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Numerical Module on Energy Efficiency Literature Review of Solar Panel Tracking System

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Abstract: *The growth of any power system grid in the world always has been on an accelerating speed. Distributed Generation (DG) is an electrical power generation unit that is directly connected to a distribution network or placed as nearly as possible to its consumer. The technologies adopted in distributed generation vary in methods of generation including small-scaled gas turbines, wind, fuel cells, solar energy and hydro… etc [1]. DG is both beneficial to the consumers and utilities, much so in places where centralize generations are unfeasible or where deficiencies can be found in transmission systems. Optimally allocating DG units may address all the issues stated before, resulting in reduced power system losses, improved voltage profile, enhance power transfer capability, reduce pollution and cut generation and transmission cost [3,4]. This paper aims to present the optimum sizing and location of DG in power system by using Particle Swarm Optimization (PSO). Particle swarm optimization (PSO) is a population-based optimization method first proposed by Kennedy and Eberhart in 1995, inspired by social behavior of bird flocking or fish schooling. The researcher in this paper trying to demonstrate some of the literature that show the maximum energy from the solar panel. Where the tracker has a to detect the misalignment between PV module and the Sun's direct beam due to its movement. Based on the literature for the development of the solar tracker, each cycle will be started by defining existing flaws and necessary improvements of the system. The process under went with further cycles until the goal of the research was achieved. Boehm-Spiral methodology was applied throughout the research, including both hardware and software designs.*

Keywords: *Electrical power network – Distribution Generation - Particle Swarm Optimization (PSO) - Photovoltaic - Boehm-Spiral methodology*

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I. INTRODUCTION

1.1 Background History

The growth of any power system grid in the world always has been on an accelerating speed, feeding the almost insatiable demand for electrical power from the past century or so [1, 2]. This in turn forces a certain level of intricacy on the power system and that intricacy compounds with time to the point where the power systems face the inability to progress with ease due to introductions of new transmission systems and construction of generating plants near load centers. As the system grows more complex and burdened with increasing load; various issues regarding cost, pollution, power quality and voltage stability takes center stage [2].

Distributed Generation (DG) is an electrical power generation unit that is directly connected to a distribution network or placed as nearly as possible to its consumer. The technologies adopted in distributed generation vary in methods of generation including small-scaled gas turbines, wind, fuel cells, solar energy and hydro… etc [1]. DG is both beneficial to the consumers and utilities, much so in places where centralize generations are unfeasible or where deficiencies can be found in transmission systems. Optimally allocating DG units may address all the issues stated before, resulting in reduced power system losses, improved voltage profile, enhance power transfer capability, reduce pollution and cut generation and transmission cost [3,4]. Benefit-wise, DG may offer solutions to the majority of power systems crave. However, installation of a unit at a non-optimal place may have the reverse effect instead to the system; such as increases in system losses followed by an increase in cost [5-8]. With that in mind, selecting the most appropriate place for installation paired with the ideal size of a DG unit is of most importance in a large power system. Nevertheless, the optimum choice and allocation of DG is a complex integrative optimization method for which common or older optimization method falls short in implementing such a concept in the system [9].

In order to calculate the power loss and voltage magnitude at each bus, load flow studies is used by Gauss Saidel, Fast Decouple and Newton Raphson is one of the method of load flow studies in this paper, only Newton Raphson method is discussed to solve the load flow problem. This method can operate in high efficiency for large power system.

1.2 Problem Statement

For maximum energy, the solar panel has to be perpendicular to the sun. The tracker has a to detect the misalignment between PV module and the Sun's direct beam due to its movement. To solve this problem the tracker must be investigated and studied.

1.3 Objectives

The objectives of the paper are as follow:

1. To present and investigate the literature of solar System Starts for the First Time or After Power cut.
2. To study Angle Control of solar panel.

1.4 Research Methodology

In order to simulate and test the control systems of Solar Tracker Modeling, the Simulink models for all the blocks have been developed. The Simulink models are given in the appendix of this paper.

II. LITERATURE REVIEW

In this section, description and literature survey of the following concepts are presented:

2.1 Sun's Path

It's a fact that Earth revolves around the Sun. Sun's path is the relative change of the position of the Sun, both hourly and seasonal, as viewed from the earth. The position of the Sun at a given time is different in different seasons or even months. The path of the Sun during different seasons can be seen in the Figure 2.1 below.

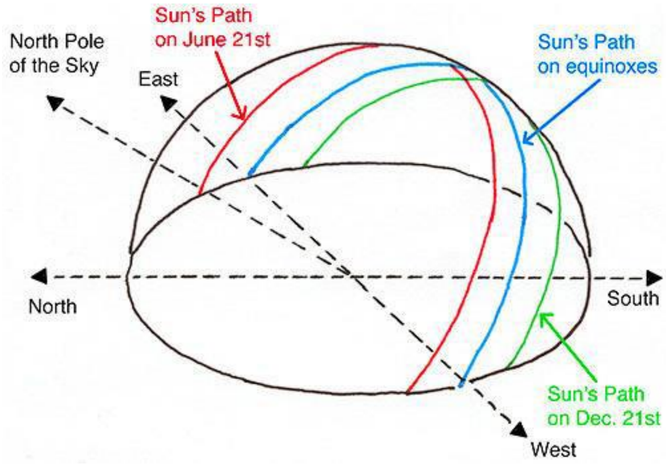


Figure 2.1 Sun's path during different seasons [5]

It is important to know the different angles that a Sun makes with the earth and they are shown below in the Figure 2.2

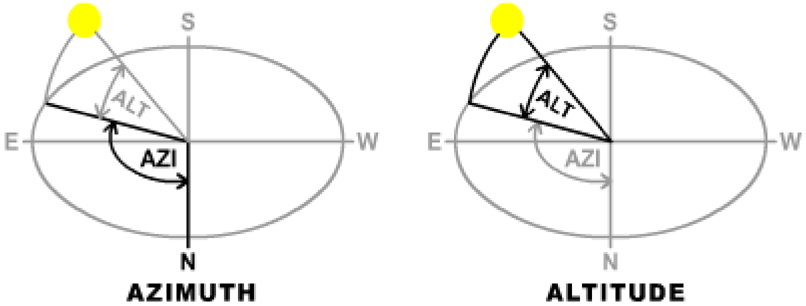


Figure 2.2 Sun's angles with an earth's object [6]

2.2. Photovoltaic System (PV System)

Photovoltaic system is a relatively new source of clean energy. The high demand of clean energy sources might have played a vital role in research and development of the PV system. The new PV systems are much more efficient now as the earliest PV systems had just efficiency around 6% [7].

One important aspect in PV systems is the charge controller that adjust the charging rates based on battery's charge level. It charges the battery's closer to its maximum capacity. It also monitors the battery's temperature thus preventing overheating. Maximum power point tracking (MPPT) and pulse width modulation (PWM) are the two commonly used charge controllers. A good comparison between the two techniques are given in the references [8], [9]. There are many MPPT techniques, some of the popular MPPT techniques are explained in reference [10], and in more detail in the reference [11].

Another important part of a PV system is its stability and control. The PV systems output has poor stability. There are only few papers that have emphasized the control and stability for PV systems [12] shows the study on stability control of dispatchable grid connected PV system; It explains that with energy storage system the dispatchable grid-connected PV system can effectively improve the power quality system and can stabilize the power fluctuation of the system and reference [13] shows the stability control of large scale dispatchable grid connected PV system by using super capacitor and batteries as energy storage system.

2.3 Solar Position

In order to track the Sun continuously it is needed to be able to calculate the exact position of the Sun at a given time. There are many algorithm that can calculate the position of Sun quiet efficiently. Michalsky's calculation can calculate the solar position with uncertainty greater than □ 0.01 and the calculations are limited from 1950 AD to 2050 AD [14]. Blanco-Muriel et al.'s calculations have uncertainty greater than □ 0.01 and the calculations are limited from 1999 AD to 2015 AD [15]. Jean Meeus's algorithm can calculate the solar position with uncertainties 0.00003 □ □ and the calculations are limited from -2000 AD to 6000AD [16].

