from the sun to determine where the solar modules should be pointing. Light sensors are positioned on the tracker at various locations or in specially shaped holders. If the sun is not facing the tracker directly there will be a difference in light intensity on one light sensor compared to another and this difference can be used to determine in which direction the tracker has to tilt in order to be facing the sun[23],[16].

c) Open Loop Trackers

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

Timed Trackers: These use a timer to move the tracker across the sky. The main disadvantage of timed systems is that their movement does not take into account the seasonal variation in sun position. Unless measures are taken to adjust the tracker position seasonally, there will be a noticeable difference in efficiency depending on the season [16], [6].

Altitude/Azimuth Trackers: use astronomical data or sun position algorithms to determine the position of the sun for any given time and location. Tracker location, date and time are used by a micro controller to fix the position of the sun. Once the position has been calculated, the modules are moved using servo motors and their position measured by encoders built into the tracker frame [6].

2.6.3. Tracking techniques

There are several forms of tracking currently available, these vary mainly in use are fixed control algorithms and dynamic tracking. 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[17], [23].

The dynamic tracking system, on the other hand, actively searches for the sun's position at any time of day or night. 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. That is utilized for this movement is called Solar Trackers [20].

2.6.4. Advantages and disadvantages of a solar tracker system

Advantages:

- Solar trackers automatically move to "track" the progress of the sun across the sky, thereby maximizing output
- Solar trackers generate more electricity
- Trackers change their orientation throughout the day to follow the sun's path to maximize energy capture.
- Solar trackers are highly efficient installations, and are a great fit for many smaller jobsites.

Disadvantages:

- Adding a solar tracking system means added more equipment, moving parts and gears, which will require regular maintenance and repair or replacement of broken parts.
- If the solar tracker system breaks down when the solar panels are at an extreme angle, the loss of production until the system is functional again can be substantial.
- A fixed-solar system that will last 30 years usually comes with a 25-year power performance guarantee. But a solar-tracked system comes only with a 5 to 10-year warranty.
- Tracking is also not suitable for typical residential rooftop photovoltaic installations.

2.6.5. Types of solar trackers

There are many different types of solar tracker which can be grouped into single axis and double axis models [6], [16], [24].

a) Single Axis Solar Tracker

b) Dual Axis Solar Tracker

2.6.5.1. Single-axis solar trackers

Single-axis solar trackers rotate on one axis moving back and forth in a single direction. It has one degree of freedom that acts as an axis of rotation. 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 tracking algorithms [24].

The microcontroller based single-axis solar tracking system analyzed in this project consist of a PV panel rotating around a tilted shaft under the action of a stepper motor controlled according to the real sun position estimated by means of two light intensity sensors [20]. The light sensor's consists of two LDR's placed on either side of the panel separated by an opaque plate. Depending on the intensity of the sun rays one of the two LDR's will be shadowed and the other will be illuminated.

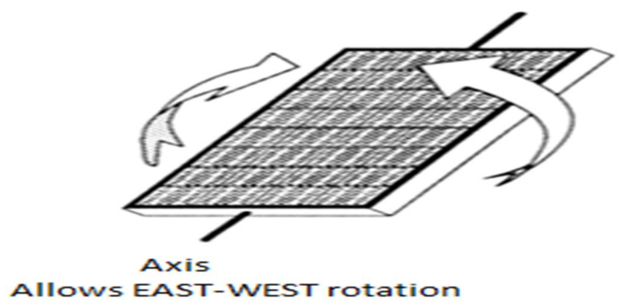

Figure 2- 6 Single axis solar tracker [20]

Single axis solar trackers can either have a horizontal or a vertical axle. The horizontal type is used in tropical regions where the sun gets very high at noon, but the days are short. The vertical type is used in high latitudes (such as in UK) where the sun does not get very high, but summer days can be very long. These have a manually adjustable tilt angle of 0 - 45 °and automatic tracking of the sun from East to West. They use the PV modules themselves as light sensor to avoid unnecessary tracking movement and for reliability. At night the trackers take up a horizontal position [23].

Advantages and disadvantages of single axis tracking solar mount

Advantages

- Ideal for remote area installation
- Minimal maintenance required
- Low cost foundations
- Can increase productivity of solar modules up to 35%

Disadvantages

This kind of tracker is most effective at equatorial latitudes where the sun is more or less overhead at noon. Due to the annual motion of the earth the sun also moves in the north and south direction depending on the season and due to this the efficiency of single-axis is reduced since the single-axis tracker only tracks the movement of sun from east to west. During cloudy days the efficiency of the single axis tracker is almost close to the fixed panel.

2.6.5.2. Dual-axis trackers

To overcome the disadvantages in the single-axis tracking system, a dual-axis tracking system was introduced. In dual-axis tracking system the sun rays are captured to the maximum by tracking the movement of the sun in four different directions. The dual-axis solar tracker follows the angular height position of the sun in the sky in addition to following the sun's east-west movement [23]. The dual-axis works in the same way as the single-axis but measures the horizontal as well as the vertical axis. Continually face the sun because they can move in two different directions. Double axis solar trackers have both a horizontal and a vertical axle and so can track the Sun's apparent motion exactly anywhere in the world this type of system is used to control astronomical telescopes. Dual axis trackers track the sun both East to West and North to South for added power output (approx 40% gain) and convenience. Because these trackers follow the sun vertically and horizontally they help obtain maximum solar energy generation [16].

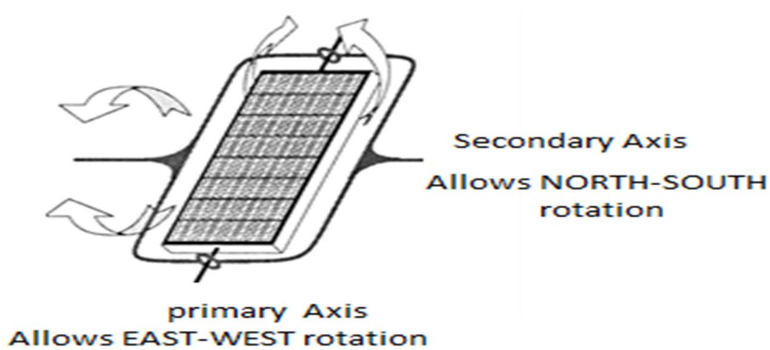

Figure 2-7 Double Axis Trackers [16]

Single Axis Vs Dual Axis Solar Tracking

Single Axis Trackers

- Track the sun from east to west using a single pivot point

- Increase solar yield up to 34%
- Simple, effective design
- Low maintenance
- Lower cost compared to dual axis

Dual Axis Trackers

- Track the sun from east to west, and north to south using two pivot points
- Increases solar yield up to 37%
- Complex design – more motors and sensors
- Higher maintenance
- Higher cost due to additional parts and installation time
- Additional points of failure

Selecting a solar tracker

Selecting a solar tracker depends on: system size, electric rates, land constraints, government incentives, latitude and weather, while dual-axis trackers are mostly used in smaller residential applications and locations with high government Feed-In-Tariffs. Vertical-axis trackers are suitable for high latitudes because of their fixed or adjustable angles [17].

2.7. Charge Controllers

The purpose of solar regulators, or charge controllers is to regulate and to transfer the energy from the solar panels and also prevent the batteries from overcharging. Over charging causes gassing and loss of electrolyte resulting in damage to the batteries. Solar regulators are rated by the amount of current they can deliver to the batteries. The common voltages in off-grid systems are 12/24V and 48V, which means the voltage of system batteries [18], [23], [20].

Figure 2-8 Charge Controller [20]

2.7.1. Controller Types

Solar charge controllers are specified by the system voltage they are designed to operate on and the maximum current they can handle. The system voltage is usually 12 or 24 Volts, or occasionally 48 Volts. The maximum current is determined by the number and size of solar panels used. The two main types of charge controller are: **PWM** and **MPPT**.

2.7.1.1. Pulse wide modulation solar charge controller

Pulse Wide Modulation charge controller reduces the voltage from the PV module to that of the battery, resulting in a decrease in efficiency. PWM charge controllers are less expensive (than MPPT) and are an ideal solution for smaller PV systems where the price can be a critical point, or where the maximum efficiency (as in MPPT 98%) and additional power is not really needed [18].

In PWM charge controller the max. PV voltage (Voc) cannot exceed:

- for 12V systems = 41V (max panel Voc)
- for 24V systems = 52V (max panel Voc)

2.7.1.2. MPPT solar charge controllers

There are two fundamental advantages (comparing to PWM controllers): system efficiency and applicable for big PV panels. The MPPT charge controllers allow PV modules to operate at their higher optimum voltage in varying light conditions: summer, winter, morning, noon, cloudy etc. MPPT tracking of the optimal power point, improves performance by as much as 30% (annual energy production), compared with the PWM charge controller [18], [24].

2.8. Batteries

There are two basic types of batteries that are available for use in a standard solar energy production system: sealed batteries (AGM or Gel cell) and flooded lead acid (FLA) batteries. Sealed batteries require only little maintenance in order to keep them working properly; the FLA batteries have a longer lifespan [15], [16], [24].

Figure 2-9 Storage Battery [24]

Flooded lead-acid batteries vs. Valve regulated lead-acid batteries

Flooded lead-acid batteries (wet-cell batteries): are also the most maintenance-intensive, needing to be occasionally topped-off with water if/when the discharged electrolyte evaporates. Their open nature can also lead to the release of hydrogen, which is flammable and can be dangerous in the absence of proper ventilation [15].

The two types of valve regulated lead-acid batteries

1. Absorbed glass mat (AGM)
2. Gel types.

In both types, the electrolyte is enclosed and does not require manual topping-off as with wet-cell batteries, and they are therefore often referred to as 'maintenance-free'. In AGM batteries the electrolyte is trapped between layered lead-calcium plates or coils. They are not requiring maintenance; these batteries are prepared to have longer life-spans than traditional wet-cell batteries.

Gel-cell batteries: are maintenance-free, they are very robust, having a higher tolerance to being knocked-about than wet-cell batteries. However, there are limitations to the charging current that can be used with these batteries, and care must be taken not to overcharge them. In addition, it is not possible to easily undertake maintenance, and their life-spans tend to be shorter than AGM or wet-cell batteries [15].

You may also see batteries that are not lead-acid types. These are much less common although their life-spans are much longer and it is possible to discharge them to greater depths with little or no negative consequences for the battery life essentially, there is a much higher limit on the number of cycles, and deep discharges do not affect battery life as negatively as with lead-acid [15], [23].

In large scale PV off-grid projects the batteries connected in series. Whereas is in small scale PV off-grid projects the batteries are connected in parallel [15].

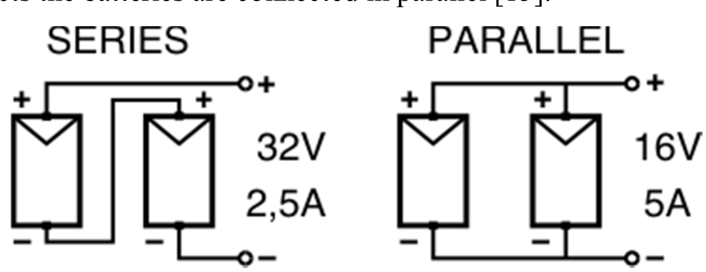

Figure 2-10 Connection of batteries [15]

Choosing the right battery

When choosing your battery take the following things in to consideration cost of the system before buying, find out what batteries are locally available on the market-both locally manufactured and imported. Because of their very short life span in off-grid PV system, avoid automotive-type batteries use trunk rather than car batteries and make sure the following criteria such as; price, capacity, cycle life, replacement and availability, maintenance, size and mobility [15].

State of charge: is used to describe how full a battery is. When a battery is fully charged, we can say that the SoC of this battery is 100%. SoC can be used to describe how fully the lead acid battery charged, because lead acid battery always needs to be fully charged for storage. Later nickel batteries and lithium batteries also take SoC to describe energy reserve. Here is a formula describing the relationship of SoC and DoD, i.e. "SoC = 100% - DoD" [13].

2.9. Power Inverters

The power inverter is the main component of any independent power system which requires AC power. The power inverter will convert the DC power stored in the solar batteries into AC power to run conventional appliances [10], [11].

Figure 2-11 Power Inverters [11]

a) **Square Wave power inverters:-**This is the least expensive and least desirable type. These inverters are usually fairly inexpensive, 500 watts or less [10].
b) **Modified Sine Wave power inverters: -** This is probably the most popular and economical type of power inverter. It produces an alternating current waveform somewhere between a square wave and a pure sine wave [10].
c) **True Sine Wave power inverters: -** A True Sine Wave power inverter produces the closest to a pure sine wave of all power inverters and in many cases produces cleaner power than the utility company itself. It will run practically any type of alternating current equipment and is also the most expensive [11].

Power inverter considerations

The power inverter is connected directly to the batteries and the main AC breaker panel to supply power from the batteries to the loads (appliances). Check out wires & cables for more info on the necessary wire size for installing one or use our new Wire Size Calculator. The power inverter converts the low voltage DC to 220 volts alternating current. Power Inverters is available for use on 12, 24, or 48 volt battery bank configurations. Most power inverters can also charge the batteries if connected to the volts alternating current line. Alternatively, the volts alternating current line input could be our own AC Generator in the case of a stand-alone solar power system [10], [11].

DC to AC conversion losses

The dc power generated by the solar module must be converted into common household AC power using an inverter. Some power is lost in the conversion process, and there are additional losses in the wires from the rooftop array down to the inverter and out to the house panel. Modern inverters commonly used in residential PV power systems have peak efficiencies of 92-94% or 0.92-0.94 [20].

2.10. Microcontroller

The micro-controller is the brain of single axis solar tracking system, and it controls the tracking system. Basically, it receives input from the sensors, specifying the position of the sun and in response, it sends signal to the motors that are connected to the solar panel to move to the panel to the position of the sun in which optimum solar rays could be received. The micro-controller is made up of software and hardware components [22]. The software component is basically computer programs that decode the input signals and sends out appropriate signal in response to the inputs to control the tracking system. It is connected to the sensors and the motors. The hardware executes the command. It requires 5V DC.

PIC family: is the best controller and easily available in the market with low cost as well as easily interfaced with programme. Due to these basic reasons, PIC16F877A controller has been selected inbuilt ISP (in system programmer) option [16].

There are minimum six requirements for proper operation of microcontroller.

These are:

- Power supply section
- pull-ups for ports (it is must for PORT0)

- Reset circuit
- Crystal circuit
- ISP circuit (for program dumping)
- EA/VPP pin is connected to Vcc.

2.11. Liquid Crystal Display

A liquid crystal display (LCD) is a thin, flat panel used for electronically displaying information such as text, images, and moving pictures. Its use includes monitors for computers, televisions, instrument panels, and other devices ranging from aircraft cockpit displays etc. LCD is a passive component that is it does not make any light but just modifies the light passing through it for alphanumeric displays. This type of LCD screen can display 2 lines with 16 characters each. Every character consists of 5×8 or 5×11 dot matrix [24], [6]. It can display all the letters of alphabet, Greek alphabet, mathematical symbols, punctuation marks etc.

Major features of LCD: are its light weight construction, its portability, and its ability to be produced in much larger screen sizes than are practical for the construction of cathode ray tube (CRT) display technology. Its lower electrical power consumption enables it to be used in battery powered electronic equipment [24].

2.12. Light Dependent Resistor

Light Dependent Resistors (LDRs) are very useful especially in light/dark sensor circuits. Normally the resistance of an LDR is very high, sometimes as high as 1,000,000 ohms, but when they are illuminated with light, the resistance drops dramatically[17].Thus in our project, LDR plays an important role in controlling stepper motor based on the intensity of light.

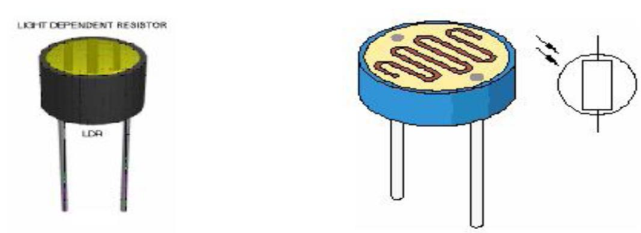

Figure 2- 12 Electrical symbol of light dependent resistors [17]

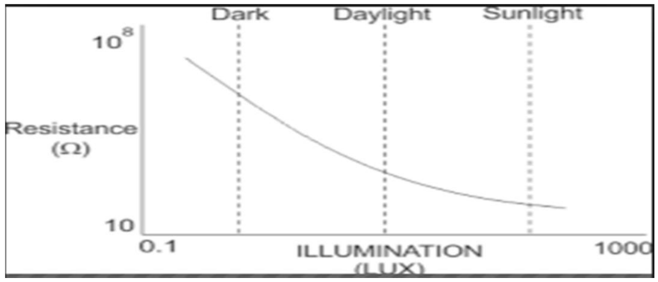

Figure 2- 13 Resistance Vs Solar radiation [17]

Selection of LDR

LDR or light dependent resistor has been chosen as the sensor because LDR is commonly used in sun tracking system. This is because LDR is sensitive to the light. The resistance of LDR will decrease with increasing incident light intensity [17].Thus, in our project the two LDRs play important roles in sun tracking based on the intensity of light.

2.13. Voltage Regulator

Voltage regulators are of different types. In this thesis/project, our interest is only with IC based voltage regulator. It is an integrated circuit whose basic purpose is to regulate the unregulated input voltage (definitely over a predefined range) and provide with a constant, regulated output voltage [14]. An IC based voltage regulator can be classified in different ways. A common type of classification is 3 terminal voltage regulator and 5 or multi terminal voltage regulator. Another popular way of classifying IC voltage regulators is by identifying them as linear voltage regulator & switching voltage regulator. There is a third set of classification as 1) Fixed voltage regulators (positive & negative) 2) Adjustable voltage regulators (positive & negative) and finally 3) Switching regulators. In the third classification, fixed & adjustable regulators are basically versions of linear voltage regulators [7], [17].

