Simulation Studies on Dual Axis Solar Photovoltaic Panel Tracking System

Thesis submitted in partial fulfillment of the requirements for the award of the degree of

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in
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CERTIFICATE

I hereby declare that the Thesis entitled **"Simulation Studies on Dual Axis Solar Photovoltaic Panel Tracking System"** is an authentic record of my own work carried out as the requirements for the award of the degree of M.E. (Power Systems & Electric Drives) at Thapar University, Patiala, under the guidance of **Dr. Sanjay K. Jain**, Associate Professor, EIED.

The matter presented in this Thesis has not been submitted for the award of any other degree of this or any other university.

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It is certified that the above statement made by the student is correct to the best of my knowledge and belief.

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Sukhraj Singh Cheema

ABSTRACT

The need of the tracking system for solar photovoltaic panel arises to extract maximum solar energy. The work reported in this thesis involves the mathematical simulation and control of dual axis solar tracking system for solar photovoltaic panel. The tracking system can be installed in the regions considered rich in solar energy. The dual axis solar photovoltaic panel is characterized by the capability to move in horizontal and vertical directions. The vertical and horizontal motion of the panel is obtained by taking altitude angle and azimuth angle as reference. The fuzzy controller has been used to control the position of dc motors. The mechanical design consists of rotary joints and two DC motors. This tracking system makes the solar photovoltaic array more efficient by keeping the panel's face perpendicular to the sun and therefore extracts maximum solar energy resulting into increased overall efficiency. Point to point control ensures intermittent motion when tracking the sun. The performance has been studied with data for various regions. It is found that tracking system is effective in pointing the solar array toward the sun. The proposed control has the capability to be installed in different regions with minor modifications.

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ABBREVIATIONS

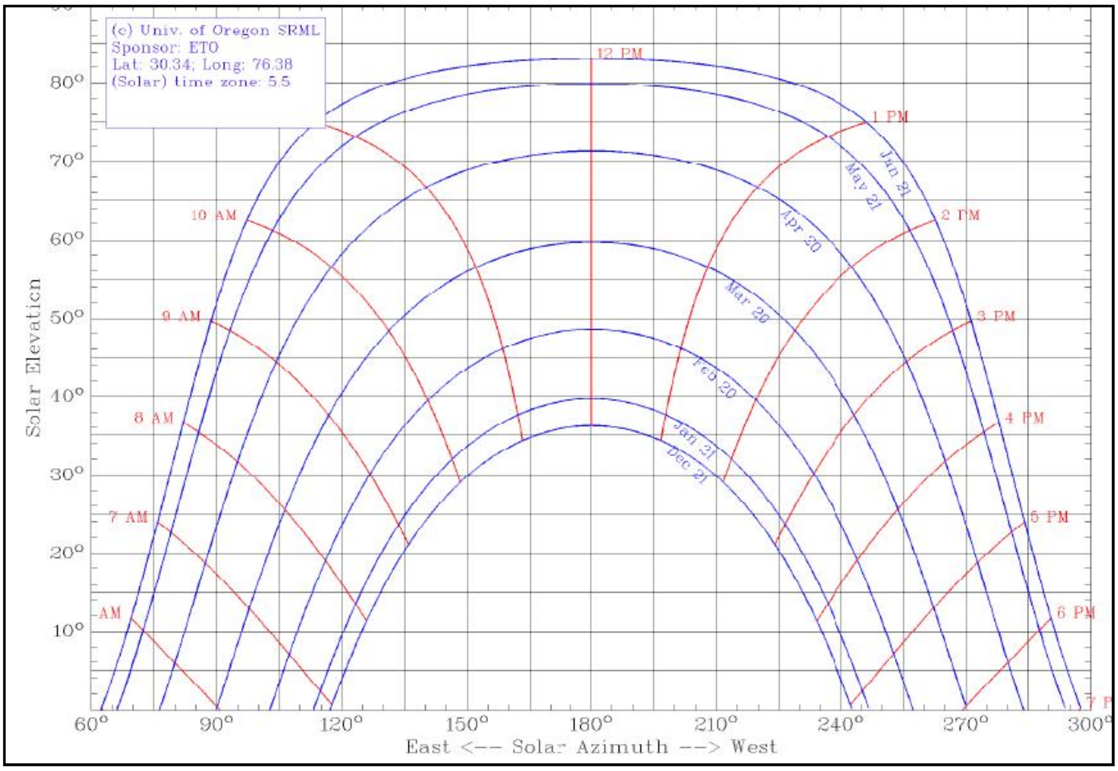
PV	Photovoltaic
DOF	Degrees of Freedom
PV panels	Photovoltaic panels
MPPT	Maximum Power Point Tracking
SCM	Single-chip microcomputer
DC	Direct current
HSAT	Horizontal single axis trackers
VSAT	Vertical single axis trackers
AADAT	Azimuth-Altitude dual axis trackers
$^{2}{}_{A}$	Altitude angle torque
$^{2}{}_{B}$	Azimuth angle torque
θz	Altitude angle
θ_A	Azimuth angle
MoU	Memorandum of understanding

CHAPTER- 1

INTRODUCTION

1.1 OVERVIEW

The world population is increasing day by day and thedemand for energy is increasing accordingly. Oil and coal as themain source of energy nowadays, is expected to end upfrom the world during the recent century which exploresa serious problem in providing the humanity with anaffordable and reliable source of energy. The need of the hour is renewable energy resources with cheaprunning costs. Solar energy is considered as one of themain energy resources in warm countries.



. Fig. 1.1Sun path at latitude of 31^0(at Patiala)

In general, India has a relatively long sunny day formore than ten months and partly cloudy sky for most ofthe days of the rest two months. This makes ourcountry, especially the desert sides in the west, which include Rajasthan, Gujarat, Madhya Pradesh etc. very rich is solar energy. Many projects have been done onusing photovoltaic cells in collecting solar radiation andconverting it into electrical energy but most of theseprojects did not take into account the difference of thesun angle of incidence by installing the panels in a fixedorientation which influences very highly the solarenergy collected by the panel.

As we know that the angle of inclination ranges between -90^o after sun rise and +90^o before sun set passing with 0^o at noon. This makes the collected solar radiation to be 0% at sun rise and sun set and 100% at noon. This variation of solar radiations collection leads the photovoltaic panel to lose more than 40% ofthe collected energy. Fig. 1.1 shows the yearly sun path at the latitude of30^o (at Patiala). From the figure 1.1, one can estimate the exact position of sun inevery

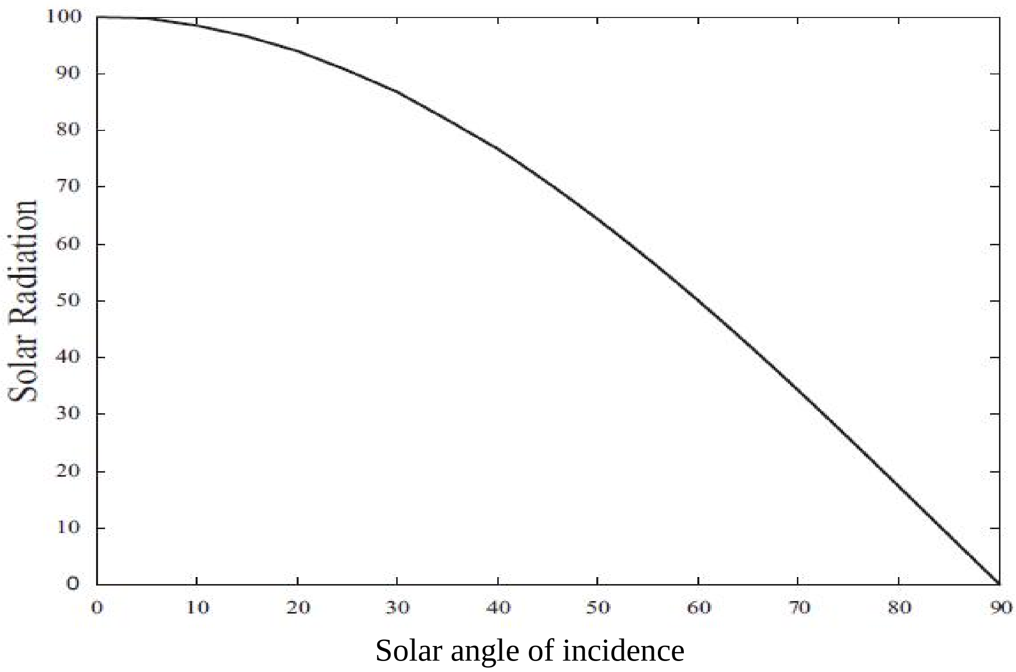


Fig1.2Curve for the relationship between the solar radiation and the solar angle of incidence.

monthand at any time during the day. Theposition is decided by two angles in sphericalcoordinates; the Altitude angle which is the angle of thesun in the vertical plane in which the sun lies, and theAzimuth angle which represents the angle of theprojected position of the sun in the horizontal plane.These two angles will be discussed deeply later in thisdocument. Fig. 1.2 shows a curve forthe relationship between the solar radiation and the solarangle of incidence.This figure shows that solar radiations falling on the solar array will be maximum when the angle of incidence on the panel is 0^0 which means that the panel is perpendicular to the sun.

1.2 SOLAR POWER IN INDIA

In July 2009, India unveiled a US$19 billion plan to produce 20 GW (20,000MW) of solar power by 2020. Under the plan, the use of solar-powered equipment and applications would be made compulsory in all government buildings, as well as hospitals and hotels. On November 18, 2009, it was reported that India was ready to launch its National Solar Mission under the National Action Plan on Climate Change, with plans to generate 1,000 MW of power by 2013.

India's largest photovoltaic (PV) power plants

1. Reliance Power Pokaran Solar PV Plant, Rajasthan, 40MW 02011-06 June 2011 Commissioning in March 2012
2. AdaniBitta Solar Plant, Gujarat, 40MW 02011-06 June 2011 To be Completed December 2011
3. Moser Baer - Patan, Gujarat,30MW 02011-06 June 2011 Commissioned July 2011
4. Azure Power - Sabarkantha, Gujarat, 10MW 02011-06 June 2011 Commissioned June 2011

5. Green Infra Solar Energy Limited - Rajkot, Gujarat, 10MW 02011-11-29 November 29, 2011 Commissioned November 2011

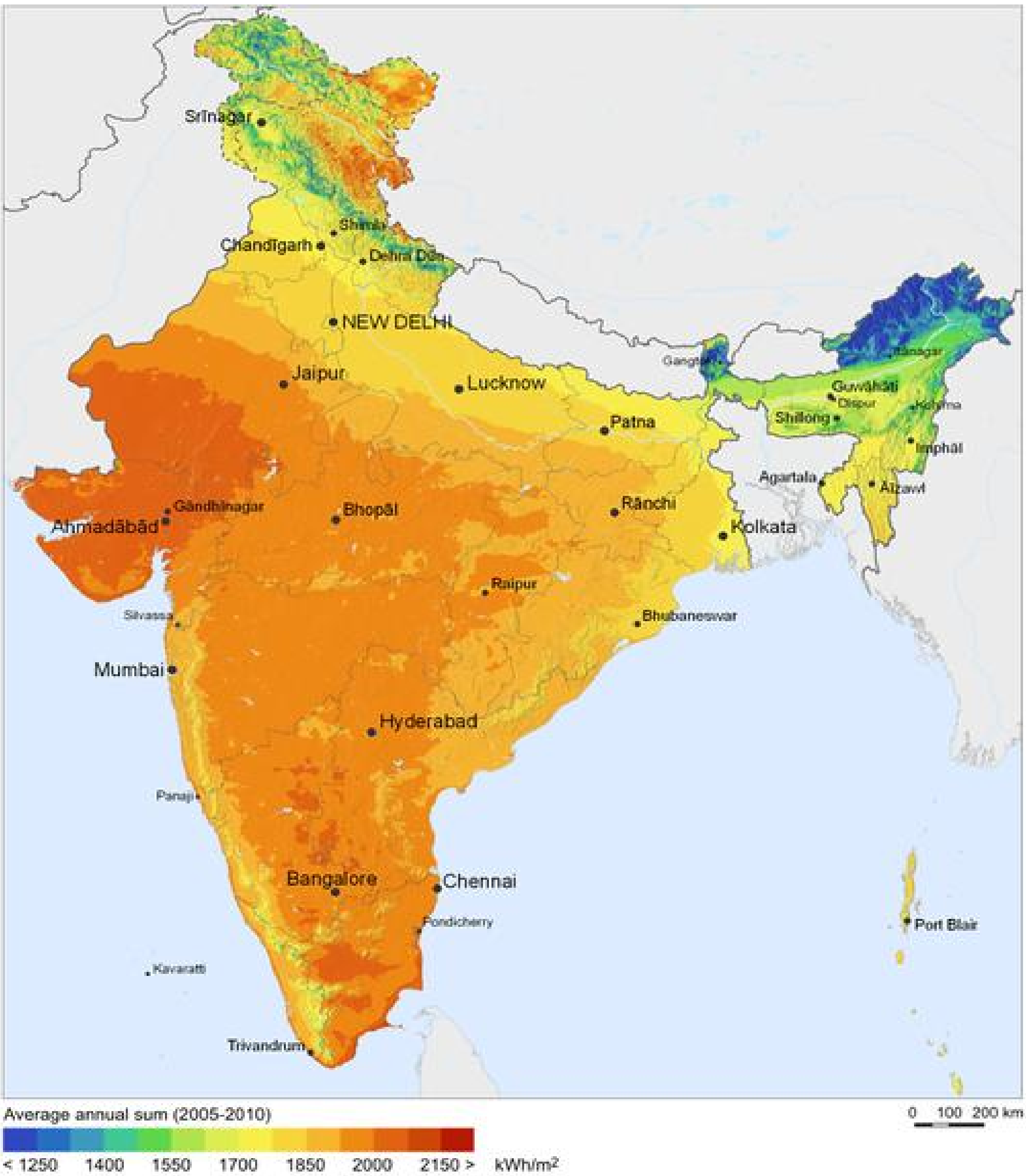


Fig 1.3The avarage solar radiations receiver by different regions in India.

The daily average solar energy incident over India varies from 4 to 7 kWh/m^2 with about 1500–2000 sunshine hours per year (depending upon location), which is far more than current total energy consumption. For example, assuming the efficiency of PV modules were as low as 10%, this would still be a thousand times greater than the domestic electricity demand projected for 2015. Fig 1.3 shows the avarage solar radiations receiver by different regions in India.

Gujarat government has signed a MoU with Clinton Foundation to build the world’s largest solar-power plant in the region. The 3,000-megawatt plant near the border between India and Pakistan would be one of four planned by the initiative, a William J. Clinton Foundation program to promote renewable energy. The other proposed sites are in California, South Africa, and Australia.

1.3LITERATURE REVIEW

Sun-synchronous navigation is related to moving the solar powered rover (robot) in such a way that its solar panel always points toward the sun and which results into maximum battery charging and hence the rover can work for long hours [1].The unique feature of the this solar tracking system is that instead of taking the earth as its reference, it takes the sun as a guiding source. Its active sensors constantly monitor the sunlight and rotate the panel towards the direction where the intensity of sunlight is maximum. The light dependent resistor’s do the job of sensing the change in the position of the sun. The control circuit does the job of fetching the input from the sensor and gives command to the motor to run in order to tackle the change in the position of the sun. By using this system the additional energy generated is around 25% to 30% with very less consumption by the system itself[2].The paper gives the design and implementation of a fuzzy logic computer controlled sun tracking system to enhance the power output of photo voltaic solar panels. The tracking system was driven by two permanent magnet DC motors to provide motion of the PV panels in two axis[3].The paper describes the use of a microcontroller based design methodology of an automatic solar tracker. Light dependent resistors are used as the sensors of the solar tracker. The tracking system maximizes solar cell output by positioning a solar panel at the point of maximum light intensity[4**].**This paper describe the use of DC motors, special motors like stepper motors, servo motors, realtime actuators, to operate moving parts of the solar tracker. The system was designed as the normal line of solar cell always move parallel to the rays of the sun[5].The Aim of this project is to develop and implement a prototype of two-axis solar tracking system based on a microcontroller. The parabolic reflector or parabolic dish is constructed around two feed diameter to capture the sun's energy. The focus of the parabolic reflector is pointed to a small area to get extremely high temperature. The temperature at the focus of the parabolic reflector is measured with temperature probes. This auto-tracking system is controlled with two 12V, 6W DC gear box motors. The five light sensors (LDR) are used to track the sun and to start the operation (Day/Night operation)[6]. The paper adopts the PWM DC motor controller. It is capable of archiving the timeliness, reliability and stability of motor speed control, which is difficult to implement in traditional analog controller[7].Theresearch project concentrates on the design and control of dual axis orientation system for the photovoltaic solar panels. The orientation system calculations are based on astronomical data and the system is assumed to be valid for any region with small modifications. The system is designed to control the Altitude angle in the vertical plane as well as the Azimuth angle in the horizontal plane of the photovoltaic panel workspace. And this system is expected to save more than 40% of the total energy of the panels by keeping the panel's face perpendicular to the sun[8]. In the previous solutions, each tracking direction is controlled by using a Sun sensor made by a pair of phototransistors. The single matrix Sun sensor (MSS) controls both axes of the tracking system. The inspiration for the MSS is the antique solar clock. MSS comprises 8 photo resistors and a cylinder The difference between a shaded photo resistor cell and a lighted cell is recognized using an electronic circuit and corresponding output voltage signals are given to the DC motors which will move the array toward sun[9]. In order to improve the solar tracking accuracy, the author comes up with combining program control and sensor control. Program control include calendar-check tracking and the local longitude, latitude and time, to calculate the solar altitude and solar azimuth by SCM (single-chip microcomputer), step motor is used to adjust the attitude of the solar panel. Sensor control is that sunray is detected by photoelectric detector and then the changed signal is transmitted to control step motor to adjust the attitude of the solar [10]. The paper discusses the technology options, their current status and opportunities and challenges in developing solar thermal power plants in the context of India. [11]. The National Solar Mission is a major initiative of the Government of India and State Governments to promote ecologically sustainable growth while addressing India's energy security challenge. It will also constitute a major contribution by India to the global effort to meet the challenges of climate change [12].