The technical report presented by National Renewable Energy Laboratory (NREL) has used the Jean Meeus's algorithm and has developed codes written in C++, Python and Matlab [17]. It takes input as date, time, latitude, longitude and elevation and gives output Sun's current elevation and altitude.

2.4 Solar Tracking Methods

In this solar tracking methods literature survey, the researcher would like to mention few of many mechanisms that are currently used. One of the most common method used today comprises of two photo-sensors placed at two opposite sides of solar panel. Tracking is done by comparing the output of two photo-sensors. If the output of the two sensors mismatches by more than a certain acceptable error value then the solar panel is moved in the respective direction [18]. Another interesting method uses image processing to track the Sun's current position. It uses a designed reflecting type Cassegrain telescope to get an image.

It then uses image processing to get the coordinate of center of the Sun and then aims the panel at the Sun's center [19].

The third methods include GPS receiver and the output from the GPS receiver is fed into a microcontroller which calculates the Sun's current elevation and altitude; then solar panel is pointed to that particular direction [20].

Reference [21] uses both the photo-sensors as well as astronomical equations to build a standalone solar tracker.

This topic is about the research of possibility of solar tracking using astronomical angles as well as perturbation taking astronomical angles as reference to find the optimum angles. The optimization of tilt and azimuth angles is done by comparing the output power from the PV panel at different angles.

2.5 Solar Trackers

Solar tracker is a device that orients the payloads (typically PV panels) towards the direction of Sun [22]. Is it worth to have solar tracker? References [23] and [24] discusses in detail about finding out if it is worth to have solar trackers in terms of initial costs, available space and advantages and disadvantages of having a solar tracker.

There are mainly two types of solar trackers

2.5.1 Single Axis Solar Trackers

These type of trackers have only one degree of freedom, and can rotate only in one direction. It usually rotates to follow the Sun's elevation only [25]. A typical single axis solar tracker looks like in Figure 2.5.1.

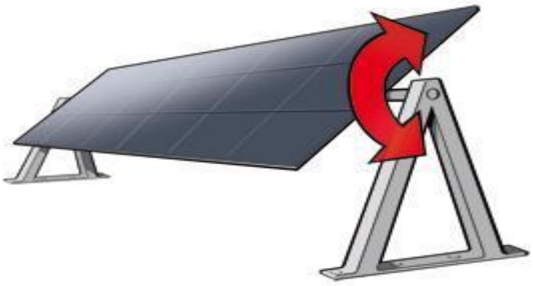


Figure 2.5.1 Horizontal type single-axis trackers [25]

2.5.2 Dual-Axis Solar Trackers

These type of trackers have two degree of freedom and has two axes of rotation. Normally these axes are perpendicular to each other. The axis that is fixed with respect to the ground is considered as primary axis. Two common implementations of dual-axis solar trackers are given below [26].

2.5.2 .1 Tip-Tilt Dual-Axis Solar Trackers

In this type of dual-axis solar tracker configuration the PV panel is mounted at the top of the pole. The east-west movement is performed by rotating around the pole. The vertical rotation of PV panel is governed by a T- or H-shaped mechanism placed at the top of the pole [26]. A typical tip-tilt dual-axis solar tracker looks like Figure 2.5.2.

Figure 2.5.2 Tip-Tilt Dual-Axis Solar Tracker [27]

2.5.2.2 Azimuth-Altitude Dual-Axis Solar Trackers

Azimuth axis is considered as primary axis and is vertical to the ground. The secondary axis is considered as elevation axis and is normal to the primary axis. As opposed to the tilt-tip dual axis solar trackers it uses a large ring mounted on the ground with the PV panel mounted on a series of rollers. This type of arrangement is suitable for the large and heavy PV panels [26]. A typical azimuth-altitude dual-axis solar tracker is shown in Figure 2.5.3.

Figure 2.5.3 Azimuth-Altitude Dual-Axis Solar Tracker [28]

III. RESULT AND DISCUSSION (SOLAR TRACKER MODELING)

3.1 Top Level Functional Block diagram

The top level block diagram of a complete solar tracking system is shown below in Figure 3.1.1 this research contains the work within angle optimizer and angle controller part only.

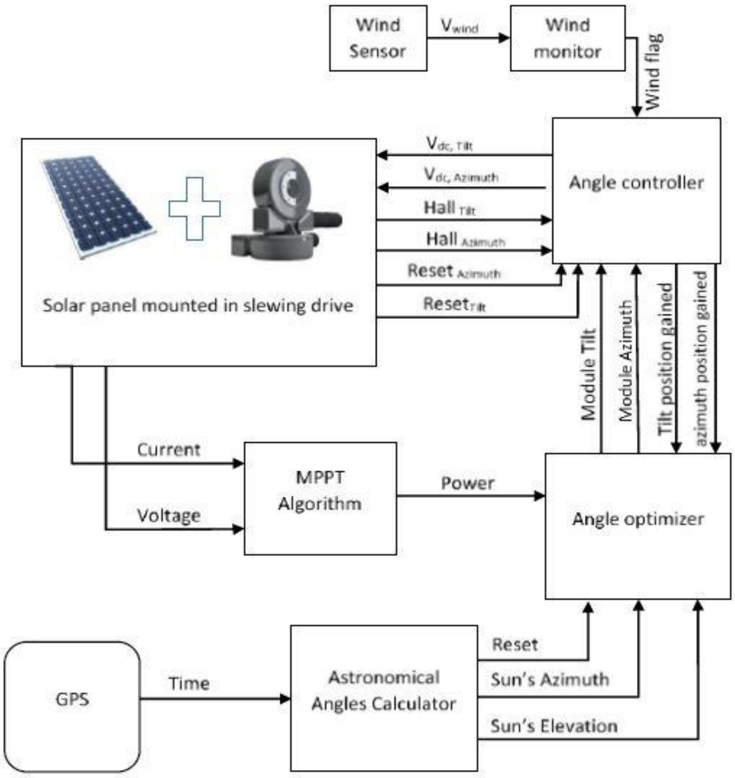


Figure 3.1.1 Top level block diagram of complete system

First let us suppose that the PV module (Solar panel mounted in the slewing drive) is in any arbitrary position and has a certain power (current × voltage) output. The GPS Block outputs the current time to the block Astronomical angles calculator. The Astronomical angles calculator then calculates the current position of Sun at that particular time in terms of azimuth and elevation angles. The Sun's azimuth and elevation angles are passed on to the block angle optimizer. The angle optimizer also receives or generates a reset signal in every 5 minutes to restart it's optimization process. The Angle optimizer block also receives the output power from the PV module. The Angle optimizer block is responsible to output the respective tilt and azimuth angles the PV panel has to move. It then finds the optimal angles for the PV module where it receives maximum sunlight by using iterative method. The optimization method is described in the respective sub-topic for Angle optimizer block.

The Angle controller takes the azimuth and tilt angles from the Angle optimizer block continuously. Compares it with the current azimuth and elevation angles of the PV module in the form of hall signals. And generates the required signal to the slewing drive in terms of negative, positive and zero voltages. When the desired position is reached then it sets the position reached flags to indicate the Angle controller that the PV panels has reached the desired position and the Angle controller is ready for another movement.

The Angle controller block also has a wind sensor attached to it. When the storm is dangerously high, it sets the PV module to parallel to the ground to prevent it from mechanical damage.

The brief description of each of the components is given in the following headings.

3.2 PV Panel

In order to simulate and test the control systems that we are going to develop, the researcher need a test model that can give the power output at any direction from the Sun. Let's consider first a tilted PV panel against the Sun's elevation as shown in Figure 3.2.1.