2.14. Stepper Motor

The stepper motor is an electromagnetic device that converts digital pulses into mechanical shaft rotation. The shaft or spindle of a stepper motor rotates in discrete step increments when electrical command pulses are applied to it in the proper sequence [25]. The sequence of the applied pulses is directly related to the direction of motor shafts rotation. Many advantages are achieved using this kind of motors, such as higher simplicity, since no brushes or contacts are present, low cost, high reliability, high torque at low speeds, and high accuracy of motion. Many systems with stepper motors need to control the acceleration/ deceleration when changing the speed [23].

Bipolar vs Unipolar Stepper Motors

The two common types of stepper motors are the bipolar motor and the unipolar motor. The bipolar and unipolar motors are similar, except that the unipolar has a center tap on each winding. The bipolar motor needs current to be driven in both directions through the windings, and a full bridge driver is needed .The center tap on the unipolar motor allows a simpler driving circuit, limiting the current flow to one direction. The main drawback with the unipolar motor is the limited capability to energize all windings at any time, resulting in a lower torque compared to the bipolar motor. The unipolar stepper motor can be used as a bipolar motor by disconnecting the center tap [23], [25].

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

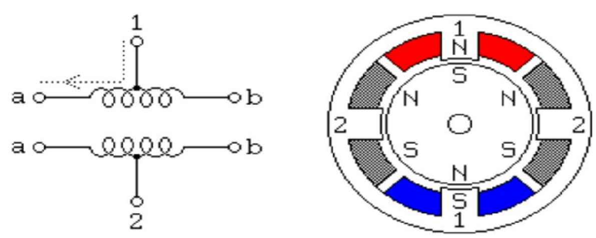

Figure 2-14 2- Phase winding unipolar Stepper Schematic [25]

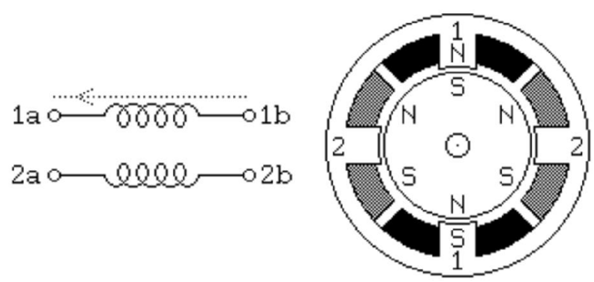

Figure 2-15 Two phase winding bipolar stepper motor [25]

Step Angle: Step angle of the stepper motor is defined as the angle traversed by the motor in one step [8]. To calculate step angle, simply divide 360 by number of steps a motor takes to complete one revolution. As we have seen that in half mode, the number of steps taken by the motor to complete one revolution gets doubled, so step- angle reduces to half. Stepper motor rotating in full mode takes 4 steps to complete a revolution [6], [25].

Therefore, step- angle can be calculated as:

In case of full mode:

Step Angle $ø = 360°/ 4 = 90°$ and

In case of half mode:

Step Angle $ø = 360°/ 8 =45°$.

So, in this way we can calculate step angle for any stepper motor [25].

Advantages and Disadvantages of Stepper Motor

Advantages

- The rotation angle of the motor is proportional to the input pulse.
- Precise positioning and repeatability of movement since good stepper motors have an accuracy of 3-5% of a step and this error is non-cumulative from one step to the next.
- Excellent response to starting/ stopping/reversing.
- Very reliable since there are no contact brushes in the motor. Therefore, the life of the motor is simply dependent on the life of the bearing.
- A wide range of rotational speeds can be realized as the speed is proportional to the frequency of the input pulses.

Disadvantages

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

Open Loop Operation: One of the most significant advantages of a stepper motor is its ability to be accurately controlled in an open loop system. Open loop control means no feedback information about position is needed. This type of control eliminates the need for expensive sensing and feedback devices such as optical encoders. Position of stepper motor is known simply by keeping track of the input step pulses [25].

Selection of Stepper Motor

In our project stepper motor can be a good choice to controlled movement panel (rotation angle, speed, position) depending up on the intensity of light from sun radiation.

Torque Generation

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

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

In a stepper motor a torque is developed when the magnetic fluxes of the rotor and stator are displaced from each other. The stator is made up of a high permeability magnetic material. The presence of this high permeability material causes the magnetic flux to be confined for the most part to the paths defined by the stator structure in the same fashion that currents are confined to the conductors of an electronic circuit. This serves to concentrate the flux at the stator poles. The torque output produced by the motor is proportional to the intensity of the magnetic flux generated when the winding is energized [16], [25].

2.15. Motor Driver Circuit

Driver is used to increase the strength of signal. In this application we are using stepper motor to rotate the solar panel. So to drive the stepper motor we have to increase the strength of signal. The ULN2003 is a monolithic high voltage and high current Darlington transistor arrays. It consists of seven NPN Darlington pairs that feature high-voltage outputs with common-cathode clamp diode for switching inductive loads [16], [17].

2.16. Literature Survey

In this section previous works which are directly or indirectly related to the idea of this thesis work are examined. Works reviewed in this section are generally categorized in to three as: a recently published journal papers, M.Sc. thesis and Ph.D. thesis. Even though this work is benefited from ample related materials, due to space limitation, only some selected materials from each category are reviewed. The rest are listed in the reference section and mentioned within the text.

Ashok Kumar Saxena and V. Dutta had 'designed a versatile microprocessor based controller for solar tracking in 1990. Controller had the capability of acquiring photovoltaic and meteorological data from a photovoltaic system and controlled the battery /load. These features were useful in autonomous PV systems that were installed for system control as well as monitoring in remote areas .Solar tracking was achieved in both open loop as well as closed loop modes. The controller was totally automatic and did not require any operator interference unless needed [5].

A. Zeroual et al. had designed an automatic sun-tracker system for optimum solar energy collection in 1997. They used electro-optical sensors for sun finding and a microprocessor controller unit for data processing and for control of the mechanical drive system. This system allowed solar energy collectors to follow the sun position for optimum efficiency. Many parameters had been controlled for system security such as temperature, pressure and wind velocity. The system had been tested for a long period in variable illumination. The result showed that it operated satisfactorily with high accuracy [1].

Chee-Yee Chong et al. had given the process architectures for track fusion in 2000.They used the concept of multiple targets tracking because it had shown that tracking with multiple sensors can provide better performance than using a single sensor. Two processing architectures for track fusion were presented: sensor to sensor track fusion and sensor to system track fusion. They presented different approaches for fusing track state estimates, and compared their performance through theoretical analysis and simulations [8].

CHAPTER THREE

3. METHODOLOGY

3.1. Introduction

This section discusses the methodology involved in the design and implementation of solar PV system with microcontroller based single axis tracking system for Adama polytechnic college administration offices.

The purpose of this study is to provide comprehensive information on design and implementation of solar PV system with microcontroller based single axis tracking system. From this point of view the study could be considered as a reference for any single axis solar tracking system utilization technology, which is now considered as a possible solution to minimize the energy problems of the college Administration offices. Finally, the input parameters like temperature, total daily AC energy demand requirement, together with the estimated monthly average of daily local solar irradiation/insolation are gathered as data sources.

3.2. Sources of Data

In order to fulfill the objective of the study, both quantitative and qualitative data have been gathered from primary and secondary sources of data for the study. The primary sources of data have been generated from interviews and site observation from all the selected bodies/organizations such as from National Meteorological Agency Adama Branch Directorate, Ethiopian electric utility south east region retail business office, Copex solar panel and equipment shop ,and APTC dean, vice dean, human resource management , Te-CAT process owner, finance and logistic and accounting. The secondary sources of data have been collected from different online documents, journals, different books which were available in ASTU central and engineering library and other former related works have been referred and applied for the method to succeed the project.

3.3. Data Collection Instruments

Relevant data for research has been collected through different tools such as interview, desk study and site observation. The study involved field visits to the sites (APC) and National Meteorological Agency Adama Branch Directorate. Thus, by using following methods of data collection instruments, we have collected the necessary data for our project successfulness.

Interview: Interviews have been conducted to establish the number of hours that different electrical appliances were most likely to be kept on total daily AC energy demand requirement. In this method, we have interviewed the responsible bodies who use the electrical appliances type and consumption hours in each office.

Observation: by technical visit method, we have gathered the necessary data about power consumption of electrical appliances (loads) such as: lamp, computers, refrigerators, receivers, TV, cooling fun, printer. From these data collection, we have calculated the total daily AC energy demand requirement and which helped us to determine the size panels and its accessories.

Desk Study: A desk study has also been carried out to obtain technical information from Ethiopian electric utility south east region retail business office, concerning about the frequently interruption of electrical power to electrical loads in Adama polytechnic college Administration Offices. In addition this, the input parameters like temperature, latitude, longitude, altitude, and together with the estimated monthly average of daily local solar irradiation/insolation from National Meteorological Agency Adama Branch Directorate has been gathered by this method.

This thesis can be considered as investigating study for the design and implementation of solar PV system with microcontroller based single axis tracking system for Adama Polytechnic College Administration Offices. The information that is gathered through literature reviews, case studies, field trips, and key informant interviews has been used to make recommendations about design and implementation of solar PV system with microcontroller based single axis tracking system for Adama Polytechnic College Administration Offices.

3.4. Data Analysis and Design

Depending on the data collected and information gathered, the hardware have been designed by using software micro C PRO and Proteus 8.0 Professional (ISIS) for the implementation of microcontroller based single axis solar tracking system.

Block diagram of the Design System:

The following block diagram shows the Design System of the project.

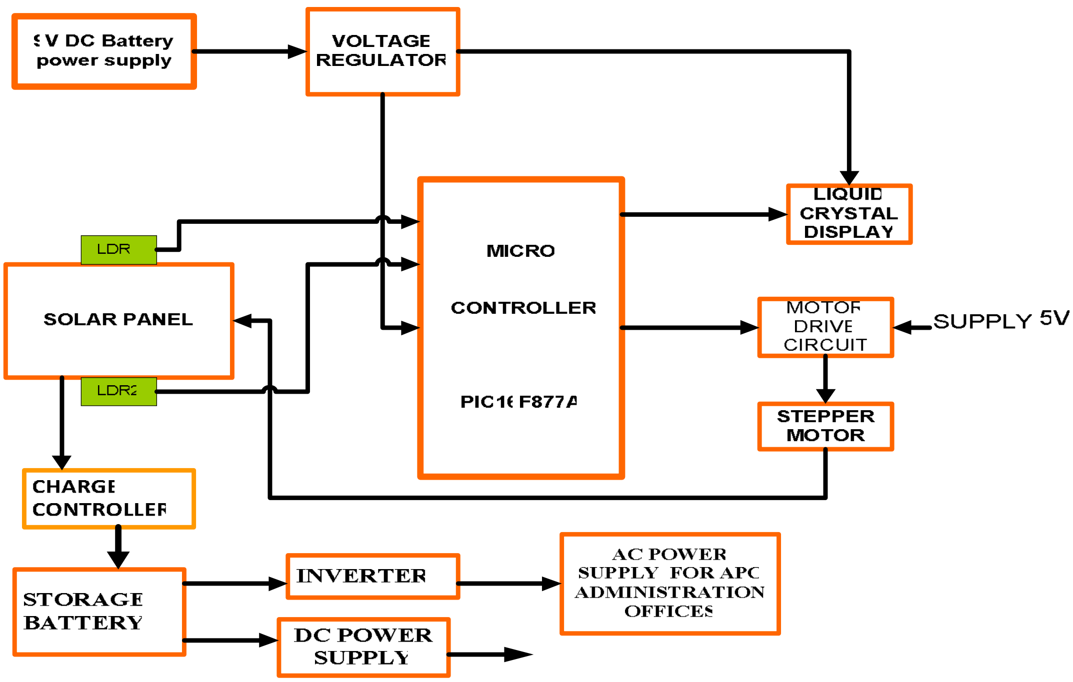

Figure 3-1 General Block diagram of the Design System

Block diagram description

The electrical power from 9VDC dry cell battery has been supplied to the regulator (LM7805) and then the regulator reduced voltage to 5VDC and supplied to the PIC16F877A microcontroller. The microcontroller has sent the message to the circuit driver that rotates the motor according to the intensity of the light received by the solar panel. The stepper motor only draws a very small current, and is used to search for the position where maximum possible energy could be extracted from the sun. The design depends on two light dependent resistor sensors (LDRs).The micro-controller uses for tracking the solar radiation and this solar radiation has been converted to the DC voltage by photovoltaic cell, while the charge controller ensures that the storage battery is never overcharged and prevented the storage battery from being damaged. The generated power has been stored in the storage battery and from this, both inverted AC and DC outputs have been obtained. Finally, the LCD has displayed the direction of the rotation of stepper motor either clockwise or counter clockwise direction while carrying the PV panel.

Flow chart of the project

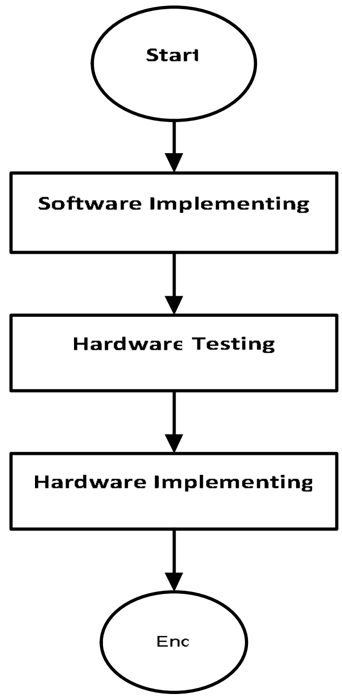

Figure 3- 2 Flow chart of microcontroller based single axis solar tracking system

The above figure shows the project flowchart of the "microcontroller based single axis solar tracking system". Firstly, the software has been designed based on the system that we want to construct. Lastly, the hardware circuit must be tested part by part to make sure that the circuit that we design is correct. If not, the system cannot be operated smoothly. Next, the circuit has been made on the printed circuit board (PCB) and tested its functionality.

3.5. Hardware Implementation

In hardware designing, different types of components have been selected according to their specifications and connected together to build the complete system. For this reason, to implement the hardware design in this project, we have used the following basic hardware components:-

- Microcontroller (PIC16F877A)
- Light Dependent Resistor (LDR/5V)
- Liquid Crystal Display(16x2 alphanumeric LCD)
- Motor Driver circuit (ULN2003/5V)

- Stepper Motor (5V/500mA)
- Voltage Regulator (LM7805 (12VDC/5VDC)
- Solar Panel (300W/36.8V/8.15A)
- Charge Controller(12V/20A)
- Storage Battery(12v/200Ah)
- Inverter (1500W/6.5A)
- Switch (SW-SPST)

Other auxiliary components are:

- Resistors (3x10KΩ)
- Resistor (1x100Ω)
- Potentiometer (1x50kΩ)
- Ceramic Capacitor (2x0.1μF,2 x22pF,and 1x47μF)
- Crystal Oscillator (1x8MHz)
- Power supply (9VDC, 12VDC)
- Diode (1x1N4007)

3.6. Software Implementation

For software implementation, Proteus 8.0 Professional (ISIS) for circuit making and to build the PCB of the system, and Micro C PRO compiler have been used to compile the source code written in C program language. Microsoft Office Excel for the design of PV, charge controller, inverter, battery size and MATLAB for modeling circuit.

3.7. Integration of the System

In this stage, the hardware of the system with that of the software of the system have been integrated or interfaced for the successful implementation of the project. The following figure shows the integration of these systems.

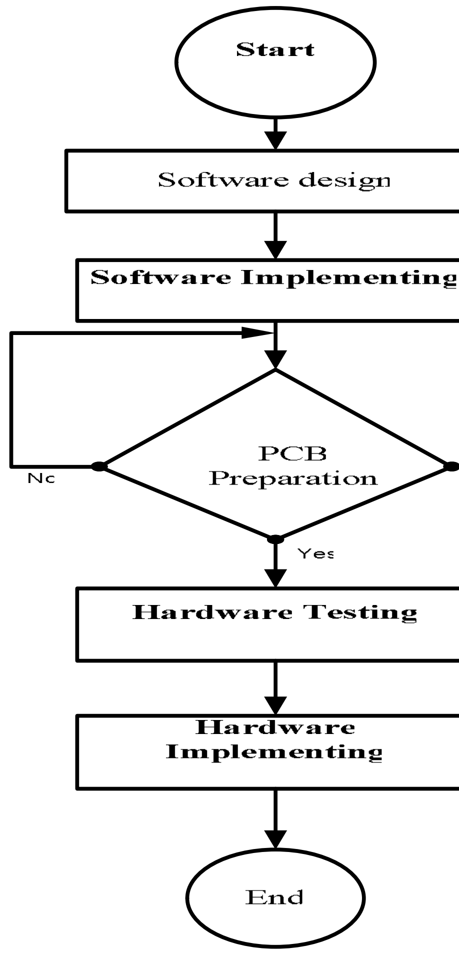

Figure 3-3 Flowchart of the Integration of the System

The above figure shows the integration flowchart of the “microcontroller based single axis solar tracking system”. Firstly, the software has been designed and implemented based on the system that we want to construct. Next, the circuit has been made on the printed circuit board (PCB) and tested its functionality if it is not Ok, the PCB should be prepared again and tested. If it is Ok, the hardware circuit must be tested part by part to make sure that the circuit that we have designed is corrected and can implemented.