1.4 MOTIVATION FOR THE RESEARCH

Probably the biggest concern with conventional energy sources is the amount ofPollutants that are released into the atmosphere. These growing concerns over theenvironmental changes caused by power generation with conventional energy sourceshas lead to the need for developing an alternative energy source; one that is highlyefficient and pollution free.The most common method of electrical power generation uses fossil fuels such as coal.However, the burning of fossil fuels releases CO_2 gas which has been directlyassociated with global warming due to the greenhouse effect. Photovoltaic's representone of the few energy generation options that do not create pollutants or hazardouswastes. Other factors that increase the appeal of solar energy as an alternative energy source are the high reliability of solar cells, the steadily improving performance and decreasingmanufacturing costs of solar cells, and the fact that there is no fuel cost for the cells.

1.5 AIM OF THE THESIS

The aim of the thesis is to keep the solar photovoltaic panel perpendicular to the sun throughout the year in order to make it more efficient. The dual axis solar photovoltaic panel takes astronomical data as reference and the tracking system has the capability to always point the solar array toward the sun and can be installed in variousregions with minor modifications. The vertical and horizontal motion of the panel is obtained by taking altitude angle and azimuth angle as reference. The fuzzy controller has been used to control the position of DC motors. The mathematical simulation control of dual axis solar tracking system ensures the point to point motion of the DC motors while tracking the sun.

1.6 ORGANIZATION OF THESIS

This thesis is primarily concerned with the analysis and simulation of the dual axis solar photovoltaic tracker. The thesis is organized into five chapters. The chapters are described as:

The Chapter 1 outlines introduction to solar energy, its scenario in India, motivation and aim of the thesis. This chapter also incorporates a review of the relevant literature in the field of solar tracking.

The Chapter 2 outlines the important concepts of solar and tracker system. The difference between dual axis solar tracking systems compared to other photovoltaic systems such as standalone system is highlighted.

The Chapter 3 outlines design of the solar tracker and the methodology used in the implementation of the project.

The Chapter 4 outlines the astronomical data based simulation and results for the dual axis solar photovoltaic tracker. This is important to determine whether the objective of this project is achieved or not.

The Chapter 5 outlines the conclusion and future scope of this thesis.

CHAPTER-2

CONCEPTS OF SOLAR AND TRACKER SYSTEM

2.1 CONCEPTS ON SOLAR RADIATION

Before talking about the solar tracking systems, we will review some basicconcepts concerning solar radiation and mention some important values to betterunderstand the results of this work.

The sun, at an estimated temperature of 5800 K, emits high amounts of energy in the form of radiation, which reaches the planets of the solar system. Sunlight has two components, the direct beam and diffuse beam.Direct radiation (also called beam radiation) is the solar radiation of the sun that hasnot been scattered (causes shadow). Direct beam carries about 90% of the solar energy, and the "diffuse sunlight" that carries the remainder. The diffuse portion is the blue sky on a clear day and increases as a proportion on cloudy day's.The diffuse radiation is the sun radiation that has beenscattered (complete radiation on cloudy days). Reflected radiation is the incident radiation(beam and diffuse) that has been reflected by the earth. The sum ofbeams, diffuse and reflected radiation is considered as the global radiation on a surface. As the majority of the energy is in the direct beam, maximizing collection requires the sun to be visible to the panels as long as possible.

Declination Angle-The declination of the sun is the angle between the equator and a line drawn from the centre of the Earth to the centre of the sun. The declination is maximum (23.45^0) on the summer/winter (in India 21 June and 22 December) The declination angle, denoted by δ, varies seasonally due to the tilt of the Earth on its axis of rotation and the rotation of the Earth around the sun. If the

Earth were not tilted on its axis of rotation, the declination would always be 0°. However, the Earth is tilted by 23.45° and the declination angle varies plus or minus this amount. Only at the spring and fall equinoxes is the declination angle equal to 0°.

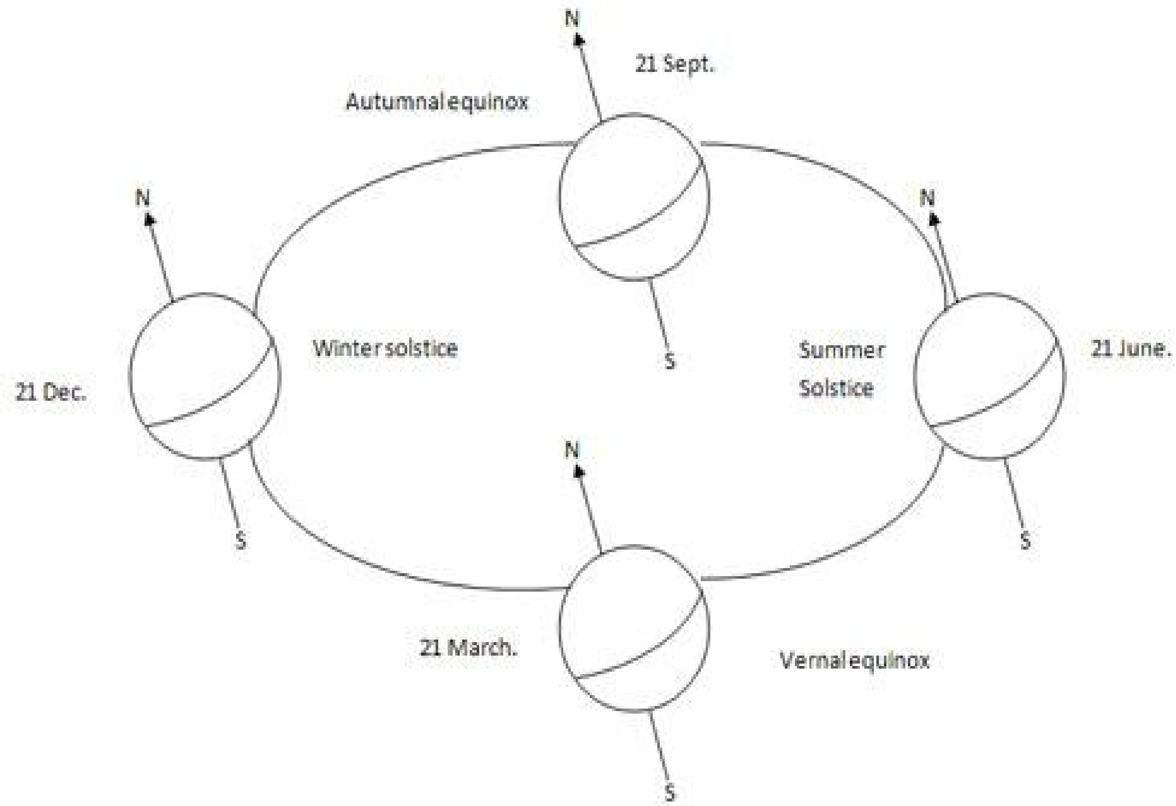


Figure 2.1: The Declination Angles

Hour Angle-The Hour Angle is the angular distance that the earth has rotated in a day. It is equal to 15 degrees multiplied by the number of hours from local solar noon. This is based on the nominal time, 24 hours, required for the earth to rotate once i.e. 360 degrees.

Solar hour angle is zero when sun is straight over head, negative before noon, and positive after noon.(here noon means 12.00 hour).

Solar Altitude **(θ_z)-**The solar altitude is the vertical angle between the horizontal and the line connecting to the sun. At sunset/sunrise altitude is 0 and is 90 degrees when the sun is at the zenith. The altitude relates to the latitude of the site, the declination angle and the hour angle.

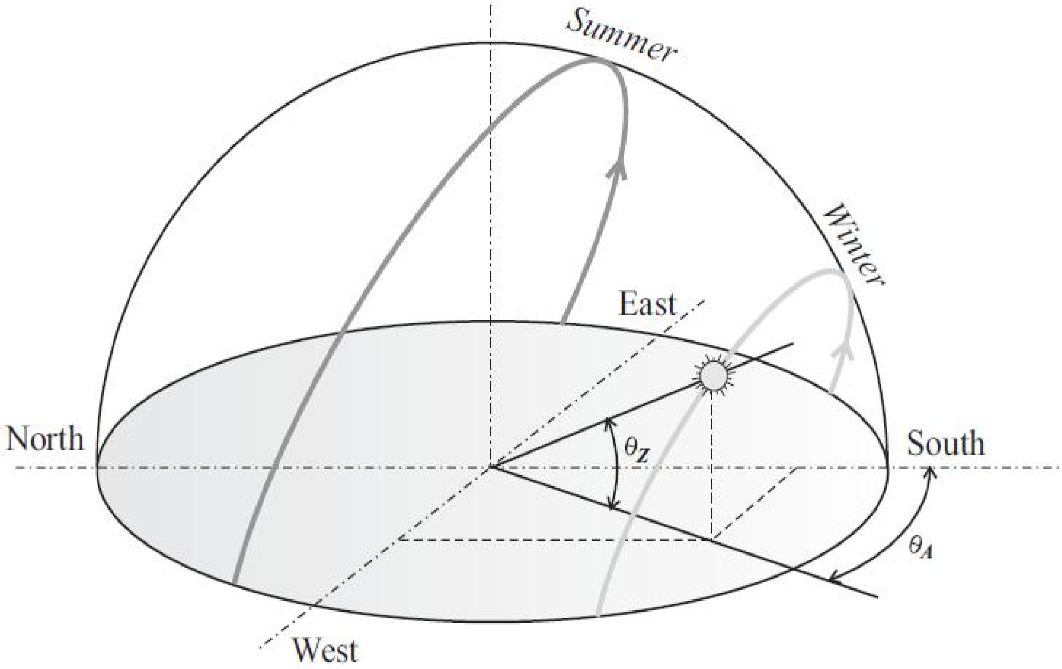


Figure 2.2Solar altitudes and azimuthstypical behavior of sun path

Solar Azimuth (θ_A)-The azimuth angle is the angle within the horizontal plane measured from true South or North. The azimuth angle is measured clockwise from the zero azimuth. For example, if you're in the Northern Hemisphere and the zero azimuth is set to South, the azimuth angle value will be negative before solar noon, and positive after solar noon.

2.2INSOLATION

Insolation is a measure of solar radiation energy received on a given surface area and recorded during a given time. It is also called solar irradiation and expressed as hourly irradiation if recorded during an hour, daily irradiation if recorded during a day, for example. The unit recommended by the World Meteorological Organization is MJ/m^2 (megajoules per square meter) or J/cm^2 (joules per square centimeter).Practitioners in the business of solar energy may use the unit Wh/m^2 (watt-hours per square meter). If this energy is divided by the recording time in hours, it is then a density of power called irradiance, expressed in W/m^2 (watts per square meter). Over the course of a year the average solar radiation arriving at the top of the Earth's atmosphere at any point in time is roughly 1366 watts per square meter. The Sun's rays are attenuated as they pass through the atmosphere, thus reducing the irradiance at the Earth's surface to approximately 1000 $W\ m^{-2}$ for a surface perpendicular to the Sun's rays at sea level on a clear day.The insolation of the sun can also be expressed in Suns, where one Sun equals 1000 W/m^2

2.3PROJECTION EFFECT

The insolation into a surface is largest when the surface directly faces the Sun. As the angle increases between the direction at a right angle to the surface and the direction of the rays of sunlight, the insolation is reduced in proportion to cosine of the angle; see effect of sun angle on climate.

This 'projection effect' is the main reason why the polar regions are much colder than equatorial regions on Earth. On an annual average the poles receive less insolation than does the equator, because at the poles the Earth's surface are angled away from the Sun.

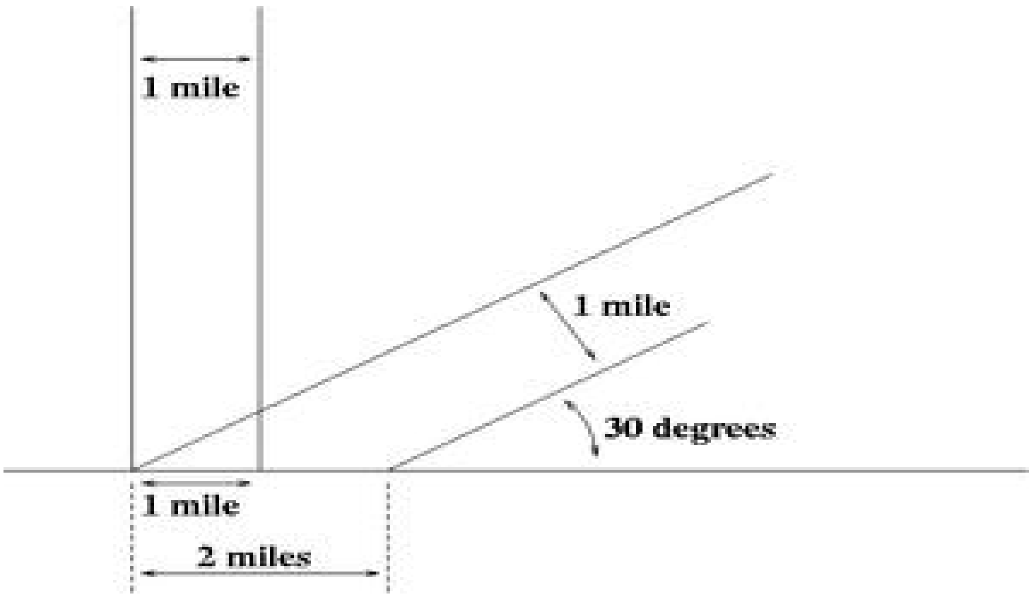


Figure 2.3One sunbeam one mile wide shines on the ground at a 90° angle, and another at a 30° angle. The one at a shallower angle distributes the same amount of light energy over twice as much area.

2.4 HOW DO PHOTOVOLTAICS WORK?

Photovoltaics is the direct conversion of light into electricity at the atomic level. Some materials exhibit a property known as the photoelectric effect that causes them to absorb photons of light and release electrons. When these free electrons are captured, an electric current results that can be used as electricity.

A solar cell (also called photovoltaic cell or photoelectric cell) is a solid state electrical device that converts the energy of light directly into electricity by the photovoltaic effect.Crystalline silicon PV cells are the most common photovoltaic cells in use today.

A number of solar cells electrically connected to each other and mounted in a support structure or frame is called a photovoltaic module. Modules are designed to supply electricity at a certain voltage, such as a common 12 volts system. The current produced is directly dependent on how much light strikes the module. Multiple modules can be wired together to form an array. In general, the larger the area of a module or array, the more electricity that will be produced. Photovoltaic modules and arrays produce direct-current (DC) electricity. They can be connected in both series and parallel electrical arrangements to produce any required voltage and current combination.