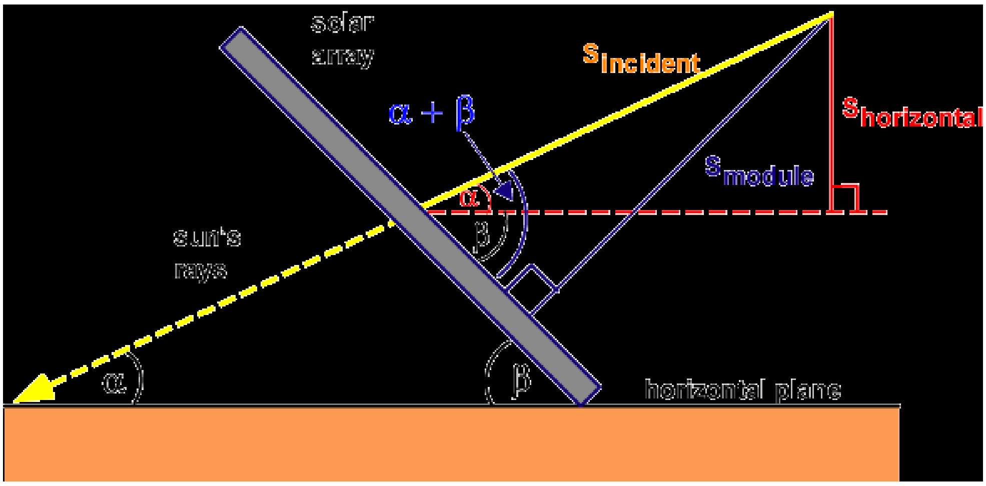


Figure 3.2.1 Sun's elevation and PV panel's tilt [29]

Here α = Sun's elevation angle (E,sa), it would be 90˚ when Sun is perpendicular to the horizontal plane (ground). and β= Module's tilt angle ($Atilt$), It would be 0˚when the PV module is parallel to the ground. Azimuth angle is considered 0˚at true North and 90˚at East and so on. If we consider a small variation (δγ) is added in both astronomical tilt and astronomical azimuth angles. Then the relation between optimum angles and astronomical angles would be as follows.

$$Toptm = 90° - (Es\ , a + \delta\ ) \qquad (1.1)$$

, and

$$,Aoptm = As\ a\ + \gamma \qquad (1.2)$$

A relation for Solar Intensity out of the PV panel ($Sout$) and Solar intensity incident (Si)on the PV panel can be given below as [30]:

$$Sout = Si[\cos(Es, a + \delta\ )\sin(Tout)\cos(Aout - (As, a + \gamma\ )) + \sin(Es, a + \delta\ )\cos(Tout)] \qquad (1.3)$$

So, $Sout$ would be maximum when $T\ out = Toptm$ and $Aout = A\ optm$

3.3 Slewing Drive

To build a solar tracker a mechanical device is needed that can rotate in any tilt and azimuthal direction. So a slewing drive SDE7C is chosen by other students of industrial engineering faculty. The data sheet of that slewing drive is given in the appendix.

The only things about the slewing drive that is required to build the Angle controller block are

- It contains two identical brushed dc motors in the tilt and azimuth directions.
- Both motors has same gear ratio (reducer ratio = 236:1 and slewing drive gear ratio = 73).
- Operating voltage is equal to 24 volts.
- Both DC motors are fitted with dual hall sensors (+12 volts peak) for position feedback.
- The slewing drive will be able to rotate from 0˚ to 90˚ in tilt direction and from 0˚ to 330˚ in the azimuth direction.
- Four reset switches will be place at 0˚and 90˚tilt and 0˚and 330˚azimuth directions respectively.

Then a Hall encoder is built to convert the motor position to dual hall signal.

The output of the Dual Hall Senor looks like in Figure 3.3.1 below.

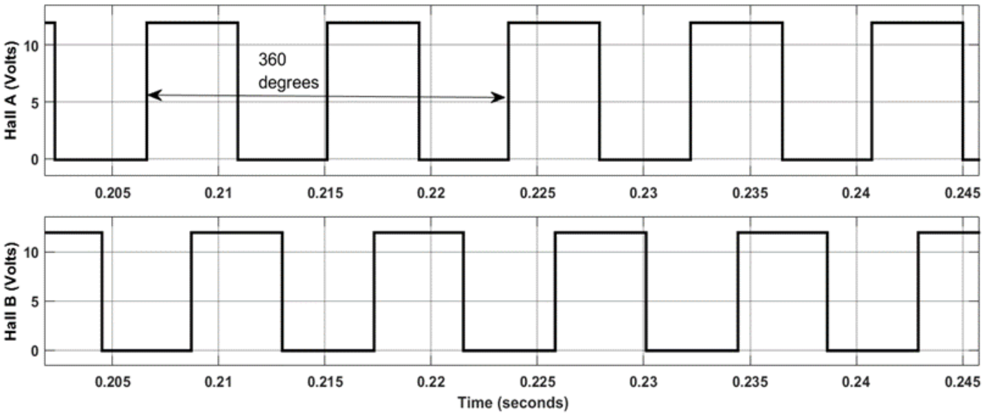


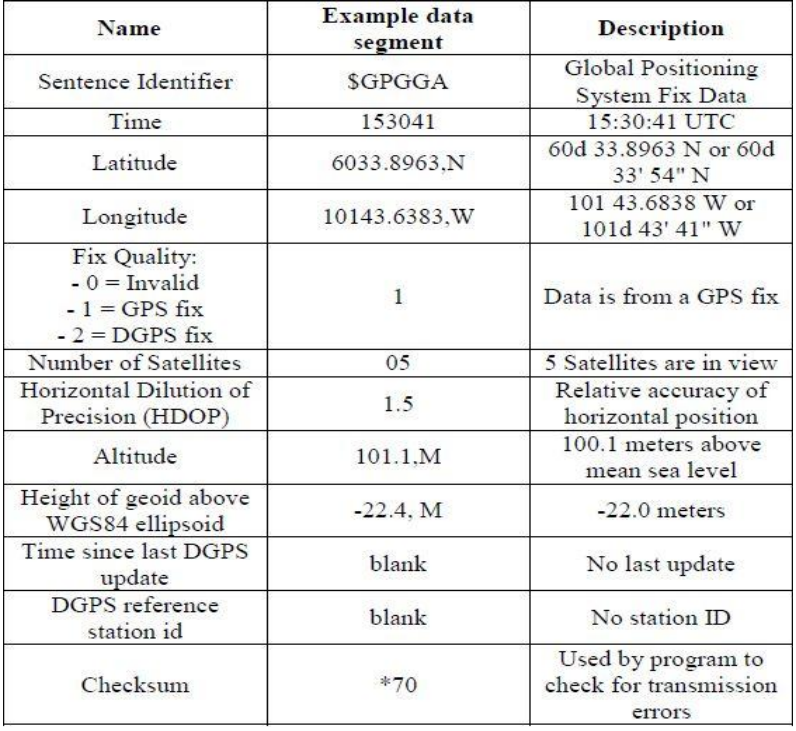
Figure 3.3.1 Dual hall output

When the system starts for the first time or after the power cut. The current position of the PV panel cannot be determined. So to set itself to the correct position the four reset switches are used. The PV module will always rotate in the positive tilt direction until the reset switch at 90° tilt is hit. And the PV module will rotate to the negative azimuthal direction until the reset switch at
0° azimuth is hit.
It can be said that when the system starts it should always set itself at 90° tilt and 0° azimuth. This is further explained in the sub-topic 3.8.

3.4 Global Positioning System (GPS)

GPS was developed by U.S. Department of Defense (DoD). It is a satellite based navigation system. It continuously provides timing and positioning information's for unlimited number of users under any weather conditions and anywhere in the world [31].
The standard format for data received from GPS is in NMEA-0183 format. It outputs lots of sentences such as GGA, GLL, GSA, GSV, RMC, and VTG. But for our needs we only need to look at sentences starting with GGA [32].
An example of NMEA V3.01 GGA data received from the GPS looks like:
$GPGGA,153041,6033.8963,N,10143.6383,W,1,05,1.5,101.1,M,- 22.4,M,*70. [32].
Data from the GPS can be viewed as given in the following Table 1

Table 1 Data contained in GPS output message [32]



Name	Example data segment	Description
Sentence Identifier	$GPGGA	Global Positioning System Fix Data
Time	153041	15:30:41 UTC
Latitude	6033.8963,N	60d 33.8963 N or 60d 33' 54" N
Longitude	10143.6383,W	101 43.6838 W or 101d 43' 41" W
Fix Quality: - 0 = Invalid - 1 = GPS fix - 2 = DGPS fix	1	Data is from a GPS fix
Number of Satellites	05	5 Satellites are in view
Horizontal Dilution of Precision (HDOP)	1.5	Relative accuracy of horizontal position
Altitude	101.1,M	100.1 meters above mean sea level
Height of geoid above WGS84 ellipsoid	-22.4, M	-22.0 meters
Time since last DGPS update	blank	No last update
DGPS reference station id	blank	No station ID
Checksum	*70	Used by program to check for transmission errors

So the time should be extracted from the GPS's message and should be sent to the next block Astronomical angles calculator.

