Sudan University of Science and Technology
College of Graduate Studies
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Dual Axis Sun Tracking System Using a Microcontroller and a Stepper Motor

نظام تتبـــع الشمس ذو المحوريـــن
بإستخدام المتحكم الدقيق ومحرك الخطوة

A Thesis submitted in partial fulfillment for the requirements of the degree of M.Sc. in Electrical Engineering (Power)

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الآية

قال تعالي:

﴿هوَ الَّذي جَعَلَ الشَّمْسَ ضِيَاءً وَالقَمَرَ نُوراً وَقَدَّرَهُ مَنَازِلَ لِتَعْلَمُوا عَدَدَ السِنِينَ وَالحِسَاب مَا خَلَقَ الله ذلكَ إِلاَّ بِالحقِّ يُفصِّلُ الأياتِ لِقَومٍ يَعْلَمُون﴾.

صدق الله العظيم

(سورة يونس – آية **5**)

Dedication

This thesis is dedicated to my father, who taught me that the best kind of knowledge is to have which is learned for its own sake. It is also dedicated to my mother, who taught me that the largest task could be accomplished if it is done step by step in a period time.

Acknowledgement

All the thanks, praises and glorifying is due to Almighty ALLAH and to my mother and father, who grew me up, fed me and guided me through life.

I owe my deepest gratitude to my advisor Dr. Elfadil Zakaria Yahia, first for accepting me as a student, then for the support and help, he has given me throughout the project.

Besides, I also want to thank Eng. Osman Mohammed for his significant assistance and help.

Many thanks to my colleagues and all the staff at Department of Electrical Engineering, for the pleasant working atmosphere and any friendship.

ABSTRACT

This study pursuit develop solar energy systems in the light of technological advances to develop these systems, especially those moving (solar Tracking) to take advantage of sunlight for a longer period.

The Objective of Thesis is to find a design of the sun Tracker with two axes follow the movement of the sun throughout the sunrise to take advantage of the rays and solve the problem of environmental factors and the alternation of night and day to produce the greatest amount of solar energy.

The circuit of the solar tracker system is dividing into three sections. Firstly, there is the input stage that is composed of sensors and potentiometers, secondly a program in BASCOM software in the microcontroller and lastly the driving circuit that has the stepper motor. And the main results are as follows:

- The study obtained on a model to track the sun in two directions (East, West), (North, South) using the microprocessor and step motor.
- Solve the problem of different classes and the factors that affect the natural rays fall on the cell.
- Solve the problem of stopping the cell at night and daytime running system

مستخلص البحث

الدراسة تسعى لتطوير أنظمة الطاقة الشمسية في ظل التقدم التكنولوجي لتطوير هذه الأنظمة خاصة تلك المتحركة (المتعقبات الشمسية) للإستفادة من ضوء الشمس لأطول فترة.

تكمن أهداف البحث في إيجاد تصميم متتبع للشمس ذي محورين تتابع حركة الشمس طيلة فترة شروقها للإستفادة من أشعتها وحل مشكلة العوامل البيئية وإختلاف الليل والنهار لإنتاج أكبر قدر من الطاقة الشمسية.

وتنقسم دائره منظومة التتتبع الشمسي إلى ثلاثه أقسام. أولا ، هناك مرحله المدخلات التي تتالف من الحساسات الضوئية و المفاتيح الحدية ، وثانيا برنامج الباسكوم للبرمجة علي المتحكم وأخيرا الدائرة المقودة للتيار ومحركات الخطوة. وأهم نتائج البحث كالأتي:

- تحصلت الدراسة على نموذج لتتبع الشمس في إتجاهين (شرق ، غرب) ، (شمال ، جنوب) بإستخدام المعالج الدقيق ومحرك الخطوة.
- حل مشكلة إختلاف الفصول والعوامل الطبيعية التي تؤثر على سقوط الأشعة على الخلية.
- حل مشكلة إيقاف الخلية ليلاً وتشغيل المنظومة نهاراً.

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List of Abbreviations

PV	Photovoltaic
CSP	Concentrating Solar Power
EHPs	Electron Hole Pairs
LDR	Light Dependent Resistor
ALU	Arithmetic Logic Unit
VRM	Variable Reluctance Motor
PMSM	Permanent Magnet Stepper Motor
HSM	Hybrid Stepper Motor
RAM	Random Access Memory
EPROM	Erasable Programmable Read Only Memory
EEPROM	Electrically Erasable Programmable Read Only Memory
I/O	Input/Output
RTD	Resistance Temperature Detector
USART	Universal Synchronous Asynchronous Receiver Transmitter
ADC	Analog-To-Digital Converter

CHAPTER ONE

INTRODUCTION

1.1 General background:

Solar energy is clean and available in abundance. Solar technologies use the sun for provision of heat, light and electricity. These are for industrial and domestic applications. With the alarming rate of depletion of depletion of major conventional energy sources like petroleum, coal and natural gas, coupled with environmental caused by the process of harnessing these energy sources, it has become an urgent necessity to invest in renewable energy sources that can power the future sufficiently. The energy potential of the sun is immense. Despite the unlimited resource however, harvesting it presents a challenge because of the limited efficiency of the array cells. The best efficiency of the majority of commercially available solar cells ranges between 10 and 20% [1], [2]. This shows that there is stillroom for improvement. This project seeks to identify a way of improving efficiency of solar panels. Solar tracking is used. The tracking mechanism moves and positions the solar array such that it is positioned for maximum power output. Other ways include identifying sources of losses and finding ways to mitigate them.

When it comes to the development of any nation, energy is the main driving factor. There is an enormous quantity of energy that is extracted, distributed, converted and consumed every single day in the global society. Fossil fuels account for around 85 percent of energy that is produced. Fossil fuel resources are limited and using them is known to cause global warming because of emission of greenhouse gases. There is a growing need for energy from such sources as solar, wind, ocean tidal waves and geothermal for the provision of sustainable and power. Solar panels directly convert radiation from the sun into electrical energy. The panels are mainly manufactured from semiconductor materials, notably silicon. Their efficiency is 24.5% on the higher side. Three ways of increasing the efficiency of the solar panels are through increase of cell efficiency, maximizing the power output and the use of a tracking system.

Maximum power point tracking (MPPT) is the process of maximizing the power output from the solar panel by keeping its operation on the knee point of P-V characteristics. MPPT technology will only offer maximum power, which can be, received from stationary arrays of solar panels at any given time. The technology cannot however increase generation of power when the sun is not aligned with the system.

Solar tracking is a system that is mechanized to track the position of the sun to increase power output by between 30% and 60% than systems that are stationary. It is a more cost effective solution than the purchase of solar panels.

There are various types of trackers that can be used for increase in the amount of energy that can be obtained by solar panels. Dual axis trackers are among the most efficient, though this comes with increased complexity. Dual trackers track sunlight from box axes. They are the best option for places where the position of the sun keeps changing during the year at different seasons. Single axis trackers are a better option for places around the equator where there is no significant change in the apparent position of the sun.

The level to which the efficiency is improved will depend on the efficiency of the tracking system and the weather. Very efficient trackers will offer more efficiency because they are able to track the sun with more precision. There will be bigger increase in efficiency in cases where the weather is sunny and thus favorable for the tracking system.

1.2 Problem Statement:

A solar tracker is using in various systems for the improvement of harnessing of solar radiation. The problem that the implementation of a system, which is capable of enhancing production of power by 30-40%.

The research problem can be summarized in how to create and design a Tracker microprocessor, using axes and step motor, taking into account finding a solution to the problem of the alternation of night and day, and the factors that affect the natural sunrise.

1.3 Objective:

Design a solar tracker to achieve the maximum power produced from a solar cell at any time, Solve the problem of different classes and the factors that affect the natural rays fall on the cell and solve the problem of stopping the cell at night and daytime running system.

1.4 Methodology:

The circuit of the solar tracker system is dividing into three sections. Firstly, there is the input stage that is composed of sensors and potentiometers, secondly a program in BASCOM software in the microcontroller and lastly the driving circuit that has the stepper motor. The input stage has two LDRs that are so arranging to form a voltage divider circuit. A C program loaded into the Atmega16 forms by BASCOM and PROTEUS software. A metallic frame houses the components. The three stages are designing independently before being joining into one system. This approach, similar to stepwise refinement in modular programming, that has been employed to ensure an accurate and logical approach, which is straightforward and easy to understand and also ensures that if there is any error, it will be independently considered and corrected.

1.5 Thesis Layout:

This chapter has represented a general overview, a problem and a methodology to solve the problem. Chapter Two is providing a literature review and tracking system.

Chapter Three is given an introduction to solar Energy and Solar energy in Sudan. Chapter Four is showing the circuit components precisely like stepper motor, (LDR), microcontroller (Atmega16), and the drive components. Also is providing the installation of the circuit components and the operation of all of them.

Chapter Five is discussed the result which has been obtained from solar tracker system after using BASCOM and PROTEUS programs. Lastly, Chapter Six is composed of conclusion and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction:

A solar tracker is a device used for orienting a photovoltaic array solar panel or for concentrating solar reflector or lens toward the sun. The position of the sun in the sky is varied with both seasons and time of day as the sun moves across the sky. Solar powered equipment work best when they are pointed at the sun. Therefore, a solar tracker increases how efficient such equipment are over any fixed position at the cost of additional complexity to the system. There are different types of trackers. Extraction of usable electricity from the sun became possible with the discovery of the photoelectric mechanism and subsequent development of the solar cell. The solar cell is a semiconductor material, which converts visible light into direct current. Using solar arrays, a series of solar cells electrically connected; there is generation of a DC voltage that can be used on a load. There is an increased use of solar arrays as their efficiencies become higher. They are especially popular in remote areas where there is no connection to the grid. Photovoltaic energy is that which is obtained from the sun. A photovoltaic cell, commonly known as a solar cell, is the technology used for conversion of solar directly into electrical power. The photovoltaic cell is a non-mechanical device made of silicon alloy.

The photovoltaic cell is the basic building block of a photovoltaic system. The individual cells can vary from 0.5 inches to 4 inches across. One cell can however produce only 1 or 2 watts that is not enough for most appliances. Performance of a photovoltaic array depends on sunlight. Climatic conditions like clouds and fog significantly affect the amount of solar energy that is received by the array and therefore its performance. Most of the PV modules are between 10 and 20 percent efficient [3].

Figure 2.1 Solar Cell

2.2 The Earth: Rotation and Revolution

The earth is a planet of the sun and revolves around it. Besides that, it also rotates around its own axis. There are thus two motions of the earth, rotation and revolution. The earth rotates on its axis from west to east. The axis of the earth is an imaginary line that passes through the northern and southern poles of the earth as in the figure 2.2. The earth completes its rotation in 24 hours. This motion is responsible for occurrence of day and night. The solar day is a period of 24 hours and the duration of a sidereal is 23 hours and 56 minutes. The difference of 4 minutes is because of the fact that the earth’s position keeps changing with reference to the sun.

The movement of the earth round the sun is known as revolution. It also happens from west to east and takes a period of 365 days. The orbit of the earth is elliptical. Because of this, the distance between the earth and the sun keeps changing. The apparent annual track of the sun via the fixed stars in the celestial sphere is known as the ecliptic. The earth’s axis makes an angle of 66.5 degrees to the ecliptic plane. Because of this, the earth attains four critical positions with reference to the sun as in the figure 2.3 [4].

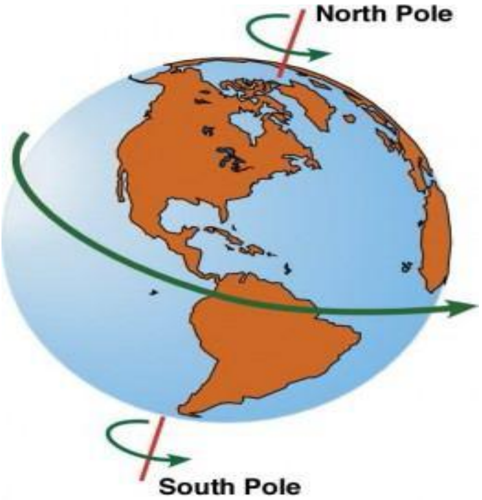


Figure 2.2 Earth's rotation

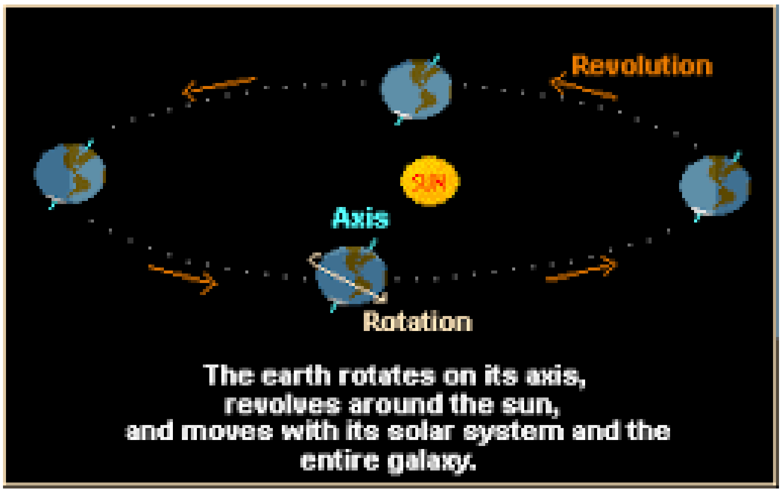


Figure 2.3 Revolution and rotation

2.3 Solar Irradiation: Sunlight and the Solar Constant:

The sun delivers energy by means of electromagnetic radiation. There is solar fusion that results from the intense temperature and pressure at the core of the sun. Protons are converted into helium atoms at 600 million tons per second. Because the output of the process has lower energy than the protons, which began, fusion gives rise to lots of energy in form of gamma rays that are absorbed by particles in the sun and re-emitted. From The law of Stefan and Boltzmann can estimate the total power of the sun $P = 4\pi r^2\ \sigma\epsilon T^4$ W ……….……..2.1.

T is the temperature that is about 5800K, r is the radius of the sun which is 695800 km and σ is the Boltzmann constant which is $1.3806488 \times 10^{-23}\ m^2\ kg\ s^{-2}\ K^{-1}$. The emissivity of the surface is denoted by ϵ. Because of Einstein's famous law E=mc2 about millions of tons of matter are converted to energy each second. The solar energy that is irradiated to the earth is 5.1024 Joules per year this is 10000 times the present worldwide energy consumption per year.

Solar radiation from the sun is received in three ways: direct, diffuse and reflected, Direct radiation: is also referred to as beam radiation and is the solar radiation, which travels on a straight line from the sun to the surface of the earth [5].

2.4 **Sunlight:**

Photometry enables us to determine the amount of light given off by the Sun in terms of brightness perceived by the human eye. In photometry, a luminosity function is used for the radiant power at each wavelength to give a different weight to a particular wavelength that models human brightness sensitivity. Photometric measurements began as early as the end of the18th century resulting in many different units of measurement, some of which cannot even be converted owing to the relative meaning of brightness. However, the luminous flux (or lux) is commonly used and is the measure of the perceived power of light. Its unit, the lumen, is concisely defined as the luminous flux of light produced by a light source that emits one candela of luminous intensity over a solid angle of one steradian. The candela is the SI unit of luminous intensity and it is the power emitted by a light source in a particular direction, weighted by a luminosity function whereas a steradian is the SI unit for a solid angle; the two-dimensional angle in three-dimensional space that an object subtends at a point.

One lux is equivalent to one lumen per square metre;

$$1\ \mathrm{lx} = 1\mathrm{lm} \cdot \mathrm{m}^{-2} = 1\ \mathrm{cd} \cdot \mathrm{sr} \cdot \mathrm{m}^{-2}$$

I.e. a flux of 10 lumen, concentrated over an area of one square metre, lights up that area with illuminance of 10 lux. Sunlight ranges between 400 lux and approximately 130000 lux, as summarized in the table below.

Table 2.1 Sunlight in day

Time of day	Luminous flux (lux)
Sunrise or sunset on a clear day	400
Overcast day	1000
Full day (not direct sun)	10000 – 25000
Direct sunlight	32000 – 130000

2.4.1 Elevation angle

The elevation angle is used interchangeably with altitude angle and is the angular height of the sun in the sky measured from the horizontal. Both altitude and elevation are used for description of the height in meters above the sea level. The elevation is 0 degrees at sunrise and 90 degrees when the sun is directly overhead. The angle of elevation varies throughout the day and depends on latitude of the particular location and the day of the year.

2.4.2 Zenith angle

This is the angle between the sun and the vertical. It is similar to the angle of elevation but is measured from the vertical rather than from the horizontal. Therefore, the zenith angle = 90 degrees – elevation angle as in the figure2.4 [5].