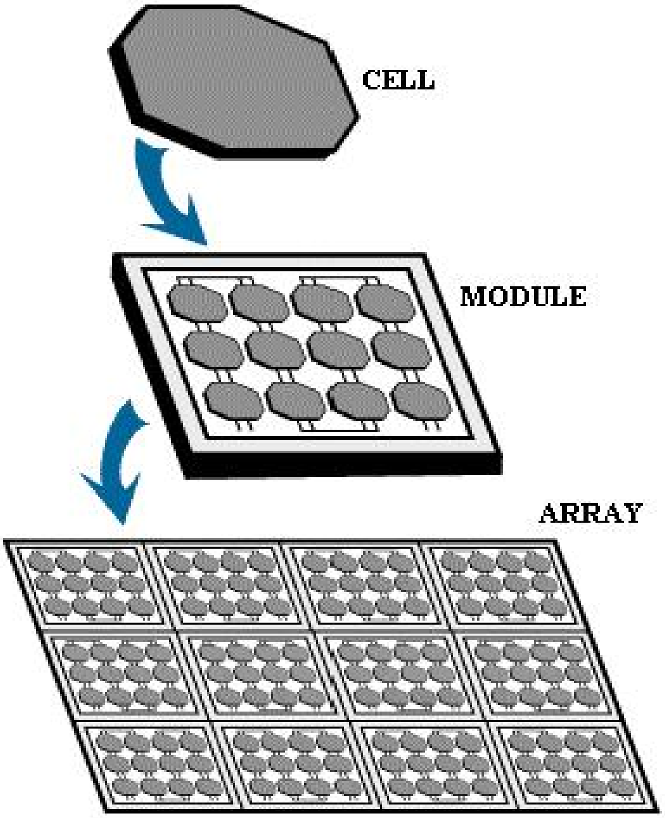


Figure 2.4: Photovoltaic panel or array

2.5 SOLAR TRACKER

2.5.1 INTRODUCTION-Solar Tracker is a Device which follows the movement of the sun as it rotates from the east to the west every day.The main function of all tracking systems is to provide one or two degrees of freedom in movement.Trackers are used to keep solar collectors/solar panels oriented directly towards the sun as it moves through the sky every day. Using solar trackers increases the amount of solar energy which is received by the solar energy collector and improves the energy output of the heat/electricity which is generated. Solar trackers can increase the output of solar panels by 20-30% which improves the economics of the solar panel project.The main tracking types are described closer in the following chapters.

2.5.2 NEED FOR SOLAR TRACKER

The energy contributed by the direct beam drops off with the cosine of the angle between the incoming light and the panel. The table no. 2.1 shows the Direct power lost (%) due to misalignment (angle *i*).

Table no-2.1 Direct power lost (%) due to misalignment (angle *i*)

Misalignment (angle *i*)	Direct power lost (%)=1-cos(i)
0^0	0
1^0	.015
3^0	.14
8^0	1
23.4^0	8.3
30^0	13.4
45^0	30
60^0	>50
75^0	>75

The sun travels through 360 degrees east-west a day, but from the perspective of any fixed location the visible portion is 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 above, 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 8.3% A tracker that accounts for both the daily and seasonal motions is known as a dual-axis tracker.

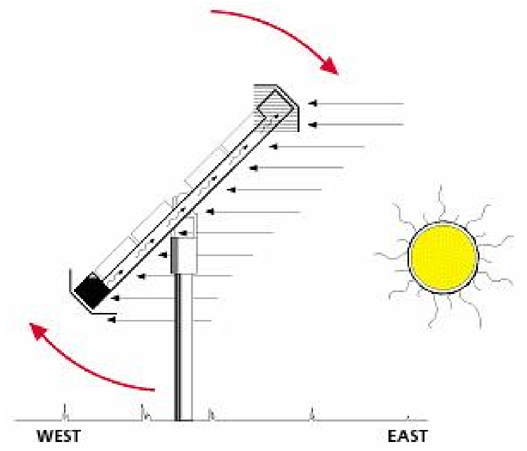
2.5.3 TYPES OF SOLAR TRACKERS

PASSIVE TRACKING SYSTEMS

The passive tracking system realizes the movement of the system by utilizing a low boiling point liquid. This liquid is vaporized by the added heat of the sun and the center of mass is shifted leading to that the system finds the new equilibrium position.

ACTIVE TRACKING SYSTEMS

The two basic types of active solar tracker are single-axis and double-axis.



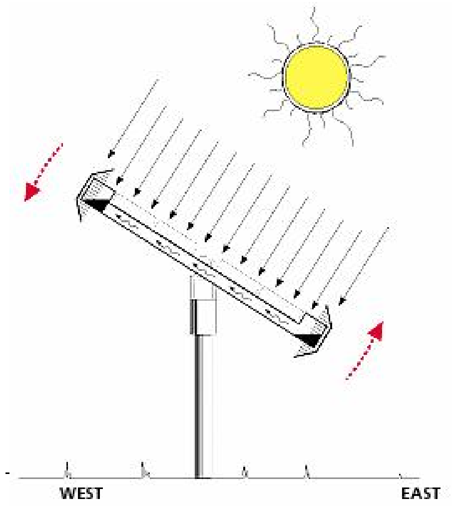


Figure 2.5: Passive tracking system

<u>Single axis trackers</u>

The single axis tracking systems realizes the movement of either elevation or azimuth for a solar power system. Which one of these movements is desired, depends on the technology used on the tracker as well as the space that it is mounted on. For example the parabolic through systems utilize the azimuthal tracking whereas the many rooftop PV-systems utilize elevation tracking because of the lack of space. A single-axis tracker can only pivot in one plane – either horizontally or vertically. This makes it less complicated and generally cheaper than a two-axis tracker, but also less effective at harvesting the total solar energy available at a site.Trackers use motors and gear trains to direct the tracker as commanded by a controller responding to the solar direction. Since the motors consume energy, one wants to use them only as necessary.

Single axis trackers have one degree of freedom that acts as an axis of rotation. There are several common implementations of single axis trackers. These include horizontal single axis trackers (HSAT) and vertical single axis trackers (VSAT).

A horizontal-axis tracker consists of a long horizontal tube to which solar modules are attached. The tube is aligned in a north-south direction, is supported on bearings mounted on pylons or frames, and rotates slowly on its axis to follow the sun's motion across the sky. This kind of tracker is most effective at equatorial latitudes where the sun is more or less overhead at noon. In general, it is effective wherever the solar path is high in the sky for substantial parts of the year, but for this very reason, does not perform well at higher latitudes. For higher latitude, a vertical-axis tracker is better suited. This works well wherever the sun is typically lower in the sky and, at least in the summer months, the days are long.

Dual Axis Trackers

Dual axis trackers as shown in the figure 2.6 have two degrees of freedom that act as axes of rotation. Double-axis solar trackers, as the same suggest, can rotate simultaneously in horizontal and vertical directions, and so are able to point exactly at the sun at all times in any location.

Dual axis tracking systems realize movement both along the elevation- and azimuthal axes. These tracking systems naturally provide the best performance, given that the components have high enough accuracy as well.

Fig2.6 Dual axis solar tracker

CHAPTER 3

DESIGN OF SOLAR TRACKER

3.1TRACKER DESIGN

A solar tracker is a device that orient photovoltaic array toward the sun. In flat-panel photovoltaic (PV) applications trackers are used to minimize the angle of incidence between the incoming light and a photovoltaic panel. This increases the amount of energy produced by the photovoltaic array.

Here we can use azimuth-altitude dual axis trackers (AADAT). Dual axis trackers extract the maximum solar energy levels due to their ability to follow the sun vertically and horizontally. No matter where the sun is in the sky, dual axis trackers are able to angle themselves to be in direction toward the sun.

Fig. 3.1 Setup of a squared solar panel

The Fig. 3.1 shows a setup of a squared solar panel with two degrees of freedom. Here Two DC motors are used to drive the two rotational degrees of freedom. The motors can mounted directly on the rotation pins of the rotational joints to reduce losses caused by linkages and joints and to avoid using more linkages and mechanisms

3.2DC MOTOR AND MOTOR DRIVER THEORY

Introduction

The tracking systems would need to consist of two motors, which control the position of the array, and a control circuit (either analog or digital) to direct these motors. The following sections discuss some possible types of motors that could be used for this type of application.

DC Motors

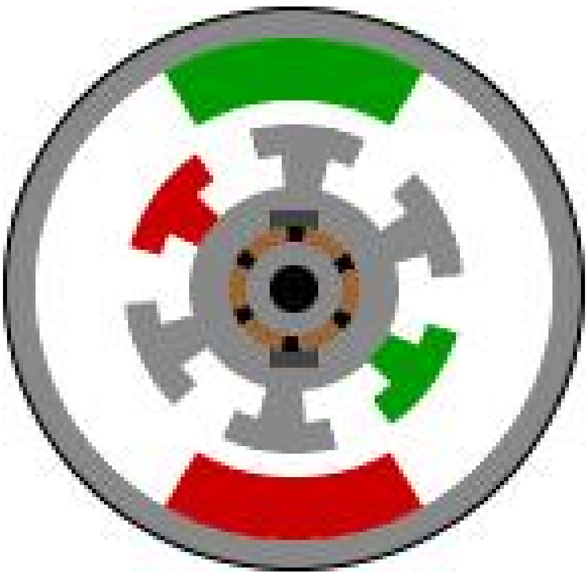


Figure 3.2: Inner Workings of a DC Motor

Figure 3.2 shows the inner workings of a basic DC motor. The outside section of the motor is the stator (stationary part), while the inside section is the rotor (rotating part).The stator is comprised of two (or more) permanent magnet pole pairs, while the rotor is comprised of windings that are connected to a mechanical commutator. The opposite polarities of the energised winding and the stator magnet attract each other. When this occurs the rotor will rotate until perfect alignment with the stator is achieved. When the rotor reaches alignment, the brushes move across the commutator contacts (middle section of rotor) and energies the next winding.

There are two other types of DC motors: series wound and shunt wound. These motors also use a similar rotor with brushes and a commutator. However, the stator useswindings instead of permanent magnets. The basic principle is still the same. A series wound DC motor has the stator windings in series with the rotor. A shunt wound DC motor has the stator windings in parallel with the rotor winding.

DC Servomotors

By itself the standard DC motor is not an acceptable method of controlling a suntracking array. This is due to the fact that DC motors are free spinning and subsequently difficult to position accurately. Even if the timing for starting and stopping the motor is correctly achieved, the armature does not stop immediately. DC motors have a very gradual acceleration and deceleration curves, therefore stabilisation is slow. Adding gearing to the motor will help to reduce this problem, but overshoot is still present and will throw off the anticipated stop position. The only way to effectively use a DC motor for precise positioning is to use a servo .The servomotor is actually an assembly of four things: a normal DC motor, a gear reduction unit, a position-sensing device (usually a potentiometer), and a control circuit. The function of the servo is to receive a control signal that represents a desired output position of the servo shaft, and apply power to its DC motor until its shaft turns to that position. It uses the position-sensing device to determine the rotational position of the shaft, so it knows which way the motor must turn to move the shaft to the commanded position. The shaft typically does not rotate freely round and round like a DC motor.DC geared motor also been chosen because it has a hold torque up to 24 kg.cm and low rpm. The solar panel that attached to the motor will be reacted according to the direction of the motor.

3.3MATHEMATICAL MODEL

The fig. 3.3 shows a typical behavior for the sun path in December (winter) and June (summer). The rotational angle of the orientation system in the vertical plane can be calculated from the following equation:

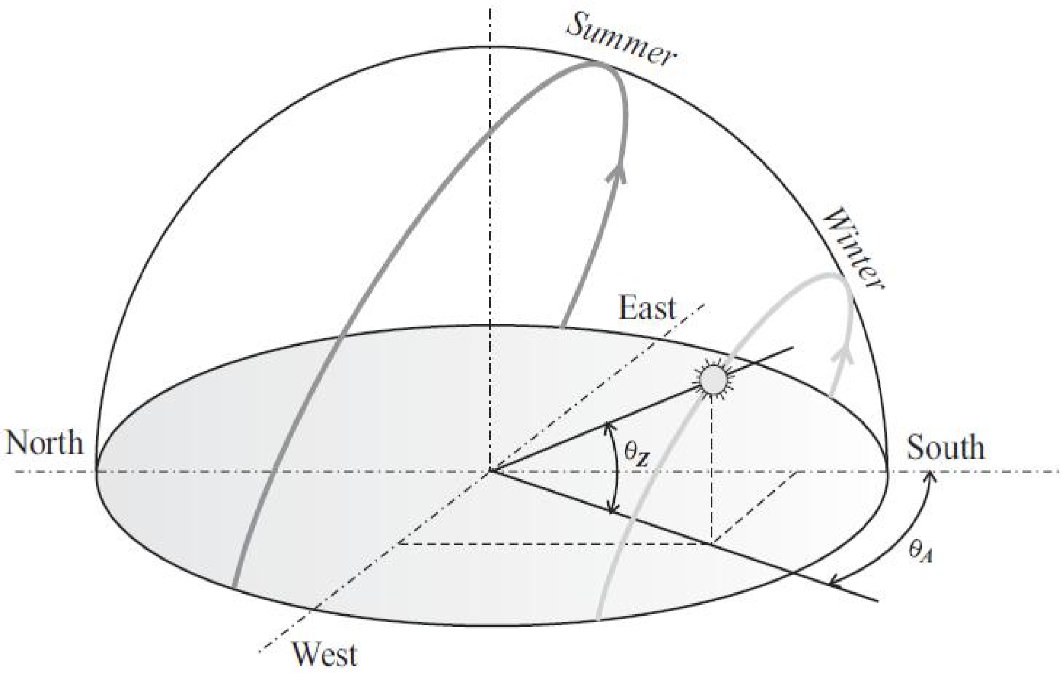


Fig. 3.3Typical behavior for the sun path in December (winter) and June (summer)

$Sin\theta = Sin\Phi.Sin\delta + Cos\Phi.Cos\delta.Cos\omega$ ………………….1

where

θ_z^o is the altitude angle of the system.

$\theta_z = 90^o$ -Zenith angle of the sun

Φ is the latitude ($\Phi = 30^o$ for our example)

ω is the hour angle(15^o/hour), where ω =0 at local noon.

δ is the solar declination.

the δ is calculated from Cooper's equation.

$\delta = 23.45.Sin[360/365(284+N)]$ ……………………………….2

Here, N is the day of the year (1 to 365),

N=1 on the 1^{st} of January

The rotational angle of the system in the horizontal plane (θ_A) is calculated from the equation:

where

$Sin\theta_A = Cos\delta.Sin\omega / Cos\theta_z$ ………………………………………..3

θ_A is the azimuth angle of the system.

3.4KINEMATICS

Earth receives energy of 1000w/m^2 which means we can generate 1000 watts of energy from 1m^2 area. If we assume a 10% total efficiency of the photovoltaic panels, the predicted output power from the panel will be 100 Watt. Although, it is known that there are panels with higher efficiency but it is preferable to calculate for the least case. Earth complete its one rotation around its axis in 24 hours which means that it rotate by 360 degrees in 24 hour or one day. Therefore one hour cover $360^0/24=15^0$,which means one hour angle $=15^0$. The system can be designed to move discretely to cover the total daily track in desired steps to reduce the operating time. After sunset, the panel can be designed to return back pointing towards the east to collect the sun radiation next morning. This return process can be done in desired time interval. While the maximum needed power is required by the motors forms 1% of the output of the panel. So it is feasible to rotate the panel using electric motors fed by the output of the panel itself.

3.5DYNAMICS

The solar array can be rotated in two directions, horizontal and vertical direction by taking azimuth and inclination angle as reference.

Two control techniques can be applied here:

1. Open-loop control technique that depends on calculating the voltage corresponding to the output angles and feeding them into the DC motors (to which our work is concerned).
2. Closed-loop technique which depends mainly on the signals sent by the two solar tracking sensors attached at the surface of the panel. The function of these sensors is to detect the position of the sun and feed the signal back to the electronic control circuit which in turn sends the signals to the motor to correct the real position of the panel perpendicular to the sun.

Each technique has its advantages and drawbacks, where the open-loop technique is safe and continuous but it needs to keep the motors operating all the time even when there is no sun in the cloudy days. The closed-loop technique saves power because it turns the motors onwhen the sun is shining only, while the system stops working in cloudy periods. The main disadvantage of the closed-loop technique is that it is expensive to be applied that it needs sensors, electronics and control kits. A timer can be used to return the whole system pointing towards the east after sunset to put the panel in a ready position facing the sun in thenext morning.Consider the solar panel drawing shown in Fig. 3.4. In this drawing, *a* and *b* are the dimensions of the rectangular plate panel, *d* is the perpendicular distance from the center of gravity of the panel to the point of action of the rotating motor. θz and θ_A are the Altitude and Azimuth angles, respectively. $^{2}{}_{A}$ and$^{2}{}_{B}$ are the torques produced by the motors around the Altitude and the Azimuth directions respectively. These torques are responsible for the rotation of the two degrees of freedom of the system.