3.5 Astronomical Angles Calculator

The only function of this block is to feed in the current time then it outputs the current position of Sun in terms of Sun's elevation angle and Sun's azimuth angle.

There are certain calculations involved to complete this process. The different methods to calculate these angles and their relative accuracy is explained in the sub-heading 2.3 Solar Position of this paper. The most accurate method till date to calculate astronomical angles is developed by National Renewable Energy Laboratory (NREL) and their source code in C language can be found in reference [17]

3.6 Angle Optimizer

The inputs to this block are astronomical angles and the power from a PV panel. The power from the PV panel is fetched via MPPT charge controller. The MPPT charge controller part is already done by a previous research. So, in this paper will only consider that the angle optimizer block is receiving the maximum power possible to start with angle optimizing. The function of this block is basically to track for the optimal angles at which the PV panels receives the maximum power possible. The optimal angles for the solar panel might be slightly different from the astronomical angles (i.e. PV panel facing perpendicular with the position of the Sun) due to the reflection from snow or other factors. A block diagram of this block is shown below in Figure 3.6.1.

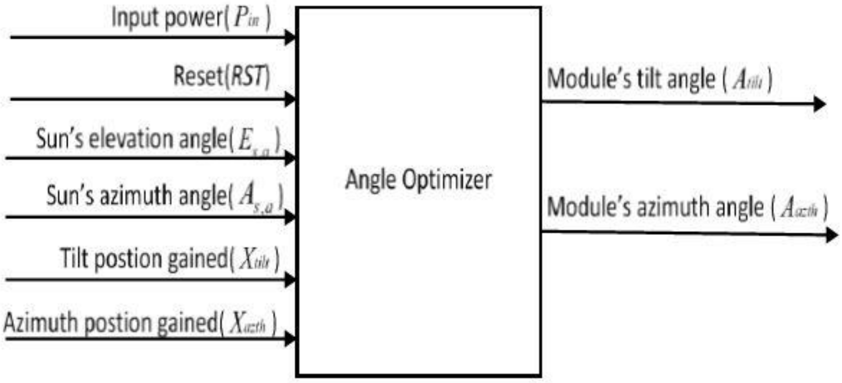


Figure 3.6.1 Angle optimizer outer block view

The definitions of I/O signals of Figure 3.6.1 is given below

1. Inputs
a. Input Power (*Pin*) : Input power from the PV panel through MPPT block.
b. Reset (*RST*) : Should get a pulse input to restart the optimization process again. In this report the input *RST* is given a pulse in every 5 minutes.
c. Astronomical Sun's elevation (*Esa*): The elevation angle of the Sun at the current time.
d. Astronomical Sun's azimuth (*Asa*): The azimuth angle of the Sun at the current time.
e. Tilt position reached (*Xtilt*): A feedback input from the angle controller block. It indicates that the slewing drive in the tilt direction has reached the required position. Logical
1 when the PV panel has finished rotating to a given tilt angle else logical 0.
f. Azimuth Position reached (*Xazth*):A feedback input from the angle controller block. It indicates that the slewing drive in the tilt direction has reached the required position.
Logical 1 when the PV panel has finished rotating to a given azimuth angle else logical 0.

2. Outputs
a. Tilt (*Atilt*) :Tilt angle the PV panel should rotate to.
b. Azimuth (*A azth*) : Azimuth angle the PV panel should rotate to.
The function of this block can be explained as below:

- Takes the input power continuously from the MPPT block.
- Takes Sun's elevation and azimuth angle as given by the Astronomical Angles Calculator block. Astronomical Angles Calculator block gives a new Sun's elevation and azimuth angles continuously.
- Reset input should receive a pulse every 5 minutes. When a pulse is received at the Rest input, the process of angle optimizing will start again.
- The output tilt gives the changing tilt (based on step size for iteration) and then when the optimum tilt angle is found then it outputs that optimal tilt angle until the reset signal is given at the Reset input of this block. When it receives the reset signal, the whole process repeats.
- The output at the Azimuth output port is same as Sun's Azimuth until the optimal tilt angle is found. Then it gives the changing Azimuth (based on the step size for iteration) and when the optimal Azimuth angle is found it outputs the optimal Azimuth angle until it receives the reset signal at the Reset input port. When it receives the reset signal, the whole process is repeated.

3.6.1 Tracking Process for the Optimal Angles

The main idea behind the tracking is moving the PV module by a fixed step size of 0.5° continuously and measuring the comparing the output power at each step it takes . The PV panel is first moved to the Sun's astronomical angles. PV module's tilt angle is the difference between 90° and the Sun's elevation angle. The module's azimuthal angle is equal to the Sun's azimuthal angle. Then the optimization process starts.

The optimization process starts with the tilt angle first . The PV panel is moved in the positive direction first by a step size of 0.5°. If the new output power from the solar panel is less than the old output power then it changes the direction of the step size and the solar panel starts moving in the negative direction. The power then starts increasing and the PV module is further moved in that direction. The output power from the PV panel is compared between each steps it takes. If the power starts decreasing again then the angle that generated the maximum power is taken as a new tilt angle for the solar panel.

After the tilt angle optimization is finished, the azimuth angle optimization starts with exactly same process but the PV panel stays at the new tilt angle.

When both optimal tilt and optimal azimuthal angles are calculated then the solar panel stays in that position until the next reset pulse(*RST*) is given.

3.6.2 Inside the Angle Optimizer Block

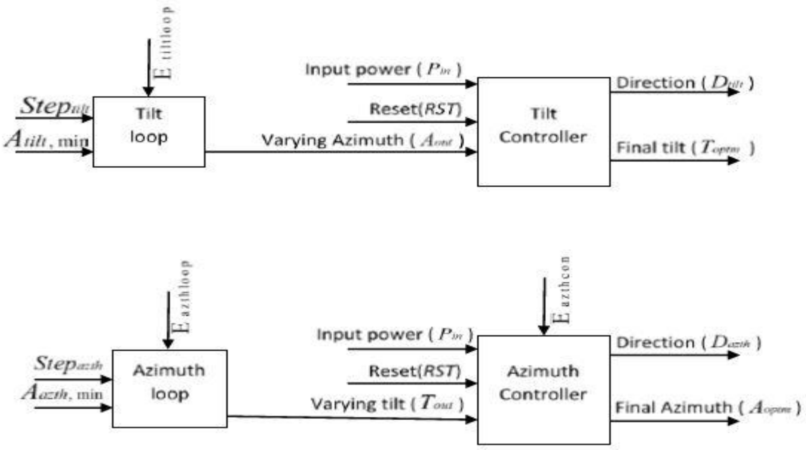


Figure 3.6.2 Inner view of angle optimizer block

The definitions of I/O of Figure 3.6.2 is given below

i. Tilt loop: It just increment or decrement the current tilt angle value by step.

1. , *A* min *tilt* :The reference tilt angle for the optimization process. It is given by,

,*A* min *tilt* = 90° *s a–E* (1.4)

2. *Step tilt* : The step size by which the tilt angle changes during the tilt optimization and is given by,

Steptilt = 0.5×*Dtilt* (1.5)

Where, *Dtilt* is the output from the tilt controller block.