3.8. Testing, Simulating and Analysis of the System

In this section, the system functionality has been tested by using Proteus 8.0 Professional (ISIS) and Micro C PRO compiler simulation environments, and Microsoft offices excel software.

3.9. Practical Implementation

In this last stage, the final work of the project or prototype has been practically implemented and its functionality has also been illustrated.

CHAPTER FOUR

4. FINDINGS AND ANALYSIS (MODEL, SIMULATION)

4.1. Design Method

Designing methods are techniques which make a system design simple by decomposing it. A system can be designed using either top-down or bottom-up design approaches for the purpose of studying how well those component parts work and interact to accomplish their purposes. In this study, we have selected the top-down decomposition method for the system design.

4.1.1. Top-Down Decomposition

It is easier to understand the operation of the whole by looking at its pieces and their interactions. We divide a design system into subsystems and components in order to more easily overcome the problem and build the larger system. This is a good strategy for constructing any kind of complex system. The process of top-down decomposition starts with the description of a whole system and replaces it with a series of smaller steps; each step is a more primitive subsystem.

Figure 4-1Decompositions of microcontroller based single axis solar tracking system. It is broken down into power supply unit subsystem, input subsystem, controller unit subsystem (microcontroller), output unit subsystem are stepper motor and LCD display for microcontroller based single axis solar tracking system.

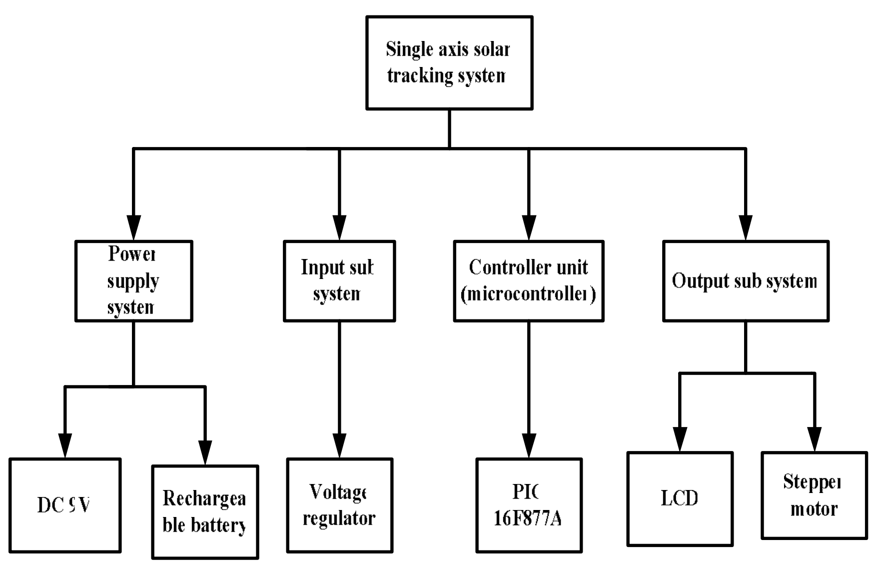

Figure 4- 1 Decompositions of microcontroller based single axis solar tracking system

The power supply unit subsystem: uses two alternatives of electric power supply from dry cell 9VDC and storage battery 12VDC to the system.

The input subsystem: supplies regulated power supply for initialization of microcontroller, stepper motor, motor driver (ULN2003), LCD and LDRs and to perform their duties.

The controller unit subsystem (PIC16F877A microcontroller): controls all the operations. The solar panel is aligned according to the intensity of sunlight under the control of the microcontroller.

The output subsystem: consists of stepper motor to rotate PV panel to the desired directions such as clock wise and counter clock wise, and LCD which is used to display the direction of motor rotation.

4.1.2. Power Supply Unit Subsystem

Power supply is a reference to a source of electrical power. A device or system that supplies electrical or other types of energy to an output load is called a power supply unit. Here for this thesis application we need 9VDC power supply from dry cell and 12VDC from rechargeable battery. Rechargeable battery is for the storage of electrical energy received from the panel. It is normally employed for storage and supply the power to the system.

4.1.3. Input Subsystem

Voltage regulator

A regulated power supply is very much essential for several electronic devices due to the semiconductor material employed in them have a fixed rate of current as well as voltage. The device may get damaged if there is any deviation from the fixed rate. By the help of a voltage regulator DC unregulated output will be fixed to a constant voltage. The circuit is made up of linear voltage regulator 7805 along with diode, capacitors and resistors [14], [7].

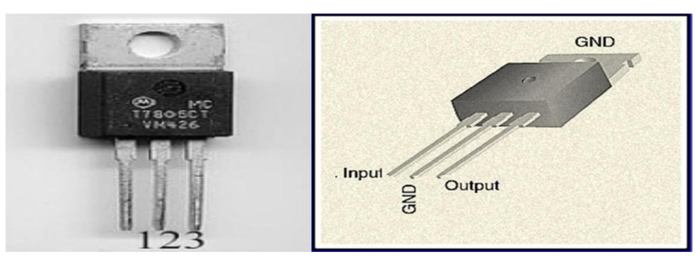

Figure 4- 2 LM7805 Voltage regulators [14].

Schematic circuit diagram of Voltage regulator

Voltage regulators are of different types. In this thesis, our interest is only with IC based voltage regulator which is available in the market is the popular 7805 IC which regulates the output voltage at 5 volts. The schematic circuit below shows the design details of power supply from 9V DC power supply to all electronics components and stepper motor in our projects. LCD, microcontroller, LDRs and stepper motor requires a regulated 5 volt supply voltage to be initialized. For this case an LM 7805 voltage regulator is used. The circuit shown in Figure 4-3 converts an unregulated supply of 9 volts to regulated 5 volts for electronics components and stepper motor in our projects.

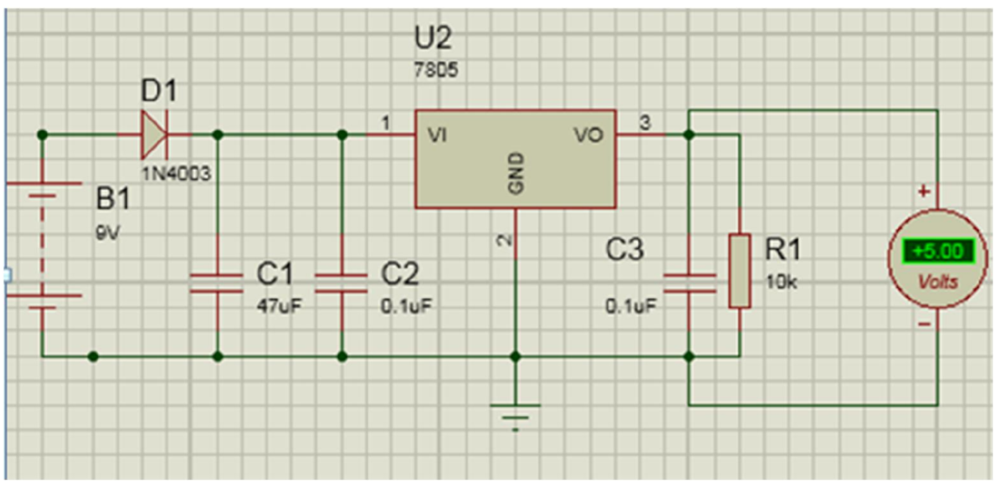

Figure 4-3 Schematic circuit diagram of Voltage Regulator

Analysis of Light Sensor Design

According to our design, micro controller based single axis solar tracking system uses two LDRs for detection of light radiation. A complementary resistor value of each LDR of 10 KΩ is used to construct the circuit. In this configuration, the output voltage will increase as light intensity increases. The complementary resistor value should be chosen such as to achieve the widest output range possible. LDR was measured under dark conditions, average light conditions, and bright light conditions. The results are listed in the table below.

Table 4-1 Light dependent resistor testing data

Measured Resistance	Comments
166K	Dark
0.87KΩ	Average (normal room lighting level)
150Ω	Bright(flash light directly in front of cell)

The selected 10K complementary resistor resulted in the following minimum and maximum voltages.

Minimum = 5 V × (10 KΩ / (10 KΩ + 166 KΩ)) = 0.28 V

Maximum = 5 V × (10000Ω / (10000Ω + 150 Ω) = 4.92V

Thus, an output swing of 4.64V is resulted.

4.1.4. The Controller Unit Subsystem

Since the focus of this project is on embedded software control, the microcontroller is the heart of the system. The microcontroller selected for this project had to be able to convert the analog LDR voltage into digital values. For this project, the type of controller used is PIC16F877A microcontroller [21], [22].

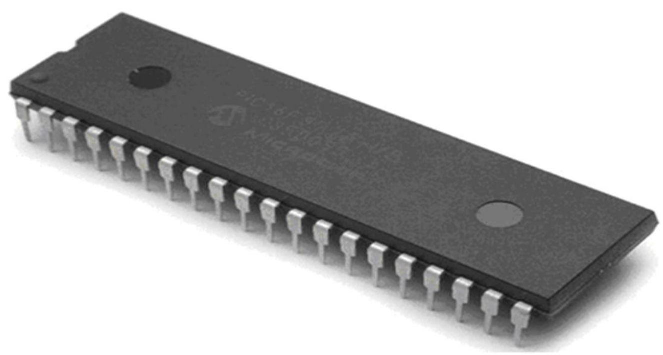

Figure 4-4 PIC 16F877A Microcontroller [22]

4.1.4. 1. Architecture of the PIC microcontroller

Harvard architecture

Harvard architecture is newer concept than Von-Neumann's. In Harvard architecture, data bus and address bus are separate. Thus a greater flow of data is possible through the central processing unit, and of course, a greater speed of work. The Harvard Architecture executes instructions in fewer instruction cycles than the Von-Neumann architecture.

Microcontrollers with Harvard architecture are called "RISC microcontrollers". RISC is a short form for Reduced Instruction Set Computer. Microcontrollers with von-Neumann's architecture are called 'CISC microcontrollers'. CISC is a short form for Complex Instruction Set Computer. PIC 16F877A uses Harvard architecture which is one of the most commonly used microcontrollers especially in industrial, automotive ,appliances and consumer applications. The major advantage with this architecture is that while an instruction is being executed the next can be fetched. The execution speed is doubled [21], [24].

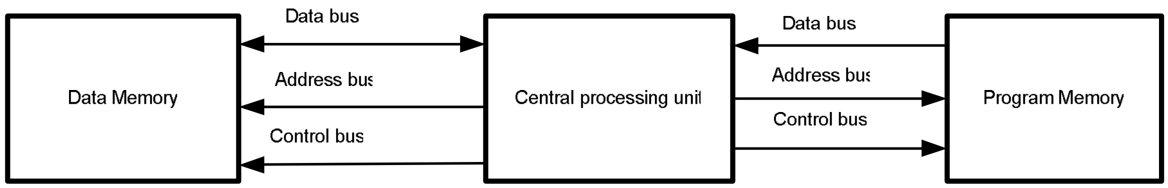

Figure 4-5 Harvard Architecture [21].

The PIC architecture is characterized by the following features:

- Separate code and data spaces(Harvard architecture)
- A small number fixed length instructions.
- Most instructions are simple cycle execution (4 clock cycles) with single delay cycles upon branches and skips.
- A single accumulator (W), the use of which (as source operand) is implied (i.e is not encoded in the opcode).
- All RAM location function as registers as both source and/or destination of math and other functions.
- A hardware stack for storing return addresses.
- A fairly small amount of addressable data space (typically 256 bytes),extended through banking
- Data space mapped CPU, port and peripheral registers

Table 4-2 Key Features of PIC 16F877A

FLASH Program Memory (14-bit Word)	8K Words
Data Memory (RAM)	368 Bytes
Data Memory (EEPROM)	256 Bytes
Interrupts	14
I/O ports	Port A, B, C, D, E
Timers	3
Capture/compare/PWM	2
Serial Communication	MSSP, USART
Package	40 pin DIP
A/D channels	8 (10Bit)

4.1.4. 2. Why Prefer PIC16F877A?

PIC is popular because of low cost, in this project PIC 16F877A is used because it is cheap, very easy to assemble, wide availability, useful for different application and reprogramming with flash memory capability. This PIC microcontroller also can be programmed and erased up to 10,000 times. Many programming language are supported by this PIC such as C language, high -tech C and PIC Basic. But in our case we use the C language for programming using Mikro C PRO and Proteus Professional (ISIS) for simulation [21], [22].

PIC16F877A pin Layout:

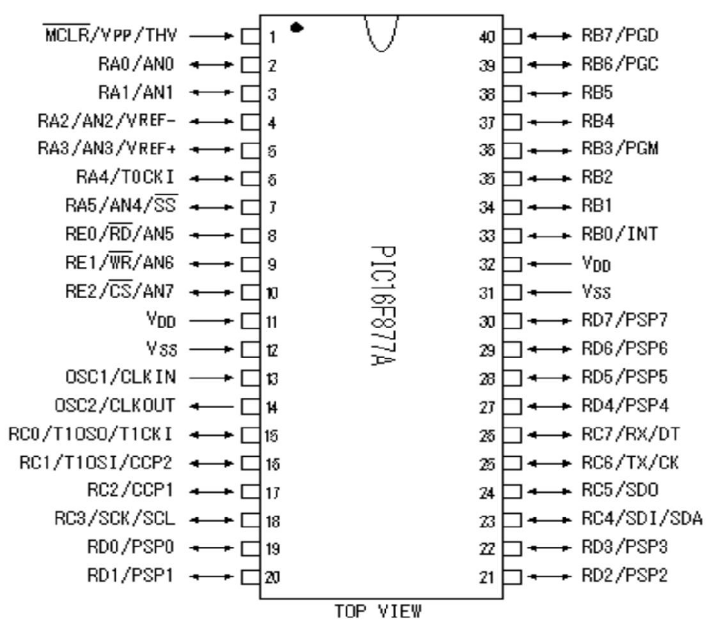

Figure 4-6 Pin Diagram of PIC16F877A [22].

I/O Pins

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

VSS and VDD

These are power supply pins .VDD is the positive supply and VSS is the negative supply or 0V.The maximum supply voltage that you can use is 6V and the minimum is 2V.

MCLR

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

OSC1/CLK IN and OSC2/CLKOUT

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

Table 4- 3 Description of Pins used in Circuit

Pin Name	**Pin No.**	**Description**	**Application**
VDD	11,32	positive Supply (+5V)	Positive supply to chip
VSS	12,31	Ground Reference	Ground Reference
OSC	13,14	For Oscillator or resonator	Connected to Resonator 8MHz with 22pF
MCLR 1	Reset Input	Always connected to +5V	

4.1.4.3. Analog to Digital Converter

The analog-to-digital (A/D) converter module can have up to eight analog inputs for a device. The analog input charges a sample and hold capacitor. The output of the sample and hold capacitor is the input into the converter. The converter then generates a digital result of this analog level via successive approximation. This A/D conversion of the analog input signal, results in a corresponding 10-bit digital number. The analog reference voltages (positive and negative supply) are soft ware selectable to either the device’s supply voltages (AVDD, AVSS) or the voltage level on the AN3/VREF+ and AN2/VREF pins.

4.1.5. The output subsystem

4.1.5.1 Liquid Crystal display (LCD)

It is an electronically modulated optical device made up of any number of pixels filled with liquid crystals and arrayed in front of a light source (backlight) or reflector to produce images in color or monochrome [23]. LM016L LCD is used in this project to display the desired direction of rotation of stepper motor.

LCD Pin Diagram

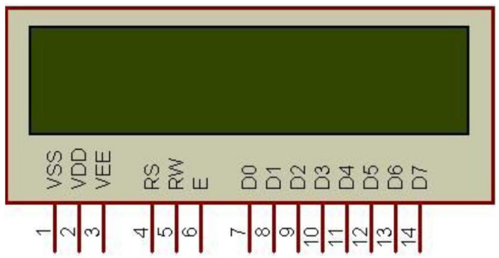

Figure 4-7 LCD Pin Diagrams [23].

Table4- 4 Functional pins of LM016L LCD

Pin No	Symbol	Function
1	VSS	GND
2	VDD	Power supply(+5V)
3	Vo/VEE	Contrast adjust
4	RS	Register selector
5	RW	Data read/write
6	E	Enable signal
7	DB0	Data bus line
8	DB1	Data bus line
9	DB2	Data bus line
10	DB3	Data bus line
11	DB4	Data bus line
12	DB5	Data bus line
13	DB6	Data bus line
14	DB7	Data bus line
15	A	Power supply for LCD B/L(+)
16	K	Power supply for LCD B/L(-)

4.1.5.2. Stepper Motor and Driver Circuit

Stepper motors are special motors that are used when motion and position have to be precisely controlled. Unlike asynchronous motor, in its application, the motor may not rotate continuously; instead, it "steps" from one position to the next as field windings are energized and de-energized in sequence. Depending on the sequence, the rotor may turn forwards or backwards. The stepper motor is turned one step at a time or can turn at a specific. Stepper motor has more advantages in software control. A stepper motor can be controlled by stepper-motor controlled chips, such as the ULN2003 [25], [16].

A single unipolar stepper motor was chosen to position microcontroller based single axis solar tracking. A stepper motor was selected because of the precision it offers in positioning applications. Additionally, complicated drive circuitry is not required with the unipolar type motor. The motor specifically used in the project was a 5 volt, 12 degree-per-step, 4 phase, and unipolar motor. It was decided to half-step the motor in order to provide greater positioning accuracy. This results in 12 degrees-per-step.