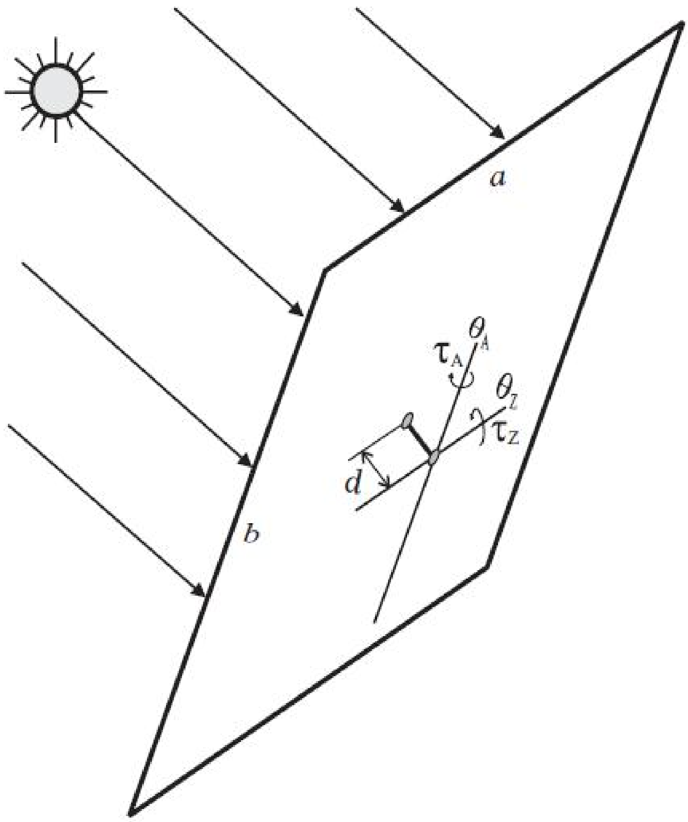


Fig 3.4 Configuration and angles of panel

3.6DC MOTOR SPEED CONTROL USING SIMLINK IN MATLAB

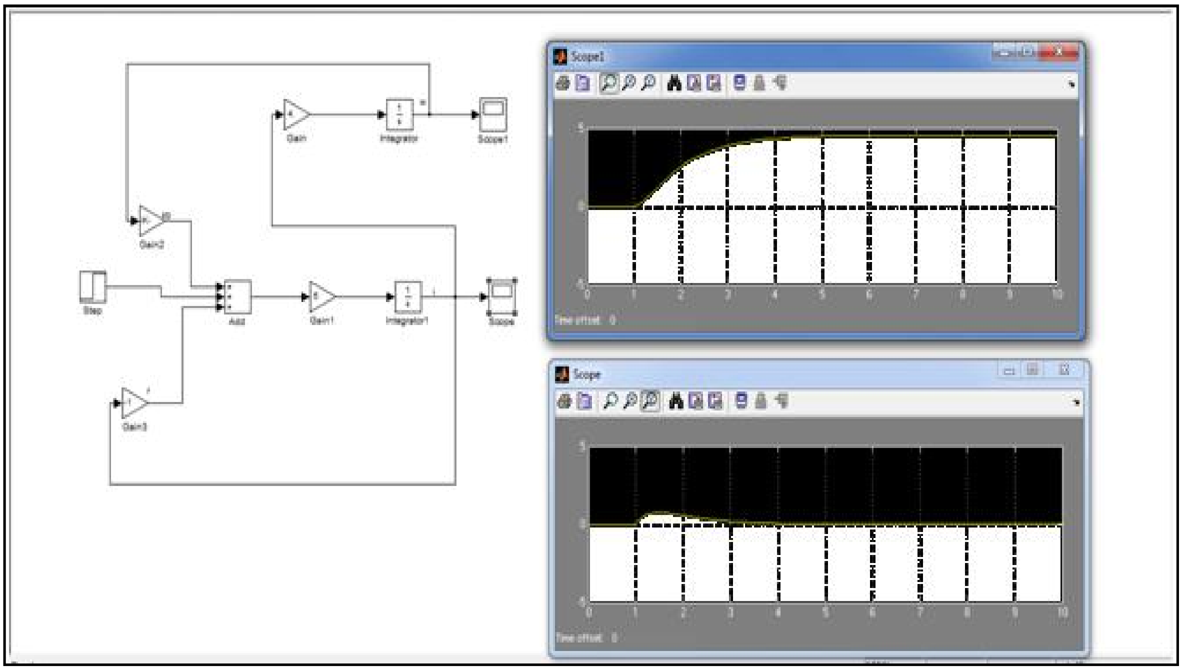


Fig3.5DC motor speed control using simlink in matlab,results are also shown

The electric circuit of the armature and the free body diagram of the rotor are shown in the following figure:

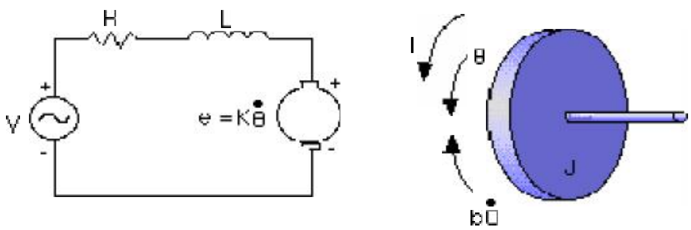


Fig 3.6 DC Motor model

DC motor system gives the following equations:

$$\omega(t) = \int \frac{kt}{Il} I(t) + I(0)$$

$$I(t) = \int \frac{1}{L} [Vs - R\, I(0)_{-} - Kb \;\; \omega(0)]$$

By simulating these two equations in matlab we get the DC motor current and angular velocity as shown in the figure 3.5.For this example, we will assume the following values for the physical parameters.

ω= Angular velocity

Kt=Torque constant=.02 Newton meter/ampere

Kb=Back emf constant=.22 volts/radians/second

Moment of inertia of the rotor (I_L) = 0.005 kg.m^2

Electric resistance (R] of coil inside the motor = 1 ohm

Electric inductance (L) = 0.2 H

Input (Vs) = Source Voltage

Output (theta): position of shaft

3.7 ASTRONOMICAL DATE BASED SIMULATION

MATHEMATICAL RELATIONS ARE IMPLEMENTED AND RESULTS ARE SHOWN IN THE FIGURES-

The figure 3.3 shows a typical behavior for the sun path in December (winter) and June (summer). The rotational angle of the orientation system in the vertical plane can be calculated from the following equation:

$Sin^{-} = Sin\Phi . Sin¢ + Cos\Phi . Cos¢ . Cos\mu$ ………………….1

where

¯z^o is the altitude angle of the system.

¯$z = 90^o$ -Zenith angle of the sun

Φ is the latitude ($\Phi = 30^o$ for our example)

µ is the hour angle(15^o/hour), where µ =0 at local noon.

¢ is the solar declination.

where ¢ is calculated from Cooper's equation.

¢ $= 23.45.Sin[360/365(284+N)]$ ……………………………………….2

Here, N is the day of the year (1 to 365),

N=1 on the 1st of January

The rotational angle of the system in the horizontal plane (θ_A) is calculated from the equation:
where

Sin¯$_A = Cos$¢$.Sin$µ $/ Cos$¯$_Z$ ………………………………………..3

¯$_A$ is the azimuth angle of the system..

Simulation of these equations as shown in the figure 3.7 gives altitude and azimuth angles for any value of hour angle, latitude and day of the year.For example here we take inputs as hour angle= 40, latitude=30^o, and the day of year=1-365 and the outputs are yearly variations of solardeclination, azimuth angle and altitude angle as shown in the figure 3.8, 3.9 & 3.10 .

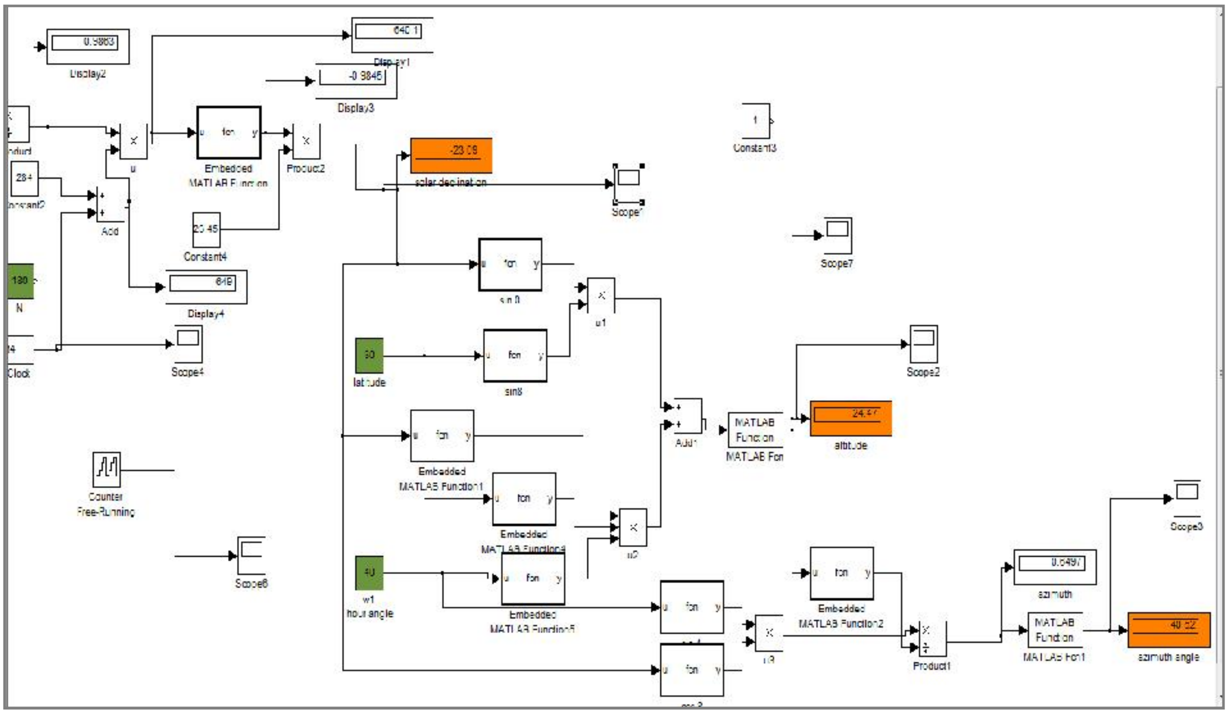


Fig 3.7Astronomical data based simulation

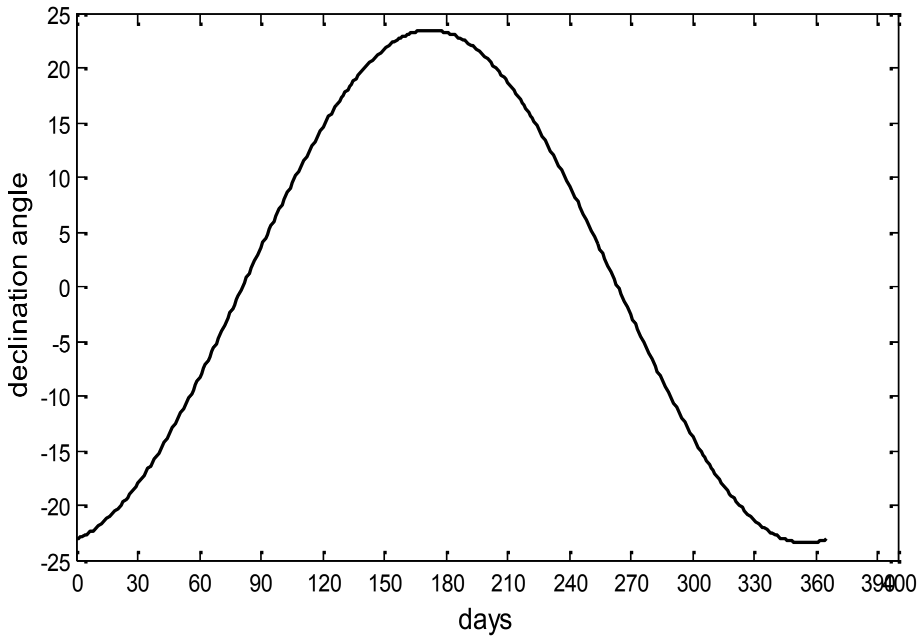


Fig 3.8 Declination angle variation throughout the year

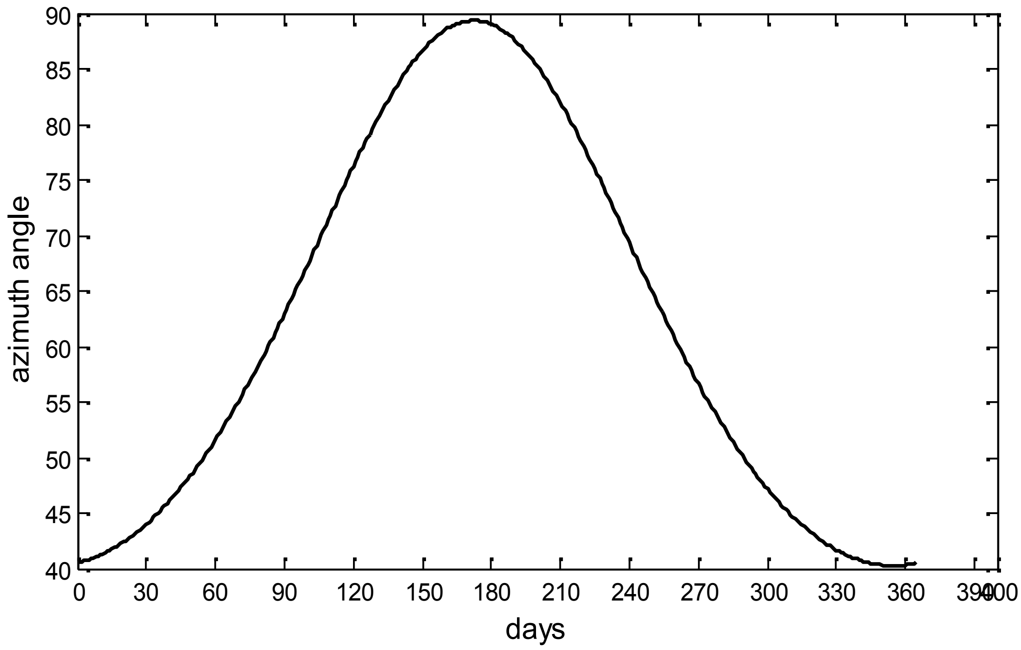


Fig 3.9 Azimuth angle variation throughout the year

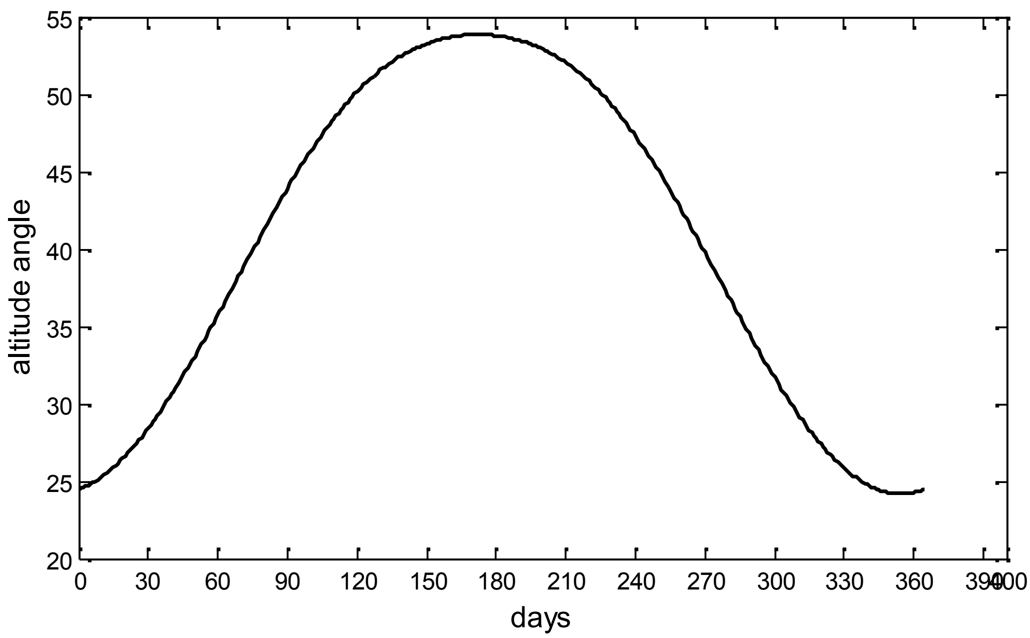


Fig 3.10Altitude angle variation throughout the year

3.8PROPOSED FLOW CHART FOR DUAL AXIS SOLAR PHOTOVOLTAIC PANEL

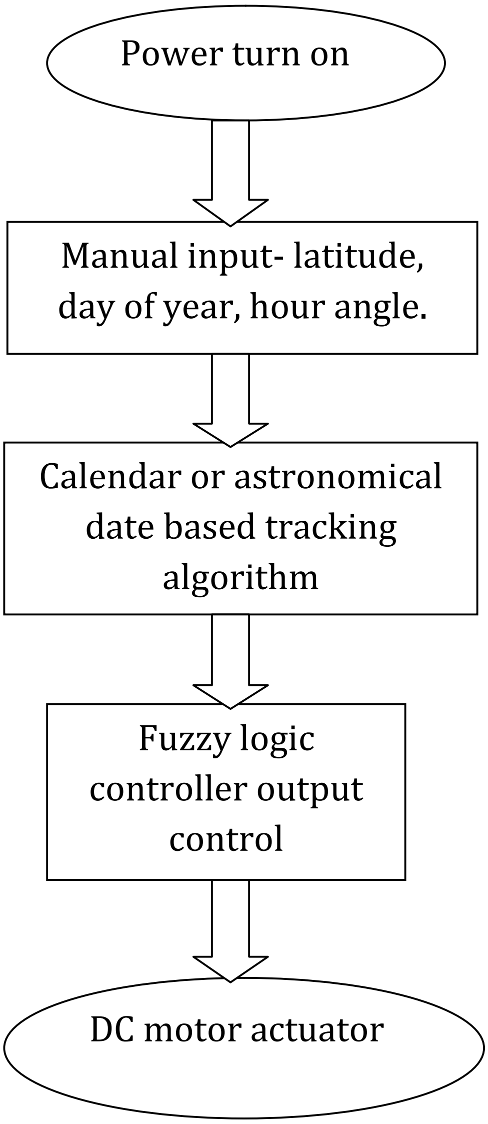


Fig 3.11 Flow chart

The initialization process is to manually feed the inputi.e. the latitude, hour angle and day of the year. Then by calendar based algorithm we will calculate the azimuth and altitude angle. And then the controller would control the solar altitude and azimuth motors to adjust the direction of the solar panel.