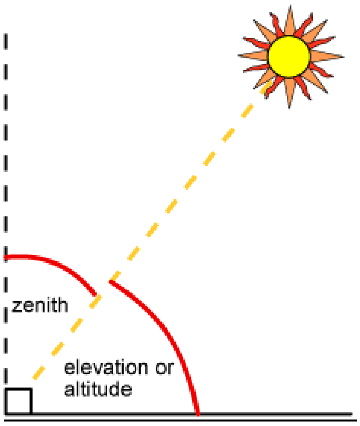


Figure 2.4 Angle of elevation and zenith angle

2.4.3 Azimuth angle

This is the compass direction from which the sunlight is coming. At solar noon, the sun is directly south in the northern hemisphere and directly north in the southern hemisphere. The azimuth angle varies throughout the day. At the equinoxes, the sun rises directly east and sets directly west regardless of the latitude. Therefore, the azimuth angles are 90 degrees at sunrise and 270 degrees at sunset [5].

2.5 Tracking System:

Solar Panels are a form of active solar power, a term that describes how solar panels make use of the sun’s energy; solar panels harvest sunlight and actively convert it to electricity. Solar Cells, or photovoltaic cells, are arranged in a grid-like pattern on the surface of the solar panel. Solar panels are typically constructed with crystalline silicon, which is used in other industries (such as the microprocessor industry), and the more expensive gallium arsenide, which is produced exclusively for use in photovoltaic (solar) cells. Solar panels collect solar radiation from the sun and actively convert that energy to electricity. Solar panels are comprised of several individual solar cells. These solar cells function similarly to large semiconductors and utilize a large area p-n junction diode. When the solar cells are exposed to sunlight, the p-n junction diodes convert the energy from sunlight into usable electrical energy. The energy generated from photons striking the surface of the solar panel allows electrons to be knocked out of their orbits and released, and electric fields in the solar cells pull these free electrons in a directional current, from which metal contacts in the solar cell can generate electricity. The more solar cells in a solar panel and the higher the quality of the solar cells, the total electrical output the solar panel can produce. The conversion of sunlight to usable electrical energy has been dubbed the Photovoltaic Effect. A solar tracker is a device that orients a payload toward the sun. The use of solar trackers can increase electricity production by around a third, and some claim by as much as 40% in some regions, compared with modules at a fixed angle. In any solar application, the conversion efficiency is improved when the modules are continually adjusted to the optimum angle as the sun traverses the sky. As improved efficiency means improved yield, use of trackers can make quite a difference to the income from a large plant.

2.5.1 Need For Solar Tracker:

The energy contributed by the direct beam drops off with the cosine of the angle between the incoming light and panel.

The sun travels through 360 degrees east west a day, but from the perspective of any fixed location the visible portion 180 degrees during a 1/2 day period. Local horizon effects reduce this somewhat, making the effective motion about 150 degrees. A solar panel in a fixed orientation between the dawn and sunset extremes will see a motion of 75 degrees on either side, and thus, according to the table 2-2, will lose 75% of the energy in the morning and evening Rotating the panels to the east and west can help recapture these losses. A tracker rotating in the east west direction is known as a single-axis tracker.

The sun also moves through 46 degrees north south over the period of a year. The same set of panels set at the midpoint between the two local extremes will thus see the sun move 23 degrees on either side, causing losses of 83% a tracker that accounts for both the daily and seasonal motion is known as a dual axis tracker.

Table 2.2 Direct power lost (%) due to misalignment (angle I)

Misalignment (angle *I*)	Direct power lost (%)=1-cos(I)
0^0	0
1^0	0.015
3^0	0.14
8^0	1
23^0	8.3
30^0	13.4
45^0	30
75^0	>75

2.5.2 Commercial purpose of solar tracking system:

- Increase Solar Panel Output.
- Maximum efficiency of the panel.
- Maximize Power per unit area.
- Able to grab the energy throughout the day.

The sun's position in the sky varies both with the seasons (elevation) and with time of day as the sun moves across the sky. Hence, there are also two types of solar tracker:

- Single Axis Solar Tracker.
- Dual Axis Solar Tracker.

Single Axis Solar Tracker: Single axis solar trackers can either have a horizontal or a vertical axle. The horizontal type is used in tropical regions where the sun gets very high at noon, but the days are short. The vertical type is used in high latitudes (such as in UK) where the sun does not get very high, but summer days can be very long.

Dual Axis Solar Tracker: Double axis solar trackers have both a horizontal and a vertical axle and so can track the sun's apparent motion exactly anywhere in the world. This type of system is used to control astronomical telescopes, and so there is plenty of software available to automatically predict and track the motion of the sun across the sky. Dual axis trackers track the sun both east to west and north to south for added power output (approx. 40% gain) and convenience.

Solar tracker drives, can be divided into three main types depending on the type of drive and sensing or positioning system that they incorporate.

- Passive Trackers: Use the sun’s radiation to heat gases that move the tracker across the sky.
- Active Trackers: Use electric or hydraulic drives and some type of gearing or actuator to move the tracker.
- Open Loop Trackers: Use no sensing but instead determine the position of the sun through prerecorded data for a particular site

Passive Trackers: Passive trackers use a compressed gas fluid in two canisters each place in west and east of the tracker. The mechanism is in such a way that if one side cylinder is heated other side piston rises causing the panel to tilt over the sunny side. This affects the balance of the tracker and caused it to tilt. This system is very reliable and needs little maintenance.

Active Trackers: Active trackers measure the light intensity from the sun by using light sensors to determine where the solar modules should be pointing. Light sensors are positioned on the tracker at various locations 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 causes to determine in which direction the tracker has to tilt with the help of the stepper or dc motor in order to be facing the sun.

CHAPTER THREE

Solar Energy

3.1 Introduction:

The twenty-first century is forming into the perfect energy storm. Rising energy prices, diminishing energy availability and security, and growing environmental concerns are quickly changing the global energy panorama. Energy and water are the keys to modern life and provide the basis necessary for sustained economic development. Industrialized societies have become increasingly dependent on fossil fuels for myriad uses. Modern conveniences, mechanized agriculture, and global population growth have only been made possible through the exploitation of inexpensive fossil fuels. Securing sustainable and future energy supplies will be the greatest challenge faced by all societies in this century. Due to a growing world population and increasing modernization, global energy demand is projected to more than double during the first half of the twenty-first century and to more than triple by the end of the century. Presently, the world's population is nearly 7 billion, and projections are for a global population approaching 10 billion by midcentury. Future energy demands can only be met by introducing an increasing percentage of alternative fuels. Incremental improvements in existing energy networks will be inadequate to meet this growing energy demand. Due to dwindling reserves and ever-growing concerns over the impact of burning carbon fuels on global climate change, fossil fuel sources cannot be exploited as in the past. Finding sufficient supplies of clean and sustainable energy for the future is the global society's most daunting challenge for the twenty-first century. The future will be a mix of energy technologies with renewable sources such as solar, wind, and biomass playing an increasingly important role in the new global energy economy. The key question is: How long it will take for this sustainable energy changeover to occur? And how much environmental, political, and economic damage is acceptable in the meantime? If the twenty-first century sustainable energy challenge is not met quickly, many less-developed countries will suffer major famines and social instability from rising energy prices. Ultimately, the world’s economic order is at stake. Approximately one-third of the world’s population lives in rural regions without access to the electric grid, and about half of these same people live without access to safe and clean water. Solar energy is unique in that it can easily provide electricity and purified water for these people today with minimal infrastructure requirements by using local energy resources that promote local economic development. Unfortunately, traditional fossil fuel energy use has had serious and growing negative environmental impacts, such as CO2 emissions, global warming, air pollution, deforestation, and overall global environmental degradation. Additionally, fossil fuel reserves are not infinite or renewable; the supply is limited. Without a doubt, there will be significant changes in our society’s modern energy infrastructure by the end of the twenty-first century. A future mix that includes sustainable energy sources will contribute to our prosperity and health. Our future energy needs must be met by a mix of sustainable technologies that have minimal environmental impacts. Potentially, many of these technologies will use solar energy in all its forms, permitting gradual evolution into a hydrogen-based economy. A renewable energy revolution is our hope for a sustainable future. Clearly, the future belongs to clean energy sources and to those who prepare for it now.

3.2 Renewable energy for rural Development:

Given that the need for power grows much faster for less developed nations than for those that are already industrialized, this changing energy panorama will significantly impact how power is supplied to developing regions. Industrialized countries need to clean up their own energy production acts, while encouraging developing countries not to follow in their footsteps, but rather to leapfrog to clean energy technologies directly. Despite three decades of major investments by less developed nations and multilaterals on electrification projects (often at huge environmental and social costs), nearly 2 billion people in developing regions around the globe still lack electricity. Over 1 billion people are also without access to safe drinking water. Millions of households rely solely on kerosene lamps for lighting and disposable batteries for radios. For most of these people, there is little likelihood of ever receiving electricity from conventional grid sources. However, there is growing momentum in supplying electricity to developing regions using solar and wind energy sources. Both solar and wind energy technologies offer energy independence and sustainable development by using indigenous renewable energy resources and by creating long-term local jobs and industries. The cost of bringing utility power via transmission and distribution lines to non-electrified villages is great. This is largely due to small household electrical loads and the fact that many villages are located at great distances over difficult terrain from the existing grid. Stand-alone solar and wind energy systems can provide cost-effective, modest levels of power for lighting, communication, fans, refrigerators, water pumping, etc. Using a least-cost model, some governments and national utilities, such as those in Brazil, India, Central America, South Africa, Mexico and elsewhere, have used PV and wind systems as an integrated development tool for electrification planning as either centralized or distributed solutions. Two decades ago, PV technology was relatively unknown. The Dominican Republic was one of the early proving grounds for developing rural PV electrification efforts. The nonprofit group Enersol Associates began work in 1984, offering technical assistance and training to Dominican businesses. Nonprofit organizations also worked to develop a market for rural PV technology. Enersol began to work closely with the Peace Corps using seed funding from the U.S. Agency for International Development (USAID) to help set up a revolving fund offering rural farmers low-interest loans to purchase small PV systems. The work of this nongovernment organization (NGO) later evolved into private enterprise as companies such as Soluz formed in the Dominican Republic and Honduras. Gradually throughout the developing world, small solar companies began to form as PV module manufacturers began to establish distributor networks to serve remote, non-electrified areas. The model of rural off-grid PV systems (Figure 1.1) has spread globally with over 5 million systems installed. More total kilowatts of grid-tie PV systems are installed each year; however, numerically more small, off-gird systems are installed annually. Over time, the focus of PV projects has changed. Installation of PV systems solely for remote sites has expanded to include the promotion of rural economic development through PV. PV provide power for remote water pumping, refrigeration, and water treatment of community water supplies. Solar distillation can meet individual household potable water needs from even the most contaminated and brackish water sources. For larger load requirements, the combination of PV and wind technologies with diesel generators and battery storage has proved that hybrid configurations provide higher system reliability at a more reasonable cost than with any one technology alone. Solar thermal energy represents the most competitive but often overlooked solar technology option. Domestic solar hot water heating systems typically have cost paybacks from 5 to 7 years— much better than grid-tied PV systems, where payback may take decades, if ever. Additionally, large-scale solar thermal concentrating solar power (CSP) plants have better economies of scale than PV for utility power generation at almost half the kilowatt-hour cost.

3.3 Solar energy in Sudan:

Energy is an essential factor in the development movement, since it stimulates and supports the economic growth and development. In recent years, Sudan has increased efforts to exploit renewable energy sources and reduce its dependence on oil [6]. Application of new and renewable sources of energy available in Sudan is now a major issue in the future energy strategic planning as alternative of fossil conventional energy to provide part of the local energy demand. The Government of the Sudan, in cooperation with various international development agencies, had explored the role of traditional and renewable energy technologies in meeting the demand of energy to the rural communities. There appears to be general agreement that the most significant of the renewable energy sources is solar energy. Solar energy posses characteristics, which make it highly attractive as a primary energy source. It is based upon a continuously renewable resource which cannot be depleted and which is not subject to political control. Of all energy sources, it is the least encumbered by environmental and safety hazards. And, most significantly, it is possible to collect, convert and store solar energy with present technology. Long-term operating economy is another characteristic of solar energy systems. Solar energy development was taking a long time to become technically viable and economically competitive with conventional.

energy sources. The main source of energy which applicable in Sudan for rural now is solar energy, and Northern State has been considered as one of the best parts of the Sudan for exploiting solar energy as shown in Fig 3.1. Solar energy applications can be divided into two main categories: solar thermal application and photovoltaic technologies (PV). Solar thermal is a technology where the heat from solar energy is harnessed for heating purposes, while photovoltaic is a technology where arrays of cells which contain solar photovoltaic material convert the solar radiation into direct current electricity. A study was conducted to understanding the characteristics and contribution of PV technologies; as one of the solar energy technologies, in Northern State (Sudan) and provided a baseline research on the specific applications to assess the appropriateness of these technologies, and to found out the elements of sustainability within the introduced technologies. For the purpose of this study both secondary and primary data were obtained. The secondary data had been obtained from general literature review and Administration of Energy and Mining within Ministry of Physical Planning, Housing and Public Utilities (Northern State). The primary data had been collected through a visit to some selected locations where solar energy applications were used. Photographs were taken at the selected locations for illustration of both technologies besides its documentation.

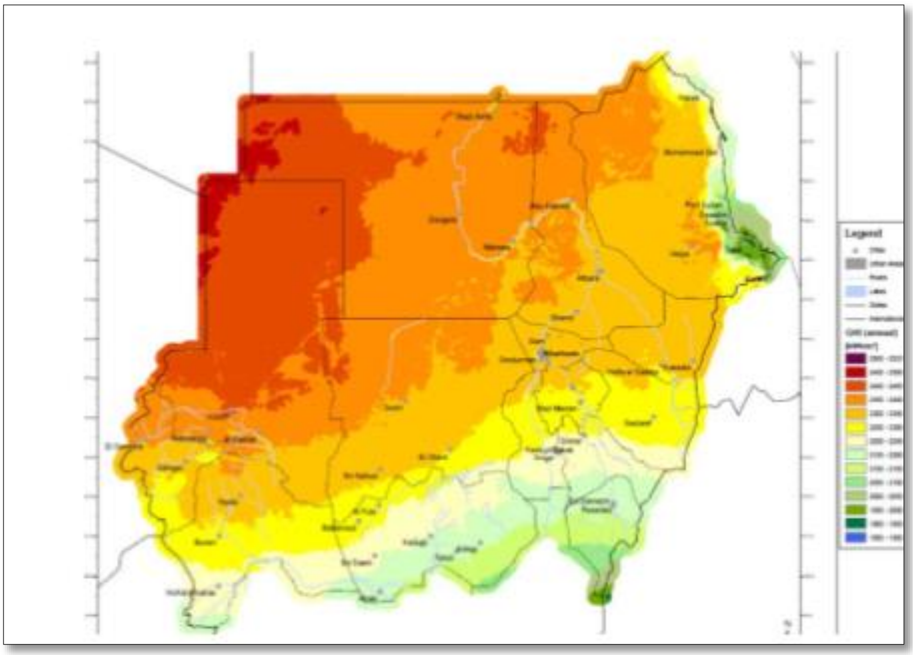


Figure 3.1 Solar energy resource available in Sudan (Solar Atlas)

3.4 Applications of Solar Energy Systems in Sudan:

To evaluate the potential of different solar applications, a clear understanding of the fundamental criteria of success is obviously a first requirement [7]:

Criterion 32: Energy demand:

The energy demand should be important enough, micro economically speaking, to justify investment costs in a solar system for the individual user. At the same time, the macroeconomic importance should be sufficient, in order to justify the development of solar systems.

Criterion 32: Energy supply:

Obviously the chances for the successful application of a solar system are greater in a climate with greater amounts of solar radiation.

Criterion 32: Solar system efficiency:

High radiation intensity values greatly contribute to solar system efficiency. Thus the climate can have a significant influence on efficiency.

Criterion 32: Solar system cost:

Spreading the use of a solar system over the whole year rather than over just a few months. In evaluating the solar system cost versus performance, its feasibility should be compared not only with the conventional system, but with all the other alternatives.

Criterion 33: Socio-economic outlook:

Different elements can play a crucial role here, e.g. the attitude of the users towards this new technology, the size and the degree of intensity of the populations. In this same socio-economic context, it is appropriate to stress the widely recognized desirable aspects of solar system from the environmental point of view.

Small villages, particularly the isolated ones and/or low population density, are the most appropriate location for solar applications because conventional supplies of electricity are both difficult and expensive to provide it to these villages. Camped et al. [8] suggest that, photovoltaic technologies has been often shown to be the most effective solution for improving such services in remote, un-electrified areas. The PV system includes a solar system consists of a photovoltaic solar panel; which convert the suns energy into electricity form depending on a propriety of certain semi-conductors; such as silicon, cadmium sulfide and gallium arsenide, battery, charging controller and end uses.