3. Varying tilt (*T out*): Output tilt angle for during the optimization process. This can simply be expressed as follows:

For the first step,

$$T_{out} = A_{tilt,\min} \qquad (1.6)$$

For other steps,

$$T_{out} = T_{out} + Step_{tilt} \qquad (1.7)$$

When the optimal tilt angle is found,

$$T_{out} = T_{optm} \qquad (1.8)$$

4. E tilt loop : This signal is used to enable or disable the tilt loop. This gets enabled with an input greater than zero. And gets disabled by an input equals to zero. It is enabled at the start of optimization process and is disabled after finding the optimal tilt angle (*T optm*) and *out* stays at *optm T* until the next optimization process starts.

ii. Azimuth loop: Same as tilt loop but for Azimuth angle

1. , *A* min *azth* :The reference azimuth angle for the azimuth angle optimization process. It is equal to the astronomical azimuth each time the optimization process starts.

$$A\ azth, \text{min} = A\ s,a \qquad (1.9)$$

2. $Stepazth$: The step size by which the azimuth angle changes during optimization process and it is given by,

$$Stepazth = 0.5 \times Dazth \qquad (1.10)$$

3. $Aout$: The azimuth angle output during optimization process. This can be expressed as follows: for the first step,

$$Aout = Aazth, \text{min} \qquad (1.11)$$

For other steps,

$$Aout = Aout + Stepazth \qquad (1.12)$$

When the optimal azimuth angle is found,

$Aout = Aoptm$ (1.13)

4. E azthloop : Enables or disables the azimuth loop based on the logical value of this input. It's only enable after the tilt optimization process is finished.

iii. Tilt controller

1. Varying tilt ($Tout$): This is the output from tilt loop block. The output tilt angle during each iteration.
2. Input power (Pin): Current power input from the PV panel.
3. Direction ($Dtilt$) : It gives the direction for the tilt slewing drive. Output is +1 for the positive step and -1 for the negative step.
4. Final tilt ($Toptm$) = Optimal Tilt angle for which the output power of PV panel is maximum.

iv. Azimuth controller

1. Varying Azimuth ($Aout$): The output from the azimuth loop block. The output tilt angle during each iteration.
2. Input power (Pin): Current input power from the PV panel.
3. Direction ($D\ azth$)=It gives the direction for the azimuth slewing drive. Output is +1 for the positive step and -1 for the negative step.
4. Final Azimuth ($A\ optm$) = Optimal azimuth angle at which the output power of PV panel is maximum.

3.6.3 Tilt Controller Block

The tilt controller block deals with finding the optimal tilt angle by comparing the input power at different tilt angles. It changes the tilt direction of the PV module if it was moving in wrong direction at start. The block diagram of the tilt controller is shown in Figure 3.6.3.

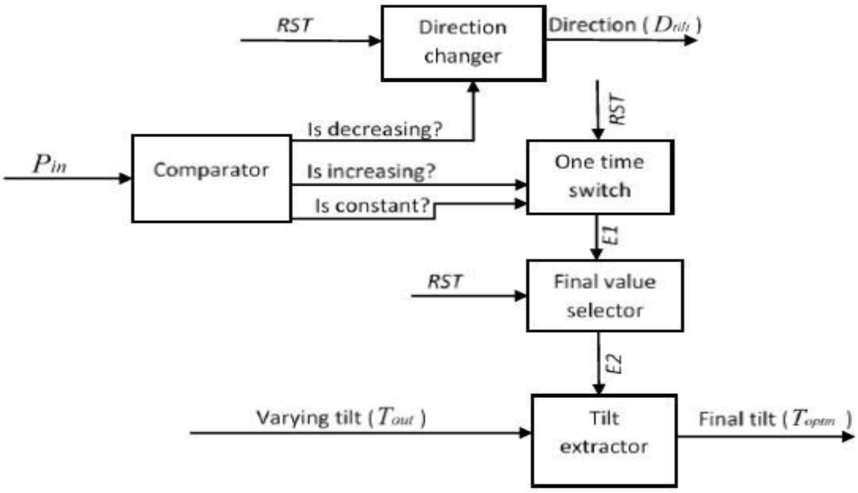


Figure 3.6.3 Tilt controller block diagram

The inputs and outputs (I/O) of this block diagram is already defined in subheading 3.6.2 Inside the Angle Optimizer Block. The function of different blocks is explained below.

3.6.3.1 Comparator

The comparator block just compares the power at current tilt angle with the power at tilt angle one step earlier and gives the logical outputs depending upon the states below.

- If power at current tilt angle is less than the power at previous tilt angle then it gives ‘is decreasing?’ flag as 1 else 0. The others two flags ‘is increasing?’ and ‘is constant?’ has value 0.
- If power at current tilt angle is greater than the power at previous tilt angle then it gives ‘is increasing?’ flag as 1 else 0. The others two flags ‘is decreasing?’ and ‘is constant?’ has value 0.
- If power at current tilt angle is equal to the power at previous tilt angle then it gives ‘is constant?’ flag as 1 else 0. The others two flags ‘is decreasing?’ and ‘is increasing?’ has value 0.

3.6.3.2 Direction changer

The main function of the direction changer block is to detect whether the PV panel is moving in the wrong direction. If it is moving in wrong direction, then change the direction multiplier to -1. It should only change the direction once until the next reset signal is received to avoid the PV panels moving back and forth continuously. The flowchart is given below in Figure 3.6.4.

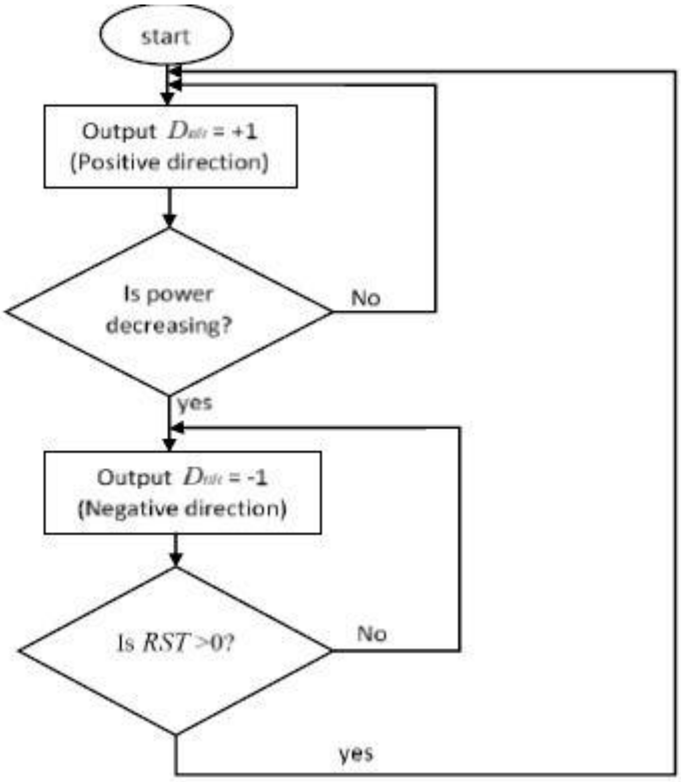


Figure 3.6.4 Flow chart of direction changer

The starting state is always positive and it outputs $Dtilt = 1$. If the power starts to decrease it goes to the negative block and outputs $D\ tilt = 1-$. When $D\ tilt = -1$, it gets multiplied with the step and results in the varying tilt angle to decrease.

3.6.3.3 One Time Switch

The main function of this block is to generate a pulse having on-time equal to the time when the current power input is greater than delayed power input (i.e. when the power is increasing). The output of this block is given below in Figure 3.6.5.