Selection of Driver

Driver is used to increase the strength of signal. In this application we are using stepper motor to rotate the solar panel. So to drive the stepper motor we have to increase the strength of signal. In the market so many IC’s are available but we selected ULN 2003. The ULN2003 is a monolithic high voltage and high current Darlington transistor arrays. It consists of seven NPN Darlington pairs that feature high-voltage outputs with common-cathode clamp diode for switching inductive loads [20]. The collector current rating of a single Darlington pair is 500mA and the working voltage of this IC is 5 volts which is same as microcontroller working voltage. And there is no need to design any other power supply section that’s why we selected this IC in our project [25].

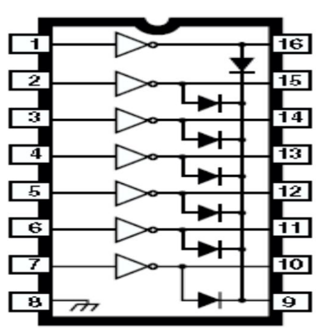

Figure 4- 8 Pins diagram of ULN 2003 [25].

Key Features of ULN2003

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

Analysis of Connections of Driver IC (ULN 2003)

ULN 2003A has 16 pins in this project pins of ULN 2003A are connected accordingly 1st pin is connected to 15 pin and 2nd pin is connected to 16 and 3rd pin is connected to 17 and 4th pin is connected to 18 pin of the PIC16F877A microcontroller. And 8th pin is connected to ground 9th to VDD and 13th to 16th pins are connected to the stepper motor. And other pins are not connected [25].

4.2. Auxiliary Circuit Components of design system

4.2.1. Crystal oscillator

Crystal oscillator is a device that produces electrical oscillations at a frequency determined by the physical characteristics of a piezoelectric quartz crystal. This oscillator circuit is used to generate the device clock. Most microcontrollers can use a crystal oscillator as their clock source. For this project we used 8 MHZ crystal oscillator because its high accuracy, stability, and low power consumption, it is connected to the (13-14) pin of PIC. A ceramic capacitor of 22pF with one leg grounded is connected to the leg of an oscillator [14], [6].

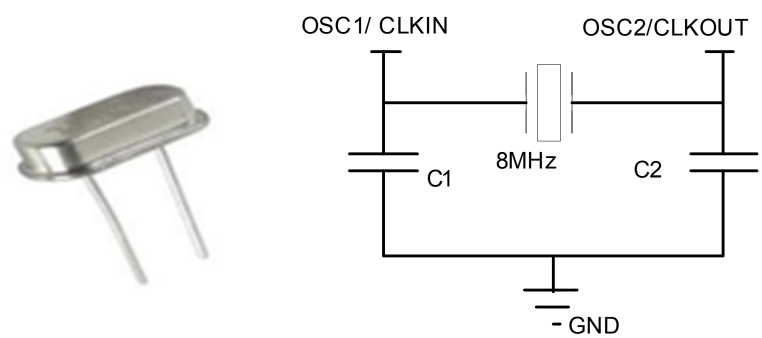

Figure 4-9 Symbols of Crystal oscillator and its circuit diagram [6].

4.2.2. Capacitors

Capacitors are a passive two-terminal electrical component used to store electrical energy temporally in an electric field. Capacitors are widely used in electronics circuits for blocking DC current while allowing AC current to pass. In analog filter networks; they smooth the output of power supplies. In resonant circuits they tune frequency [10]. For this project we used ceramic capacitors of 22pF, 0.1µF, and 47 µF [14].

Figure 4- 10 Ceramic Capacitor [10].

4.2.3. Resistors

Resistors are passive two terminal electrical components that implement electrical resistance as circuit elements. In electronics circuits, resistors are used to limit current flow, to adjust signal levels, bias active elements. There are two types of resistors fixed and variable resistors. Fixed resistors have resistances that only change slightly with temperature, time or operating voltage. Variable resistors can be used to adjust circuit elements such as: a volume control or a lamp dimmer). For this project we used 10KΩ and 100Ω fixed value resistors and 10 KΩ potentiometer (to adjust brightest of LCD) [14].

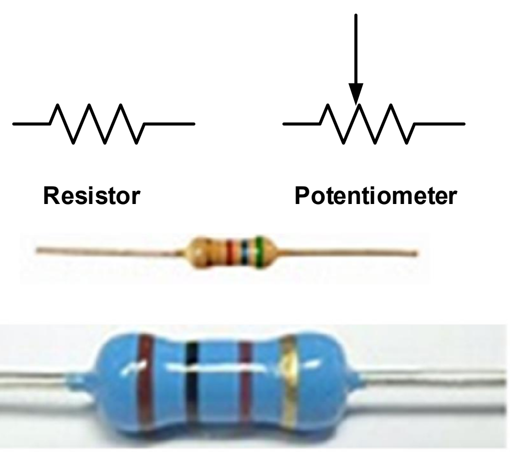

Figure 4-11 Symbols of resistors [14].

4.2.4. Diode

A diode is a device which only allows unidirectional flow of current if operated within a rated specified voltage level. A diode only blocks current in the reverse direction while the reverse voltage is within a limited range otherwise reverse barrier breaks and the voltage at which this breakdown occurs is called reverse breakdown voltage. The diode acts as a valve in the electrical and electronic circuit. A particular arrangement of diodes can convert AC to pulsating DC, and hence, it is sometimes also called as a rectifier. For this project we used 1N4007 diode only for blocking current in the reverse direction while the reverse voltage is within a limited range [7], [14].

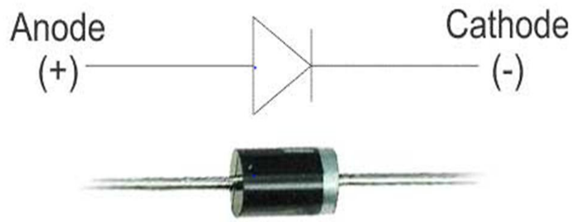

Figure 4-12 Symbols of Diode [7].

4.3. System Implementation

4.3.1. Software operation

The C programming language has been utilized for this project. It was more than adequate to satisfy the design and implementation of microcontroller based single axis solar tracking system

Software design flow chart

First we Declare symbol & variable and then we Initialize variable & input output port after that PIC16F877A read both LDRs. Two LDRs light detectors act as sensors to trace the coordinate of the sunlight by detecting brightness level of sun light. The LDR senses light intensity and sends the signals to Analog-to-Digital converter of the microcontroller.

The Analog-to-Digital converter converts these analog signals to digital form.

The digitally converted signals are then compared by the ULN2003 motor driver and the stepper motor is rotated accordingly.

When LDR1 has higher light intensity than LDR2, then the resistance of LDR1 is smaller than that of LDR2 and voltage at LDR1 is higher than that of LDR2 and the stepper motor rotates the solar panel in the counter clockwise direction.

When LDR2 has higher light intensity than LDR1, and the resistance of LDR2 is smaller than that of LDR1 then voltage at LDR2 is higher than that of LDR1 and the stepper motor rotates the solar panel in the clockwise direction. The stable/equal position is when the two LDRs having the same light intensity.

The source code was developed after the above algorithm has been developed. Code development starts by interfacing the PIC with LDRs, driver circuit, stepper motor and LCD. This is accomplished by defining output ports of the PIC and declaring stepper motor and LCD pins. The direction of each register bit of selected output port has been directed to the respective stepper motor and LCD pins and it enables initializing of the stepper motor, LCD and LDRs. Then the cursor must be cleared, thereby text will be displayed later.

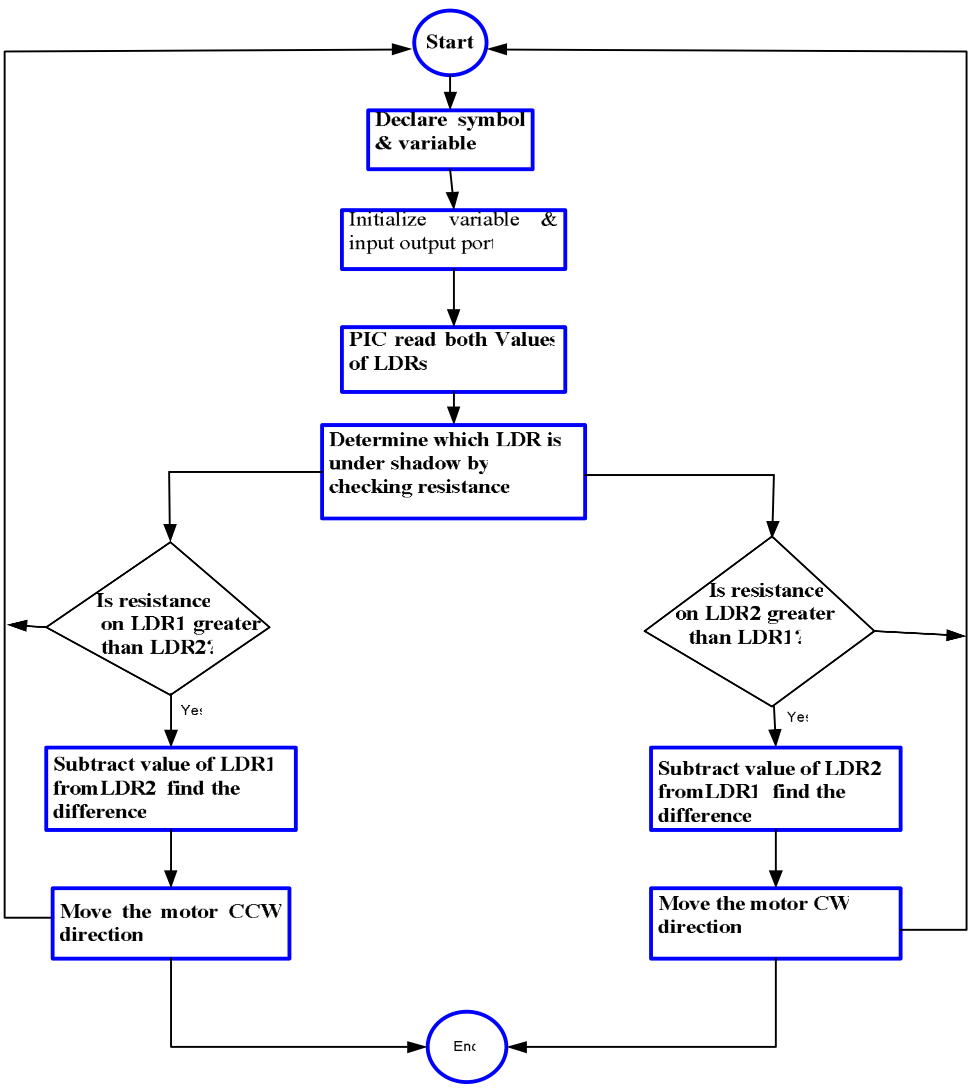

Figure 4-13 Detail Software Design Flow Charts

4.3.2 Software Implementation

4.3.2.1 Proteus 8.0 Professional (ISIS)

Proteus is very famous software in electrical, electronics, computer and telecom engineering students for simulation of electrical, electronics and microcontrollers based circuits. It provides three types of platforms for simulation and designing of electric circuits. Main platform of Proteus is intelligent schematic input system (ISIS). ISIS is used for simulation of electrical, electronics, embedded system and microcontrollers based circuits. Proteus VSM is complete software to learn microcontrollers. Proteus 8.0 is a Virtual System Modeling (VSM) that combines circuit simulation, animated components and microprocessor models to co-simulate the complete microcontroller based designs. This is the perfect tool for engineers to test their microcontroller designs before constructing a physical prototype in real time. This program allows users to interact with the design using onscreen indicators and/or LED and LCD displays and [24].

4.3.2.2 Construction of Printed Circuit Board

The schematic diagram has been plotted component by components on a program called Proteus 8.0 Professional (ISIS), which is used to make layout of circuit. A new project has been created and each of the components were selected from library and carefully placed on to the grid, each pad and holes were selected and added according to the sizes of the various components used. The components were connected and labeled carefully. Figure4-14 shows a detail picture of printed circuit board design of the project and Figure4- 15 shows Front view of 3D Visualizer.

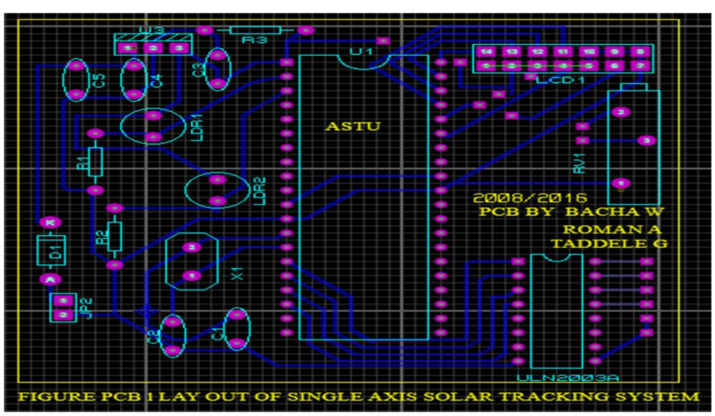

Figure 4-14 Printed circuit board design of the project

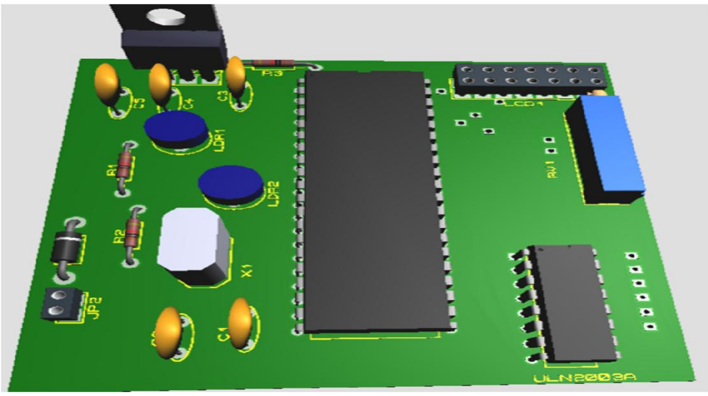

Figure 4-15 Front view (view of the board from the front side) of 3D Visualizer

Material required for prototype

For this project, before the schematic design has been plotted for the program, a prototype was made onto Veroboard and tested, all errors were rectified before final sketch was made, and figure 4.16 shows prototype components/hard ware component of the system. For the construction of the prototype we have used materials and components such as; wood, veroboard with circuit components, stepper motor, solar panel, LCD and dry cell battery 9VDC for power supply unit.

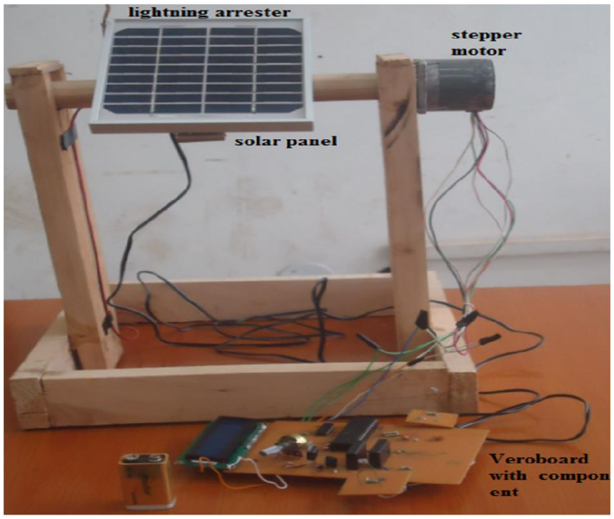

Figure 4-16 Prototype components/Hard ware component of the system

4.3.2.4 The C programming language

The C programming language was initially used for system development work, in particular the programs that make up the operating system. It was adopted as a system development language because it produces code that runs nearly as fast as code written in assembly language.

Some examples of the use of C programming language might be: operating systems, language compilers, assemblers, text editors, print spoolers, network drivers, modern programs, databases, and language interpreters [16], [22].

The C has now become a widely used professional language for various reasons.

- Easy to learn
- Structured language
- It produces efficient programs.
- It can handle low-level activities.
- It can be compiled on a variety of computer platforms.

4.3.2.5 Micro C Compiler

The source code written in source file is the human readable source for our program. It needs to be "compiled", to turn into machine language so that our CPU can actually execute the program as per instructions given. This C programming language compiler will be used to compile our source code into final executable program [15].

The advantage of 'Mikro C' is that it has so many inbuilt functions to perform different tasks along with microcontroller programming software (Boot loader- burning tool or burning software). It is the better Integrated Development Environment (IDE) for PIC family of microcontrollers and allows C language for code development.

In this section we try to describe how the control system is implemented in software and programming microcontroller using micro C PRO. The overall control system has been designed by using Proteus 8.0 professional (ISIS) microcontroller programming. The code for the microcontroller is written in C language. A software package called micro C was used. It provides a full development environment and includes a compiler for the PIC16F877A.

The development of firmware involved many stages of testing and debugging. As section of the code were written, programmed into the microcontroller and tested to ensure they worked properly. A fully commented program listing of micro programming for microcontroller based single axis solar tracking system is found in Appendix 2. When we write in the embedded C-code, first we interfaced LCD with PIC16F877A microcontroller. After interfacing LCD with PIC microcontroller, then we initialized the LCD. After initialization clear display and cursor off, on our LCD screen. Then we want to give some initial instruction for LDRs, so that it displays ‘‘WELCOME’’ on the first row and ‘‘EQUAL’’ on the second row of the LCD screen and also when the light intensity of LDR1 greater than LDR2 our stepper motor rotates in counter clockwise direction and then our LCD displays “CCW” on the second row of the LCD screen. If the light intensity of LDR2 greater than LDR1 the stepper motor rotate in clockwise direction and then the LCD displays “CW” on the second row of our LCD screen .When the value of LDR1 and LDR1 are equal our stepper motor stops its rotation and then our LCD displays “EQUAL” on the second row of our LCD screen. These are the initial instructions for our microcontroller based single axis solar tracking system after this the system ready for next solar tracking. We have used ‘Mikro C’ compiler which provides an environment to develop embedded program, test, debug and build. Hex for the microcontroller.