Grothoff [9] reported that, countries in Africa with the highest PV potential include among others, Sudan. Solar PV applications in Sudan started as early as 1970 [10]. PV technologies have a number of applications relevant to rural use in Northern State (Sudan). These include among others, electricity generation, PV pumping, telecommunication network, vaccine refrigeration for human and animal use, traffic lighting and lighting of road sign, over-speed detection on high ways, security services, schools power supply, rural health clinics, community centers and clubs, mosques and khalwa (s) lighting. A Field survey to selected locations showed that, the operators of the installed systems were certain people who were assigned to do the job, depending on where the utility was installed. Battery replacement and disposal were serious problems. Solar panels sited at ground level became dirty more quickly. Dust deposition on PV panels caused degradation of PV panel’s performance and energy yield losses, in the same manner other particulate accumulation (e.g. birds residues) causes on PV panels transmission loss. Also, there were cracks seen on the upper cover of solar panels in some sites. Solar panels mounted near ground were more susceptible to damage by animals or children. This necessitates both periodic cleaning and maintenance of the solar panels. The major problem was that solar energy technologies require high initial capital cost. Most of this capital cost for implementation of these technologies was provided by a number of international aid programs. The sustainability of most the project was not achieved and these projects had stopped after cessation of foreign funding. All of the potential uses of PV technologies are too numerous to include here, therefore, only some of the more important uses are mentioned, especially those that have been demonstrated successfully. The current contribution of solar energy systems to the energy sector in the State include:

3.4.1 Rural Electrification:

Table 3.1 presents the main sources of energy for lighting in the State, it cleared that 45% of the households doesn't used public electricity as energy source for lighting, major of these percentage is in rural area. The lack of electricity raises a lot of negative effects that dramatically limit a community's potential rate of growth, as well as residents' basic quality of life.

Table 3.1 Main sources of energy for lighting in Sudan:

Source of lighting	No. of households (%)
Without lighting	1
Candle	2
Wood	1
Kerosene lamp (lantern)	14
Generator	27
Public electricity	55

In recent years, attention has risen again regarding the issue of rural access to electricity supply and regarding the relation between energy (electricity) and poverty. Rural energy is generally recognized as an important element of rural socioeconomic development. Therefore, Barrier Removal to Secure PV Market Penetration in Semi-Urban Sudan Project (PVP) was started in 1999 and spreads over 12 states; included Northern State, to remove the barriers that hindered market penetration of PV applications in general and households in particular. The PVP funded jointly by UNDP, the Global Environment Facility (GEF) and the Government of Sudan. Generally, the project focused on dissemination of photovoltaic systems with emphasis on provision of electricity for small-scale applications to satisfy the first assessed need. The Northern State is large and sprawling, and has too Nile Islands and vast arable land. Therefore, solar electricity can be used for power supply to remote villages and locations not connected to the national grid. The main lighting systems using solar energy were installed in mosques and prayer rooms (Zaoya(s)), schools, health centers, clubs, security points and miscellaneous (some houses of authorized persons, official offices, Khalwa(s),etc.). Through PVP many such systems had been installed in the State and an achievement for improvements in social interaction was maintained. Number of solar panels in each system is illustrated in Fig 3.2; the largest number of systems is consisted of two solar panels for small uses.

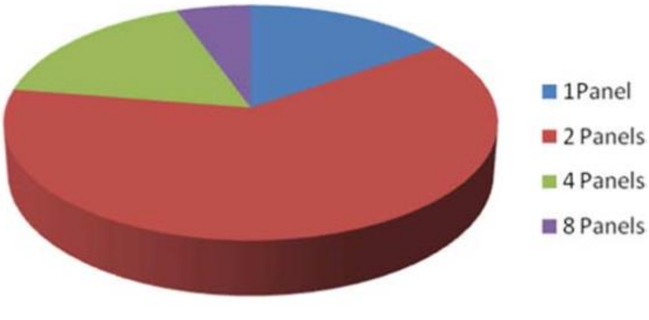


Figure 3.2 Number of solar panels in solar energy systems

Also, Fig 3.3. Shows the distribution of solar energy systems in the utilities, major part of the systems is used for operating of amplifiers and lighting of mosques and prayer room (Zaoya(s)) followed by schools power supply and health centers.

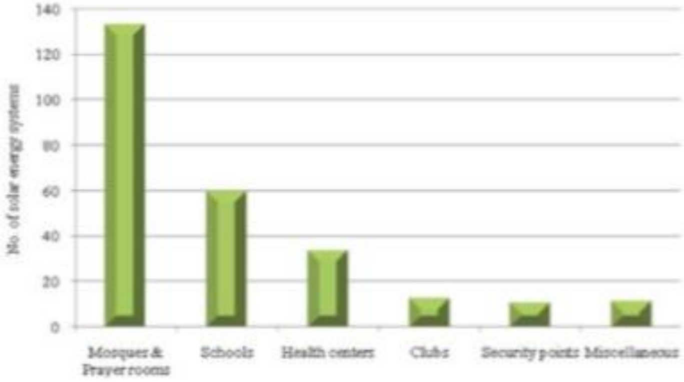


Figure 3.3 Distribution of solar energy systems in the utilities

3.5 Solar cells:

Solar cells and photodetectors are devices that convert an optical input into current. A solar cell is an example of a photovoltaic device, i.e, a device that generates voltage when exposed to light. The photovoltaic effect was discovered by Alexander-Edmond Becquerel in 1839, in a junction formed between an electrode (platinum) and an electrolyte (silver chloride). The first photovoltaic device was built, using a Si pn junction, by Russell Ohl in 1939. The functioning of a solar cell is similar to the photodiode (photodetector). It is a photodiode that is unbiased and connected to a load (impedance). There are three qualitative differences between a solar cell and photodetector 1. A photodiode works on a narrow range of wavelength while solar cells need to work over a broad spectral range (solar spectrum).

Solar cells are typically wide area devices to maximize exposure.

In photodiodes, the metric is quantum efficiency, which defines the signal to noise ratio, while for solar cells, it is the power conversion efficiency, which is the power delivered per incident solar energy. Usually, solar cells and the external load they are connected to are designed to maximize the delivered power.

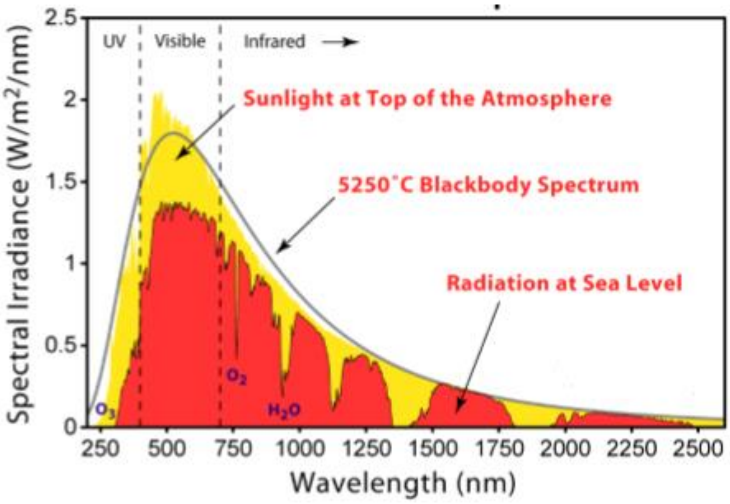


Figure 3.4 Spectral irradiance vs wavelength

3.5.1 Working principle:

A simple solar cell is a *pn* junction diode. The schematic of the device is shown in figure 3.5. The n region is heavily doped and thin so that the light can penetrate through it easily. The p region is lightly doped so that most of the depletion region lies in the p side. The penetration depends on the wavelength and the absorption coefficient increases as the wavelength decreases. Electron hole pairs (EHPs) are mainly created in the depletion region and due to the built-in potential and electric field, electrons move to the n region and the holes to the p region. When an external load is applied, the excess electrons travel through the load to recombine with the excess holes. Electrons and holes are also generated with the p and n regions, as seen from figure 3.5. The shorter wavelengths (higher absorption coefficient) are absorbed in the n region and the longer wavelengths are absorbed in the bulk of the p region. Some of the EHPs generated in these regions can also contribute to the current. Typically, these are EHPs that are generated within the minority carrier diffusion length, Le for electrons in the p side and L_h for holes in the n side. Carriers produced in this region can also diffuse into the depletion region and contribute to the current. Thus, the total width of the region that contributes to the solar cell current is wd + L_e + L_h, where w_d is the depletion width. This is shown in figure 3.6.The carriers are extracted by metal electrodes on either side. A finger electrode is used on the top to make the electrical contact, so that there is sufficient surface for the light to penetrate. The arrangement of the top electrode is shown in figure 3.7. Consider a solar cell made of Si. The band gap e.g. is 1.1 eV so that wavelength above 1.1 µm is not absorbed since the energy is lower than the band gap. Thus, any λ greater than 1.1 µm has negligible absorption. For λ much smaller than 1.1 µm the absorption coefficient is very high and the EHPs are generated near the surface and can get trapped near the surface defects. Therefore, there is an optimum range of wavelengths where EHPs can contribute to photocurrent, shown in figure 3.6.

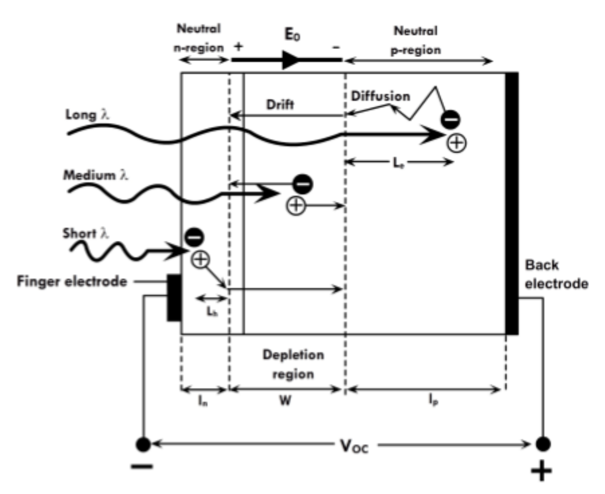


Figure 3.5 Principle of operation of solar cell

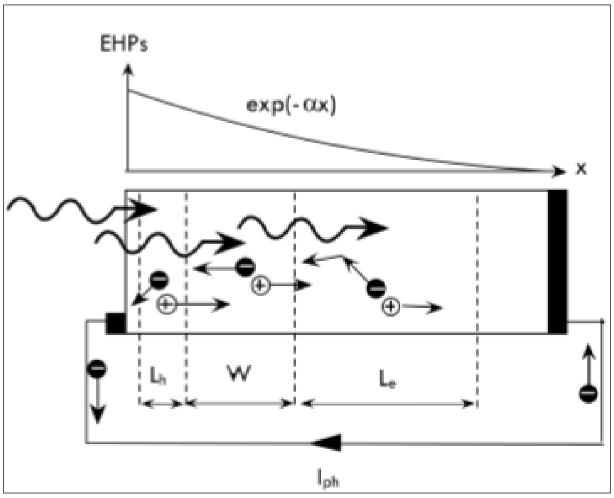


Figure 3.6 Photo generated carriers in a solar cell due to absorption of light

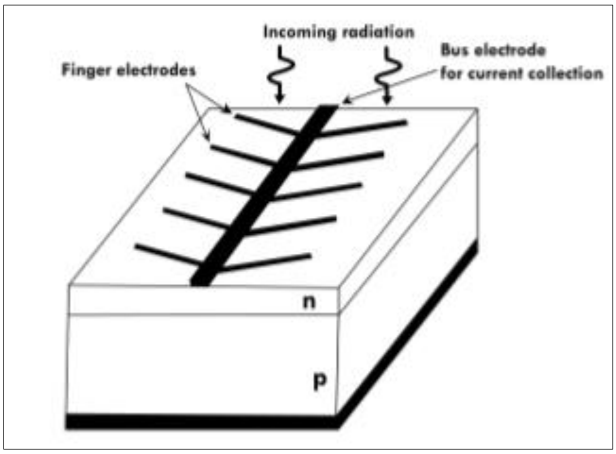


Figure 3.7 Finger electrodes on a pn junction solar cell

3.5.2 Solar cell I-V characteristics:

It possible to calculate the I-V characteristics of the solar cell by considering its equivalent circuit. The I-V characteristics depend on the intensity of the incident radiation and the operating point (external load) of the cell. Consider a pn junction solar cell under illumination, as shown in figure 3.8. If the external circuit is a short circuit, (external load resistance is zero) then the only current is due to the generated EHPs by the incident light. This is called the photocurrent, denoted by I_{ph}. Another name for this is the short circuit current,

I_{sc}. By definition of current, this is opposite to the photo current and is related to the intensity of the incident radiation, I_{op}, by

$$I_{sc} = -I_{ph} = -kI_{op} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 3.1$$

Where k is a constant and depends on the particular device. K is equivalent to an efficiency metric that measures the conversion of light into EHPs. Consider the case when there is an external load R, as shown in figure 3.8. The equivalent circuit for this case is shown in figure 3.9. There is a voltage across the external load, given by V = IR. This voltage opposes the built in potential and reduces the barrier for carrier injection across the junction. This is similar to a *pn* junction in forward bias, where the external bias causes injection of minority carriers and increased current. This forward bias current opposes the photocurrent generated within the device due to the solar radiation. This is because I_{ph} is generated due to electrons going to the n side and holes to the p side due to the electric field within the device i.e. drift current while the forward bias current is due to diffusion current caused by the injection of minority carriers. Thus, the net current can be written as

$$I = -I_{ph} + I_d \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 3.2$$

$$I_d = I_{s0}\,[\exp(\frac{ev}{K_B T}) - 1] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 3.3$$

$$I = -I_{ph} + I_{s0}\,[\exp(\frac{ev}{K_B T}) - 1] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 3.4$$

Where Id is the forward bias current and can be written in terms of the reverse saturation current, Is0 and external voltage, V. The overall I-V characteristics is plotted in figure 3.10. In the absence of light, the dark characteristics is similar to a *pn* junction I-V curve. The presence of light (I_{ph}) has the effect of shifting the I-V curve down. From figure 3.10, it is possible to define a photo current $I_{ph,}$

which is the current when the external voltage is zero and an open circuit voltage, V_{oc}, which is the voltage when the net current in the circuit is zero. Using equation 2, V_{oc} can be calculated as

$$I_{ph} = I_{s0}\left[\exp\left(\frac{ev_{oc}}{K_B T}\right) - 1\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 3.5$$

$$V_{oc} \approx \frac{K_B T}{e} \ln\left[\frac{I_{ph}}{I_{s0}}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 3.6$$

Higher the photon flux, higher is the value of I_{ph} (by equation 1), and higher the value of V_{oc}. Similarly, lower Is0 can also cause higher Voc. Since Is0 is the reverse saturation current for the *pn* junction, it is given by

$$I_{s0} = n_i^2 \, e \left(\frac{D_e}{L_e N_A} + \frac{D_h}{L_h N_D}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 3.7$$

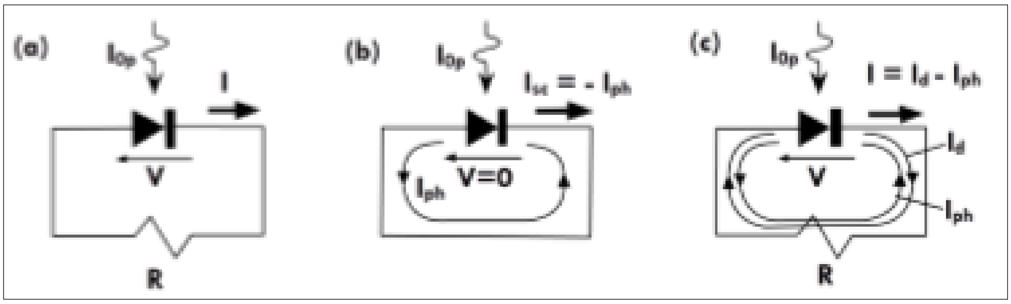


Figure 3.8 (a) pn junction solar cell under illumination with an external load. The equivalent circuit (b) without and (c) with an external load.

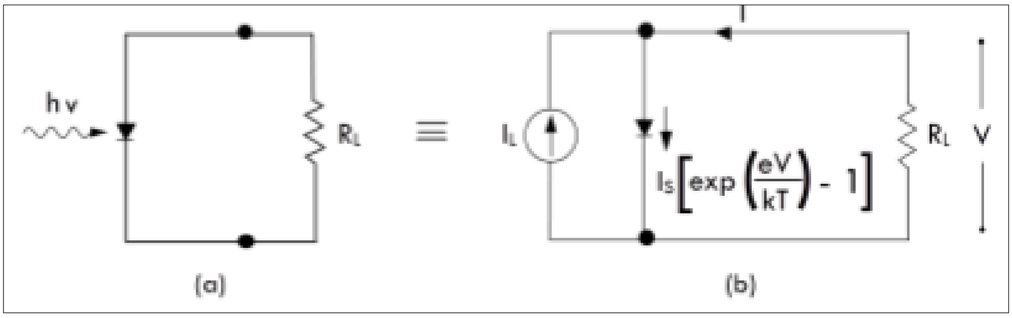


Figure 3.9 (a) A solar cell connected to an external load (b) Equivalent circuit, with a constant current source, a forward biased pn junction and the external load.