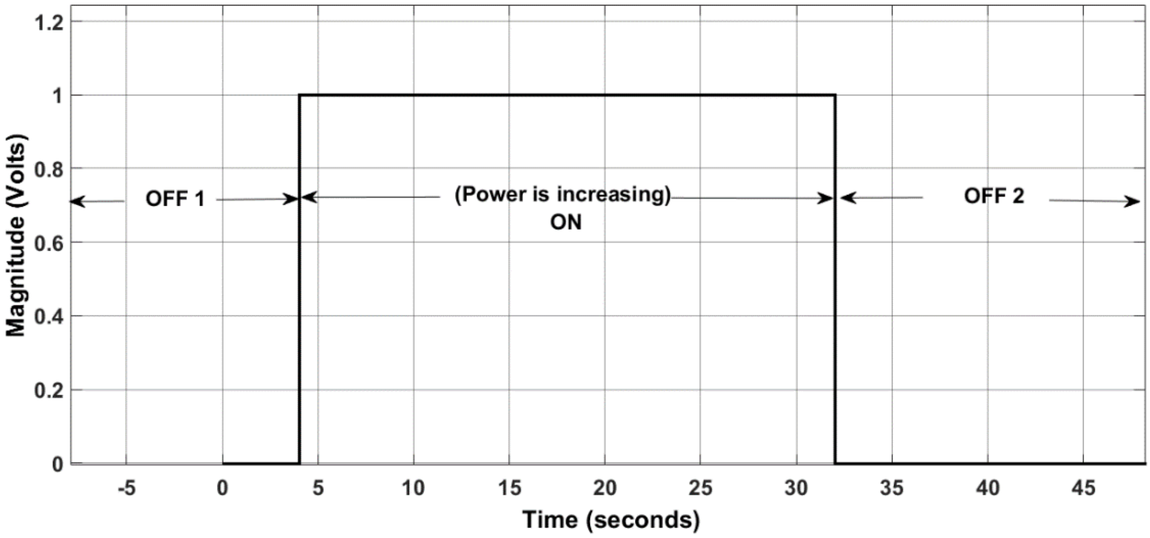


Figure 3.6.5 Output of one time switch for a single optimization cycle

This block starts it operation in OFF1 state. When the power starts increasing then it moves to ON state (i.e. start of pulse). When the power starts decreasing again then it goes to OFF2 state and outputs 0 (end of pulse). It remains on the OFF2 state until it receives the reset pulse. The 'is constant?' input denotes that this switch should not operate when the PV panel receives the constant power.

3.6.3.4 Final Value Selector

This block tracks the pulse generated by the one-time switch. First it gives logical 0 output. It starts producing continuous logical output 1 when the one-time switch's output goes to OFF2 state. When it receives a reset signal then it again gives logical 0 output and waits for the one-time switch's pulse.

3.6.3.5 Tilt Extractor

This block gives the optimal tilt angle as an output. This blocks feeds the current varying tilt angle ($Tout$). When it receives the logical 1 output from the final value selector block above, it fixes the varying tilt angle at that particular instance as optimal tilt angle. It gives '0' output before the optimal angle is found.

3.6.3.6 Flow Chart for Tilt Controller

For simplicity let's use the following notations.

- $Pin\ [n]$: The current power at current tilt angle ($Tout[n]$) of the PV module.
- $Pin[n-1]$: The power from the PV panel when it was at tilt angle one step earlier. It is the output power at $Tout[n-1]$
- $Tout\ [-n]$: The tilt angle that the module is facing now. The tilt angle that gives the output power $Pin\ \ n[n\ -1]$.
- $Tout\ [n-1]$: The tilt angle that the module was facing one step earlier. The tilt angle that gives the output power $Pin\ \ [n-1]$.

The Flow chart for this process is given below in Figure 3.6.6. The flow chart below shows how an optimal tilt angle is found for the PV module. When the current tilt angle is increased or decreased by a fixed step size. Then the current output power ($Pinn$ [n-1]) at the current tilt angle ($T\ out\ n$ [n-1]) is compared with the previous output power ($Pin\ [\ n-1]$) at the previous tilt angle ($Tout$ [n-1]).

During the first step of iteration the direction is always set as positive. After the initial step if the [$P\ in$ [n-1]is less than $Pinn$. The PV module has a wrong direction so the direction is corrected to negative. Notice that direction can only be changed one time at the starting step. So either PV module start the step in right direction, in which case the direction does not need to change. But if the starting step was in wrong direction then it will correct the direction. And the comparison between Pin [n-1] and Pin [n]continues until $Pin\ n$ is greater than $P\ in$ [n-1] . This means that the maximum power was $P\ in$ [n-1]at [1] $T\ out$ [n] . Which is our required optimal tilt angle.

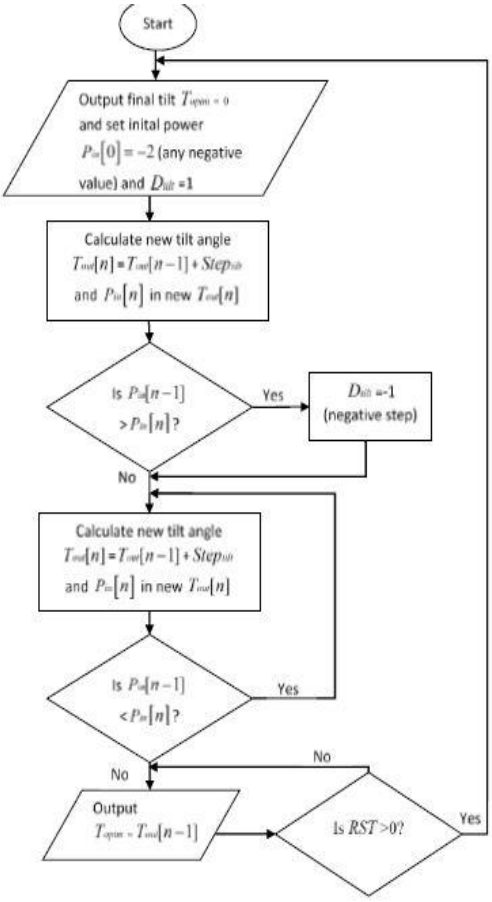


Figure 3.6.6 Flow chart for tilt controller

3.6.4 Inside the Azimuth controller

Similar to tilt controller block, this azimuth controller deals with finding the optimal azimuth angle using the iterative technique. The block diagram of this controller is shown below in Figure 3.6.7.

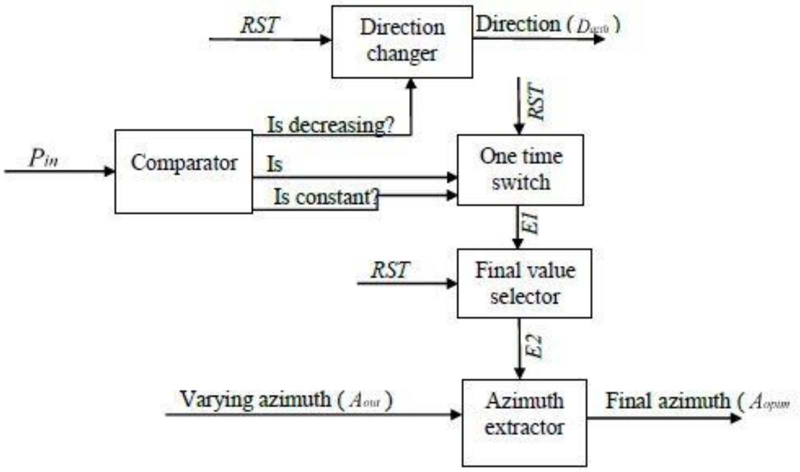


Figure 3.6.7 Block diagram of azimuth controller

The Working principle of this Azimuth controller is exactly same as that of tilt controller block. It uses exactly same principle and components so it's not needed to explain those blocks.

3.6.5 The Flow Chart of the Angle Optimizing Process

The flow chart for the Angle optimization block is given below in Figure 3.6.8 and Figure 3.6.9.