3.9 FUZZY LOGIC CONTROLLER IMPLEMENTATION

The fuzzy logic controller involves four main stages: fuzzification, rule base, inference mechanism and defuzzification as shown in Fig. 3.12.

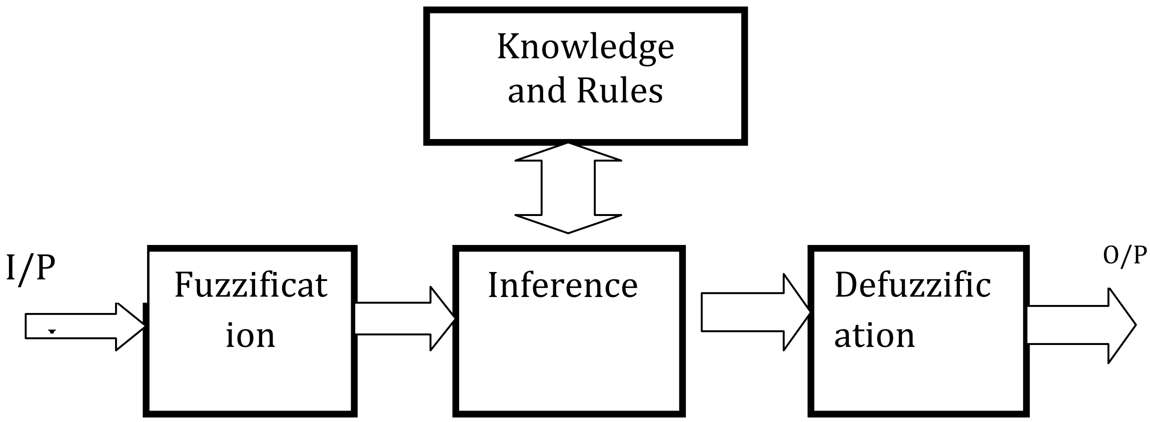


Fig 3.12-Fuzzy system diagram

The fuzzification and the defuzzification stages are needed to convert and reconvert real world crisp signals into fuzzy values and vice versa. In the fuzzy rule base, various rules areformed according to the problem's requirements. Thenumerical input values to the fuzzier are converted into fuzzyvalues. The fuzzy values along with the rule base are fed intothe inference engine which produces control values. As thecontrol values are not in usable form, they have to beconverted to numerical output values using the defuzzifier.The block diagram of the fuzzy controller used is shown in Fig. 3.12.The inference mechanism determines the matching degree of the current fuzzy input with respect to each rule and decides which rules are to be fired according to the input field. Next, the fired rules are combined to form the control actions.

The fuzzy controller takes two inputs as the references. The two inputs are:

1. Altitude angle
2. Azimuth angle

The fuzzy controller takes input (altitude and azimuth angle), processes the information and outputs a motor voltage setting.The input parameters considered in this controller is the Altitude and azimuth angle. The input membership function is divided intofive categories as negative large, negative medium, zero, positivemedium, positive large. The membership functions used in this model are triangular.These are represented as in Fig. 3.13. The range of inputs and output variables is shown in Table 3.1. These two inputs are obtained through the sensors. It is assumed that we have these inputs at our hand.

Table 3.1-Range of input and output

Membership Function Type	Altitude And Azimuth Angle	DC motor voltage range
negative large	-6 to -2	-6 to -2
negative medium	-4 to 0	-4 to 0
Zero	-2 to 2	-2 to 2
positive medium	0 to 4	0 to 4
positive large	2 to 6	2 to 6

Fuzzy control rules can be used to control the motor operation while ensuring the system control mechanism is sufficiently adjustable and has a fast response time. Fig 3.14shows the fuzzy concept applied to DC motor.

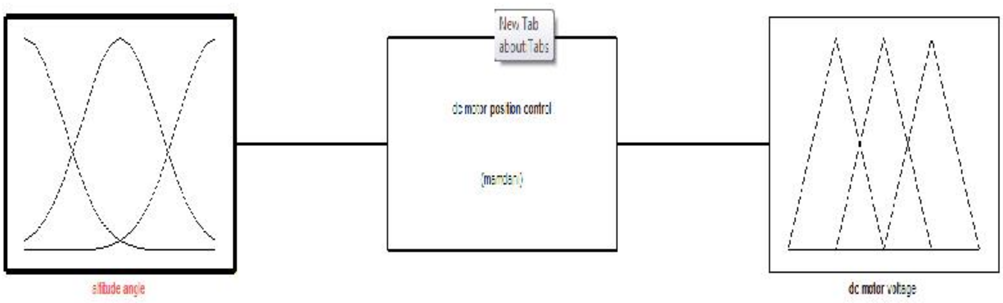


Fig 3.13-Shows the input and output membership functions

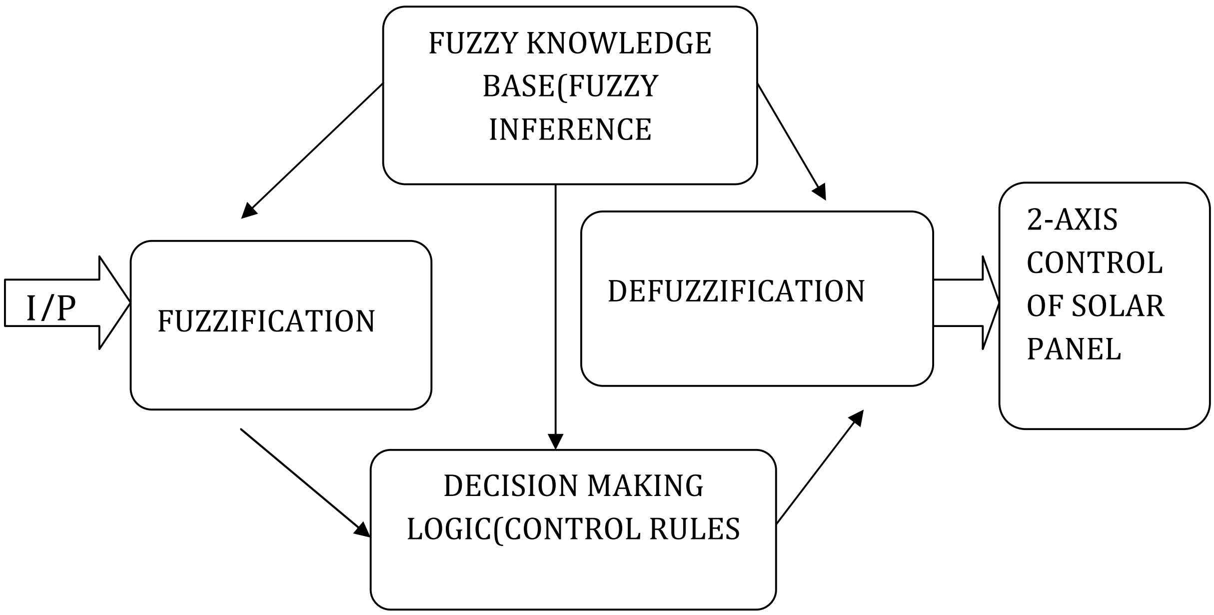


Fig 3.14The fuzzy concept applied to DC motor.

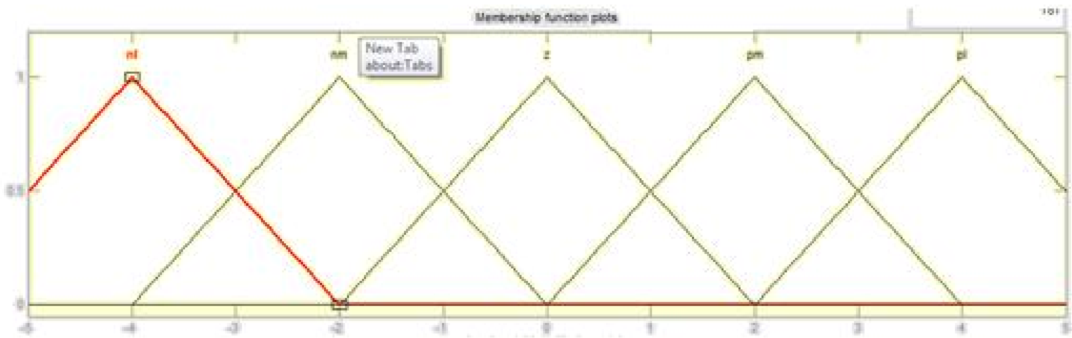


Fig 3.15Membership function for altitude and azimuth angles

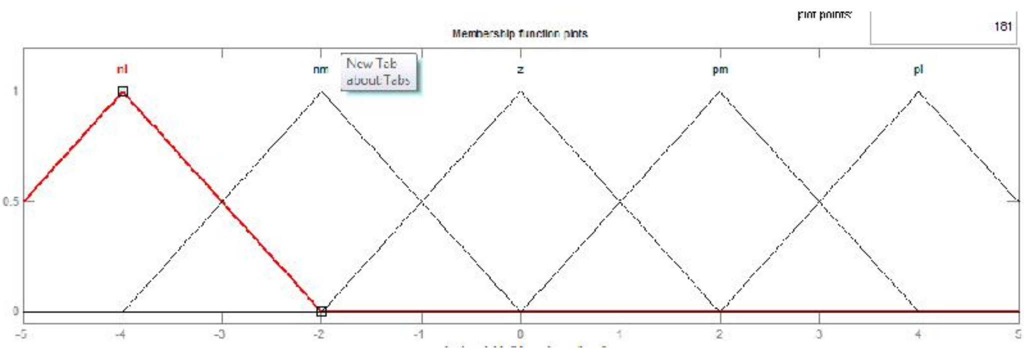


Fig 3.16 Membership function for dc motor voltage

FUZZY PROGRAMMING FOR DC MOTOR SPEED CONTROL-

Then fig 3.17& Fig 3.18shows the variation of dc motor voltage w.r.t. variation in altitude and azimuth angle.

```
clear all

clc
a=newfis('dc motor position control');
a=addvar(a,'input','altitude angle',[-5 5]);
a=addmf(a,'input',1,'nl','trimf',[-6 -4 -2]);
a=addmf(a,'input',1,'nm','trimf',[-4 -2 0]);
a=addmf(a,'input',1,'z','trimf',[-2 0 2]);
a=addmf(a,'input',1,'pm','trimf',[0 2 4]);
a=addmf(a,'input',1,'pl','trimf',[2 4 6]);
a=addvar(a,'output','dc motor voltage',[-5 5]);
a=addmf(a,'output',1,'1','trimf',[-6 -4 -2]);
a=addmf(a,'output',1,'2','trimf',[-4 -2 0]);
a=addmf(a,'output',1,'3','trimf',[-2 0 2]);
a=addmf(a,'output',1,'4','trimf',[0 2 4]);
a=addmf(a,'output',1,'5','trimf',[2 4 6]);
ruleList=[
1 1 1 1
2 2 1 1
3 3 1 1
4 4 1 1
5 5 1 1];
a=addrule(a,ruleList);
plotfis(a);
plotmf(a,'input',1);
plotmf(a,'output',1);
gensurf(a);
ruleedit(a);
ruleview(a);
mfedit(a);
surfview(a);
fuzzy(a);
a = readfis('dc motor')
```

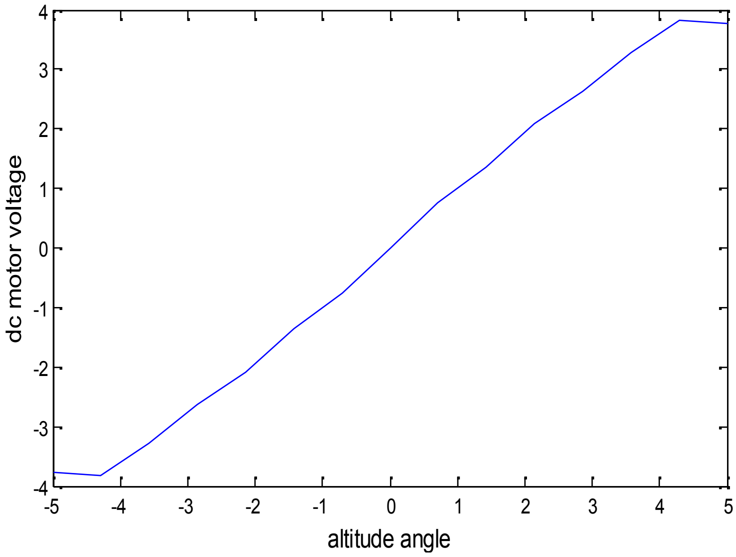
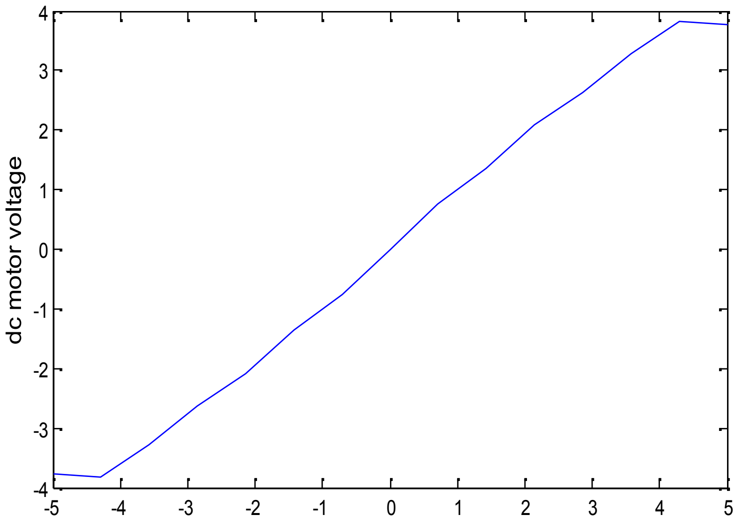


Fig 3.17 Fuzzy controller results
(DC motor voltage Vs altitude angle)



Azimuth angle

Fig 3.18Fuzzy controller results
(DC motor voltage Vs azimuth angle)

CHAPTER 4

RESULTS AND DISCUSSION

4.1 YEARLY ANGLE VARIATIONS OF SOLAR TRACKER

The inputs are hour angle= 40, latitude=30^o, and the day of year=1-365 and the outputs are yearly variations of solar declination, azimuth angle and altitude angle. The fuzzy controller takes two inputs as the references. The two inputs are:

1. Altitude angle

2. Azimuth angle

The fuzzy controller takes two inputs, processes the information and outputs a motor voltage setting. The controller would control the solar altitude and azimuth motors to adjust the direction of the solar panel accordingly.

Simulation for gettingyearly variations ofaltitude and azimuth angle of sunand dual axis solar trackeris shown in the figure 4.1. The simulation results which showtheyearly altitude and azimuth angle variation of suncalculated by astronomical data based computation, and simulated results obtained for solar tracker are shown in the figure 4.2 & 4.3.