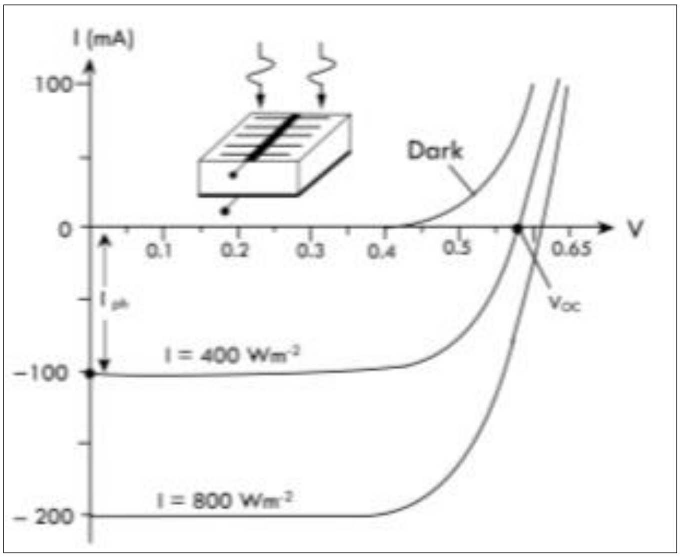


Figure 3.10 I−V characteristics of Si pn junction solar cell under dark conditions and under illumination with light of increasing intensity

3.5.3 Solar cell materials and efficiency:

Conventional solar cells are made of Si single crystal and have an efficiency of around 22-24%, while polycrystalline Si cells have an efficiency of 18%. A schematic representation of such a cell is shown in figure 3.7. The efficiency of the solar cell depends on the band gap of the material and this is shown in figure3.12. Polycrystalline solar cells are cheaper to manufacture but have a lower efficiency since the microstructure introduces defects in the material that can trap carriers. Amorphous solar cells have an even lower efficiency but can be grown directly on glass substrates by techniques like sputtering so that the overall cost of manufacturing is lowered. There are also design improvements in the solar cell that can enhance the efficiency. PERL (passivated emitter rear locally diffused) cells, shown in figure 3.13, have an efficiency of 24% due to the inverted pyramid structure etched on the surface that enhances absorption.

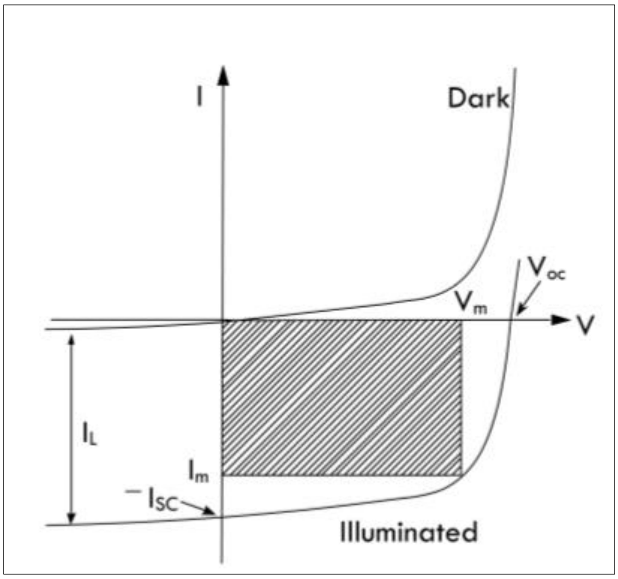


Figure 3.11 I-V curve for a solar cell with maximum power indicated by the shaded area

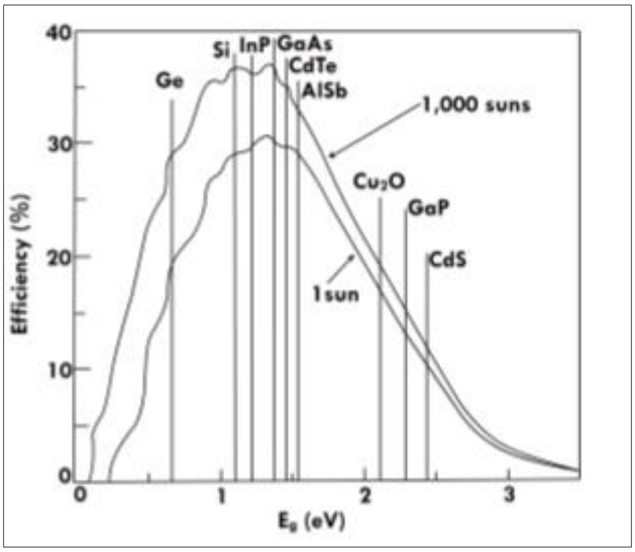


Figure 3.12 Solar cell efficiency as a function of band gap of the semiconductor material

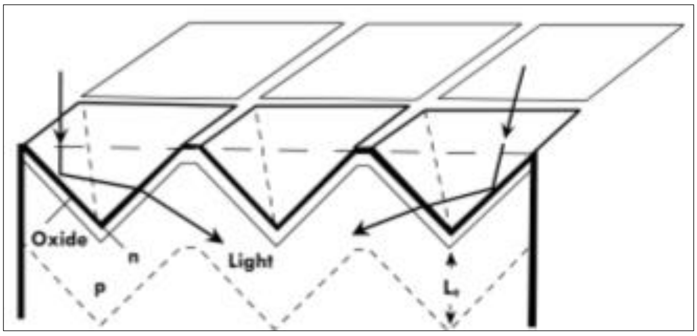


Figure 3.13 Si solar cell with an inverted pyramid structure to enhance absorption of the incoming radiation

Typical solar cells are made of the same material so that the pn junction is a homojunction. Some solar cell materials and their efficiencies are summarized in table 3.2. A comprehensive state of current research in different solar cell technologies and their efficiency is available in figure 3.14. Heterojunction solar cells are also possible and they have the advantage of minimizing absorption in regions other than the depletion region, but overall cost increases because of the use of different materials and the tight processing conditions needed to produce defect free interfaces. A schematic of such a cell based on GaAs/AlGaAs is shown in figure 3.15. The shorter wavelengths are absorbed by the AlGaAs layers while the longer wavelengths, with higher penetration depths, are absorbed by the GaAs layer. This leads to an overall efficiency of around 25%, see table 3.2. It is also possible to have a homojunction solar cell but with a passivating layer of another material at the surface to reduce defects. This is shown in figure 3.16. The surface passivating layer removes the dangling bonds and minimizes carrier trapping. The passivation layer is a thin layer of a higher band gap material to minimize absorption. Similarly, amorphous semiconductor materials like Si and Ge also have a passivating layer of H, a-Si:H or a-Ge:H, to reduce dangling bonds. Another way of improving solar cell efficiency is to have more than one cell in tandem. These are called tandem solar cells and a schematic is shown in figure 3.16. These consist of two pn junction solar cells, with the first one having a higher band gap than the second. Thus, the shorter wavelengths can be absorbed in cell 1, see figure 16, while the longer wavelengths are absorbed in cell 2. The advantage is that a larger portion of the solar radiation is used so that tandem cells have high efficiency, see table1, but it also adds a layer of complexity in growth and increases cost. Tandem cells can also be made using amorphous Si:H and Ge:H. These are cheaper to make and more efficient than individual amorphous solar cell devices.

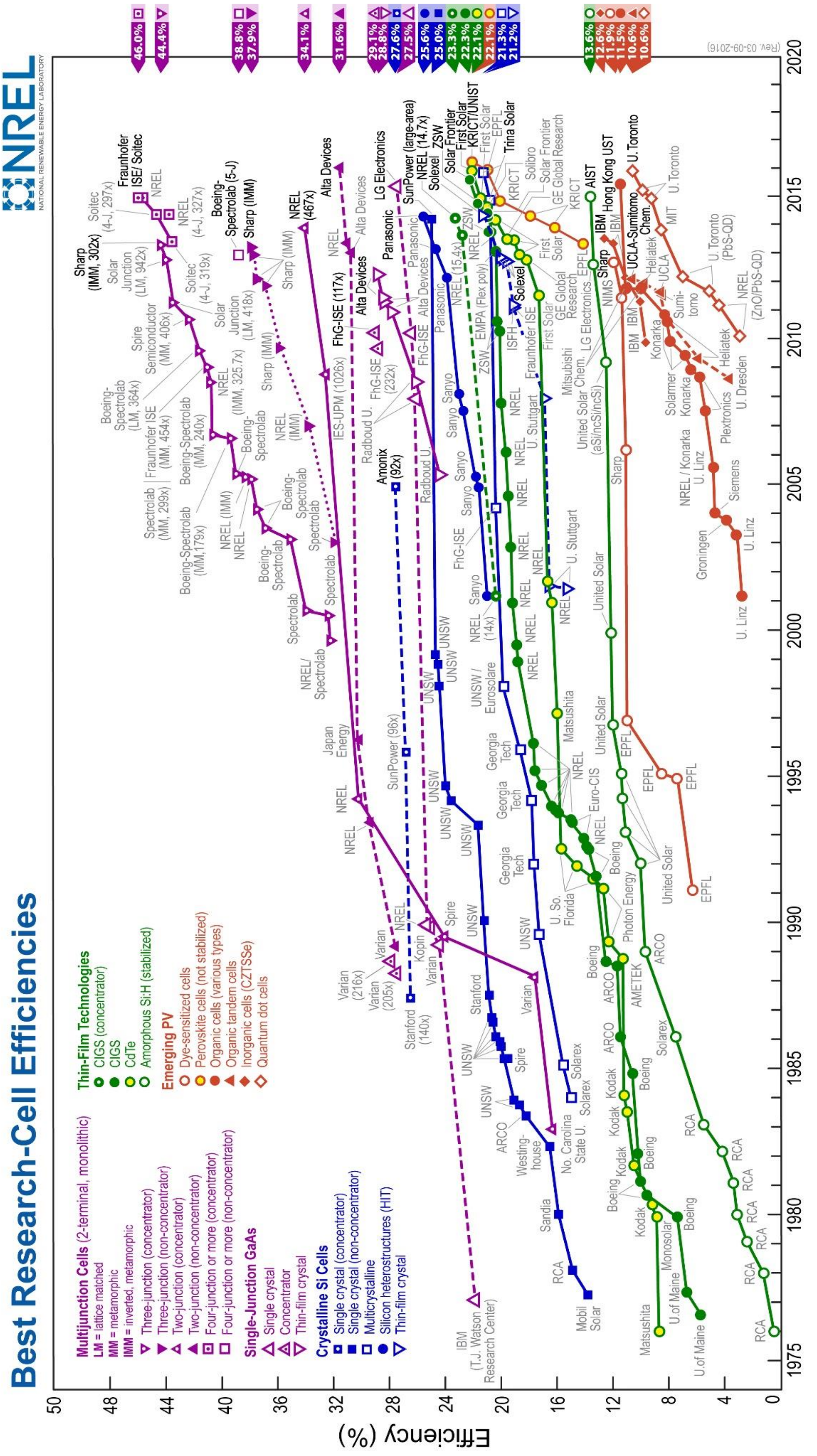


Figure 3.14 : Efficiency of various research solar cell

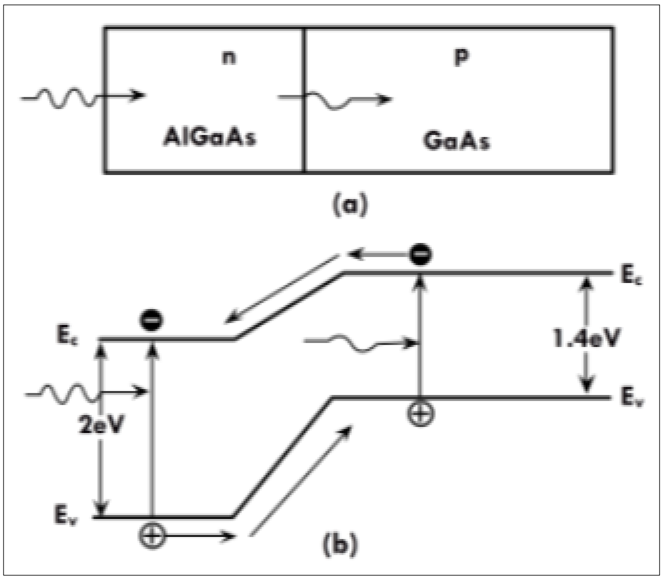


Figure 3.15 (a) GaAs/AlGaAs based heterojunction solar cell. (b) Energy band alignment across the junction

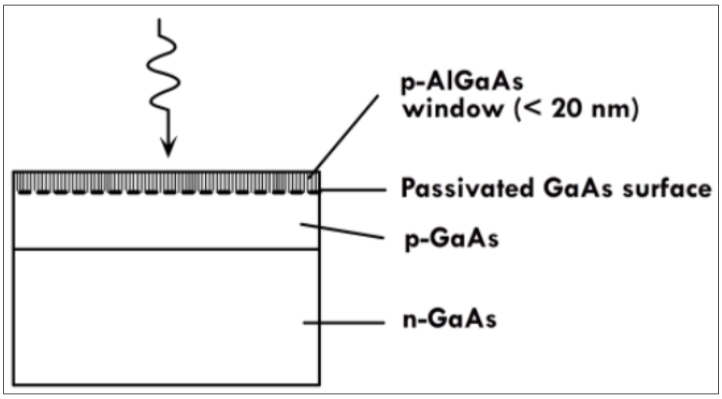


Figure 3.16 Schematic of a GaAs based homojunction solar cell with a surface passivating layer to minimize surface recombination

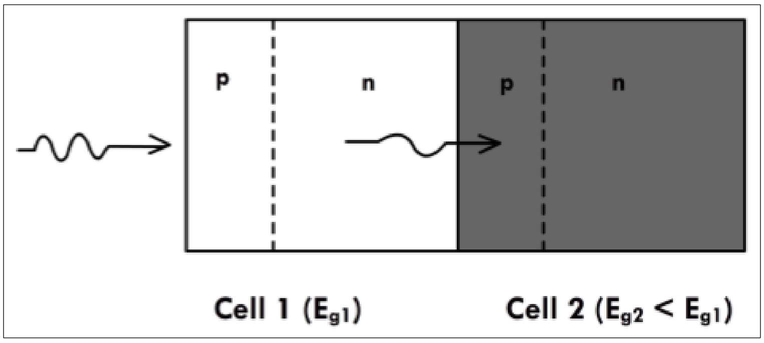
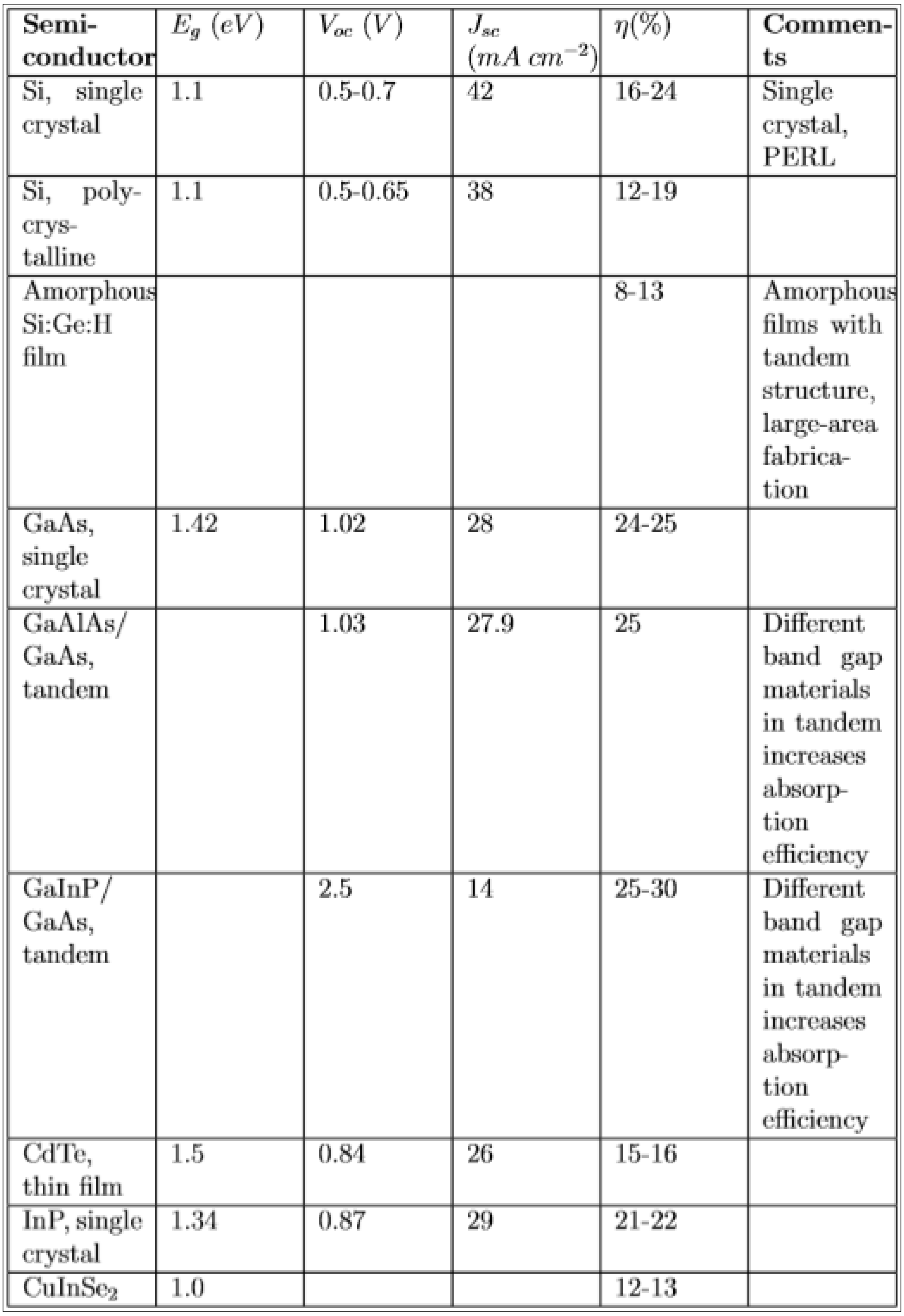


Figure 3.17 Tandem solar cells

Table 3.2 some common solar cell materials and their characteristics. Adapted from Principles of Electronic Materials - S.O. Kasap



Semiconductor	E_g (eV)	V_{oc} (V)	J_{sc} $(mA\ cm^{-2})$	$\eta(\%)$	**Comments**
Si, single crystal	1.1	0.5-0.7	42	16-24	Single crystal, PERL
Si, polycrystalline	1.1	0.5-0.65	38	12-19	
Amorphous Si:Ge:H film				8-13	Amorphous films with tandem structure, large-area fabrication
GaAs, single crystal	1.42	1.02	28	24-25	
GaAlAs/ GaAs, tandem		1.03	27.9	25	Different band gap materials in tandem increases absorption efficiency
GaInP/ GaAs, tandem		2.5	14	25-30	Different band gap materials in tandem increases absorption efficiency
CdTe, thin film	1.5	0.84	26	15-16	
InP, single crystal	1.34	0.87	29	21-22	
$CuInSe_2$	1.0			12-13	

CHAPTER FOUR

GENERAL DIFINITION (COMPONENTS)

4.1 Stepper motor:

Stepper motor is a special type of electric motor that moves in precisely defined increments of rotor position (Steps). The size of the increment is measured in degrees and can vary depending on the application [11]. Due to precise control, stepper motors are commonly used in medical, satellites, robotic and control applications. There are several features common to all stepper motors that make them ideally suited for these types of applications. They are as under High accuracy: Operate under open loop

Reliability: Stepper motors are brushless.