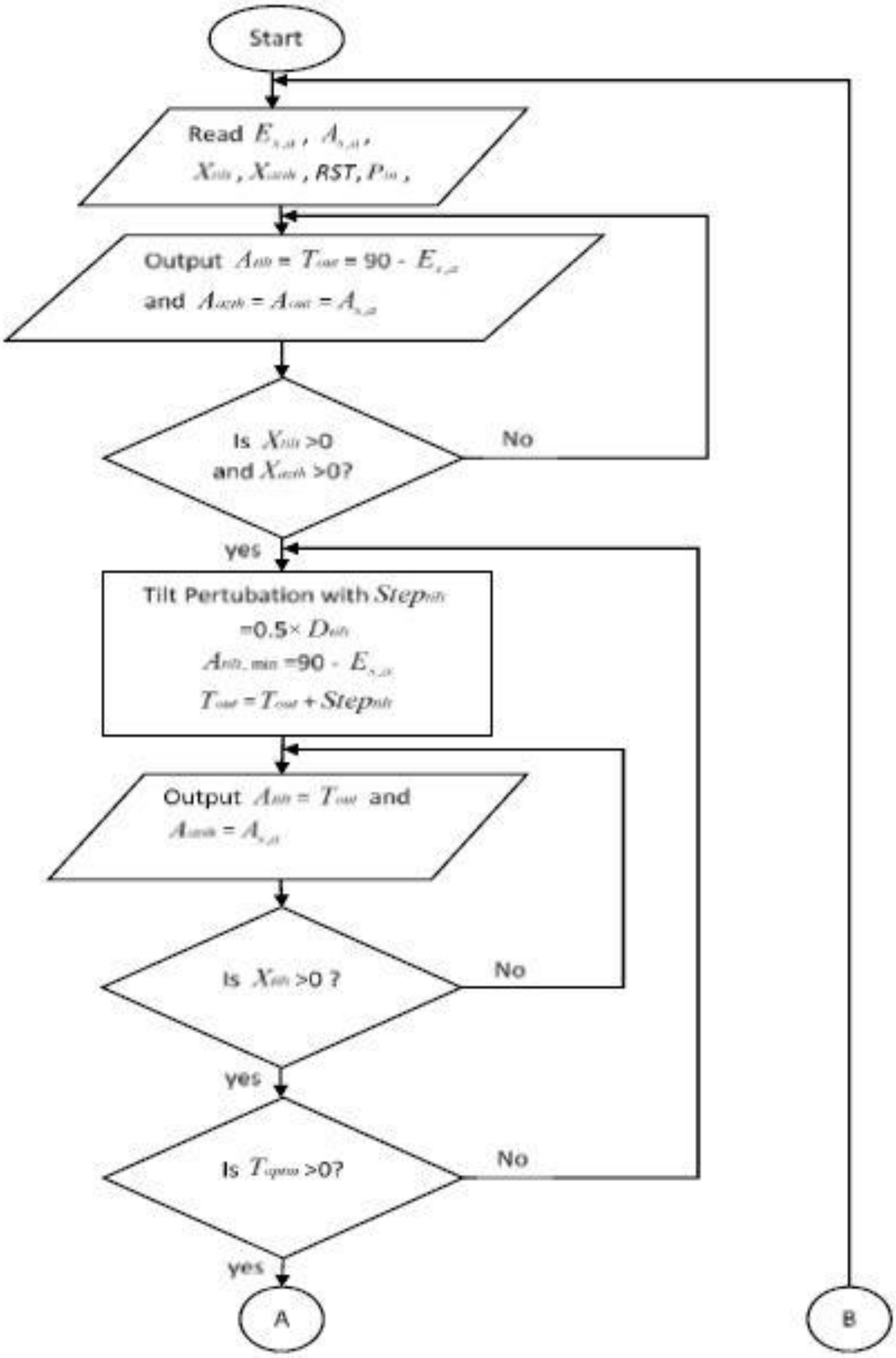


Figure 3.6.8 Flow chart for angle optimizer (part a)

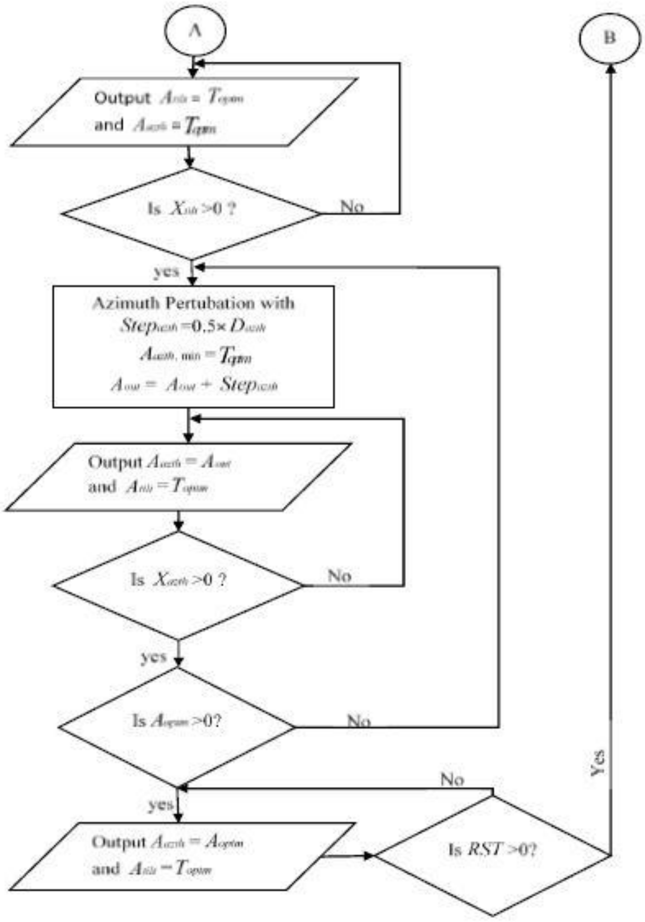


Figure 3.6.9 Flow chart for angle optimizer (pat b)

3.7 Angle controller

This blocks sits between the angle optimizer and slewing driver, its main function is to communicate between the angle optimizer and the slewing drive. The block diagram of this block is as shown below in Figure 3.7.1.

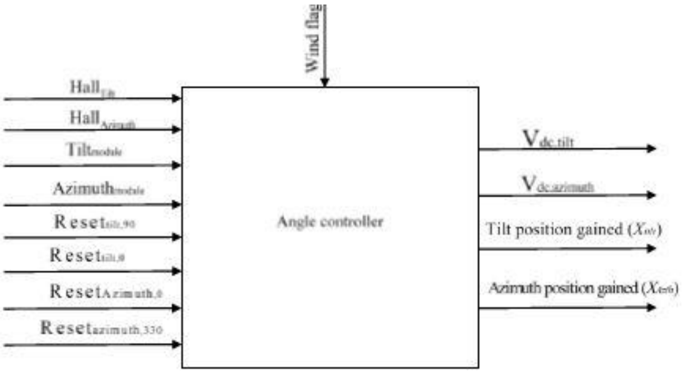


Figure 3.7.1 Angle controller block diagram

1) Inputs

a) Wind Flag : Set to 1 when there is strong wind and the PV panel should be 0° (parallel to the ground to minimize wind resistance). When it is set to 0 , It should run in normal operation mode.

b) *Hall Tilt* and *Hall Azimuth* :Current motors position fetched as outputs from the hall sensors attached to the tilt and azimuth direction motors.

c) *Tilt* module and *Azimuth* module: The output from angle optimizer (*Atilt* and *A azth*).

d) *Reset tilt, 90* and *Reset tilt, 0* : Output from reset switches for tilt direction, placed at 90˚and 0˚respectively.
e) *ResetAzimuth, 0* and *Resetazimuth, 330* : Output from reset switches for azimuth direction, placed at 0˚and 330˚respectively.
2) Outputs
a) *V dc, tilt* and *V dc, azimuth* : Positive or negative voltage for the motor of slewing drives for tilt or azimuthal direction respectively. Positive voltage turns the motor in positive direction whereas negative voltage turns the motor in negative direction.
b) Tilt position gained (*Xtilt*) and Azimuth position gained (*XAzth*) : Equals to 0 when the motor is operating and equals 1 when the motor has reached the desired position in tilt and azimuth direction respectively. This Angle Controller contains two separate and similar blocks for tilt angle control and azimuth angle control.

3.7.1 Tilt Motor Controller

The block diagram of Tilt Motor Controller is shown below in Figure 3.7.2.