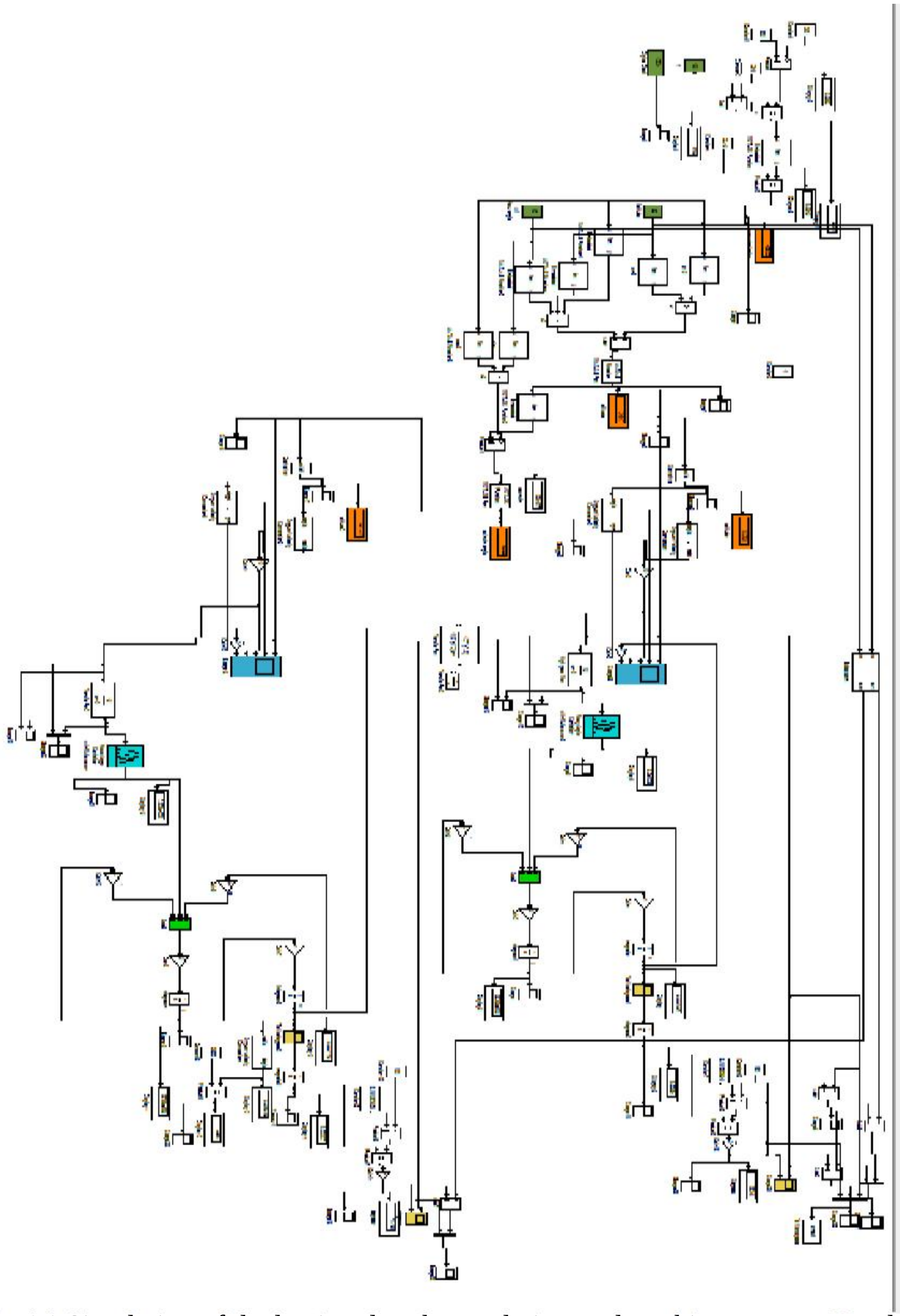


Fig 4.1 Simulation of dual axis solar photovoltaic panel tracking system- Yearly variation of solar panel angles

. The yearly altitude and azimuth angle variation of sun, calculated by astronomical data based computation, and simulated results obtained for solar tracker for hour angle= 40^0, latitude=30^o, and the day of year=1-365are shown in Figure 4.2 to 4.3 respectively. The simulated results are closely matching the computed results. The sun altitude angle varies from 25^0 in January to 58^0 in June and azimuth angle varies from 40^0 in Jan to 90^0 in June approximately. *(Continuous line represents desired angle and dotted line represent obtained angle)*(applicable to all)*

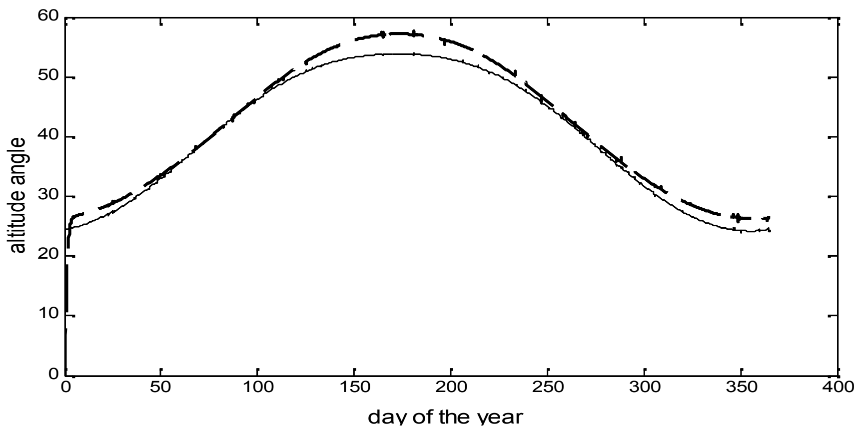


Fig 4.2 represents the yearly variation of the desired altitude angle and the obtained altitude angle

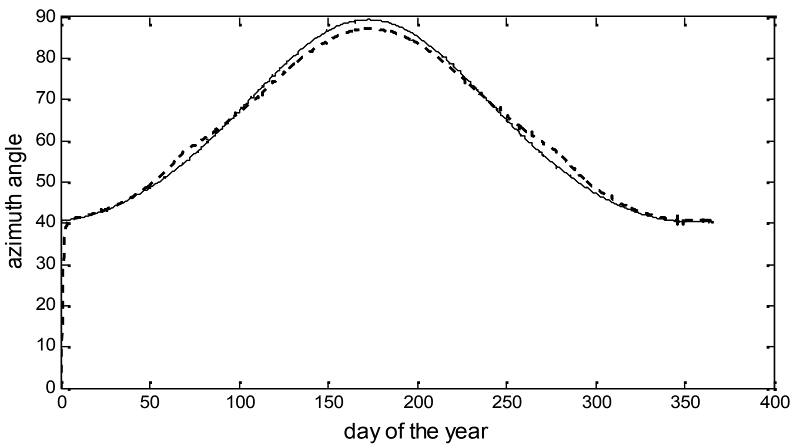


Fig 4.3 represents the yearly variation of the desired azimuth angle and the obtained azimuth angle

4.2 HOURLY ANGLE VARIATIONS OF SOLAR TRACKER

The inputs are hour angle= -90^0 to $+90^0$, latitude=30^o, and the day of year=1 to 365 and the outputs are hourly variations of solar declination, azimuth angle and altitude angle. The fuzzy controller takes two inputs as the references. The two inputs are:

1. Altitude angle

2. Azimuth angle

The fuzzy controller takes two inputs, processes the information and outputs a motor speed setting. The controller would control the solar altitude and azimuth motors to adjust the direction of the solar panel accordingly.

Simulation for gettinghourly variations of altitude and azimuth angle of sunand dual axis solar trackeris shown in the figure 4.4. The simulation results which show thehourly variations of altitude and azimuth angle variation of sun, calculated by astronomical data based computation, and simulated results obtained for solar trackercorresponding to the first day of every month of the whole yearare shown in the figure 4.5 to 4.28.

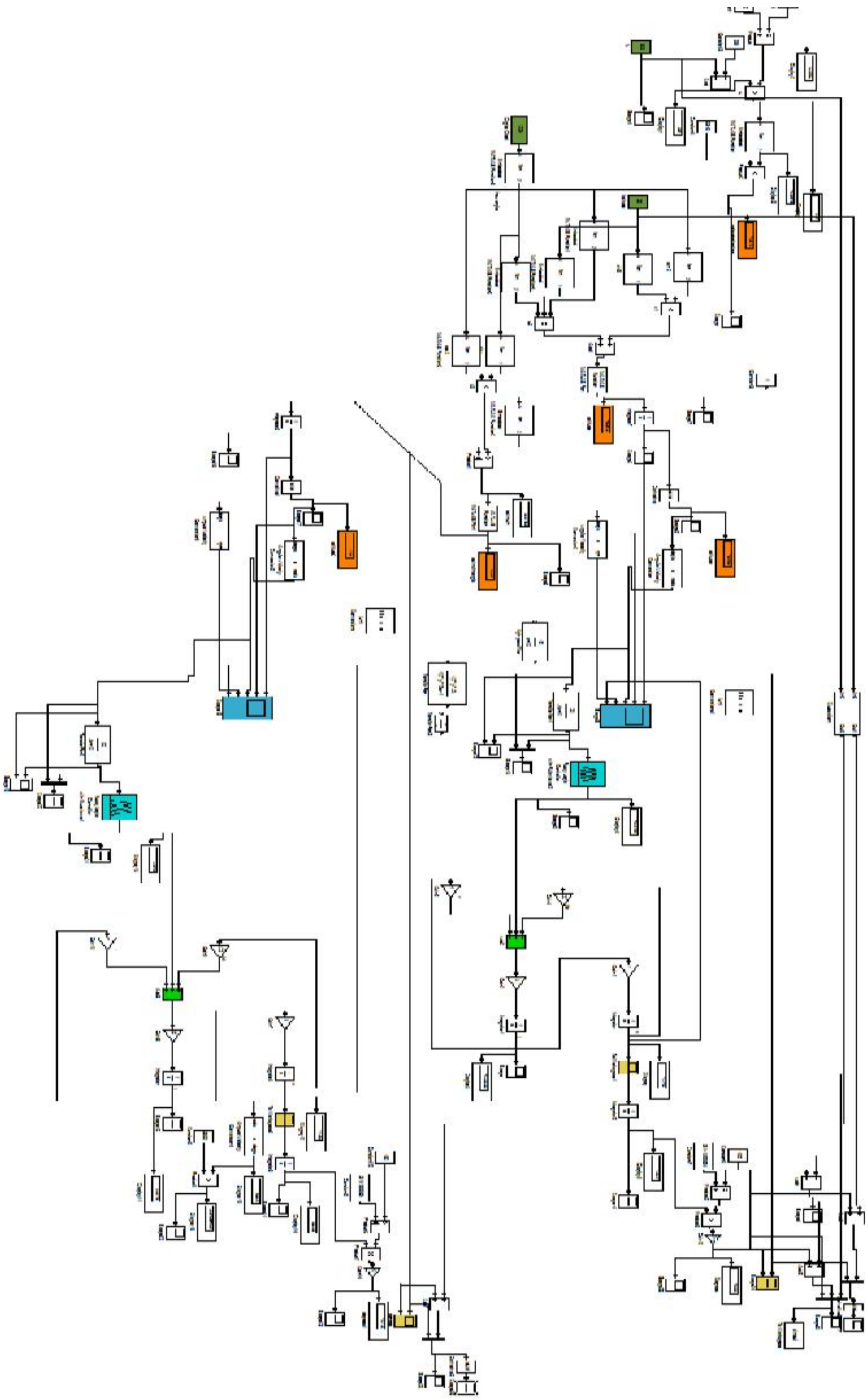


Fig 4.4 Simulation of dual axis solar photovoltaic panel tracking system-daily variation of solar panel angles

The hourly altitude and azimuth angle variation of sun, calculated by astronomical data based computation, and simulated results obtained for solar tracker on January 1are shown in Figure 4.4 & 4.5 respectively. The simulated results are closely matching the computed results. On January 1, the sun altitude angle at noon is 37^0 and azimuth angle at sun rise and sun set is 66^0(max= 66^0) approximately. *(Continuous line represents desired angle and dotted line represent obtained angle)*(applicable to all)*

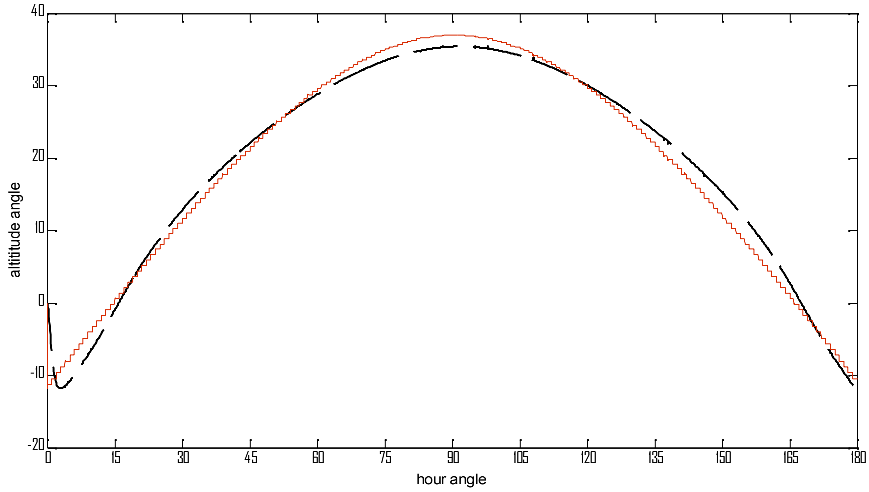


Fig 4.5 represents the hourly variation of the desired altitude angle and the obtained altitude angle on January 1

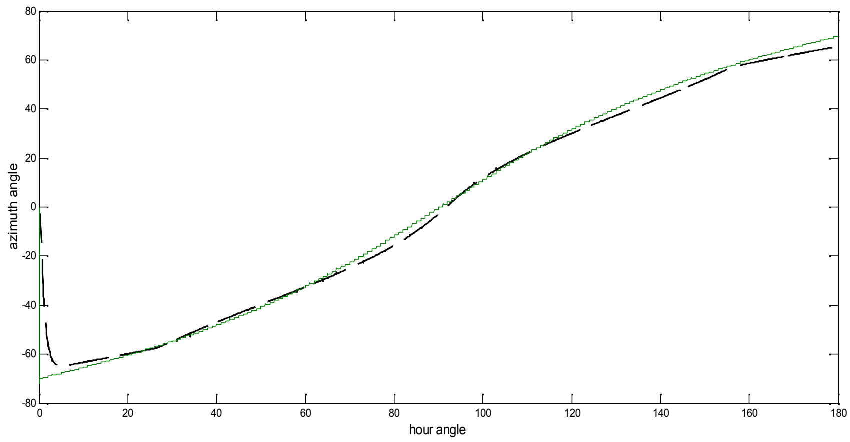


Fig 4.6 represents the hourly variation of the desired azimuth angle and the obtained azimuth angle on January 1

The hourly altitude and azimuth angle variation of sun, calculated by astronomical data based computation, and simulated results obtained for solar tracker on February 1are shown in Figure 4.7 & 4.8 respectively. The simulated results are closely matching the computed results. On February 1, the sun altitude angle at noon is 42^0 and azimuth angle at sun rise and sun set is 68^0(max= 68^0) approximately. *(Continuous line represents desired angle and dotted line represent obtained angle)*(applicable to all)*

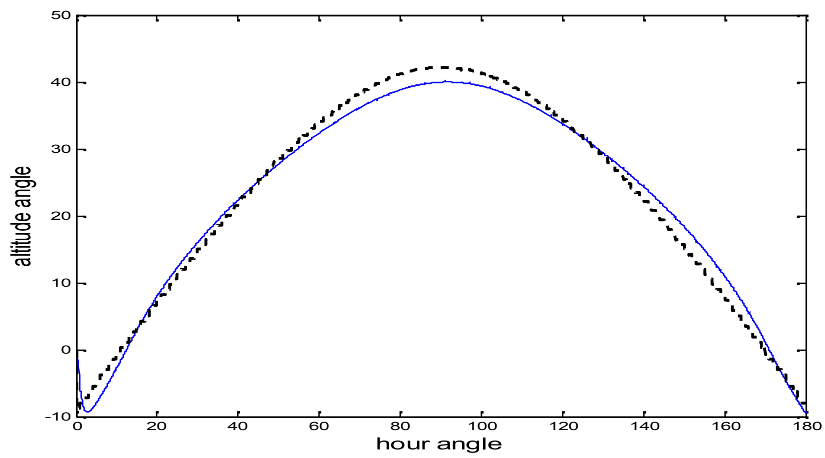


Fig 4.7 represents the hourly variation of the desired altitude angle and the obtained altitude angle on February 1

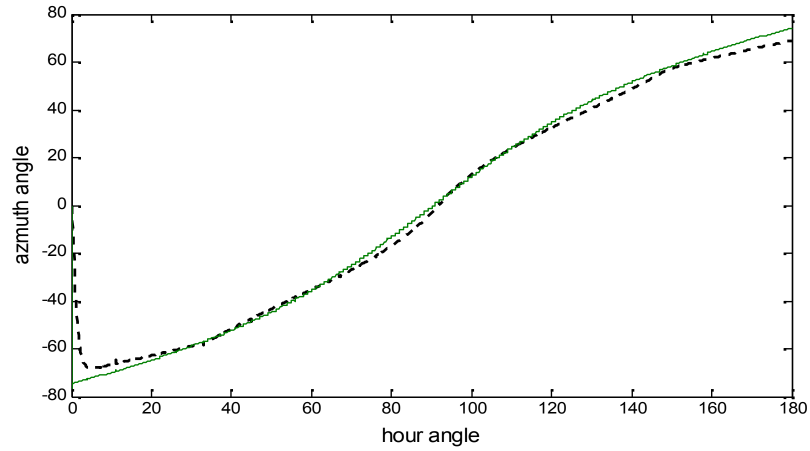


Fig 4.8 represents the hourly variation of the desired azimuth angle and the obtained azimuth angle on February 1