Finally the compiler converts the embedded C codes into .HEX file. The method of transferring our compiled .HEX (machine code) file to the memory of microcontroller using microcontroller burning software is called burning or programming of a microcontroller. Once a program is burned into the memory of the microcontroller, it then works with respect to the program logic.

Tools we used to burn the program to PIC16F877A Microcontroller:

- PIC programmer (burner) or development board
- Serial port cable
- Microcontroller burning software Boot loader in ‘Mikro C‘

Burn PIC16F877A Microcontroller:

- Our aim is to transfer our .HEX file to the memory of PIC microcontroller.
- The burner and the dedicated software perform the function of transferring .HEX file into the PIC.
- The burner is connected to the PC via a serial port cable.
- ‘Mikro C’ has inbuilt ‘boot loader’ tool to burn our PIC microcontroller.
- We Connected our PIC programmer to the PC and navigate to Tools>>mikro Boot loader in Mikro C, then a Boot loader window will appear.

4.3.2.6. Working principles of software implementation

The complete circuitry of this project mainly can be shown in three parts.

These are:

The Sensor

In this part, we understand that how we are getting the output from the LDR and given to the Port 1(RA0 & RA1) of PIC 16F877A is shown in the figure below. Firstly two LDRs are connected in the manner, one leg of each LDR is tied together and connected to power supply and that of other terminal is connected to 10k ohm resistors to the ground. This connection makes voltage divider circuit to share the voltage supply equally across two LDRs.

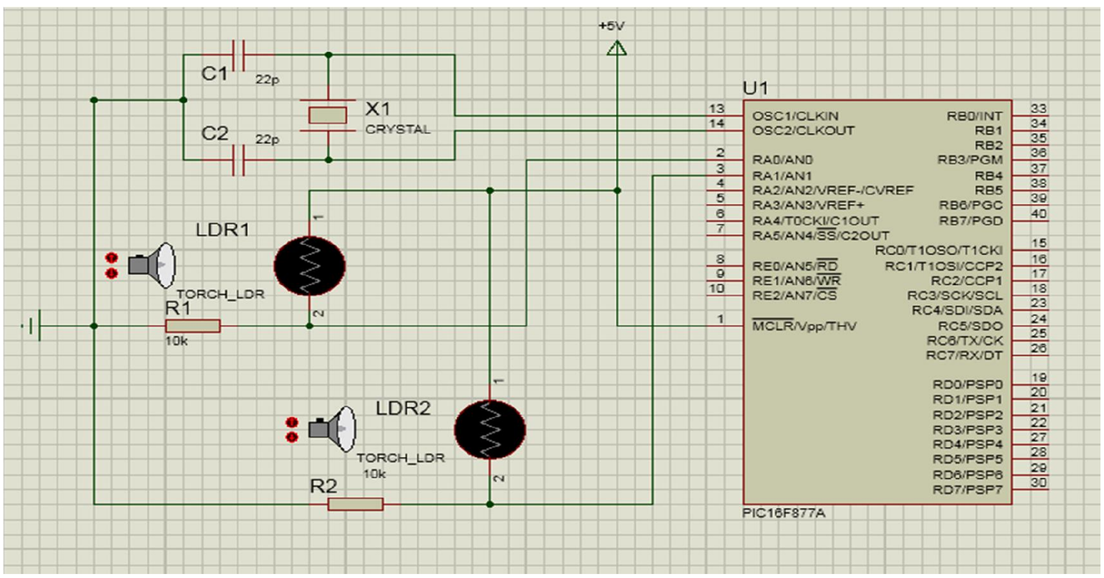

Figure 4-17 Circuit diagram for interfacing LDR sensors with microcontroller

The Microcontroller Part: In the following figure the interfacing circuitry of the Unipolar Stepper Motor with microcontroller PIC16F877A is shown. The PIC16F877A provides a set of standard features such as 4K bytes of flash, 128 bytes of RAM, 32 I/O lines, two 16-bit timer/counters, and five vector two-level interrupt architecture. Here we have used ULN2003 as the motor driver. To initialize the microcontroller, port 1 is getting the input from the output of the voltage regulator in particular LM7805. Using C programming language, comparing the voltage difference between LDR1 and LDR2, microcontroller sends signal to the driver circuit ULN2003 to drive the stepper motor in specified direction. The circuit diagram is shown in figure below.

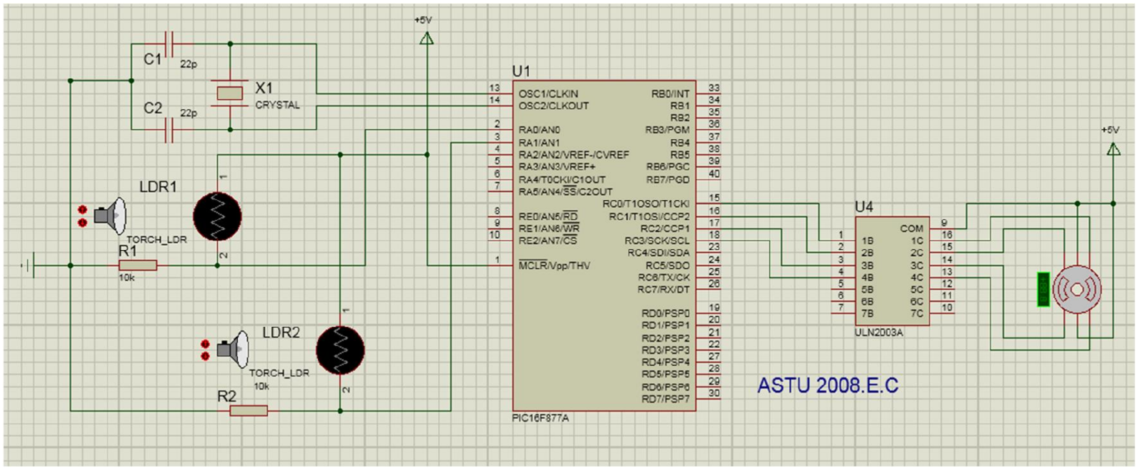

Figure 4- 18 Circuit diagram for interfacing microcontroller with stepper motor

Motor driver ULN2003 with stepper motor

There are three ways to drive unipolar stepper motors (one phase on full step, two phases on full step, or half step), each one has some advantages and disadvantages. In this project half step mode is used. In two phase mode, successive pairs of adjacent coils are energized in turn, motion is not as smooth as in one phase mode, power consumption is more important but it produces greater torque as in one phase mode, applying the steps in order makes the stepper motor run clockwise, and reversing order makes it turn counter-clockwise. The diagram of two phase full step is shown in the following figure [25], [20].

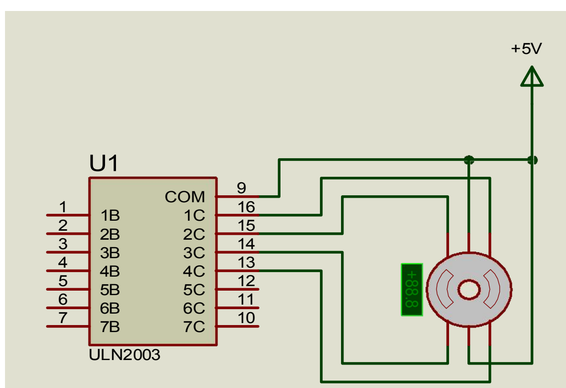

Figure4- 19 Circuit diagram for interfacing Motor driver with stepper motor

MATLAB modeling of driver with stepper motor

MATLAB is a power full high performance tool to validate our ideas by creating field like conditions using computer to model different ideas of our visualization by easily understanding block diagram connection [19]. In our case we use this software to model the modelling of the motor driver with stepper motor shown in the following figure 4-20.

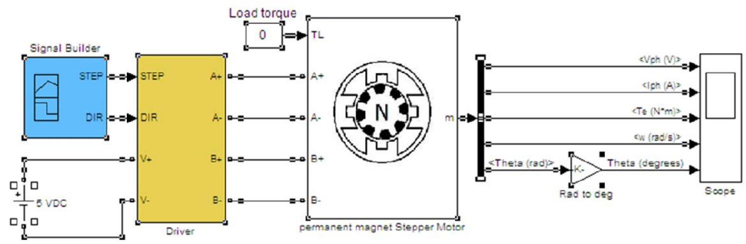

Figure 4-20 Model of driver with stepper motor

4.3.2.7. Overall description design of the project

The tracking capability of the project had been designed .Here we have supplied 9VDC dry cell battery to the voltage regulator circuit and then we obtained regulated 5VDC to initialize the microcontroller, LCD, LDR, motor driver (ULN2003) and stepper motor. After all devices in our circuits have been initialized, two LDR sensors which are based on the light intensity of the sun are used for the stepper motor to be rotated in both clockwise and counter clockwise directions automatically.

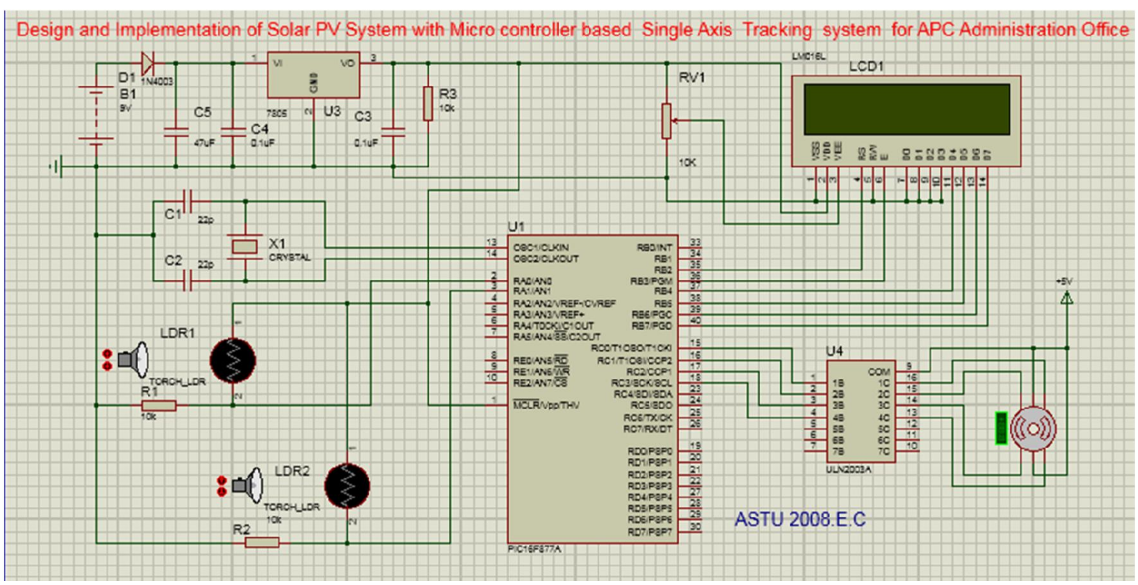

Figure 4- 21 Complete Circuit Diagram of the system

When light on both LDRs is same, their resistance is nearly the same. Hence the voltage between common point and the ground is nearly half of the threshold voltage. When light on the ground side of LDR is more, its resistance decreases. Thus, common point voltage falls below threshold voltage. Similarly, when light on power side LDR is more, the common point voltage crosses the threshold value increases. In morning when sun rises in the east LDR1and LDR2 getting maximum intensity of light the motor rotates in a specified angle. Then sometimes LDR1 greater than LDR2 the stepper motor rotates counter clockwise direction and when LDR2 greater than LDR1 stepper motor rotate in a specified angle to clockwise direction. After sun set in the west stepper motor returns back means solar panel will be at initial or center position.

4.4. Hardware Subsystem Implementations

As it is composed from different functioning blocks of input system, controller, output system and power supply subsystem, top-down approach is used. Each sub system is implemented and developed and then its functionality was checked independently. The overall project functionality is the sum total functioning of each sub system shown in the following figure 4-22.

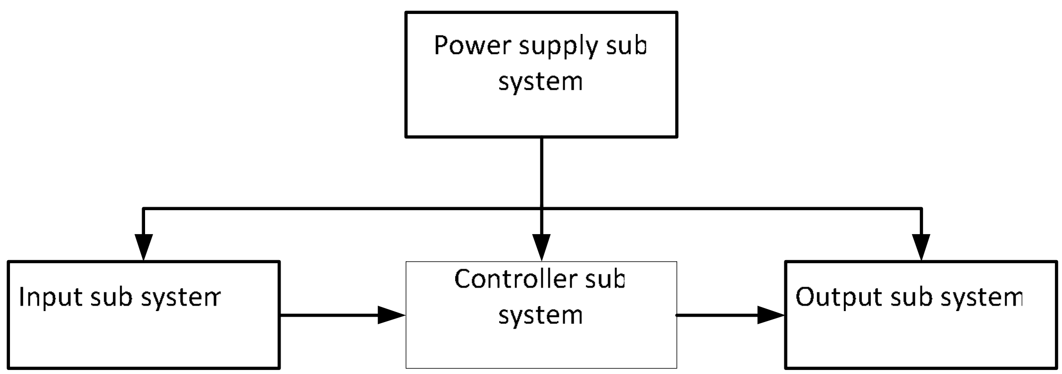

Figure 4- 22 Hardware sub system block diagram

It was checked using software Proteus 8.0 Professional (ISIS), before we go to implement the project hardware. ISIS tool of Proteus 8.0 Professional software is used to check its implementation before we go to implement practically. The software library is enriched with electrical and electronics components and ranges to different microcontroller families. Hence it enables us to check circuit performance and outputs. Each subsystem and the entire project are tested by simulation using this wonderful Proteus 8.0 Professional software. In order to reduce construction errors, the final circuitry was done using another CAD software tool Proteus ARES, which guided in the production of all the tracks (signal lines) linking one pin to the other. The CAD tool makes it possible to easily layout the various components on board. Hence the components layout was properly positioned; each component before they are linked to one another by the traces.

Once the schematic of the project has developed, the next procedure was developing PCB layout using ARES tool of Proteus. Of course our project is constructed on PCB, but we used ARES to assist the assembly of the circuit. Before we assemble the circuit we tested each component for their functionality. The final circuit was implemented after we tested using bread-board. The bread-board allowed us to assemble the circuit and test it with no need of soldering it. We can change and move each component freely so that no device is being broken.

As the project constructed on bread-board was successful, we transferred to the real read-made circuit board. It was accomplished by soldering using lead permanently. As the PIC is highly sensitive for heat, we used and soldered IC socket (holder) instead of it, so that the controller can be plugged in the socket (holder). The other main advantage of using this socket is to take out the controller for repeated use i.e. to erase and reload the program.

The input subsystem is implemented based on the power from the 9VDC dry cell power supply or 12VDC rechargeable battery. We use a switch to allow source at a time to microcontroller, LDR, LCD, motor driver (ULN2003) and stepper motor as source of electric power.

4.4.1. Simulation Result

After we successfully completed the circuit of microcontroller based single axis solar tracking system using PROTEUS 8.0 Professional (ISIS), firstly we have done simulation of power supply to get regulated 5VDC to initialize the circuit components such as LDR, Motor driver circuit, stepper motor, Microcontroller, and LCD.

Another very important step in simulation of the project is writing a program using Micro C PRO programming language for LDRs, stepper motor, and LCD and then run (build) it to check whether the program is correct or not. If the operation is correct, we have to load to PIC 16F877A by clicking build+program on the Miccro C PRO. By integrating programming codes with all necessary components in the project namely LDRs, microcontroller, motor driver (ULN2003) and stepper motor, and by using Proteus 8.0 professional (ISIS) software, we have simulated the working /functionality of the project.

Finally, we have observed the outputs such as, firstly when the intensity of the light on LDR1 and LDR2 is equal the stepper motor stops rotation and our LCD shows 'WELCOME EQUAL' as shown in the Appendix 3 Figure 4-27. Secondly, if the intensity of the light on LDR1 is greater than LDR2, the stepper motor rotates to the west (Counter Clock wise) direction and LCD display shows 'CCW' as shown in the appendix 3 Figure 4-28. In the last step if the intensity of the light on LDR2 is greater than LDR1, the stepper motor rotate to the East (clockwise) direction and our LCD shows '**CW** 'as shown in the appendix 3 Figure 4-29.This provides the working of stepper motor mechanism before prototype implementation takes place.