Load independent: Stepper motors rotate at a set speed under different load provided the rated torque is maintained.

Holding torque: For each step, the motor holds its position without brakes. Stepper motor requires sequencers and driver to operate. Sequencer generates sequence for switching which determines the direction of rotation and mode of operation. Driver is required to change the flux direction in the phase windings. The block diagram of stepper motor system is shown in Figure 4.1.

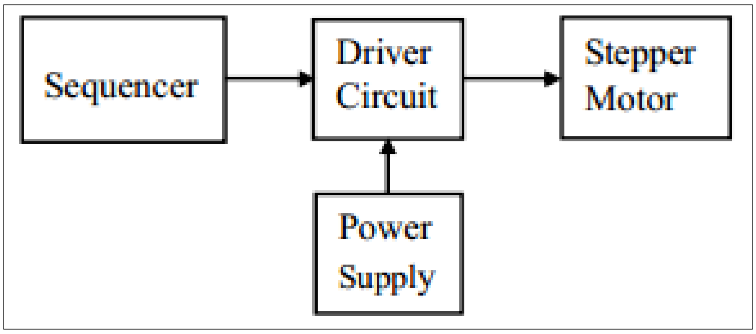


Figure 4.1 Block diagram of stepper motor system

4.1.1 Types of Stepper Motors:

It can be classified into several types according to machine structure and principle of operation as explained by Kenjo (1984). There are three types:

1. Variable Reluctance Motor (VRM)
2. Permanent Magnet Stepper Motor (PMSM)
3. Hybrid Stepper Motor (HSM)

4.1.1.1 Variable Reluctance Motor:

It consists of a soft iron multi-toothed rotor and a wound stator. When the stator windings are energized with DC current, the poles become magnetized. Rotation occurs when the rotor teeth are attracted to the energized stator poles. Both the stator and rotor materials must have high permeability and be capable of allowing high magnetic flux to pass through even if a low magneto motive force is applied. When the rotor teeth are directly lined up with the stator poles, the rotor is in a position of minimum reluctance to the magnetic flux [12].

A rotor step takes place when one stator phase is DE energized and the next phase in sequence is energized, thus creating a new position of minimum reluctance for the rotor as explained by Kenjo (1984). Cross-section of variable reluctance motor is shown in Figure 4.2.

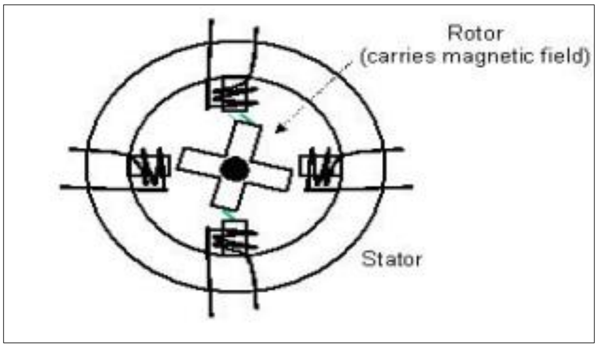


Figure 4.2 Cross-section of variable reluctance motor

4.1.1.2 Permanent Magnet Stepper Motor:

A stepper motor using a permanent magnet in the rotor is called a PMSM. The rotor no longer has teeth as with the VRM. Instead, the rotor is magnetized with alternating north and south poles situated in a straight line parallel to the rotor shaft. These magnetized rotor poles provide an increased magnetic flux intensity and, because of this the PM motor exhibits improved torque characteristics when compared with the VRM type [11], [13]. An elementary PM motor is shown in Figure 4.3, which employs a cylindrical permanent magnet as the rotor and possesses four poles in its stator. Two overlapping windings are wound as one winding on poles 1 and 3 and these two windings are separated from each other at terminals to keep them as independent windings. The same is true for poles 2 and 4. The terminals marked Ca or Cb denotes connected to the positive terminal of the power supply as explained by Kenjo (1984).

When the windings are excited in the sequence A - B - A1 - B1 --- the rotor will be driven in a clockwise direction. The step length is 900 in this machine. If the number of stator teeth and magnetic poles on the rotor are both doubled, a two-phase motor with a step length of 45^0 will be realized.

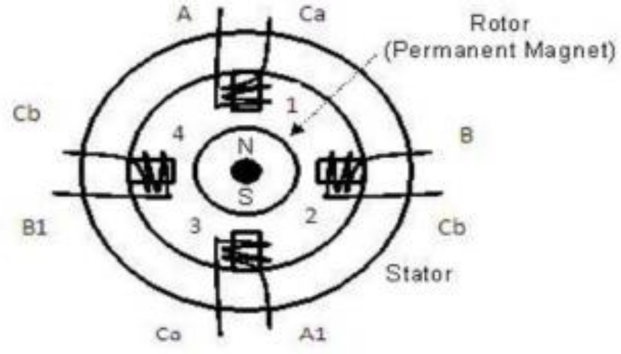


Figure 4.3 Cross-section of permanent magnet stepper motor

4.1.1.3 Hybrid Stepper Motor

The term hybrid is derived from the fact that motor is operated with the combined principles of the permanent magnet and variable reluctance motors in order to achieve small step length and high torque in spite of motor size. Standard HSM have 50 rotor teeth and rotate at 1.8 degree per step. Figures 4.4 & 4.5 show a cross section and cut view of two phase HSM. The windings are placed on the stator poles and a PM is mounted on the rotor. The important feature of the HSM is its rotor structure. A cylindrical or disk-shaped magnet lies in the rotor core. Stator and rotor end-caps are toothed. The coil in pole 1 and pole 3 is connected in series consisting of phase A and poles 2 and 4 are for phase B. If stator phase A is excited pole 1 acquires north polarity while pole 2 acquires south pole while pole 3 aligns with the rotor's north pole.

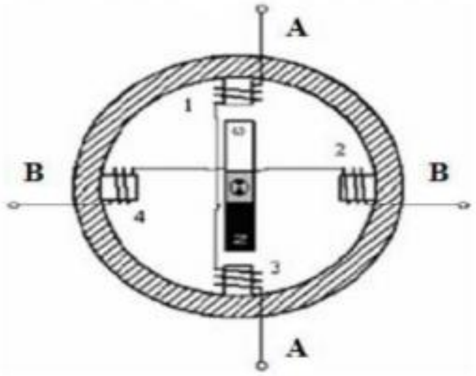


Figure 4.4 Cross-section of HSMMicrocontroller:

4.2Microcontroller:

A microcontroller often serves as the “brain” of a mechatronic system. Like a mini, self-contained computer, it can be programmed to interact with both the hardware of the system and the user. Even the most basic microcontroller can perform simple math operations, control digital outputs, and monitor digital inputs. As the computer industry has evolved, so has the technology associated with microcontrollers? Newer microcontrollers are much faster, have more memory, and have a host of input and output features that dwarf the ability of earlier models. Most modern controllers have analog-to-digital converters, high-speed timers and counters; interrupt capabilities, outputs that can be pulse-width modulated, serial communication ports, etc. [14].

A microcontroller is a self-contained system with peripherals, memory and a processor that can be used as an embedded system. Most programmable microcontrollers that are used today are embedded in other consumer products or machinery including phones, peripherals, automobiles and household appliances for computer systems. Due to that, another name for a microcontroller is "embedded controller." Some embedded systems are more sophisticated, while others have minimal requirements for memory and programming length and a low software complexity. Input and output devices include solenoids, LCD displays, relays, switches and sensors for data like humidity, temperature or light level, amongst others.

A microcontroller is a highly integrated chip, which includes on single chip, all or most of the parts needed for a controller. The microcontroller typically includes CPU (Central Processing Unit), RAM (Random Access Memory), EPROM/PROM/ROM (Erasable Programmable Read Only Memory), I/O (input/output) – serial and parallel, timers, interrupt controller. For example, Intel 8051 is 8-bit microcontroller and Intel 8096 is 16-bit microcontroller.

By only including the features specific to the task (control), cost is relatively low. A typical microcontroller has bit manipulation instructions, easy and direct access to I/O (input/output), and quick and efficient interrupt processing. Figure 4.3 shows the block diagram of a typical microcontroller.

Microcontroller includes RAM, ROM, serial and parallel interface, timer, interrupt schedule circuitry (in addition to CPU) in a single chip

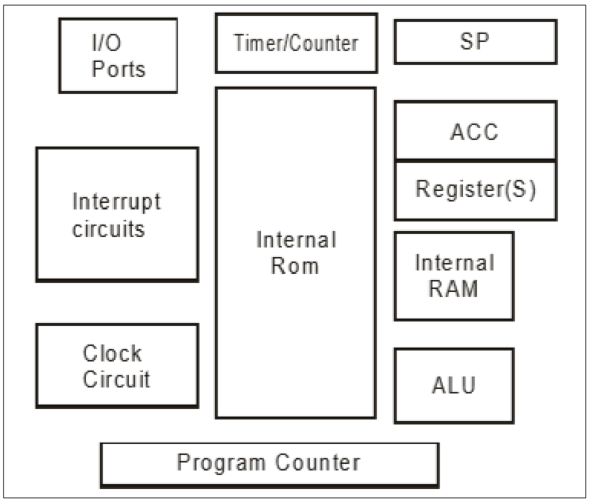


Figure 4.5 A block diagram of a microcontroller

4.2.1 Central Processing Unit (CPU):

CPU is the brain of the computer system, administers all activity in the system and performs all operations on data. It continuously performs two operations: fetching and executing instructions. It understand and execute instructions based on a set of binary codes called the instruction set.

4.2.2 Machine Cycle:

To execute an instruction–the processor must:

1. Fetch the instruction from memory
2. Decode the instruction
3. Execute the instruction
4. Store the result back in the memory.

These four steps refer to Machine Cycle. Generally one machine cycle = X clock cycles ("X" depends on the particular instruction being executed). Shorter the clock cycle, lesser the time it takes to complete one machine cycle, so instructions are executed faster. Hence, faster the processor.

4.2.3 Fetching and Executing an Instruction:

Fetching involves the following steps: (a) Contents of PC are placed on address bus. (b) READ signal is activated. (c) Data (instruction opcode) are read from RAM and placed on data bus. (d) Opcode is latched into the CPU's internal instruction register. (e) PC is incremented to prepare for the next fetch from memory. While execution involves decoding the opcode and generating control signals to gate internal registers in and out of the ALU and to signal the ALU to perform the specified operation.

4.2.4 The Buses: Address, Data, and Control:

A Bus is a collection of wires carrying information with a common purpose. For each read or write operation, the CPU specifies the location of the data or instruction by placing an address on the address bus then activates a signal on the control bus indicating whether the operation is read or write.

- Read Operations retrieve a byte of data from memory at the location specified and place it on the data bus CPU reads the data and places it in one of its internal registers.
- Write Operations put data from CPU on the data bus and store it in the location specified.

ADDRESS BUS carries the address of a specified location. For n, address lines, 2^n locations can be accessed. E.g., A 16-bit address bus can access $2^{16} = 65,536$ locations or 64K locations ($2^{10} = 1024 = 1K$, $2^6 = 64$).

DATA BUS carries information between the CPU and memory or between the CPU and I/O devices.

CONTROL BUS carries control signals supplied by the CPU to synchronize the movement of information on the address and data bus.

Control/Monitor (Input/Output) Devices:

Control Devices are outputs, or actuators, that can affect the world around them when supplied with a voltage or current. Monitoring Devices are inputs, or sensors, that are stimulated by temperature, pressure, light, motion, etc. and convert this to voltage or current read by the computer. Note: The interface circuitry converts the voltage or current to binary data, or vice versa.

4.2.5 Types of Microcontrollers:

Microcontrollers can be classified on the basis of internal bus width, architecture, memory and instruction set. Figure 4.6 shows the various types of microcontrollers.

4.2.5.1 The 8, 16 and 32-Bit Microcontrollers:

The 8-Bit Microcontroller: When the ALU performs arithmetic and logical operations on a byte (8-bits) at an instruction; the microcontroller is an 8-bit microcontroller. The internal bus width of 8-bit microcontroller is of 8-bit. Examples of 8-bit microcontrollers are Intel 8051 family and Motorola MC68HC11 family.

The 16-Bit Microcontroller: When the ALU performs arithmetic and logical operations on a word (16-bits) at an instruction; the microcontroller is a 16-bit microcontroller. The internal bus width of 16-bit microcontroller is of 16-bit. Examples of 16-bit microcontrollers are Intel 8096 family and Motorola MC68HC12 and MC68332 families. The performance and computing capability of 16-bit microcontrollers are enhanced with greater precision as compared to the 8-bit microcontrollers.

The 32-Bit Microcontroller: When the ALU performs arithmetic and logical operations on a double word (32bits) at an instruction; the microcontroller is a 32-bit microcontroller. The internal bus width of 32-bit microcontroller is of 32-

bit. Examples of 32-bit microcontrollers are Intel 80960 family and Motorola M683xx and Intel/Atmel 251 family. The performance and computing capability of 32-bit microcontrollers are enhanced with greater precision as compared to the 16-bit microcontrollers.

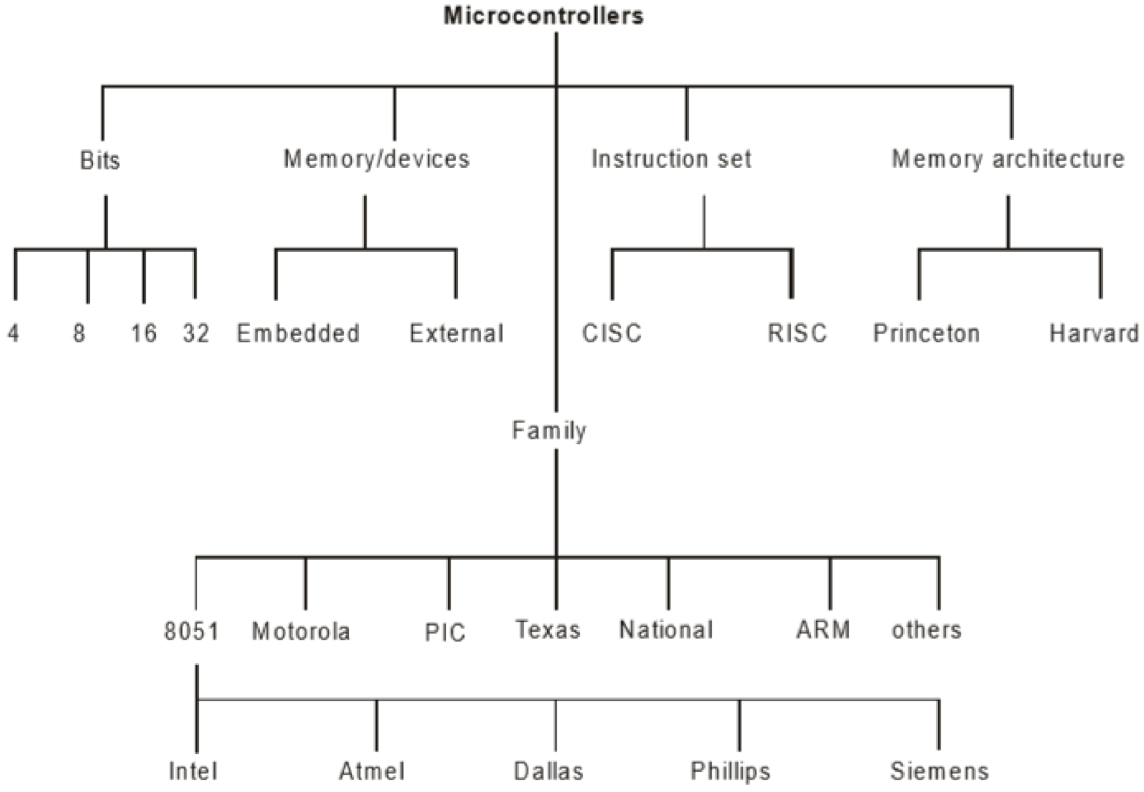


Figure 4.6 Types of microcontrollers

4.2.5.2 Embedded and External Memory Microcontrollers:

EMBEDDED MICROCONTROLLERS: When an embedded system has a microcontroller, unit that has all the functional blocks (including program as well as data memory) available on a chip is called an embedded microcontroller. For example, 8051 having Program & Data Memory, I/O Ports, Serial Communication, Counters and Timers and Interrupt Control logic on the chip is an embedded microcontroller.