The hourly altitude and azimuth angle variation of sun, calculated by astronomical data based computation, and simulated results obtained for solar tracker on March 1are shown in Figure 4.9 & 4.10 respectively. The simulated results are closely matching the computed results. On March 1, the sun altitude angle at noon is 50^0 and azimuth angle at sun rise and sun set is 81^0(max= 81^0) approximately. *(Continuous line represents desired angle and dotted line represent obtained angle)*(applicable to all)*

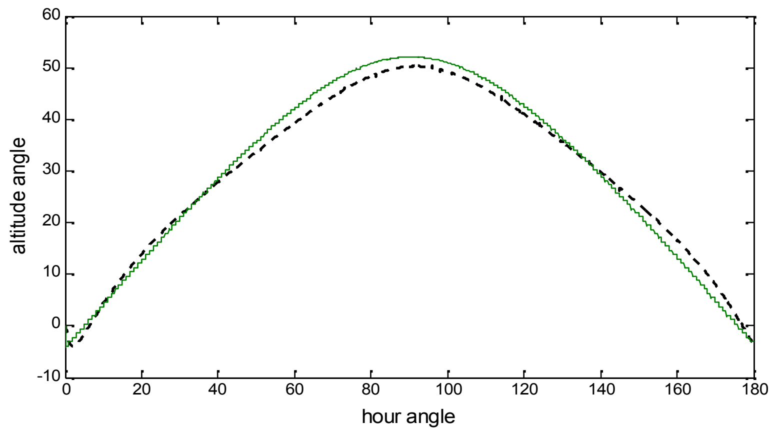


Fig 4.9 represents the hourly variation of the desired altitude angle and the obtained altitude angle on March 1

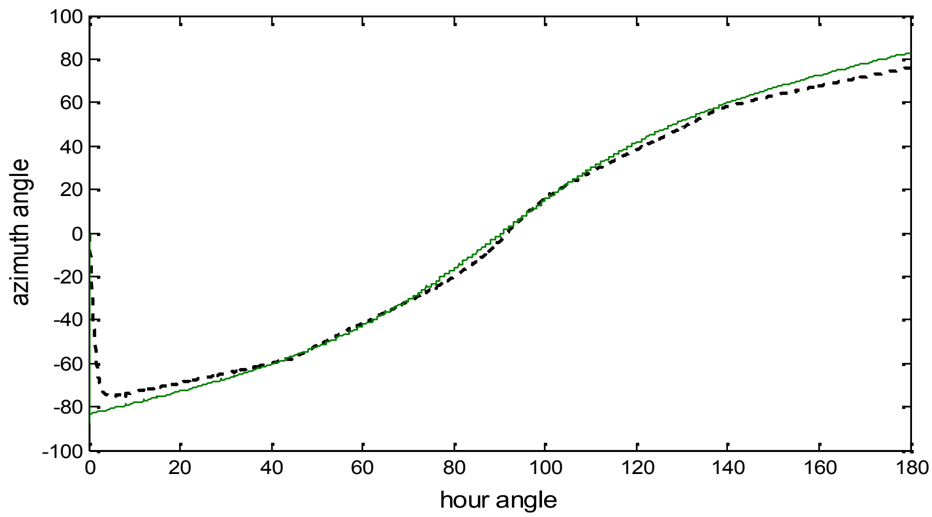


Fig 4.10 represents the hourly variation of the desired azimuth angle and the obtained azimuth angle on March 1

The hourly altitude and azimuth angle variation of sun, calculated by astronomical data based computation, and simulated results obtained for solar tracker on April 1are shown in Figure 4.11 & 4.12 respectively. The simulated results are closely matching the computed results. On April 1, the sun altitude angle at noon is 64^0 and azimuth angle at sun rise and sun set is 84^0(max= 84^0) approximately. *(Continuous line represents desired angle and dotted line represent obtained angle)*(applicable to all)*

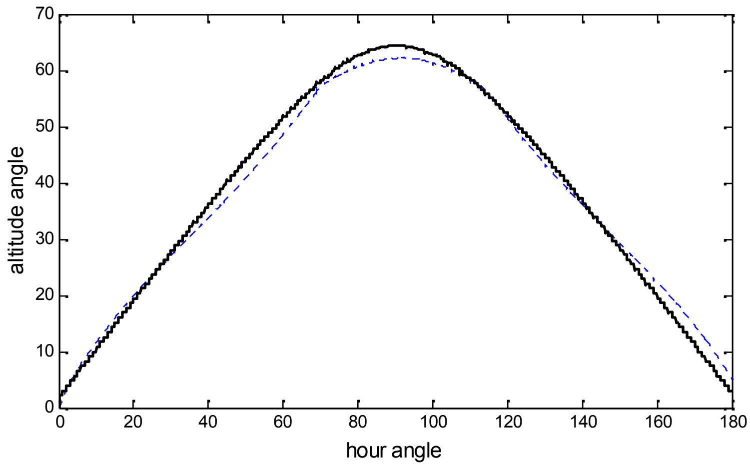


Fig 4.11represents the hourly variation of the desired altitude angle and the obtained altitude angle on April 1

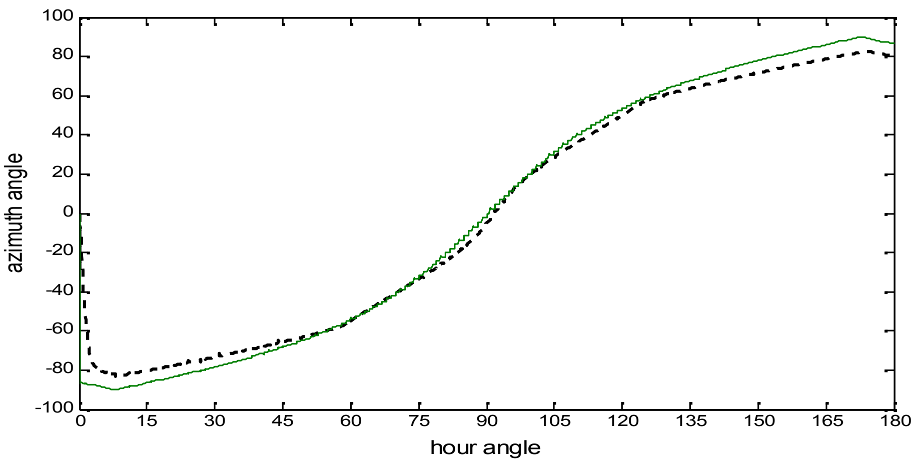


Fig4.12 represents the hourly variation of the desired azimuth angle and the obtained azimuth angle on April 1

The hourly altitude and azimuth angle variation of sun, calculated by astronomical data based computation, and simulated results obtained for solar tracker on May 1are shown in Figure 4.13 & 4.14 respectively. The simulated results are closely matching the computed results. On May 1, the sun altitude angle at noon is 74^0 and azimuth angle at sun rise and sun set is 78^0(max= 88^0) approximately. *(Continuous line represents desired angle and dotted line represent obtained angle)*(applicable to all)*

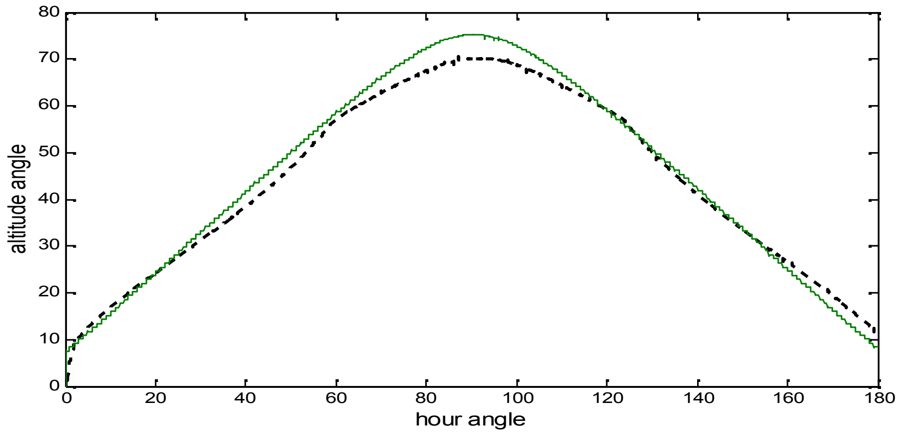


Fig 4.13 represents the hourly variation of the desired altitude angle and the obtained altitude angle on May 1

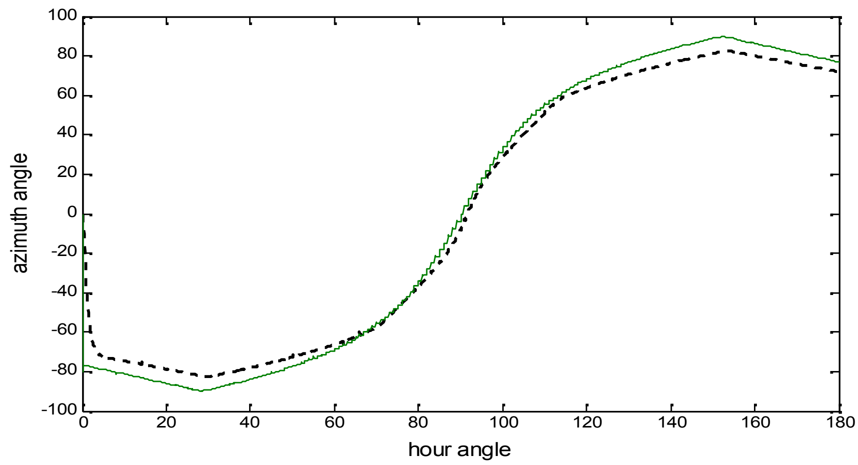


Fig 4.14 represents the hourly variation of the desired azimuth angle and the obtained azimuth angle on May 1

The hourly altitude and azimuth angle variation of sun, calculated by astronomical data based computation, and simulated results obtained for solar tracker on June 1are shown in Figure 4.15 & 4.16 respectively. The simulated results are closely matching the computed results. On June 1, the sun altitude angle at noon is 82^0 and azimuth angle at sun rise and sun set is 70^0(max= 90^0) approximately. *(Continuous line represents desired angle and dotted line represent obtained angle)*(applicable to all)*

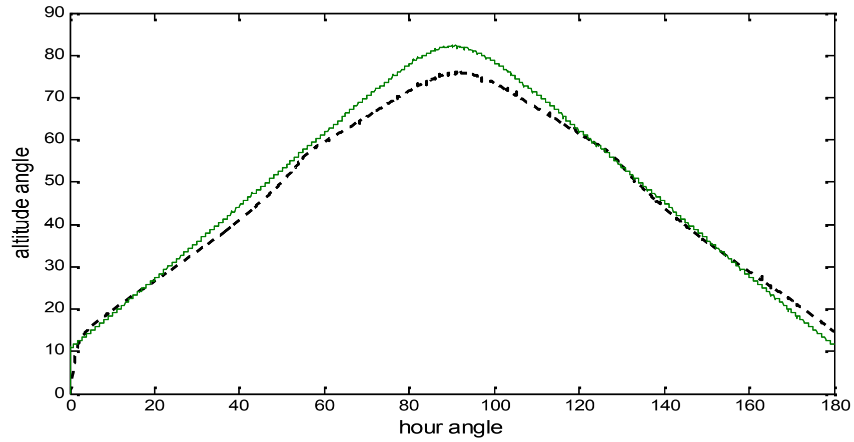


Fig 4.15 represents the hourly variation of the desired altitude angle and the obtained altitude angle on June 1

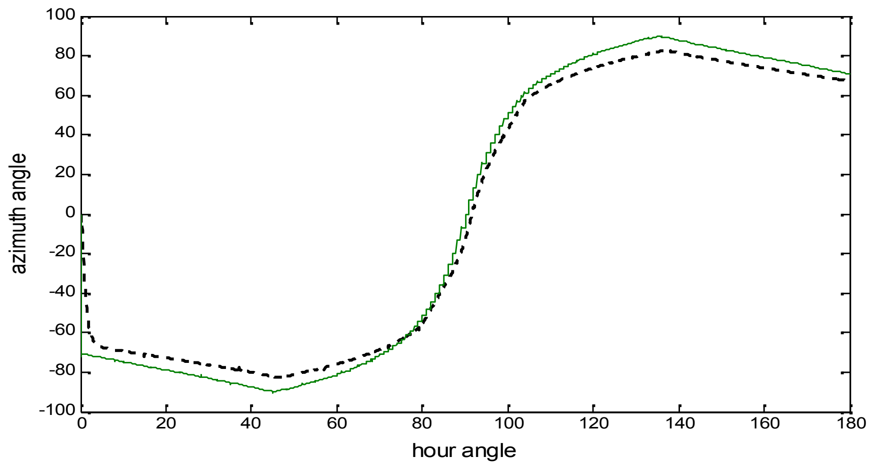


Fig 4.16 represents the hourly variation of the desired azimuth angle and the obtained azimuth angle on June 1

The hourly altitude and azimuth angle variation of sun, calculated by astronomical data based computation, and simulated results obtained for solar tracker on July 1are shown in Figure 4.17 & 4.18 respectively. The simulated results are closely matching the computed results. On July 1, the sun altitude angle at noon is 82^0 and azimuth angle at sun rise and sun set is 72^0(max= 90^0) approximately. *(Continuous line represents desired angle and dotted line represent obtained angle)*(applicable to all)*

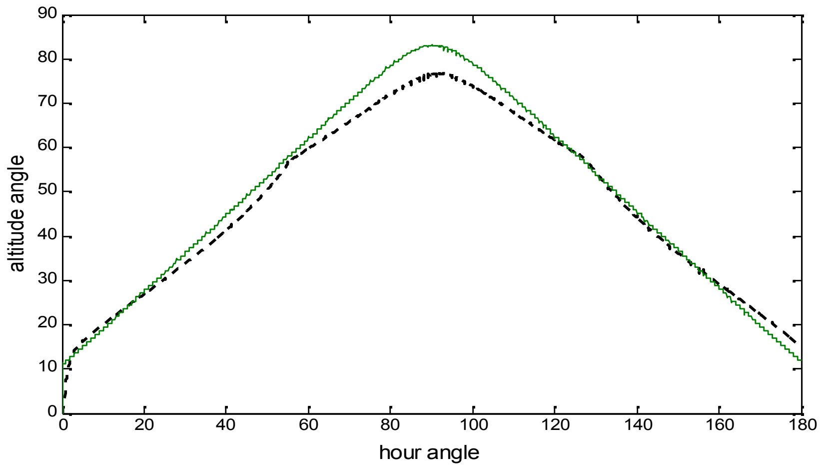


Fig 4.17 represents the hourly variation of the desired altitude angle and the obtained altitude angle on July 1

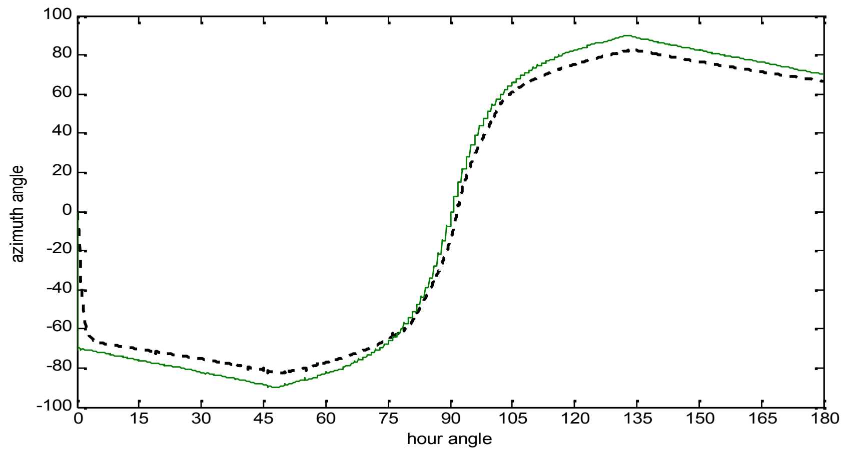


Fig 4.18 represents the hourly variation of the desired azimuth angle and the obtained azimuth angle on July 1

The hourly altitude and azimuth angle variation of sun, calculated by astronomical data based computation, and simulated results obtained for solar tracker on August 1are shown in Figure 4.19 & 4.20respectively. The simulated results are closely matching the computed results. On August 1, the sun altitude angle at noon is $77^0$and azimuth angle at sun rise and sun set is 76^0(max= 87^0) approximately.*(Continuous line represents desired angle and dotted line represent obtained angle)*(applicable to all)*