4.4.2. Hardware Testing

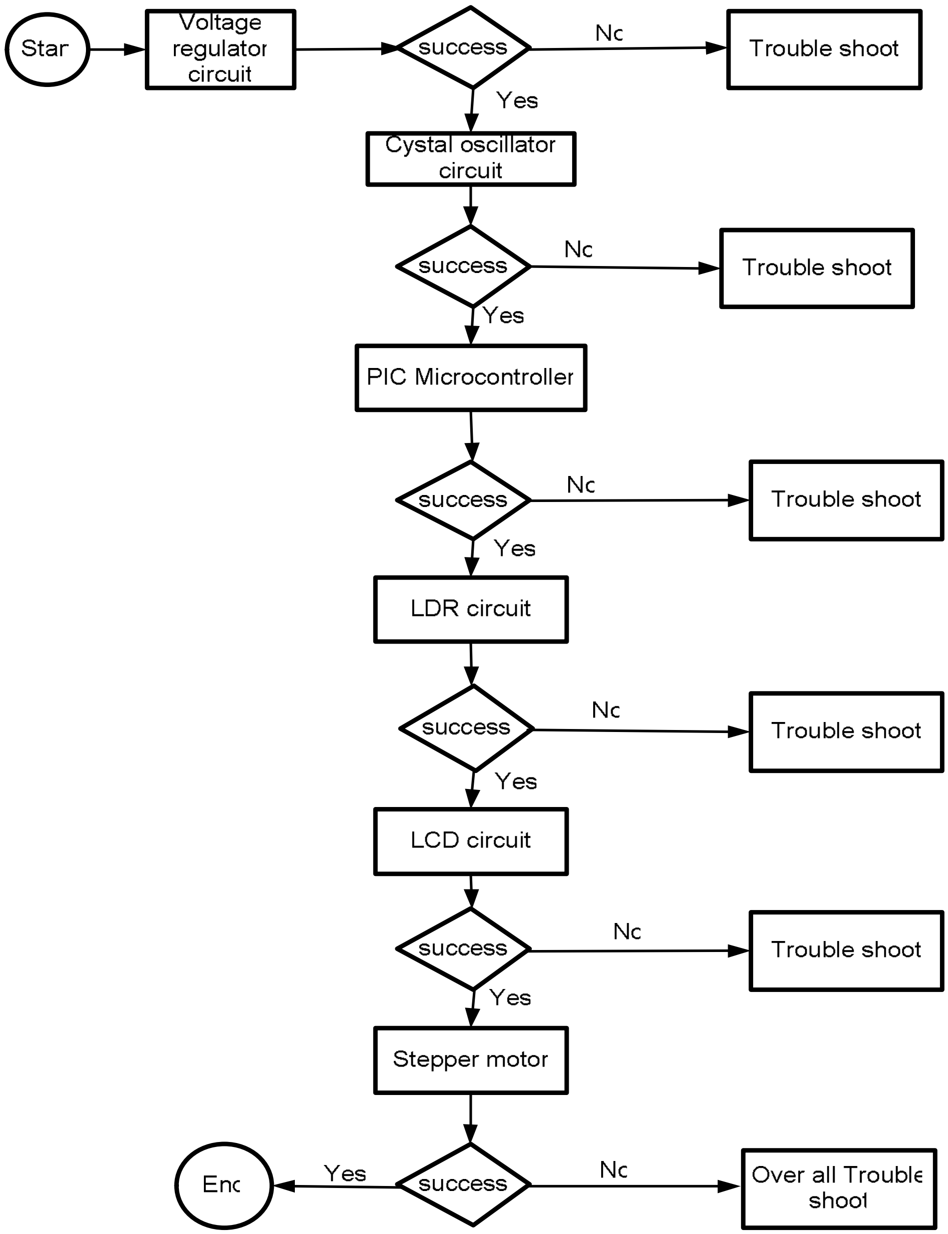

Figure 4-23 Hardware testing of the system

Flow chart description of hard ware testing

Firstly, the voltage regulator circuit needs to construct to supply a voltage to the circuit that we want to build. The overall circuit cannot be operating if no power applies to them. If the voltage regulator circuit is success, we will proceed to another circuit construction.

Next, we will construct the crystal circuit. The crystal circuit is also one of the most important circuits in board construction. If not, the PIC microcontroller cannot be operating. The PIC microcontroller will be useless without crystal. The crystal will set the frequency of the PIC microcontroller. If the crystal circuit is success, we will proceed to another circuit construction.

Then, the PIC16F877A will be combined with voltage regulator circuit and crystal circuit. The other circuit that is reset button circuit will be added so that the PIC microcontroller can be reset if the error occurred. If the combination of this circuit successful, the basic circuit for PIC16F877A microcontroller is complete. If not, we need to troubleshoot one by one of the circuit.

Subsequently, the LCD will be used to show the direction of the solar panel. The LCD need to be constructing carefully because if the input voltage is below 5 volt, the LCD will not operate. If the LCD circuit is success, we will proceed to the next circuit construction.

After that, the Light Dependant Resistor (LDR) will be use as a sensor to detect the intensity of light. The Light Dependant Resistor (LDR) will send the data to the PIC microcontroller.

Next, when the Light Dependant Resistor (LDR) circuit is complete and can be used, we have constructed the stepper motor circuit. The stepper motor will use IC ULN2003 to drive a current to stepper motor. The high current is needed to drive the stepper motor.

Lastly, we will troubleshoot all the part of circuit to make sure no problem will occur in the future.

4.5. Photo Voltaic System Design

Photovoltaic and solar tracking system, photovoltaic system component and baseline feature of Adama Polytechnic College Administration Offices such as the solar insolation/ irradiance, the power demand helps us for the next micro controller based single axis solar tracking system design. Dean office, Vice dean office, Technology capability accumulation and transfer, Human resource management, Finance and logistics, Planning, budgeting and information process, Data recording offices of Adama polytechnic college are selected for design purpose [10], [11].

Microsoft office excel is used to calculate the following parameter:-

i. **Total daily energy requirement: -** daily system charge requirement, sizing and choosing the module, desired charging current, to find number of required module, explore the load size.

ii. **Battery sizing and selection**:-to calculate required capacity of battery and to determine the battery configuration.

iii. **Charge controller/inverter sizing and selection: -** to select controller size, desired charge controller feature, inverter and charge rating.

iv. **Wiring, voltage drop and fuses**.

Fully PV system designed algorisms is found in Appendix4 Figure4- 30.

4.5.1. System Design Considerations

The following factors are important parameters in designing of microcontroller based single axis solar tracking system.

- Solar insolation/irradiance
- Tilt angle and orientation of the module(tilt angle azimuth)
- Shading
- Derate factors
- Distance from the source
- System voltage
- System availability
- Cell/module temperature

Solar insolation (irradiance)

Solar insolation (irradiance) is an amount of electromagnetic energy (solar radiation) incident on the surface of the earth at a peak of 1KW/m^{2}interms of PV module performance the current output is directly proportional to the intensity of solar irradiance [13].

Tilt angle and orientation of the module

The orientation of the module with respect to the direction of the sun determines the intensity of the sun light falling on the module surface. The sun's path sweeps a daily arc that change seasonally throughout the year and follows a prescribed solar position described by an altitude angle (vertical) and azimuth angle (horizontal).The maximum energy output depends up on a combination of orientation and tilting angle to the horizontal. The optimal photovoltaic tilt angle can be given by [10], [16].

$$\beta = \emptyset - \delta$$

Where β = tilt angle

∅ = latitude and

δ= declination angle

Tilt angle and azimuth angle are the two main parameters to determine the orientation of the module:-

a. **Tilt angle: -** is the angle between the plane of the module and the horizontal. For a fixed PV module, the tilt angle is the angle from the horizontal of the inclination of the PV module (0^o=horizontal, 90^o= vertical)

b. **Azimuth: -** is the angle clockwise from true north of the direction that the PV module faces. The default value is an azimuth angle of 180o (south facing for the locations in the northern hemisphere, and 0o (north facing).

Shade

The way solar is designed even a little shade on one panel can shut down solar production on all the other panels. Solar cells are connected in series, and will operate at the current level of the weakest cell; if one solar cell is shaded it will adversely influence the output of all other cells [10].

Derate Factor

When designing PV system the intended net energy output must be calculated by taking into consideration the losses associated with the totally integrated system .The losses known as derate factors will have a profound effect on the performance of the PV system [11].

Distance from the Source

Electricity generation system can be classified as central generation and distributed generation systems. In micro controller based single axis solar tracking system design, the electricity generation is distributed generation. Distributed system is the one which many smaller power generating systems created electrical power near the point of consumption. The panel cabling ensures that the electricity generated by the PV panel is transferred efficiently to the load and it is important to make sure that it is specified correctly for the voltage and current level which may be experienced. Since many systems operate at low voltages, the cabling on the DC side of the system should be as possible to minimize the voltage drop in wiring [10], [11].

System Availability

System availability is defined as the percentage of time that a photovoltaic system is capable of meeting load requirements over a specified period. System availability depends primarily on the size of the battery system. Generally, failure and maintenance time are the primary contributors which lower system availability for most energy system but availability takes on added uncertainty in the case of photovoltaic system because of the variability of the system sunlight [10].

System Voltage

It is common that PV modules have many different voltage figures associated with them. System voltage is essential for sizing of photovoltaic panel/module and battery size. In PV system design, the following are the main important properties [11], [20].

- Voltage at open circuit (Voc):- the voltage when the module is not connected to any load.
- Voltage at maximum power (Vmp):- the voltage that occurs when the module is to a load and is operating at its peak performance output under standard test condition (STC).

Temperature

High temperature can severely reduce the solar panel's production of power. Depending on the location, heat can reduce the output by 10% to 25% [11]. Install solar panels on a mounting system a few inches off the roof; this will help cool them by allowing air circulation. Use photovoltaic panels that are designed to be more efficient in hotter climates. Ensure that panels are constructed with light-colored materials, to reduce heat absorption.

4.5.2 Design procedures in sizing photovoltaic system

1. Collect meteorological data(site detail)
2. Determine the power consumption demand or power and energy determination
3. Power system demand optimization
4. Determination of system configuration
5. Load correction due to losses

6. Sizing and specifying battery
7. Sizing and specifying the array (optimized due to ambient temperature)
8. Sizing and specifying inverter
9. Sizing and Specifying controller
10. Sizing and specifying wiring and other balance of system requirements.

Specifically, there are two approaches to be followed for sizing optimization of PV system for APC Administration offices namely:

- Watt -Hours Method
- Ampere-Hour Method

Both methods can be used for any PV system.

System Design for the Selected Loads

Design specification

It is desired to provide electrical power for electrical appliance in Adama Polytechnic College Administration offices. The PV array will be placed 20m from Dean office, Vice dean office , Human resource , Finance and logistics management, Planning, budgeting and information process, 15m from Technology capability accumulation and transfer, Data recording offices. Pole mounting system at stationary tracking is specified [10], [26].

Power Consumption Demand Determination

Complete load estimation worksheet by putting power in watt, load type and usage information, the selected load demand for design purpose is given in Appendix1 table 4-12. Adama polytechnic college administration office is a particular site for data collection.

4.6.2.1. Total Daily System Energy Requirement and System Voltage

Step 1:- Calculate the daily load energy demand in Watt-hours:

From the table in appendix 1 table 4-12, it is possible to determine the total daily load energy demand in Watt-hours by using the formula.

Total running watt =SUM (F4:F10) = 13732 W and

Total Daily AC Energy Demand ==SUM (H4:H10) =58496Wh

Step 2:- Estimate System Energy Losses

Not all energy produced by modules is available for the system, as some is lost in the cables, batteries, charge regulators and inverter. With the watt-hour method of planning systems, there are concerns about two type of efficiency**.**

i. **General system efficiency:** the efficiency of cable, the battery and the charge controller, this can be taken to be 80% (20% of the energy is lost).

ii. **Inverter efficiency:-**a good inverter, one designed for use in off-grid PV system 85% efficient under average load. Because of the extra losses in the inverter, AC energy in a system will suffer higher losses than DC energy 80 of general efficiency multiplied by 85% inverter efficiency equal about 65% overall efficiency. This means that about 35% of the electricity fed by the PV array into the battery that is converted into AC electricity by the inverter will be lost (the sum of battery and inverter efficiency) [10], [23].

Energy is always lost due to insufficient in cables, modules, batteries, charge controllers and inverters. The extra amount of energy lost must be estimated and added to the daily demand. Therefore, **for DC energy losses** multiply total daily DC energy demand by 20% and For AC energy losses; multiply Total daily alternating current energy demand by 35%.

From the table in appendix 1 table 4-12, it is possible to determine AC energy losses by using the formula.

Alternating current loss= F14*H11= 58496*0.35 = 20473.6Watt

Step3:-calculate the total daily system energy requirement

From the table in appendix 1 table 4-12, it is possible to determine the total daily system energy requirement by using the formula.

Total daily system energy requirement =SUM (H13:H14) = 78969.6Wh

Step 4:- select system voltage

System voltage is the nominal voltage at which the batteries, charge regulators, and solar array operate. **Decide on the system voltage value** Vs, for power transfer (i.e., 24V, 48V, 12V). Voltage drop, load demand, availability of inverter and battery cost are parameters to select Vs, Most small off-grid PV systems (especially solar home system below 100Wp) use 12V DC as their system voltage. . This means batteries are configured at 12VDC and the charge regulators and modules are rated at 12V DC. Lights are normally 12VDC in such small systems. Sometimes 24 and 48V DC system voltage is used. In such case, batteries and solar modules are wired in series or series-parallel so that they are 24 or48V, and 24 or 48 charge regulators and inverter must be selected. Such system have less voltage drop in wire runs, so they are often selected to save cable costs (48V DC systems are common in off-grid telecom systems).however, note that 24 or 48VDC appliances are not readily available, so 12VDC system voltage is usually preferred. Many charge regulators and inverters can operate at either 12 or 24V DC. They sense the system voltage and adjust to it automatically. The system voltage of an inverter is between 12V and 48V. For this project we select system voltage with the value 12V DC [11], [18].

Step 5:-Calculate Daily system charge requirement

From the table in appendix 1 table 4-12, it is possible to Calculate Daily system charge requirement by using the formula.

Daily system charge requirement =H15/C17= 6580.8Ah

4.6.2.2. Sizing and Choosing the Modules

PV Array Sizing

The sizing of the PV array is determined by considering the available solar irradiation i.e. mean daily insolation in peak sun hours per day or kilowatt-hour per square meter per day (kwh/m^2/day), in design month record from a nearly metrological station, the tilt and orientation of the array and we need manufacturer data (the I-V curve) of the solar modules being considered. The array is sized to meet the average daily load requirement for the month season of the year with the lowest ratio daily irradiation to the daily load [10].

Meteorological Data

For the design of PV system methodological data like solar irradiation of the site, latitude and longitude (sun angle), temperature are important for the determination of output power from array/PV module. Array output basically depends on the above data. The details information of APC administrative office (designed site) is given below.

Latitude: 8^{o}33'23.8" North

Longitude: 39^{o}17'02.5" East

Altitude: 1648 meters

Elevation: 1770m

Tilt angle determination

Knowing the irradiation available at tilt and the power output required, the array can be sized using module specifications supplied by manufacturers. Adama, were the polytechnic college located, is found at the latitude of 8°33'23.8" North from horizontal. Therefore, the array is sized to meet the average daily demand for electricity at the average irradiance of Adama. The array will face at angle of 15+08 degree north from horizontal in order to maximize irradiance received. During winter season the array may degree at angle 15-08°32'N and during spring/fall the array will be faced to the same angle of the latitude.

Step1:-Obtain Site's Insolation Value

Table 4-5 Insolation data for solar resources

Month	Daily irradiation(KWh/m^2)	Temperature(℃)
March	5.23	30.6
April	5.05	31.7
May	4.62	31.4
June	4.63	29.8
July	4.27	28.3
August	4.79	26.7
September	4.7	27.3
October	5.3	26.9
November	5.35	27.5
December	5.19	26.2
January	5.2	28.1
February	5.22	29.5

Source: National Meteorology Agency Adama Branch Directorate

Step2:- Select Design Solar Insolation Value

We select for this project the least of the month (August) mean daily insolation value of 4.27 KWh/m^2 from the table 4-5.

Note: - The sun hours are not the same as insolation or peak sun hours, they indicate how many hours the shine at the site, but they do not give the intensity of the sun and then do not use them neither should the average nor annual [11], [24].

Step 3:- Calculate the Design Charging Current

The module in the system must be chosen so that their energy output matches to the total daily system energy requirement. For our solar electric system to succeed over the long term, the daily energy output of the modules must be to meet our energy requirement.

From the table in appendix 1 table 4-16, it is possible to calculate system design charging current by using the formula.

System Design Charging Current ='Daily System Energy Requirement'! H18/'sizing and choosing the module'! B18 = 1541.171A

Step 4:-Determine the size of the module or number of modules required to produce the system design charging current

Decide on PV panel to be installed: there are many manufacturers around the world such as PB power, EPV solar, Kyocera, DM solar, Ever green, sharp, Mitsubish power, CD technology, Copexsolar technology etc. We find out modules available in the market i.e. 300w PV module of Copexsolar technology is selected for this project shown in the table 4.6 and I-V curve and temperature data shown in the figure4.25 and Figure 4.24 below.

Table 4- 6 Specification of 300W PV Module

Company	Copexsolar technology
Nominal maximum power	300W
Optimum operating voltage	36.8V
Optimum operating current	8.15A
Open circuit voltage	44.8V
Short circuit current	8.97A
Operating temperature	$-40°C\ to + 85°C$
Maximum system voltage	1000V(IEC)
Maximum series fusing rating	10A

Characteristic curve of selected module

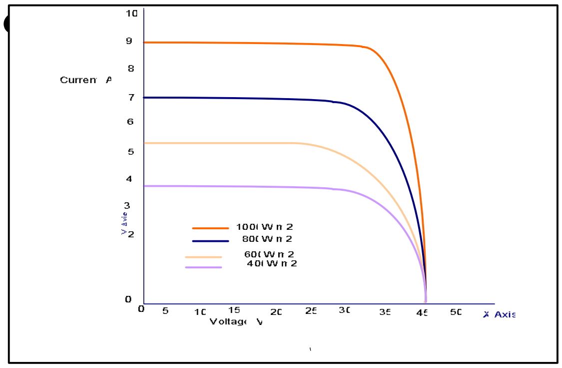

Figure 4- 25 I-V curve of the 300W solar panel [11]

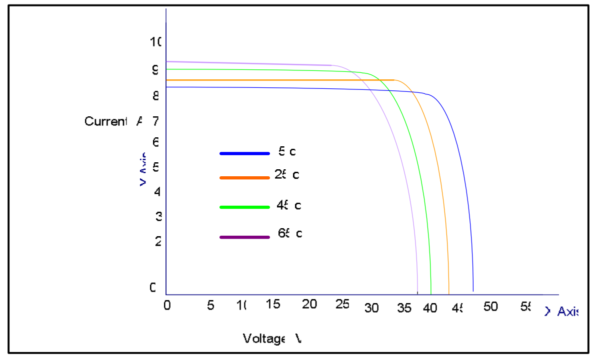

Figure 4- 24 Manufacturer data (temperature data) [11]

To select enough modules to produce the system design charging current at the operating voltage and condition at selected site, divide the system designed charging by the normal operating current output of the modules you have available. From the table in appendix 1 table 4-14, it is possible to select enough modules by using the formula.