External Memory Microcontrollers: When an embedded system has a microcontroller unit that has not all the functional blocks available on a chip is called an external memory microcontroller. In external memory microcontroller, all or part of the memory units are externally interfaced using an interfacing circuit called the glue circuit. For example, 8031 has no program memory on the chip is an external memory microcontroller.

4.2.5.3 Microcontroller Architectural Features:

There are mainly two categories of processors, namely, Von-Neuman (or Princeton) architecture and Harvard Architecture. These two architecture differ in the way data and programs are stored and accessed.

4.2.6 Microcontroller Applications:

In addition to control applications such as the home monitoring system, microcontrollers are frequently found in embedded applications. Among the many uses that you can find one or more microcontrollers: automotive applications, appliances (microwave oven, refrigerators, television and VCRs, stereos), automobiles (engine control, diagnostics, climate control), environmental control (greenhouse, factory, home), instrumentation, aerospace, and thousands of other uses. Microcontrollers are used extensively in robotics. In this application, many specific tasks might be distributed among a large number of microcontrollers in one system. Communications between each microcontroller and a central, more powerful microcontroller (or microcomputer, or even large computer) would enable information to be processed by the central computer, or to be passed around to other microcontrollers in the system. A special application that microcontrollers are well suited for is data logging. By stick one of these chips out in the middle of a cornfield or up in a balloon, one can monitor and record environmental parameters (temperature, humidity, rain, etc.). Small size, low power consumption, and flexibility make these devices ideal for unattended data monitoring and recording.

4.2.7 Microcontroller ATmega16:

ATmega16 is an 8-bit high performance microcontroller of Atmel's Mega AVR family with low power consumption. Atmega16 is based on enhanced RISC (Reduced Instruction Set Computing) architecture with 131 powerful instructions. Most of the instructions execute in one machine cycle. Atmega16 can work on a maximum frequency of 16MHz.

ATmega16 has 16 KB programmable flash memory, static RAM of 1 KB and EEPROM of 512 Bytes. The endurance cycle of flash memory and EEPROM is 10,000 and 100,000, respectively.

ATmega16 is a 40-pin microcontroller. There are 32 I/O (input/output) lines, which are divided into four 8-bit ports designated as PORTA, PORTB, PORTC and PORTD.

ATmega16 has various in-built peripherals like USART, ADC, Analog Comparator, SPI, JTAG etc. Each I/O pin has an alternative task related to in-built peripherals. The figure 4.7 shows the pin description of ATmega16.

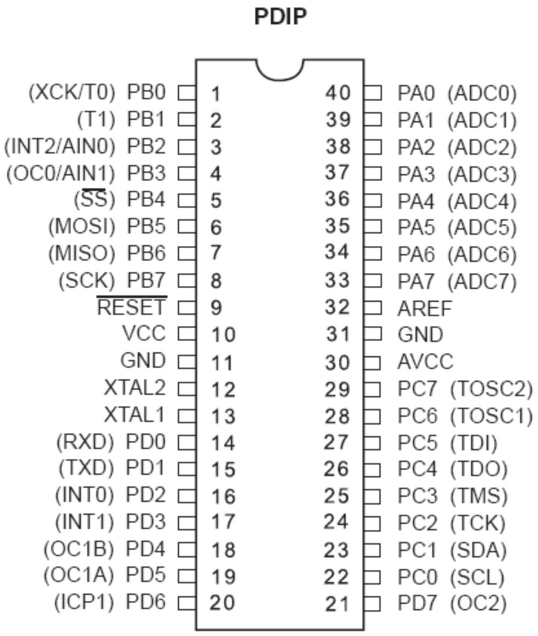


Figure 4.7 ATmega16 Pin-out diagram

4.3 Sensors:

A sensor is a device that detects and responds to some type of input from the physical environment. The specific input could be light, heat, motion, moisture, pressure, or any one of a great number of other environmental phenomena. The output is generally a signal that is converted to human-readable display at the sensor location or transmitted electronically over a network for reading or further processing.

Sensor is a device that when exposed to a physical phenomenon (temperature, displacement, force, etc.) produces a proportional output signal (electrical, mechanical, magnetic, etc.).The term soften used synonymously with sensors. However, ideally, a sensor is a device that responds to a change in the physical phenomenon. On the other hand, a transducer is a device that converts one form of energy into another form of energy. Sensors are transducers when they sense one form of energy input and output in a different form of energy. For example, a thermocouple responds to a temperature change (thermal energy) and outputs a proportional change in electromotive force (electrical energy). Therefore, a thermocouple can be called a sensor and or transducer [15].

4.3.1 Classification:

Table 4.1 lists various types of sensors that are classified by their measurement objectives. Although this list is by no means exhaustive, it covers all the basic types including the new generation sensors such as smart material sensors, micro-sensors, and Nano-sensors [15].

Table 4.1 Type of Sensors for Various Measurement Objectives (Continued)

Sensor	Features
	Linear/Rotational sensors
Linear/Rotational variable differential transducer (LVDT/RVDT)	High resolution with wide range capability Very stable in static and quasi-static applications
Optical encoder	Simple, reliable, and low-cost solution Good for both absolute and incremental measurements
Electrical tachometer	Resolution depends on type such as generator or magnetic pickups
Hall effect sensor	High accuracy over a small to medium range
Capacitive transducer	Very high resolution with high sensitivity Low power requirements Good for high frequency dynamic measurements
Strain gauge elements	Very high accuracy in small ranges Provides high resolution at low noise levels
Interferometer	Laser systems provide extremely high resolution in large ranges Very reliable and expensive
Magnetic pickup	Output is sinusoidal
Gyroscope	
Inductosyn	Very high resolution over small ranges
	Acceleration sensors
Seismic accelerometer	Good for measuring frequencies up to 40% of its natural frequency
Piezoelectric accelerometer	High sensitivity, compact, and rugged Very high natural frequency (100 kHz typical)
	Force, torque, and pressure sensor
Strain gauge	Good for both static and dynamic measurements
Dynamometers/load cells	They are also available as micro- and Nano-sensors
Piezoelectric load cells	Good for high precision dynamic force measurements
Tactile sensor	Compact, has wide dynamic range, and high
Tactile sensor	Good for small force measurements
	Flow sensors
Pitot tube	Widely used as a flow rate sensor to determine speed in aircrafts
Orifice plate	Least expensive with limited range
Flow nozzle, venturi tubes	Accurate on wide range of flow More complex and expensive
Rotameter	Good for upstream flow measurements

Ultrasonic type Turbine flow meter Electromagnetic flow meter	Used in conjunction with variable inductance sensor Good for very high flow rates Can be used for both upstream and downstream flow measurements Not suited for fluids containing abrasive particles Relationship between flow rate and angular velocity is linear Least intrusive as it is noncontact type Can be used with fluids that are corrosive, contaminated, etc. The fluid has to be electrically conductive
Thermocouples Thermistors Thermodiodes, thermos transistors RTD—resistance temperature detector Infrared type Infrared thermography	**Temperature sensors** This is the cheapest and the most versatile sensor Applicable over wide temperature ranges (-200∞C to 1200∞C typical) Very high sensitivity in medium ranges (up to 100∞C typical) Compact but nonlinear in nature Ideally suited for chip temperature measurements Minimized self-heating More stable over a long period of time compared to thermocouple Linear over a wide range Noncontact point sensor with resolution limited by wavelength Measures whole-field temperature distribution
Inductance, eddy current, hall effect, photoelectric, capacitance, etc.	**Proximity sensors** Robust noncontact switching action The digital outputs are often directly fed to the digital controller
Photo resistors, photodiodes, photo transistors, photo conductors, etc. Charge-coupled diode	**Light sensors** Measure light intensity with high sensitivity Inexpensive, reliable, and noncontact sensor Charge-coupled diode

4.3.2 Light Dependent Resistor:

A Light Dependent Resistor (LDR) or a photo resistor is a device whose resistivity is a function of the incident electromagnetic radiation. Hence, they are light sensitive devices. They are also called as photo conductors, photoconductive cells or simply photocells, hey are made up of semiconductor materials having high resistance. There are many different symbols used to indicate a LDR, one of the most commonly used symbol is shown in the figure 4.8. The arrow indicates light falling on it.

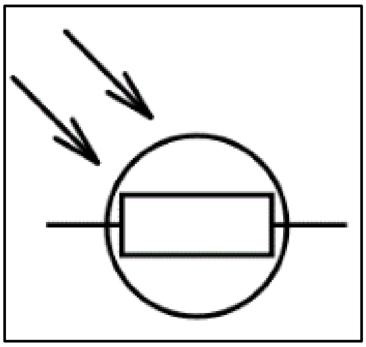


Figure 4.8 Light Dependent Resistor (LDR)

4.3.3 Characteristics of LDR:

LDR’s are light dependent devices whose resistance is decreased when light falls on them and that is increased in the dark. When a light dependent resistor is kept in dark, its resistance is very high. This resistance is called as dark resistance. It can be as high as 1012 Ω and if the device is allowed to absorb light its resistance will be decreased drastically. If a constant voltage is applied to it and intensity of, light is increased, the current starts increasing. Figure 4.9 shows resistance vs. illumination curve for a particular LDR.

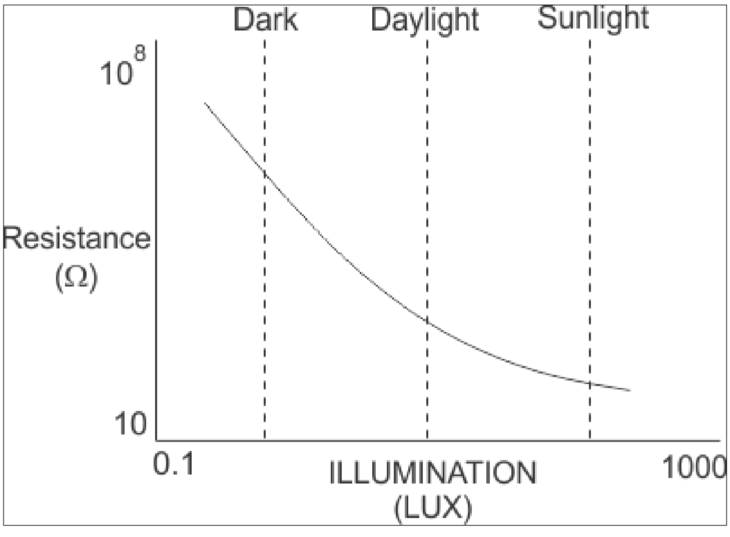


Figure 4.9 resistance vs. illumination curve for a particular LDR

Based on the materials used they are classified as:

1. Intrinsic photo resistors (Un doped semiconductor): These are made of pure semiconductor materials such as silicon or germanium. Electrons get excited from valance band to conduction band when photons of enough energy fall on it and number charge carriers is increased.
2. Extrinsic photo resistors: These are semiconductor materials doped with impurities, which are called as dopants. Theses dopants create new energy bands above the valence band, which are filled with electrons. Hence, this reduces the band gap and less energy is required in exciting them. Extrinsic photo resistors are generally used for long wavelengths.

4.3.4 Construction of a Photocell:

The structure of a light dependent resistor consists of a light sensitive material, which is deposited on an insulating substrate such as ceramic. The material is deposited in zigzag pattern in order to obtain the desired resistance and power rating. This zigzag area separates the metal-deposited areas into two regions. Then the ohmic contacts are made on the either sides of the area. The resistances of these contacts should be as less as possible to make sure that the resistance mainly changes due to the effect of light only. Materials normally used are cadmium sulphide, cadmium selenide, indium antimonide and cadmium sulphonide. The use of lead and cadmium is avoided, as they are harmful to the environment See figure 4.10.

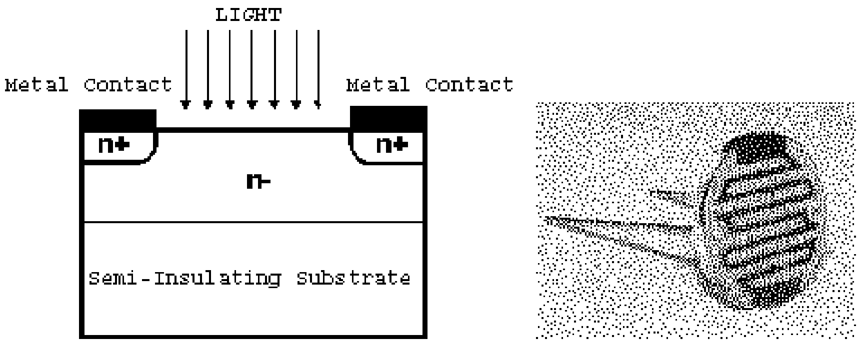


Figure 4.10 Materials of light dependent resistor (LDR)

4.4 Motor driver IC (ULN2003):

ULN2003 is a high voltage and high current Darlington array IC. It contains seven open collector Darlington pairs with common emitters. A Darlington pair is an arrangement of two bipolar transistors. ULN2003 is commonly used while driving stepper motor.

- Pin 1: Input 1: Input for 1st channel.
- Pin 2: Input 2: Input for 2nd channel.
- Pin 3: Input 3: Input for 3rd channel.
- Pin 4: Input 4: Input for 4th channel.
- Pin 5: Input 5: Input for 5th channel.
- Pin 6: Input 6: Input for 6th channel.
- Pin 7: Input 7: Input for 7th channel.
- Pin 8: Ground: Ground (0V).
- Pin 9: Common: Common freewheeling diodes.
- Pin 10: Output 7: Output for 7th channel.
- Pin 11: Output 6: Output for 6th channel.
- Pin 12: Output 5: Output for 5th channel.
- Pin 13: Output 4: Output for 4th channel.
- Pin 14: Output 3: Output for 3rd channel.
- Pin 15: Output 2: Output for 2nd channel.
- Pin 16: Output 1: Output for 1st channel.

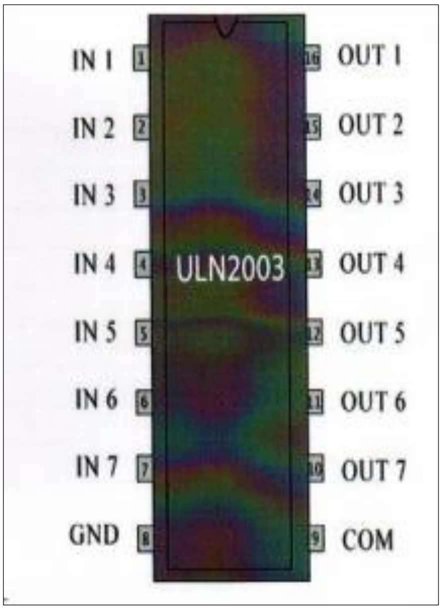


Figure 4.11 Motor driver IC

CHAPTER FIVE

RESULTS, SIMULATIONS AND DISCUSSIONS

5.1 Preview:

This project considered as the development of (solar tracking systems) in order to obtain the highest energy from the solar board, and this can only happen if we turn the solar board surface to be vertical with the sunrays the entire day.

The main purpose of this design is firstly to track the sun direction and secondly to avoid the problems that faced the previous designs such as:

- The seasonal shifts problem: where the previous designs needed to be mobilized manually.
- The problem of turning on/off the system.
- The cloud cover problem.
- The accidental undesirable light, flashing at night.

5.2 List of components:

1. Photo sensors, 4- Light Dependent Resistor (LDRs).
2. The control, (Microcontroller atmega16).
3. Drivers, 2- (ULN2003).
4. Motors, 2- (Stepper motor).
5. Resistors, 4- (Resistors 10 Ω).
6. Capacitors, 2- (Capacitors 10 nf).
7. LCD display screen, (LCD 20*2).
8. Limit Switch 3- (Solid opt switch).
9. Variable voltage source (Power Supply).