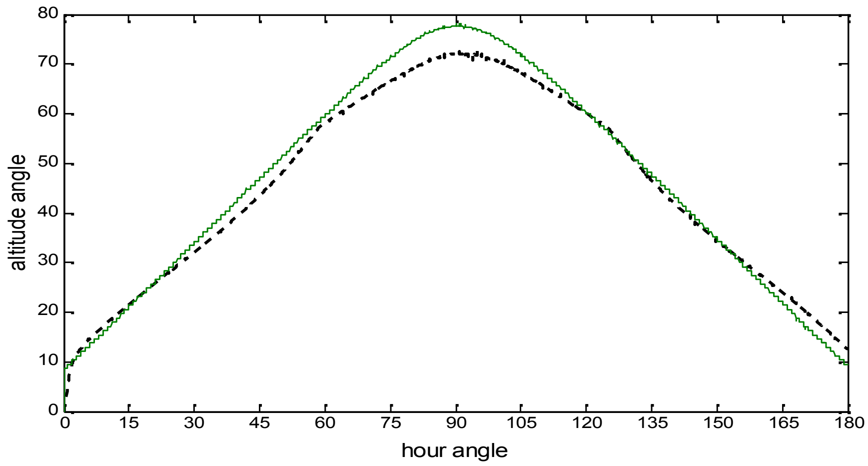


Fig 4.19 represents the hourly variation of the desired altitude angle and the obtained altitude angle on August 1

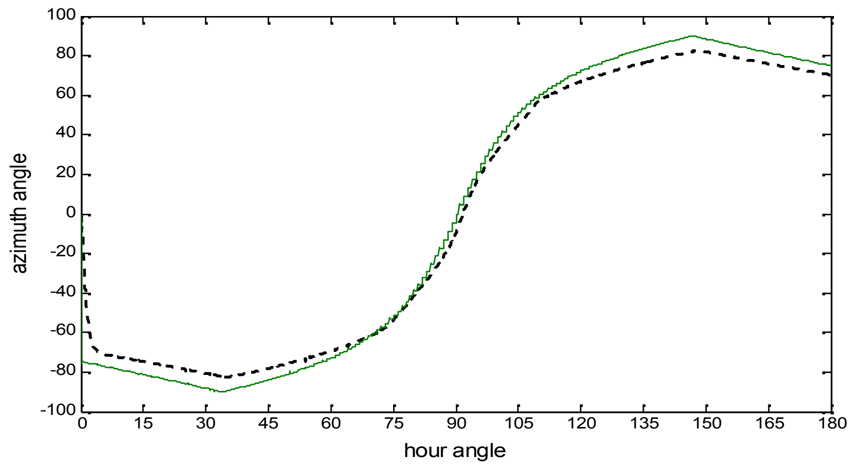


Fig 4.20 represents the hourly variation of the desired azimuth angle and the obtained azimuth angle on August 1

The hourly altitude and azimuth angle variation of sun, calculated by astronomical data based computation, and simulated results obtained for solar tracker on September 1are shown in Figure 4.21 & 4.22 respectively. The simulated results are closely matching the computed results. On September 1, the sun altitude angle at noon is 67^0 and azimuth angle at sun rise and sun set is 84^0(max= 87^0) approximately. *(Continuous line represents desired angle and dotted line represent obtained angle)*(applicable to all)*

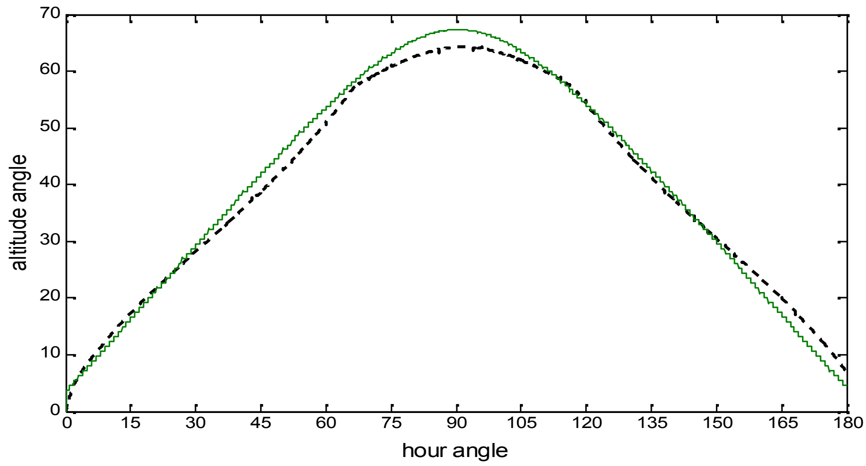


Fig 4.21 represents the hourly variation of the desired altitude angle and the obtained altitude angle on September 1

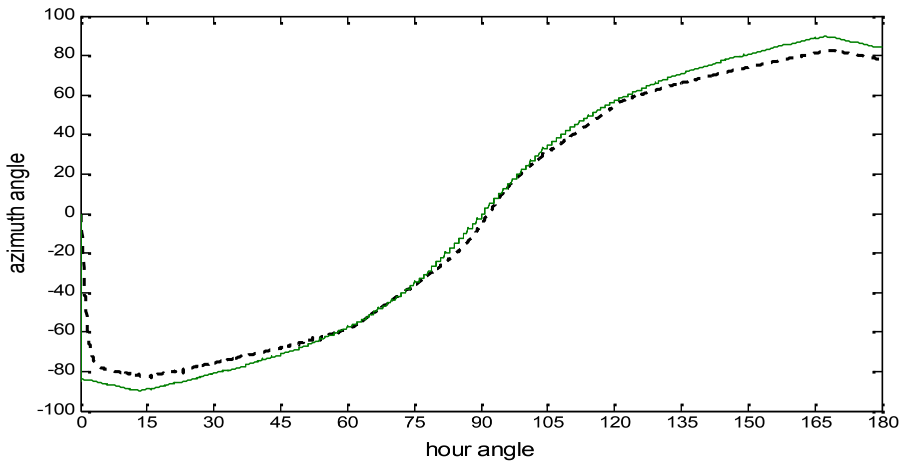


Fig 4.22 represents the hourly variation of the desired azimuth angle and the obtained azimuth angle on September 1

The hourly altitude and azimuth angle variation of sun, calculated by astronomical data based computation, and simulated results obtained for solar tracker on October 1are shown in Figure 4.23 & 4.24 respectively. The simulated results are closely matching the computed results. On October 1, the sun altitude angle at noon is 55^0 and azimuth angle at sun rise and sun set is 83^0(max= 83^0) approximately. *(Continuous line represents desired angle and dotted line represent obtained angle)*(applicable to all)*

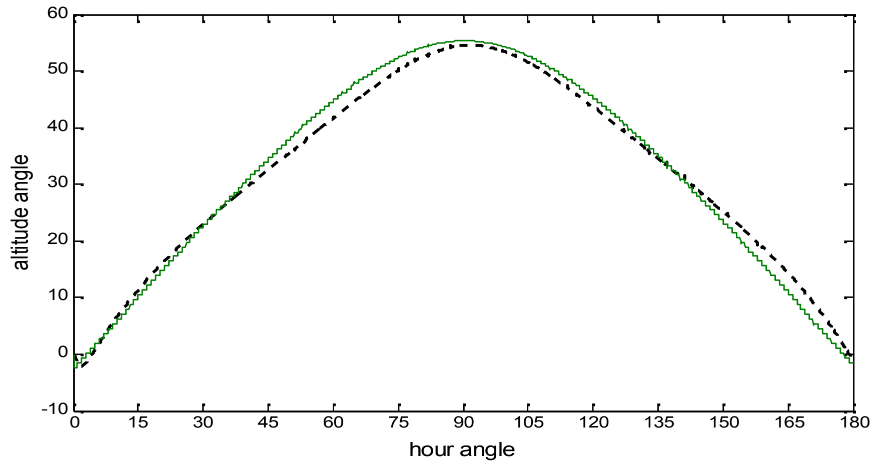


Fig 4.23 represents the hourly variation of the desired altitude angle and the obtained altitude angle on October 1

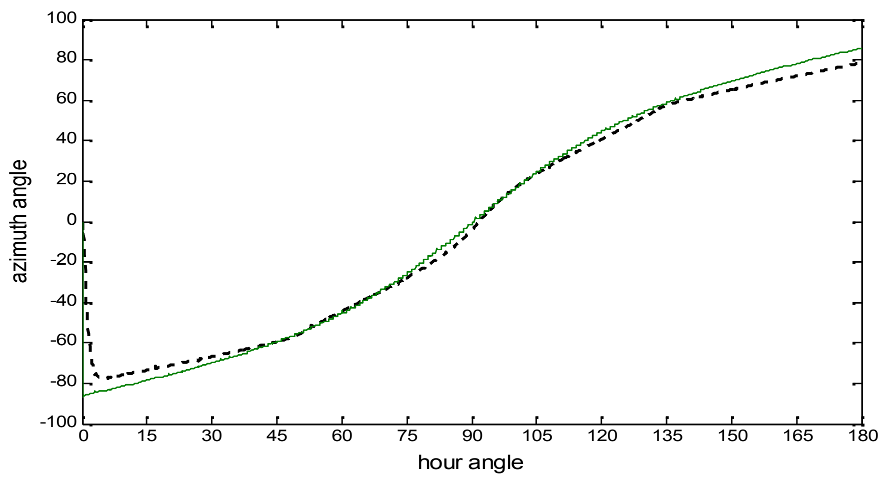


Fig 4.24 represents the hourly variation of the desired azimuth angle and the obtained azimuth angle on October 1

The hourly altitude and azimuth angle variation of sun, calculated by astronomical data based computation, and simulated results obtained for solar tracker on November 1are shown in Figure 4.25 & 4.26 respectively. The simulated results are closely matching the computed results. On November 1, the sun altitude angle at noon is 44^0 and azimuth angle at sun rise and sun set is 76^0(max= 76^0) approximately. *(Continuous line represents desired angle and dotted line represent obtained angle)*(applicable to all)*

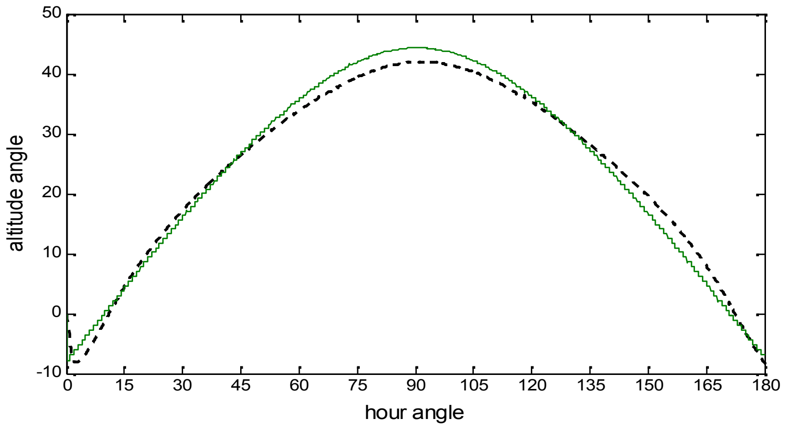


Fig 4.25 represents the hourly variation of the desired altitude angle and the obtained altitude angle on November 1

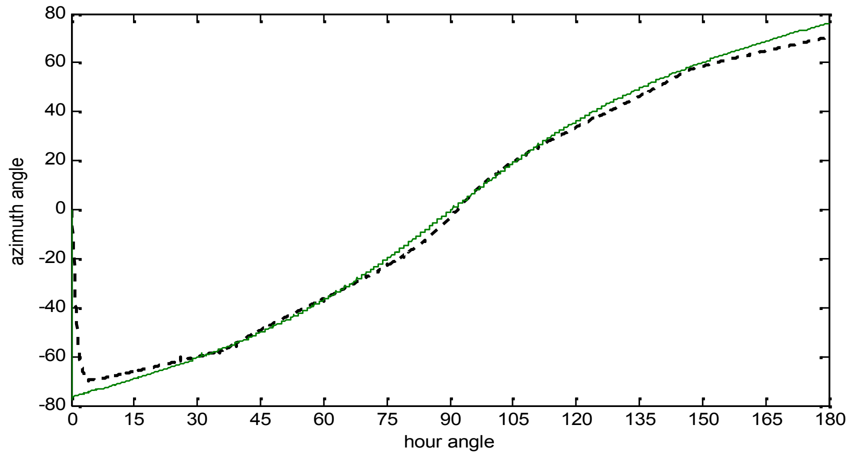


Fig 4.26 represents the hourly variation of the desired azimuth angle and the obtained azimuth angle on November 1

The hourly altitude and azimuth angle variation of sun, calculated by astronomical data based computation, and simulated results obtained for solar tracker on December 1are shown in Figure 4.27 & 4.28 respectively. The simulated results are closely matching the computed results. On December 1, the sun altitude angle at noon is 37^0 and azimuth angle at sun rise and sun set is 70^0(max= 70^0) approximately. *(Continuous line represents desired angle and dotted line represent obtained angle)*(applicable to all)*

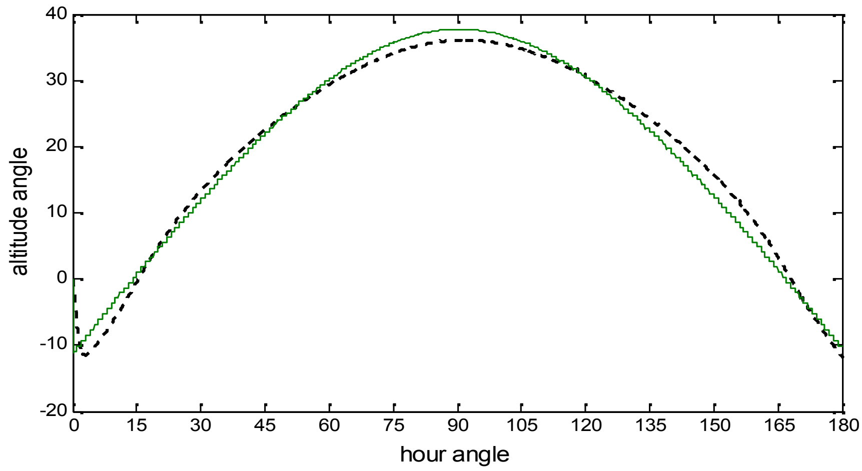


Fig 4.27 represents the hourly variation of the desired altitude angle and the obtained altitude angle on December 1

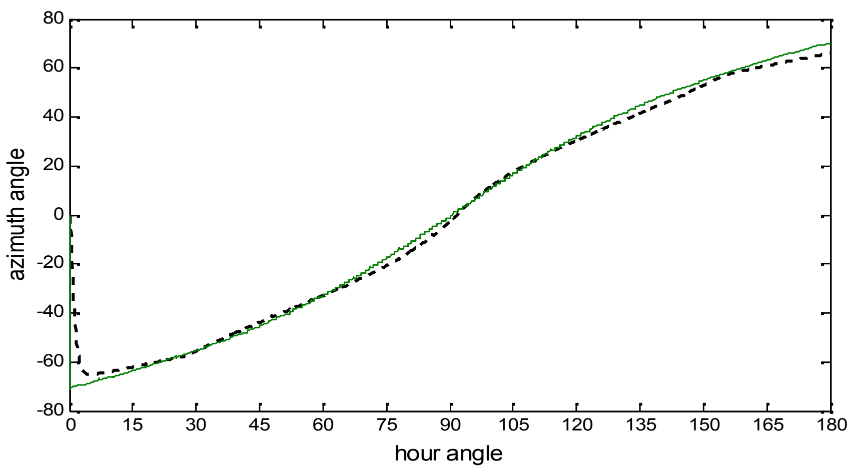


Fig 4.28 represents the hourly variation of the desired azimuth angle and the obtained azimuth angle on December 1

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

5.1 CONCLUSION

In this thesis the sun tracking system for photovoltaic array was implemented which is based on astronomical mathematical data based simulation.The following conclusions are drawn:

- The proposed mathematical simulation based dual axis solar photovoltaic panel trackeris capable to track the sun throughout the year.
- Kinematics of the system are simple and can easily be controlled using astronomic geometrical calculations taking into account the symmetry of the system.
- Two degrees of freedom orientation is feasible. The fuzzy controller has been used to control the position of DC motors which ensure point to point intermittent motion resulting from theDC motors.
- The controller is designed to rotate the panel from -90^o to $+90^o$.Thepresented dual axis solar panel tracking system keeps the solar photovoltaic panel perpendicular to the sun throughout the yearand thereby improving the efficiency of the solar system.

5.2 FUTURE SCOPE

At the completion of the work on solar tracking system, it is identified that there is a scope to implement the sun tracking to the concentrating type collectors.The efficiency of concentrating type collector with the tracking system will be improved. The work can be extended to investigate the use of battery charged by the photovoltaic panel trackeritself to run the system motors and electronics instead of using external power.

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