Number of modules =C19/B22= 189 modules.

Determine PV Configuration

The PV configuration to be designed according to the description made may have the following lay out.

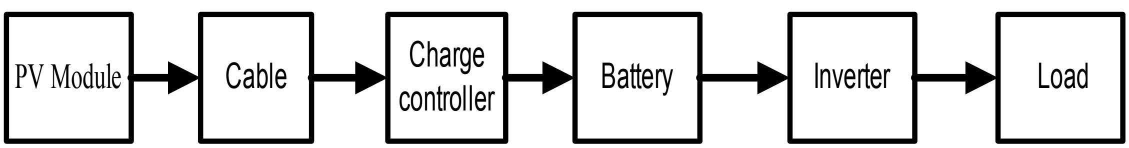

Figure 4- 26 Configurations of the PV module array

4.6.2.3. Battery Size and Selection

Choosing the Battery

The battery must be selected and sized carefully; choice of battery will be limited by what is on the market and how much you have to spend.

Step1:-Identify the available batteries in the region that fit with our budget

Once, we have information about the type of battery i.e. shown in the table 4.14 in appendix 1, we select valve regulated deep cyclic battery (AGM cell battery) because it is currently available in the market and also have long life cycle.

Step2: - Calculate the Required Capacity of Battery in Amp-Hours

The capacity of the battery required depends on three primary factors.

1. The daily system charge requirement in Amp-Hours: The system charge requirement that must be supplied to the load each day is about 6,580.8 Ah.

2. The maximum allowable depth of discharge factor: This is the deepest depth of discharge that is ordinarily allowed with the battery. Shallow cycle batteries for example should not be cycled below 20% depth of discharge, while deep discharge batteries can regularly handled 80% discharges [26]. For this project we select deep cyclic valve regulated lead acid batteries because it can regularly handle 80% discharges [15], [18].

3. The Number of Days of Storage Required: This varies with site and is higher for sites with cloudy weather. In sunny areas, depending on the application, this number may be as low as one or two days only. Do not use days of autonomy greater than four days because it will greatly increase the cost of the battery bank and it will increase the risk that, during cloudy weather or winter periods, batteries will not be fully charged and will be damaged by cycling in a low state of charge [15].

Note: Do not use a number over 0.8 as deep discharge because over 80% will damage even a good battery. The required system capacity is equal to daily system charge requirement times day of autonomy divided by DoD [15]. From the table in appendix 1 table 4-14 it is possible to calculate the required capacity of battery in Amp-Hours by using the formula.

For 2 day of autonomy:

The required system capacity =A9*B9/C9=16452Ah

Days of autonomy is reasonably reduced to 1 day since the system is supported by the grid and the sun shines 365 days in a year at Adama city. Making this will reduce the system cost by reducing battery cost. The Ah capacity of 1 day is = A8*B8/C8= 8226Ah.

Step 3:- Determine the Battery Configuration

Battery should be configured at the system voltage:

- Small off-grid PV system usually uses 12VDC as their system voltage and 12VDC batteries. If more than one 12DC battery is used they are configured in parallel [21].
- If 2VDC or 6VDC battery is used, they are configured in series so that their total equals the system voltage (i.e. at a system voltage of 12V DC, two 6VDC battery would be configured in parallel [15].

Number of Battery in Parallel (Np): number of batteries, needed to provide power for the load during cloudy day or night time is dividing the required battery capacity by the Ah capacity of the selected battery.

For 2 day of autonomy:

Np =A12/B12=$\frac{16452\text{Ah}}{200\text{Ah}}$ =82.26≈83 connected in parallel

For 1 day of autonomy

Np=A11/B11=$\frac{8\ 226\text{Ah}}{200A\text{h}}$= 41.13 ≈42 connected in parallel

Battery Voltage

The battery voltage from specification sheet is 12V.

We purchase 41or 42 batteries and connecting in parallel from the table in appendix 1 table 4-14 .we select valve regulated deep cyclic battery (AGM cell battery) because **it** is currently available in the market and also have long life cycle. Sealed AGM and gel cell battery are required a special setting on the charge controller. Since we select valve regulated lead acid batteries (AGM cell battery) it needs special charge controller setting, maintenance free, have longer life-spans and its day of autonomy is 1 day [15], [12].

4.6.2.4. Choosing the Charge Controller/Inverter Sizing and Selection

A. Charge Controller Sizing and Selection

All off-grid solar PV system need some type of charge controller and there are various type that offer a range of function before choosing a charge controller :-

- Decide what controller size (rating in amp) is needed;

- Decide what controller features are required controller need to be sized to the voltage if the system is 12V, you need 12V controller and if the system is 24V, you need a 24V controller [18], [17].

Step1:- Select Charge Controller Size

The controller must size to handle both the maximum short circuit current from the array and the maximum demand of the load. Charge controller sizes range from 5 to 50 amp or larger. Note: the charge controllers have the same charge and load output rating. For this project we select 12V charge controller [18].

To determine array input rating multiply maximum Array Short circuit current by 1.25

Array input rating (Amps) =A4*B4=8.97*1.25= 11.2125A≅12A

To determine charge controller size multiply number of module by array input rating charge

From the table in appendix 1 table 4-15, it is possible to calculate the charge controller in Amps by using the formula.

Charge controller size =A8*B8= 189* 12= 2268A. The maximum size for the regulator would be 2268A.

Table 4-7 Charge Controller Specification

Controller specification	Rating
Nominal system voltage	12V/24V auto work
Rated battery current	20A
Maximum battery voltage	32V
Self-consumption	18mA
Communication	TTL 232/8pin Rj45
Equalize charging voltage	Sealed : 14.6V,x2/24V flooded
Floating charging voltage	13.8v,x2/24v
Low disconnect voltage	11.1v,x2/24v
Working temperature	$-20°C\ to\ 55°C$
LCD temperature	$-20°C\ to\ 70°C$

Selecting desired charge controller feature

Depending on the size of the system, the appliance used and the solar insolation at the site a controller will be required to perform different functions.

Important features to be considered include: overcharge protection low voltage disconnect, solar charge and low voltage warning lamp, voltage and current meter, and load timers.

Feature: low voltage disconnect (LVD) and high voltage disconnect (HVD) are important feature of charge controllers. Make sure you know the rated value of the unit you want.

Display: simple charge controller use one or more diode to inform uses about solar charge and state of charge most elaborate charge controller have crystal liquid displays of amp-hour meter.

Charging type: be sure that the charging method your controller uses matches the needs of your modules and batteries.

B. Inverter sizing and selection

Some off-grid solar PV system requires inverter. There are various types that offer a range of functions. Because of the wide range of inverter type and price, it is a good idea to carefully consider what you need and what you can afford. Remember most inverters are not meant for solar PV system and end up causing problem because of poor efficiency and wave-shapes [20].

Step 1: Is an inverter needed?

Many small off-grid PV systems operate 100% on 12VDC electricity and do not require inverter. If the system is below 100Wp and you can procure your entire appliance in 12V. A 12V DC system without an inverter may be the best choice [18]. For this project we have to have an inverter because total daily AC energy demand of our system is greater than 100Wp.

Step2:- Inverter Rating

To determine inverter rating multiply maximum AC load watts by 1.25

From the table in appendix 1 table 4-16, it is possible to calculate the inverter rating in watts by using the formula.

Inverter rating =A56*B56 =13732*1.25=17,165watt=17.165KW

Step 3:-Select desired inverter features

Table 4- 8 Features to desire inverter specification

Specification	Rating	
	PI	PIC
Nominal input voltage DC	12V,130A	12V,137A
Output power or continuous	1500W,6.5A	1500W,6.5A
Nominal input voltage AC	220 to 240V~	220 to 240V~
Output power(Peak watt)	3000W	3000W
Frequency	50Hz/60Hz	50Hz/60Hz
Efficiency	85 -90%	85 -90%
Overload	shut down and alarm	shut down and alarm
Low battery voltage alarm	10.5+ /-0.5v	10.5+ /-0.5v
Low battery voltage shut down	10+ /-0.5v	10+ /-0.5v
Dimension(L*W*H) cm	32*19.8*(cm)	415*242*6 (cm)
Weight	4.3KG	4.5KG

For this project, we select the PI inverter type because it has less cost than PIC inverter type.

4.6.2.5. Choosing Cables and Fixtures

In sizing and specifying wiring size and other balanced of system requirements:

- Wiring should be adequate to ensure that losses are less than 2% of the energy produced
- Fuses/breakers, fuse holders, switches, and other components should be selected to satisfy both current and voltage requirements.
- All batteries and panels in series branch should contain fuse
- Fused disconnects are strongly recommended to isolate the battery from the rest of the system.

Sizing wire for PV system

In order to make the design system safe and sound, the accurate selection of system wiring cables are very important. The wiring must not reduce the performance of any of the component of the system. When sizing the cable, the restriction for the losses should be 3% [26]. In standalone PV system the module yield is reduced twice by 3. One is in the way from the PV panel to the battery panel to the battery via charge controller and second is in the way from the battery to load via charge controller. This is the goal for loss reduction in low voltage system application.

The cable must be sized correctly to reduce the voltage drops in the cable and to make sure that the safe cable is not exceeded and the voltage drop in a cable is given by[11], [26],[27].

$$Vdc = \frac{\rho l * I * 2}{Ac}$$

Where $\rho$is the resistivity of copper wire which is normally taken to be 0.0183Ωmm^2/m

l= length of the cables in meters

I=the current through the cables in amperes

Ac= cross-sectional area in mm^2

The multiplication number 2 is account for total circuit wire length moreover; the cable cross-section can be determined using equation (1) based on the given parameters in table 4-9 Below, the cross section of cables between PV component can be resolved by[26].

$$Ac = \frac{L * P}{0.03 * V2 * K}$$

For the design the cable loss is assumed to be 3% previously to allow the cables to be able to handle additional power when it is required to add, should be considered.

Table 4-9 Electrical parameter and their units

Electrical Parameter	Symbol	Unit
Line length	L	M
Power transmitted in the line	P	W
Line cross-section	A	mm^2
Electrical conductivity	K	m/Ω*mm^2
Percentage line loss (3%)	---	------
System voltage	V	V

List of material and Cost estimation for PV system design

Table 4-10 List of material need for PV design

A	B	C	D
List of materials needed			
Components	**Size**	**Description**	**Amount or numbe**
Solar module	300W	Mono crystalline	189.1007313
Battery	8226	Copex sealed battery	41.13
charge controller	2120.29195	pulse width modulation	106.0145975
inverter	17165	Sine wave	12
AC circuit cable	2.5mm2	twin flat	10 rolls
conduits	standard	for exposed cables	100 pcs
switches	10A	AC rated switches	25
sockets	220VAC,10A	normal	20
Fuses	50A	main battery fuse AC rated	10
Junction box	standard		100
Connector strips	standard		20 boxes
Earthing		earth rod	189.1007313
Bolts, screws,nuts,ect.		various boxes	

Table 4-11 Cost estimation PV design for APC Administration offices

No	Component	Quantity	Cost(Unit price)	Total cost(Birr)
1.	Solar module	190	1200	228000
2.	Battery	42	8000	252000
3.	Charge controller	107	600	64200
4.	Inverter	12	3000	36000
5.	AC circuit cable	8 roll	800	6400
6.	PVC Pipe	100	10	1000
7.	Switch	25	15	375
8.	Socket	20	15	300
9.	Fuse	2	100	200
10.	Circuit breaker	10	250	2500
11.	Changeover switch	1	600	600
12.	Distribution box	1	1000	1000

13.	Junction box	100	5	500
14.	Connecting strip	20pac	70	1400
15.	Earth road	93	50	4650
16.	Bolt, screw, nut	20	20	400
	Subtotal			599525
	Contingency	10%		59952.5
	Grand total			**659477.5 Birr**

After we have drawn the floor plan /site of the administration offices shown in appendix 1 figure 4-27, we have determined the overall costs required to install the PV system. As the following table 4-11 indicates that the overall cost of this project is estimated at **659477.5** Ethiopian Birr.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The thesis "Solar PV System with Microcontroller based Single Axis Tracking System for Adama Polytechnic College Administrative Offices" is mainly intended to design and implement a solar tracking system that follows the sun direction for producing maximum output for electrical powered applications. This project consists of sensors and a motorized mechanism for rotating the panel in the direction of sun. Microcontroller based control system takes care of sensing sunlight and controlling the motorized mechanism. This system works continuously without any interruption. The main controlling device of the project is microcontroller to which LDR's and stepper motor with panel setup to its shaft are interfaced. The microcontroller gets input from LDR sensors regarding the direction of sun and controller process this information and controls the movement of solar panel attached to stepper motor with driver ULN2003. We used Proteus 8.0 Professional (ISIS) and ARES to design overall circuit diagram and to prepare PCB of the project respectively. The microcontroller is programmed using powerful embedded C language. The project also displays the direction of rotation of stepper motor on LCD display unit.

The factors that affect the design and sizing of every piece of equipment used in the system have also been considered. These factors are: solar insolation/irradiance, tilt angle and orientation of the module (tilt angle azimuth), shading, derate factors, distance from the source, system voltage, system availability and cell/module temperature. Over and under-sizing have also been avoided to ensure adequate, reliable, and economic system design. Cost estimation for the whole system has also been provided. Technical and economical feasibility of all the system such as PV, battery, converter/inverter, charge controller and cable size have been simulated using Microsoft office excel and using highly advanced IC's that the project has been successfully designed and tested (simulated) and implementing the prototype of the system from the simulation.

5.2. Recommendations

Given the limitations of this study, it is recommended that further research should be done regarding the more technical aspects of microcontroller based single axis solar tracking system design and implementation. However, considering the over whelming benefits of utilizing alternative energy sources, the simplicity of installing microcontroller based single axis solar tracking system, and the cost savings.

Since this project is designed and implemented on microcontroller based single axis solar tracking system to supply solar electrical energy only to administrative offices of the college ,there are many remaining training workshops , ICT computer server rooms, training workshop, lecture classes, outdoor lamps and other blocks which need electrical power from solar tracking. So, we are motivated to recommend the college to facilitate favorable conditions for the installation of additional solar power for those remaining electrical loads.

Other recommendations that we have to suggest are; Adama Polytechnic College administration bodies have to be influential in encouraging their workers and stakeholders to expand and utilize such alternative and renewable energy systems. The college should also have to play important roles in encouraging and supporting the teachers/trainers to work researches on renewable energy by providing both technical assistance and financial contribution. Another way would be through facilitating purchasing of solar equipment especially of low power DC-voltage appliances, which are still not widely used in the offices. Using of low power DC- voltage appliances can reduce the costs of power converters like inverters. Furthermore, government of Oromia Regional State must be involved in encouraging the college by financial and other technical supports for maximum harvesting of solar energy and while facilitating effective and efficient training programs particularly in the college, generally in the region.

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GLOSSARY OF TERMS

Voltage: - is the electromotive force (pressure) applied to an electrical circuit measured in volts (V)

Current: - is the flow of electrons in an electrical circuit measured in amperes (I).

Resistance: - is the opposition to the flow of electrons in an electrical circuit

Continuous wattage:- is the total watts the inverter can support indefinitely.

Surge wattage: - is how much power the inverter can support for a very brief period, usually momentary.

AC (alternating current: - an electric current that periodically reverses its direction. Most household electricity supply is AC.

Array: - A group of solar panels wired together.

Base load power: - The lowest continuous power demand that must be met by the network. It includes the standby power (i.e. power drawn by an appliance when it is not in operation, such as to power clocks in microwave ovens) and appliances which operate continuously (e.g. phone chargers and security systems).

DC (direct current):- Electric current that moves in one direction only. DC current is the current produced by PV cells.

Grid-tied or grid-connected:- A generation system that is connected to the local electricity network, and can export excess electricity into the network.

Inverter: - The electrical device that converts DC electricity from generation sources such as photovoltaic's into AC electricity that can be used by modern appliances.

Kilowatt-hour (kWh):- the accumulated amount of energy used or produced. A PV array that has a rated capacity of 1 kilowatt will produce 1 kilowatt-hour of electricity in 1 hour of operation (under standard conditions).

Panel:-A group of photovoltaic cells wired together as one unit, as a sheet.

Watt (W):- A standard measure of power. Used to rate the production capacity of PVs, and also the electricity requirements (or demand) of appliances, etc.

Watts peak (Wp):- The power output generated by a PV module under standardized test conditions.

Angle of incidence: - the angle that a ray of light makes with a line perpendicular to the surface.