5.3 The Practical circuit

The practical circuit consists of two-step drives (12V DC), by step angle (0.5) degree, and display screen (LCD) with the size of (20*2), for displaying the different modes of the tracking system. A set of light dependent resistor (LDR) that have been linked with resisters to make voltage divider circuit and to produce an income signal for the microcontroller. A set of switches type (Slotted Opto switches) and two current drive circuits (ULN2003) to control the feeding access to the two stepper motors or to separate the feed from the two-stepper motors. The drive circuit is in the middle, between the stepper motor and the microcontroller

The four light dependent resistors (sensors) were connected in (PORTA), where the southern and northern light sensors were connected (PORTA.1 PORTA.0). While the eastern and western light sensors are connected to (PORTA.3, PORTA.2). The display (LCD) is also connected in (PORTC). The stepper motor which is responsible for the movement in the southern and northern directions was plugged into the upper part of the (PORTD) through current drive circuit (ULN2003). Moreover, the stepper motor responsible for the movement in the eastern and western directions was plugged into (PORTB) through current drive circuit also. The three keys (slotted Opto switches) were connected to the other (PORTB), where the top key (switch up) was connected in (PORTB.5), the lower key (switch down) is in (PORTB.4) and the key placed in the base (base switch), is plugged in (PORTB.6).

(5V DC) was used to feed the micro controller and the ADC in PORTA. In addition, the stepper motors were connected to 12V DC through adapter voltage as in the figure 5.1.

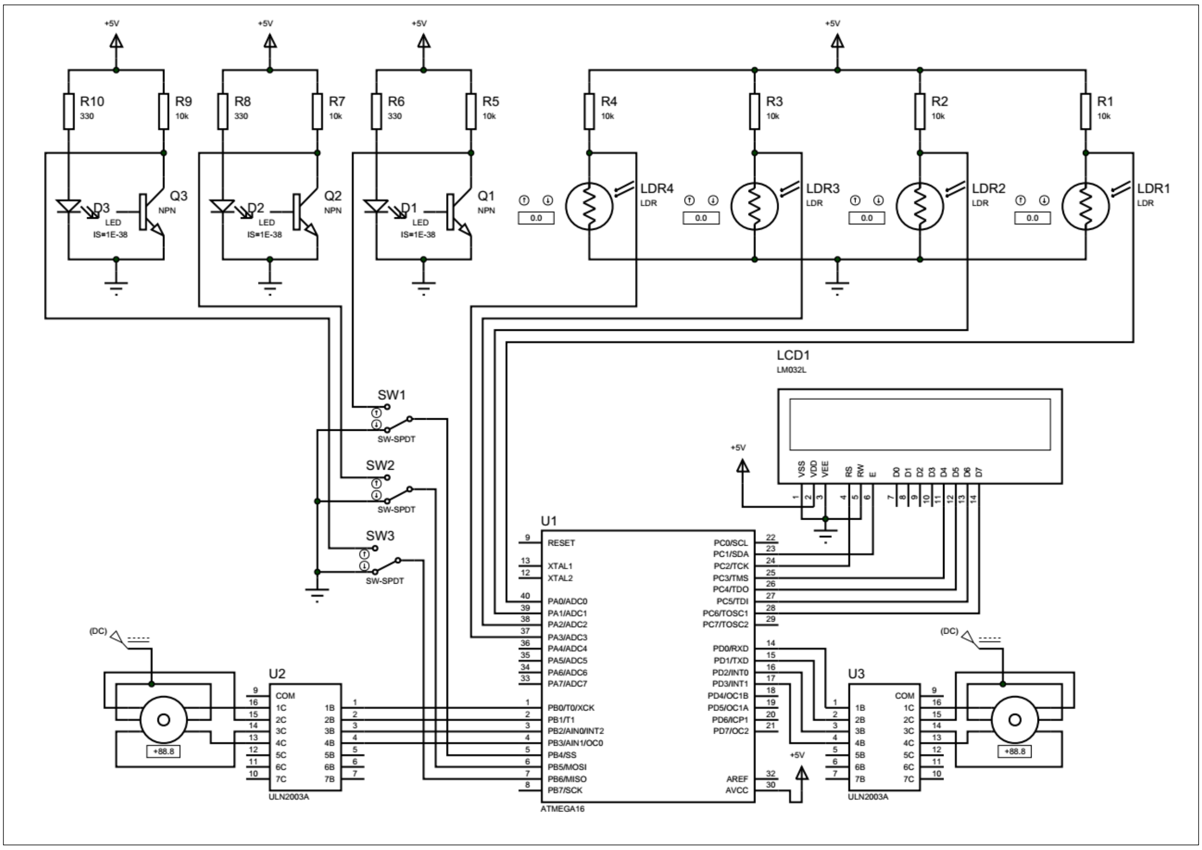


Figure 5.1 Schematic representation to the system

5.4 The operational process of the system:

We operate the system through several procedures, which includes:

5.4.1 How the system is Switching On:

The system starts functioning by the initial readings of the two sensors, the northern and southern. Where the base starts to rotate in a horizontal level by using stepper motor stationed at the bottom of the system. A searching procedure takes place and when the values of the two sensors become equals, then the motor (base) stops its rotational movement. the eastern and western sensors then begins sensing the light and the solar board starts rotating vertically by the stepper motor which stationed at the top of the system until the values of the two sensors are equal, again the motor stops its rational movement. As a result, the solar board moves towards the sun as it moves as in the figure 5.2.

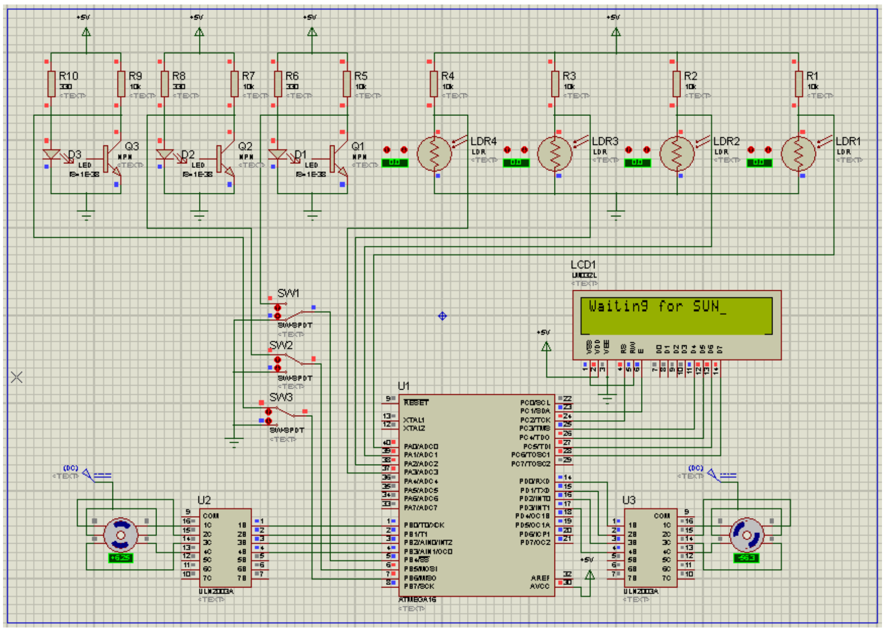


Figure 5.2 Waiting for the Sun

5.4.2 When there is a cloud cover.

In case of cloudy weather, the base remains fixed to insure that the board is still facing or tracking the exact direction of the sun after the clouds fade. In this condition, the board goes back to the home position (waiting mode) to protect itself from the heavy wind and storms, and remains stable until the sun appears again as in the figure 5.3.

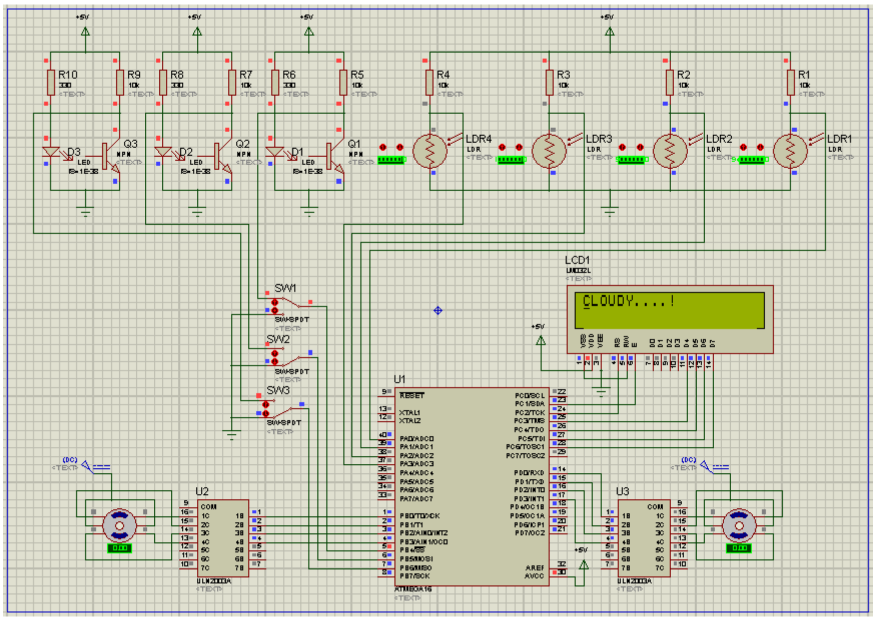


Figure 5.3 the clouds position

5.4.3 How the system is switching-Off at night:

When the east-west sensors read a very few values of light, the system will stop and the board returns to the horizontal position as the whole system gets back to the primary status (see figure 5.4).

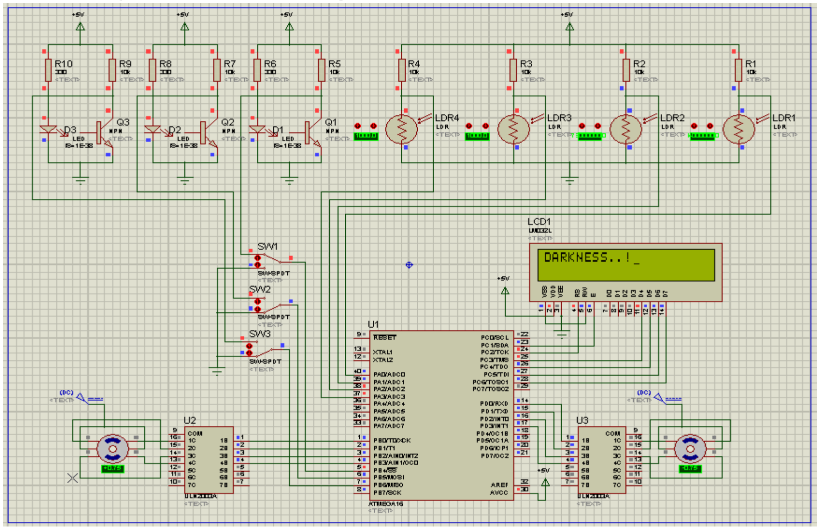


Figure 5.4 the darkness position

5.4.4 The Problem of variation between Seasons

In the different seasons, the Sun leans to the north side or the south side of this system. The tilt issue was treated by moving the whole base at the moment of sunrise and stops in the direction of the sun, and the board starts to move and follow the sun as in the figure5.5.

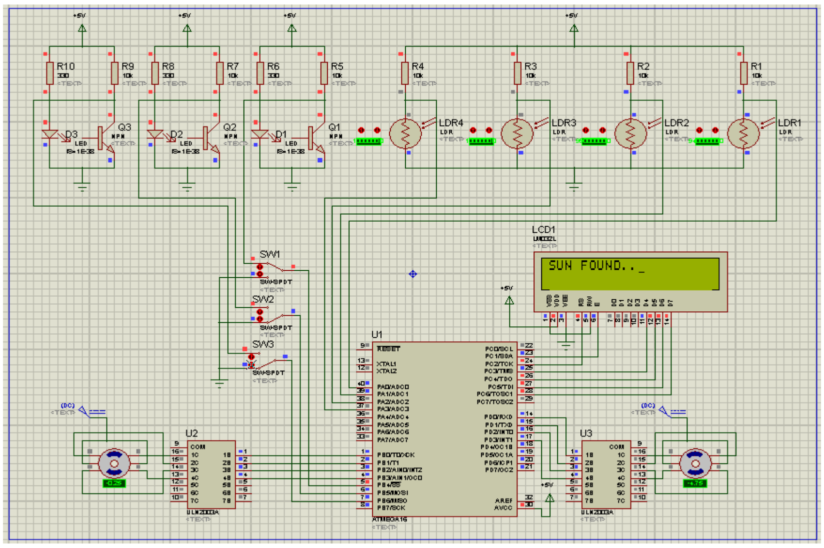


Figure 5.5 Search for the sun in the north and south direction

5.4.5 The problem of accidental light when the system is off at night

If any light fall on the system at night during the system's inactivity, the sensors feel that light, and the system will search for it, but the light is no longer there so the system will return to the primary inactive mode.

5.4.6 The movement of the system when searching for light at the beginning of the day

At sunrise, sensors are sensitive to the light. In this case, the board takes the vertical position by using the stepper motor, and then the base will move also by the motor responsible for this job towards the north-south directions, the base stops moving when the sensors values of the North and south are equal and then the board starts to move with the sun in the direction of the West as in figure 5.6 and flow chart in figure 5.8.

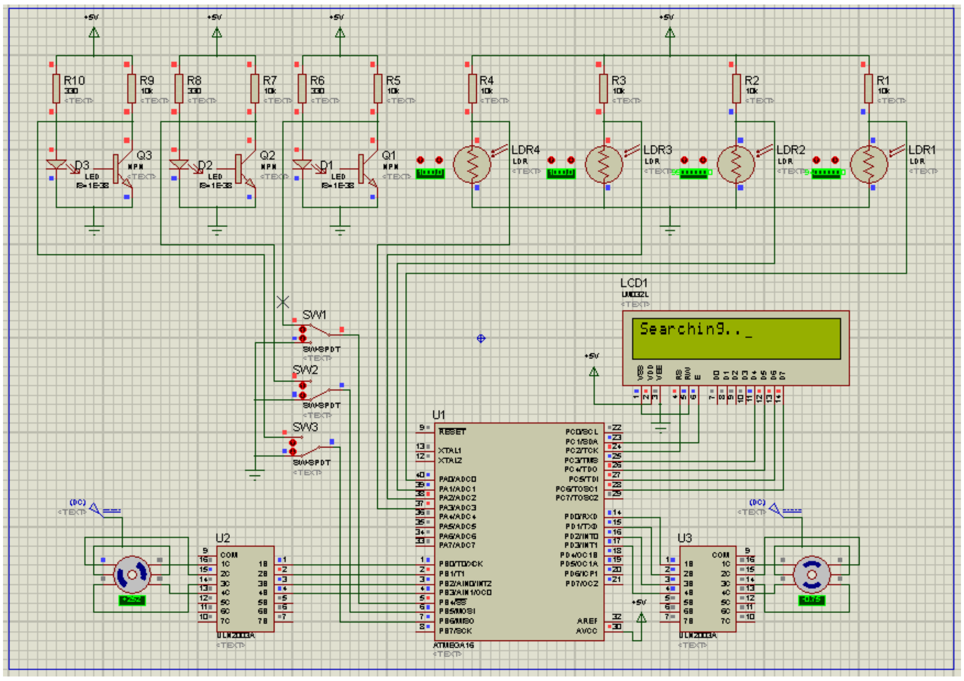


Figure 5.6 searching for light

5.5 Program Flow Chart:

The program flow chart is made of the following:

5.5.1 Searching Home Position:

A flow chart shows first work done by the solar tracker as in figure 5.7.

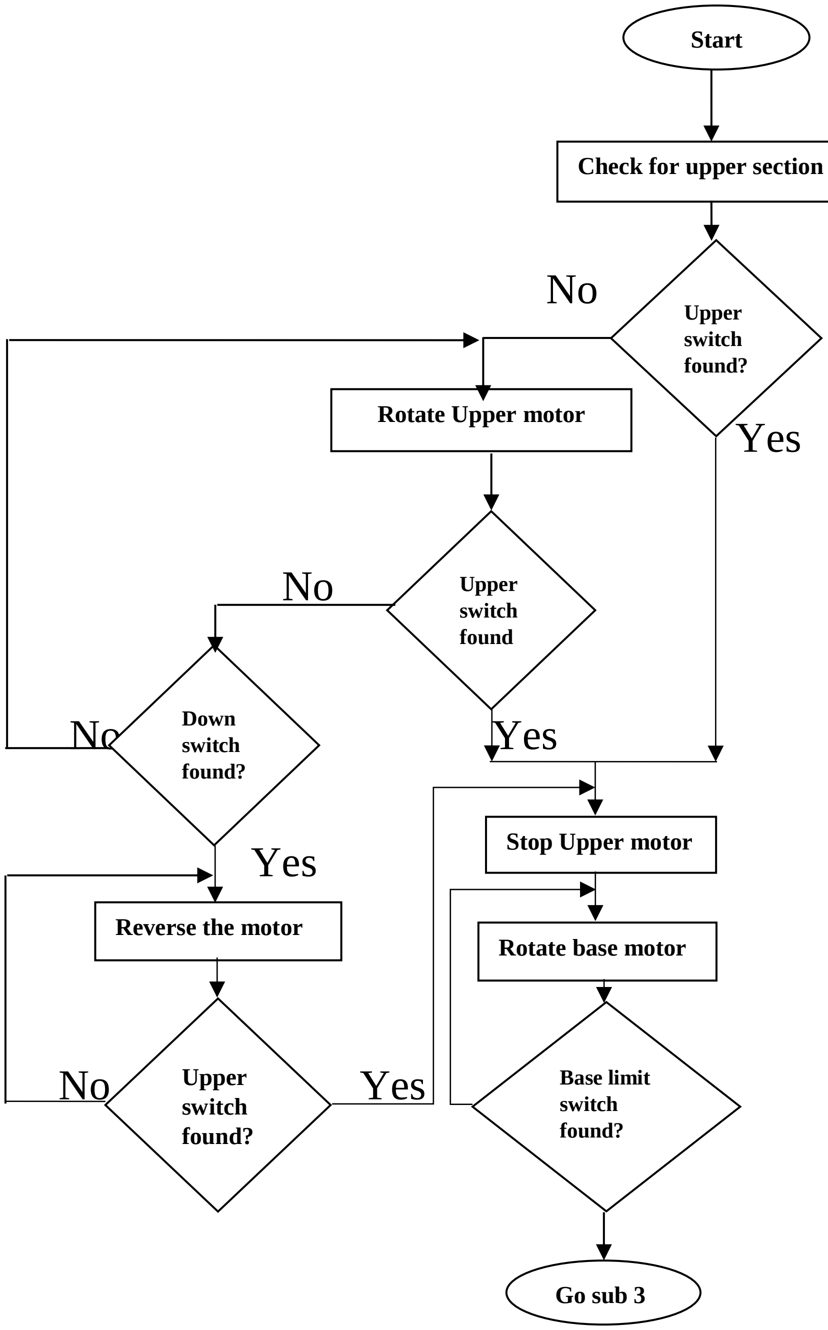


Figure 5.7 Searching Home Position

5.5.2 Searching For Sun:

A flow chart shows the process of searching for the sun as in figure 5.8.

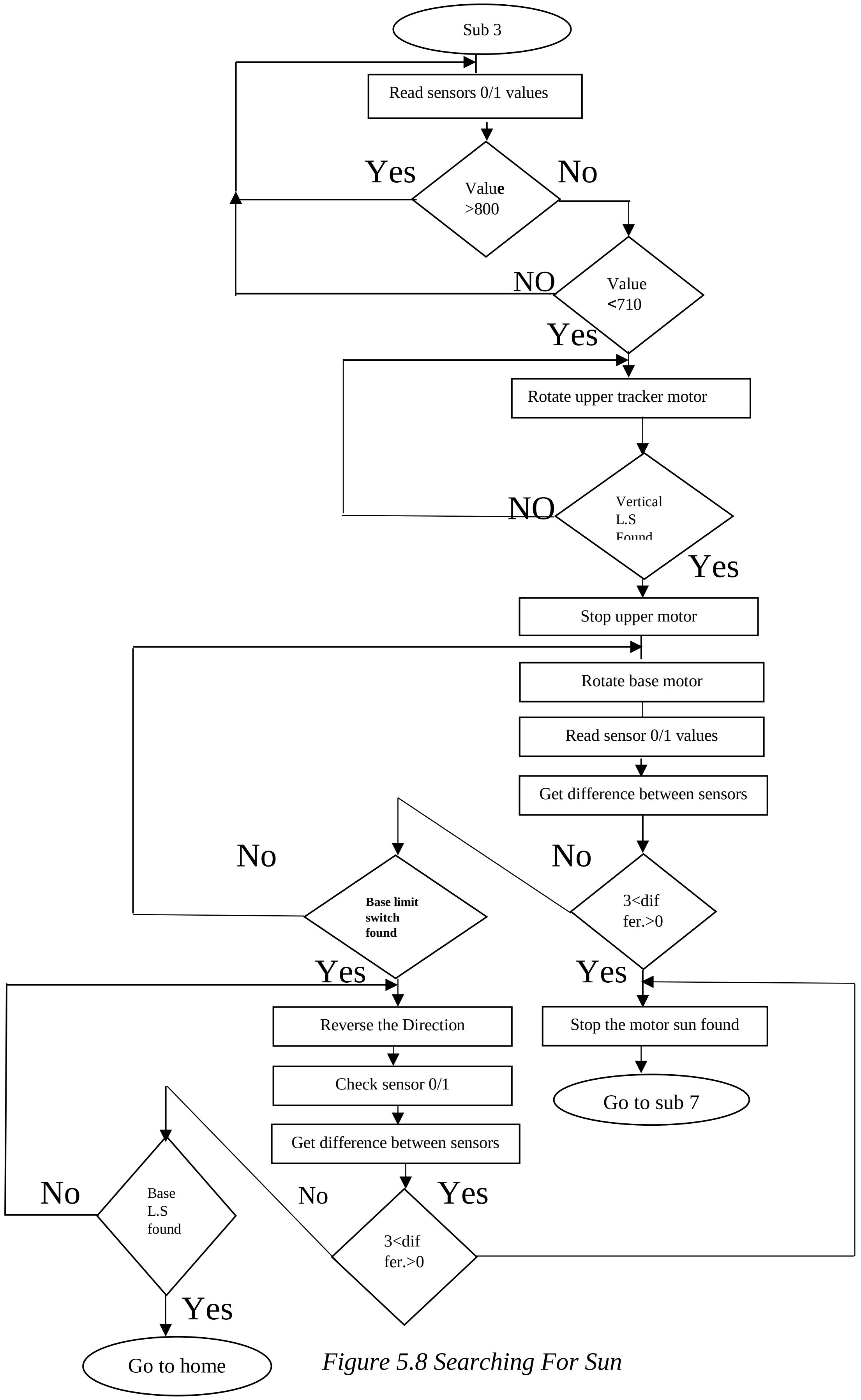


Figure 5.8 Searching For Sun

5.5.3 Tracker for Sun:

A flow chart shows the sun tracking process as in figure 5.9.

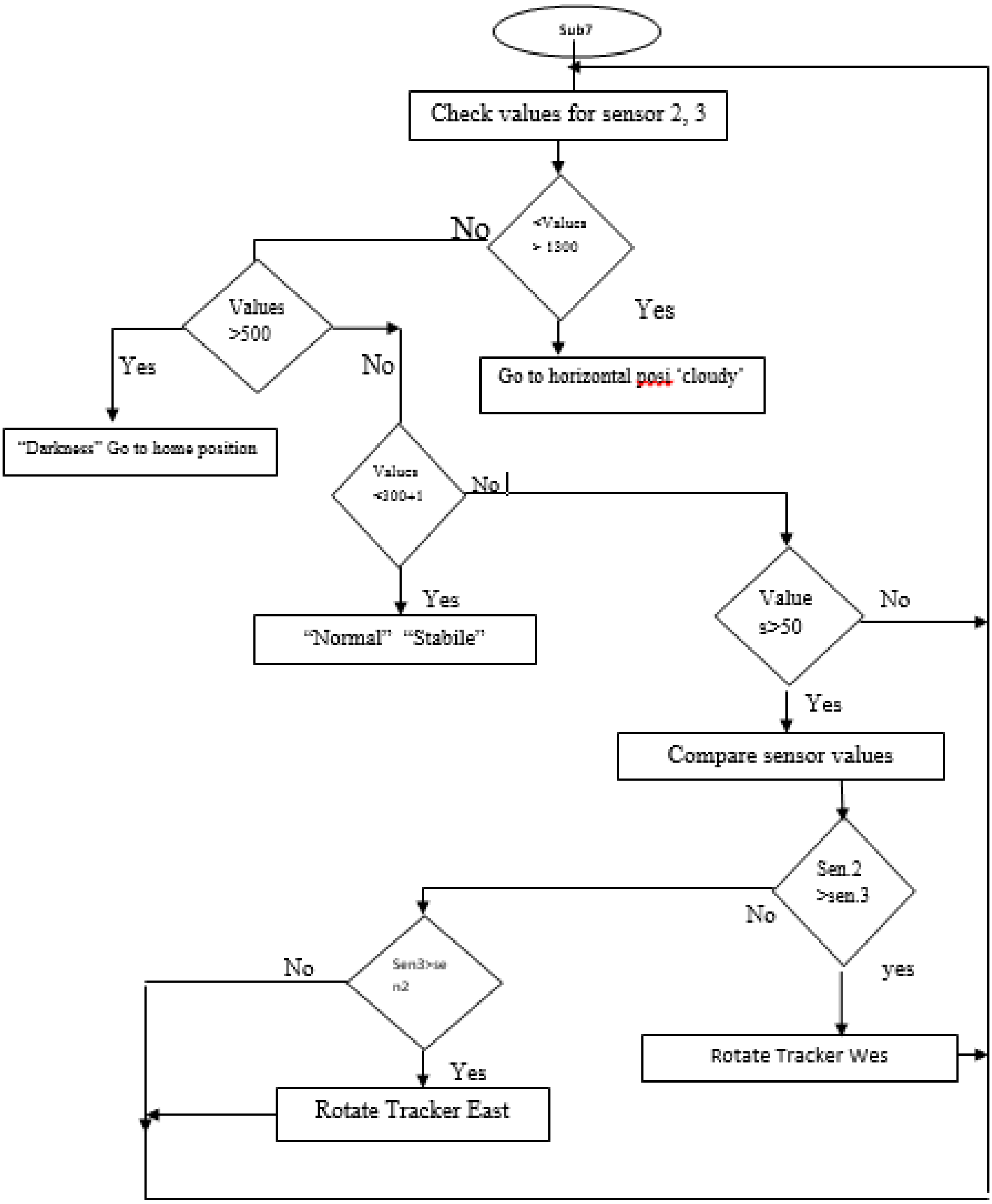


Figure 5.9 Solar Tracker

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion:

The study got a two-axis model of sun tracking system (east, west) and (north, south) using a microcontroller and stepper motor. In addition, it solves the problem of season's variation and the natural factors that affect the fall of rays on the cell.

It also solves the problem of cell shut down at night and operation of the system in the daytime. Moreover, securing maximum energy by ensuring that the cell is directed to the sun for the longest period of time.

6.2 Recommendations:

- The necessity of giving a good budget for further experimenting on this system, by applying the study of the simulator on a real cells and in different locations around Sudan, in order to take advantage of this study specially in the remote villages for the purpose of power generation.
- Finding appropriate solutions that address the impact of dust on solar cells. The most important problem facing solar energy projects is that solar cells are affected by atmospheric factors and their performance is reduced by 50% when they are exposed to dust waves.
- The emergence of solar applications from university roofs to meet the needs of society, which corresponds to the future foresight studies conducted by the (World Energy Agency) that has pointed the possibility of producing most of the world needed electricity from solar energy over the next 50 years.
- Further studies needed in the field of solar energy applications in agricultural projects and lighting houses.
- Take advantage of the application of the theories used in this system in military projects that deals with this area.
- Extra Attention to researches on the development of solar energy systems.

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APPENDIX A

Software

This appendix is about the code of the Atmega16 microcontroller:

```
/ ***********************************************************
$regfile "m16def.dat"
$crystal = 8000000


Config Lcd = 20 * 2
Config Lcdpin = Pin , Db4 = Portc.3 , Db5 = Portc.4 , Db6 = Portc.5 , Db7 =
Portc.6 , Rs = Portc.2 , E = Portc.1


Config Adc = Single , Prescaler = Auto , Reference = Avcc
Start Adc


Config Portb = Output
Config Portb.4 = Input
Config Portb.5 = Input
Config Portb.6 = Input
Config Portd = Output



Dim X As Integer , I As Integer , W As Word , Z As Word , T As Word
Dim W1 As Word , Z1 As Word , W2 As Word , Z2 As Word


Do
If Pinb.5 = 1 Then Portb = 0
```

```
If Pinb.5 = 0 Then Gosub 1
Loop

1:
Cls
Lcd "Searching.."
Do
Portb.i = 1
Waitms 50
Portb.i = 0
I = I + 1
If I > 3 Then I = 0
If Pinb.4 = 1 Then Gosub 2
Loop

2:
Cls
Lcd "Searching..."
Do
Portb.i = 1
Waitms 50
Portb.i = 0
I = I - 1
If I < 0 Then I = 3
If Pinb.5 = 1 Then
Portb.3 = 1
```

```
Waitms 50
Portb.3 = 0
Portb.2 = 1
Waitms 50
Gosub 3
End If

Loop

3:
I = 3
For I = 3 To 0 Step -1
Portb.i = 1
Waitms 50
Portb.i = 0
Next I
Portb = 0
Cls
Lcd "H.Position.."
Gosub 4

4:
Do
Portd.i = 1
Waitms 40
Portd.i = 0
```

```
I = I - 1
If I < 0 Then I = 3
If Pinb.6 = 1 Then
Waitms 500
Cls
Lcd "Home position"
Wait 2
Gosub 5
End If
Loop

5:
Cls
Do
W = Getadc(0)
Waitms 10
Z = Getadc(1)
Waitms 10
If Z > 800 And W > 800 Then
Locate 1 , 1
Lcd "Waiting for SUN"
Else
If Z < 750 And W < 750 Then Gosub 6
End If

Loop
```

```
6:

Do
Portb.i = 1
Waitms 50
Portb.i = 0
I = I + 1
If I > 3 Then I = 0
If Pinb.4 = 1 Then
Gosub 7
End If
Loop

7:
For I = 0 To 3
Portd.i = 1
Waitms 40
Portd.i = 0
Next I
Do

W = Getadc(0)
Z = Getadc(1)
'_*_*_*_*_*_*_*_*_*_*_*_*_*_*_*_*_*_*_*_
Portd.i = 1
Waitms 40
```

```
Portd.i = 0
I = I + 1
If I > 3 Then I = 0

If Pinb.6 = 1 Then
Waitms 500
For I = 3 To 0 Step -1
Portd.i = 1
Waitms 40
Portd.i = 0
Next I

Gosub 71
End If
'_*_*_*__*_*_*_*_*_*_*_*_*_*_*_*_*_*_*_

If W < 100 And Z < 100 Then
T = W - Z
If T > 0 And T < 3 Then Gosub H
End If

Loop

71:

Do
```

```
W = Getadc(0)
Z = Getadc(1)
'_*_*_*_*_*_*_*_*_*_*_*_*_*_*_*_*_*_*_*_
Portd.i = 1
Waitms 40
Portd.i = 0
I = I - 1
If I < 0 Then I = 3
If Pinb.6 = 1 Then
Waitms 500
Gosub 1
End If
'_*_*_*_*_*_*_*_*_*_*_*_*_*_*_*_*_*_*_*_
If W < 100 And Z < 100 Then
T = W - Z
If T > 0 And T < 3 Then Gosub H
End If
Loop
'_*_*_*_*_*_*_*_*_*_*_*_*_*_*_*_*_*_*_*_

H:
Cls
Do
Portd = 0
Locate 1 , 1
Lcd "SUN FOUND.."
Wait 1
```

```
Gosub 8
Loop

8:

Do
W = Getadc(2)
Waitms 10
Z = Getadc(3)
Waitms 10

W1 = W - 2
W2 = W + 2

Z1 = Z - 2
Z2 = Z + 2

If Z > 130 And W > 130 Then
If Z < 300 And W < 300 Then
Locate 1 , 1
Waitms 20
Lcd "CLOUDY....!"
Gosub Cloudy
End If
End If
```

```
If Z > 500 And W > 500 Then
Locate 1 , 1
Lcd "DARKNESS..!"
Wait 1
Gosub 1
End If

If Z > W1 And Z < W2 And Z < 30 Then
If W > Z1 And W < Z2 And W < 30 Then

Locate 1 , 1
Lcd "NORMAL...!"
Locate 2 , 1
Lcd "STABLE..."
End If
End If

If W > Z2 And W < 80 Then
Portb.i = 1
Waitms 20
Portb.i = 0
Locate 1 , 1
Lcd "Rotating.."
Locate 2 , 1
Lcd "WEST....."
I = I + 1
```

```
If I > 3 Then I = 0
End If

If Z > W2 And Z < 80 Then
Portb.i = 1
Waitms 20
Portb.i = 0
Locate 1 , 1
Lcd "Rotating.."
Locate 2 , 1
Lcd "EAST....."
I = I - 1
If I < 0 Then I = 3
End If
 Loop

 Cloudy:

Do

Portb.i = 1
Waitms 50
Portb.i = 0
I = I + 1
If I > 3 Then I = 0
While Pinb.5 = 0
W = Getadc(2)
```

```
Waitms 10

Z = Getadc(3)

Waitms 10

If W < 100 And Z < 100 Then Return

Wend

If Pinb.4 = 1 Then Gosub Cloudy2


Loop


Cloudy2:


Do

Portb.i = 1

Waitms 50

Portb.i = 0

I = I - 1

If I < 0 Then I = 3

While Pinb.5 = 1

W = Getadc(2)

Waitms 10

Z = Getadc(3)

Waitms 10

If W < 100 and Z < 100 Then Gosub 8

Wend


Loop
```