APPENDIX 1

Table 4-12Total daily energy demand Requirement

A	B	C	D	E	F	G	H	I
Daily System Energy Requirement								
1. Calculate the total daily load energy demand using the table below								
No.	**Appliance**	**voltage**	**Qty**	**power watts(W)**	**Total wattage(W)**	**Hrs/day used**	**Daily energy use watt-hour(WH)**	
1	Computer	12	15	330	4950	6	29700	
2	Printer	12	12	638	7656	2	15312	
3	Receiver	12	1	30	30	2	60	
4	Air conditioner	12	2	58	116	4	464	
5	TV	12	1	100	100	2	200	
6	Fluorescent Lamp	12	19	20	380	2	760	
7	Refrigerator	12	1	500	500	24	12000	
	Total			1676	13732	42	58496	
Total Daily AC energy demand							58496	
2. Estimate system ACenergy loss					0.35		20473.6	Wh
3. Total daily system energy requirement							78969.6	Wh
4. select system voltage								
system voltage		12	V					
5. calculate daily system charge requirement							6580.8	Ah

Table 4-13 Sizing and choosing the modules

A	B	C	D
Sizing and choosing the modules			
1. Obtain site's insolation value			
Methodological data			
column1 Month	Column 2 peaksunhours KWh/m2		
Jan	5.2		
Feb	5.22		
Mar	5.23		
Apr	5.05		
May	4.62		
Jun	4.63		
Jul	4.27		
Aug	4.79		
Sep	4.7		
Oct	5.3		
Nov	5.35		
Dec	5.19		
2 select design solar insolation value			
	4.27		
3: Calculate the system design charging current		1541.171	A
4. Determine the size of the module or number of modules required to produce the system design charging current			
	8.15	189.10073	modules

Table4 -14 Battery sizing and selection

A	B	C	D	E	F	G	H
Battery sizing and selection							
1: we select Valve regulated lead-acid batteries							
No	**Type of battery**	**voltage**	**capacit**	**recommended daily DoD (%)**	**recommended max DoD (%)**	**price(birr)**	**25%DoD cycle life**
1	Flooded lead-acid batteries	**12**	**200Ah**	**20%**	**30%**	**8500**	**800**
2	**Valve regulated lead acid batteries(AGM cell battery)**	**12**	**200Ah**	**30%**	**80%**	**8000**	**800**
We select Valve regulated lead-acid battery because it is currently avaliable in the market and also have long life cycle							
2. Calculate the Required Capacity of Battery (In Amp-Hours)							
6581	1	0.8	8226	Ah			
6581	2	0.8	16452				
3: Determine the battery configuration							
8226	200	41.13	parallel connected				
16452	200	82.26	parallel connected				

Table 4- 15 charge controller sizing and selection

A	B	C	D
Charge controller /inverter sizing and selection			
Select charge controller size			
maximum Array Short circuit current(Amps)		Array input rating(Amps)	
8.97	1.25	11.2125	A
Number of modules	Array input rating(Amps)	charge controller size	
189.1007313	11.2125	2120.29195	

Table 4- 16 Inverter sizing and selection

A	B	C	D
Inverter sizing and selection			
Column1	yes/no		
is an inverter needed?	yes		
Inverter/charger	No		
Inverter rating			
13732	1.25	17165	Watt

A	B	C	D	E
Wiring ,Voltage Drop and Fuses				
Step 1:Map the site and Estimated Cable runs				

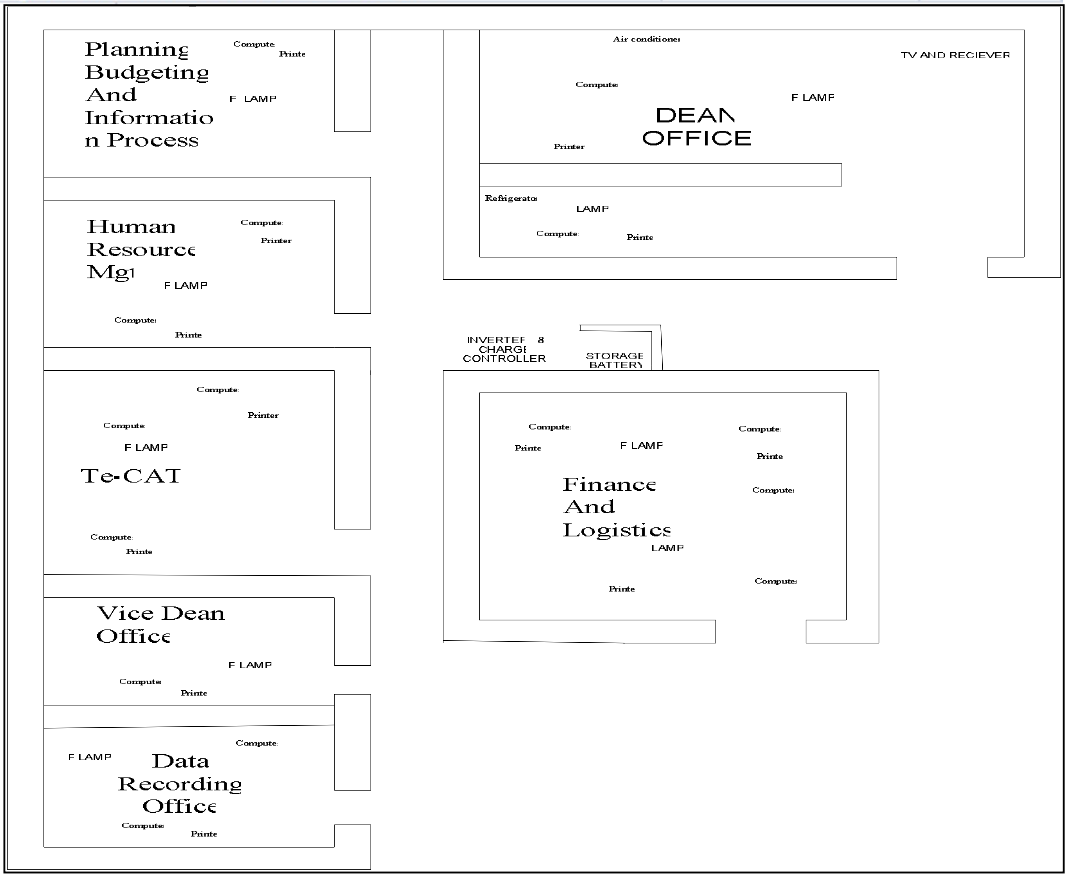

Figure 4- 27 Floor plan of the Adama polytechnic college administration offices

APPENDIX 2

```
// Program for Micro Controller based single axis solar tracking system
//include<P16F877A.h>
//include<LCD.h>
//programconfig OSC=INTI067 //select internal oscillator
//prpgram config WDT = off //turn off watch dog timer
//program config WDT = off//turn off low voltage program
 //LCD module connections initialization
sbit LCD_RS at RB2_bit;
sbit LCD_EN at RB3_bit;
sbit LCD_D4 at RB4_bit;
sbit LCD_D5 at RB5_bit;
sbit LCD_D6 at RB6_bit;
sbit LCD_D7 at RB7_bit;
// End LCD module connections
// LCD Pin direction
sbit LCD_RS_Direction at TRISB2_bit;
sbit LCD_EN_Direction at TRISB3_bit;
sbit LCD_D4_Direction at TRISB4_bit;
sbit LCD_D5_Direction at TRISB5_bit;
sbit LCD_D6_Direction at TRISB6_bit;
sbit LCD_D7_Direction at TRISB7_bit;
// End of LCD Pin direction
 //stepper motor module connection
sbit Stepper_pin1 at RC0_bit;
sbit Stepper_pin2 at RC1_bit;
sbit Stepper_pin3 at RC3_bit;
sbit Stepper_pin4 at RC4_bit;
//stepper pin direction
sbit Stepper_pin1_Direction at TRISC0_bit;
sbit Stepper_pin2_Direction at TRISC1_bit;
sbit Stepper_pin3_Direction at TRISC2_bit;
sbit Stepper_pin4_Direction at TRISC3_bit;
```

```
//End of stepper motor
int LDR1=0,LDR2=0;
char x2[7],x3[7];
int y=0;
int s1=0,s2=0;
int cnt=0;
void ccw();
void cw();
void main() {
  LCD_init();
  Lcd_Cmd(_LCD_CLEAR);
  Lcd_Cmd(_LCD_CURSOR_OFF);
  LCD_Out(1,6,"WELCOME");
  trisa=3;
  porta=0;
  trisd=0;
  portd=0;
  trisc=0;
  portc=0;
   while(1)
   {
    LDR1=ADC_Read(0);
    LDR2=ADC_Read(1);
    if(LDR1>LDR2)
    {
    ccw();
    LCD_Out(2,1,"CCW");
    }
    else if(LDR1<LDR2)
    {
     cw();
     LCD_Out(2,1,"CW");
    }
    else
```

```
    {
    LCD_out(2,1,"EQUAL");

void ccw()
{
 portc=1;
 delay_ms(250);
 portc=2;
 delay_ms(250);
 portc=4;
 delay_ms(250);
 portc=8;
 delay_ms(250);
}
void cw()
{
 portc=8;
 delay_ms(250);
 portc=4;
 delay_ms(250);
 portc=2;
 delay_ms(250);
 portc=1;
 delay_ms(250);
}
```

APPENDIX 3

Simulation Circuit Layout in Proteus 8.0 ISIS Professional for Design and Implementation of Solar PV System with Microcontroller based Single Axis Tracking System

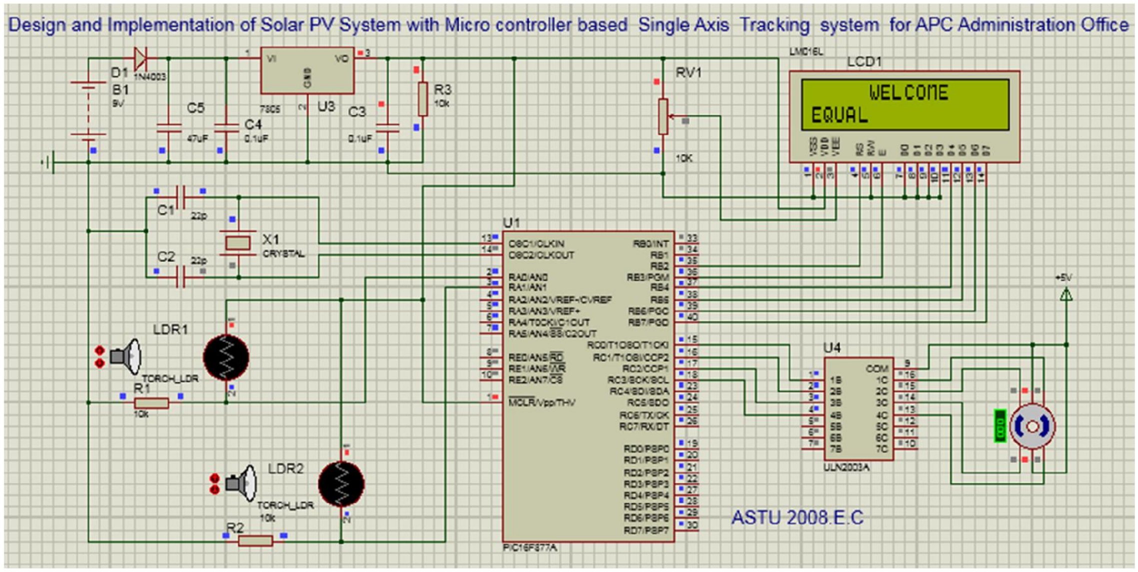

Figure 4-27 Simulation result shows "WELCOME EQUAL"

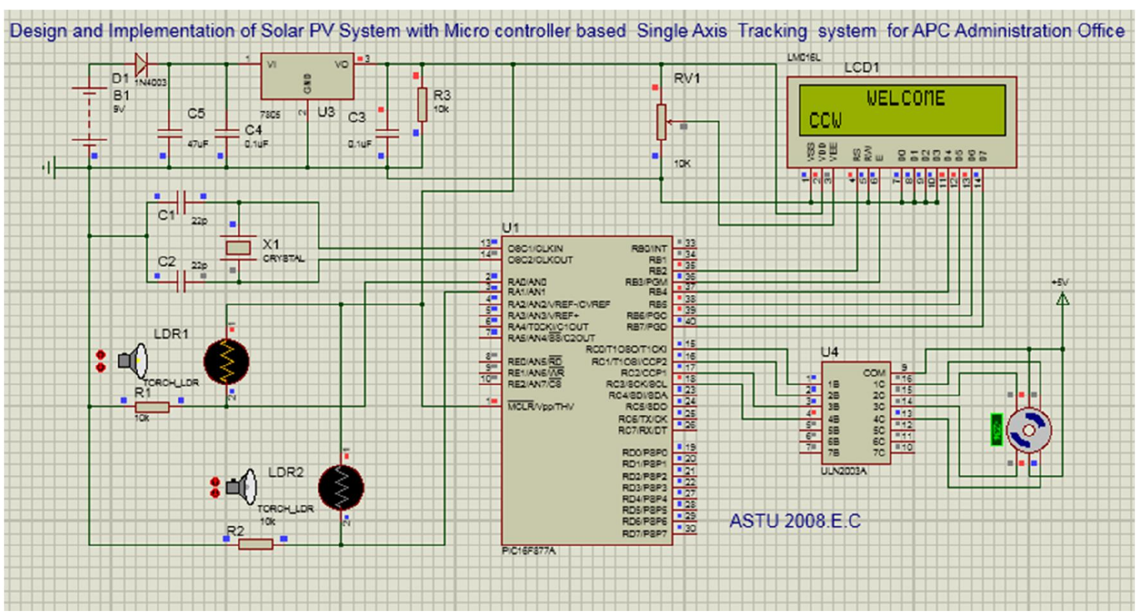

Figure 4- 28 Simulation result shows"CCW"

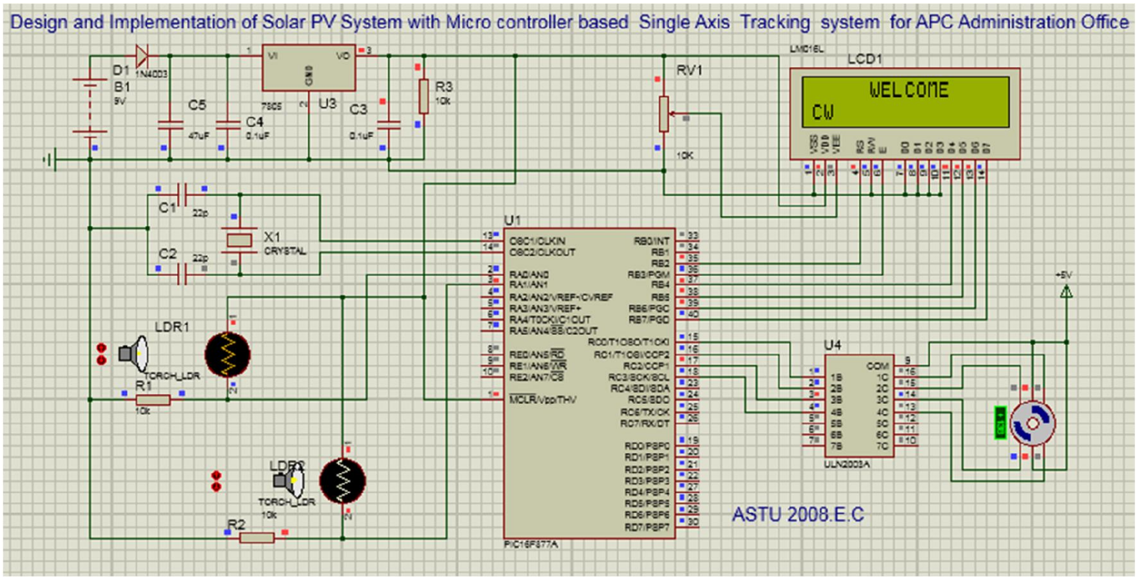

Figure 4-29 Simulation result shows ”CW”

APPENDIX 4

PV System designed algorism

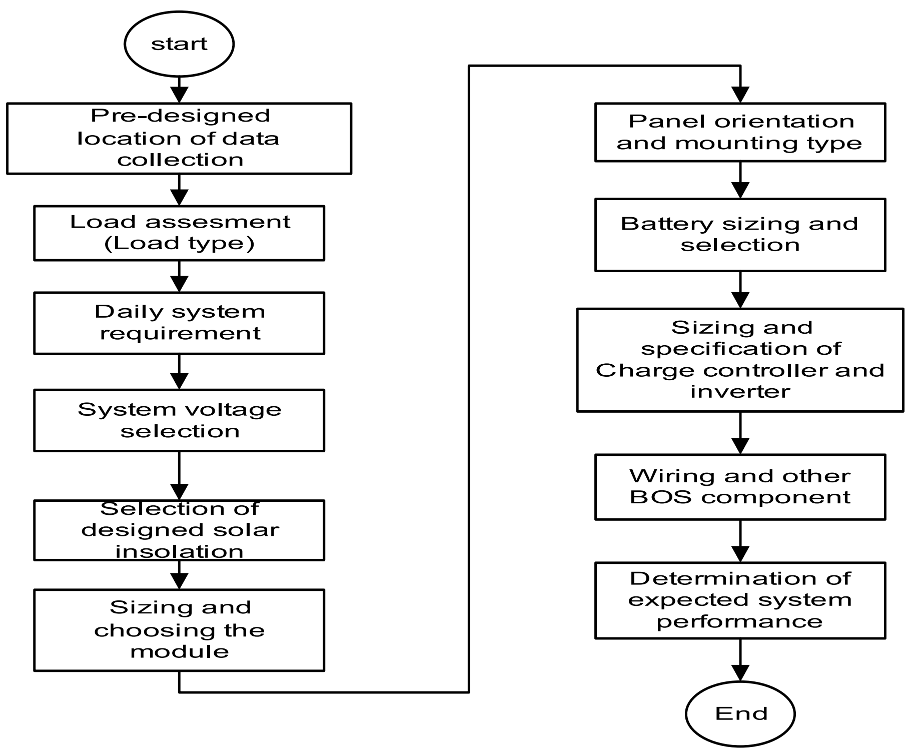

Figure 4-30 PV system designed algorism