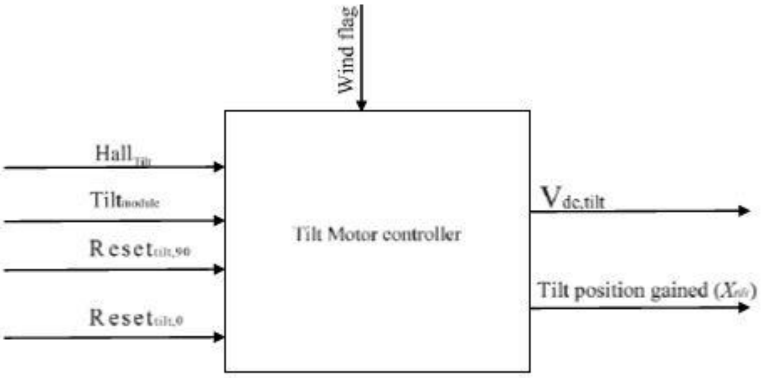


Figure 3.7.2 Tilt Motor Controller

3.7.1.1 Block Diagram of Tilt Motor Controller

The block diagram of the Tilt Motor Controller is shown below in Figure 3.7.3.
It has the basic function to controller the slewing drive of tilt direction

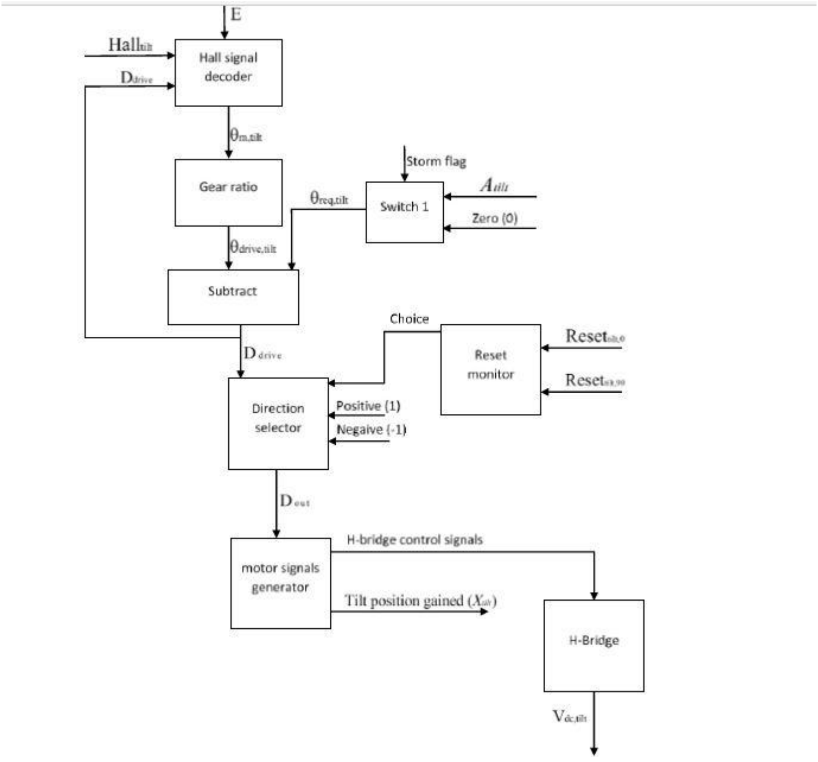


Figure 3.7.3 Block diagram of tilt motor controller

The starting point of this Tilt controller block is Hall signal decoder. It decodes the input hall signal from the slewing drive in the tilt direction and outputs the current position of that motor ($\theta_{m, tilt}$). This Hall signal decoder requires the current direction of tilt motor (D_{drive}) to calculate the current position of the motor in degrees. When it receive E = 0 , Then it resets it current direction as 90˚. The current position of tilt motor ($\theta_{m, tilt}$) is then fed to the gear ratio block. The Gear ratio block outputs the current position of the slewing drive ($\theta_{drive, tilt}$). The Switch1 block checks the Storm flag. If it's set the required angle for the tilt motor is zero degrees and if it is not set then the required angle is equal to the output tilt angle(A_{tilt}) from the angle optimizer block.

The current position of slewing drive in tilt direction is then compared with the new tilt angle (, $\theta_{reqtilt}$) to find the direction (*drive D*) that the drive needs to rotate to gain the required position.

The Reset Monitor Block checks whether any of the end-stop reset buttons (*Resetilt, 90 t* or *Reset tilt, 0*) are pressed and outputs the required choice that needs to be selected to the Direction selector block.

The Direction Selector Block then selects the new direction of the motor based on the choice input from the Reset Monitor Block. This block can either output (D_{drive} , positive, negative or stop) directions to the Motor Signals Generator block.

The Motor Signals Generator blocks then generate the control signals to the H bridge which rotates the tilt slewing drive to the direction based on control signals. When a given direction is reached then this block also sets the Tilt position gained (X_{tilt}) signal to the Angle Optimizer Block.

The H-bridge control signals are generated and sent to the H-bridge which handles the change in direction and braking. The functions and operation of each block is described in the sub-topics below.

3.7.1.2 Hall Signal Decoder

The Hall Signal Decoder block contains counters to decode the current position of the motor shafts in degrees . Hall signal decoder contains an enable port so that it could be used to reset the counter every time the tilt slewing drive reaches 90˚position. The flowchart for Hall signal decoder can be seen below in Figure 3.7.4.

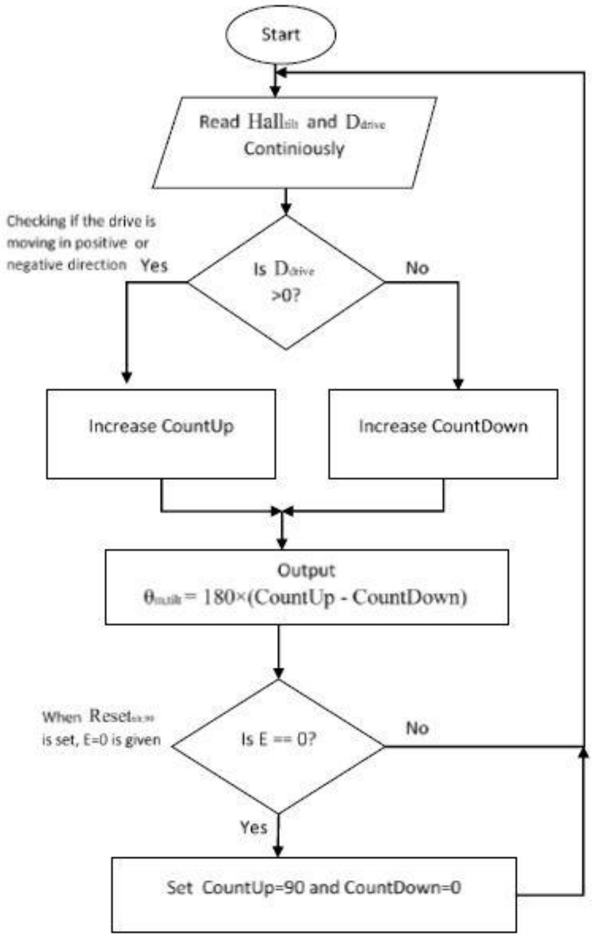


Figure 3.7.4 Flow chart for single hall decoder

3.7.1.3 Gear Ratio

This block just takes the input, tilt motor's current position (θ m,tilt) and converts it to the position of the slewing drive for tilt direction(θ drive,tilt). The slewing drive chosen has the motor reducer parameter ratio is given as 236 and the gear ratio of the slewing drive is 73 so we can simply calculate it by using the relation

$$\theta_{drive,\,tilt} = \frac{\theta_{m,\,tilt}}{236\times 73} \tag{1.14}$$

3.7.1.4 Reset Monitor and Direction Selector

This blocks handles the input from reset switches. There will be 2 reset switches for each direction (i.e. tilt and azimuth). The tilt rotation of the slewing drive is limited from 0˚to 90˚. And the azimuth rotation of the slewing drive is limited from 0˚to approximately 330˚. Therefore, there will be 4 reset switches altogether in complete system at those angles for each motions. And the signals through them are named as *Resettilt, 0* , *Reset tilt, 90* , *Reset, 0 zimuth a* and , *Reset 330 azimuth*.

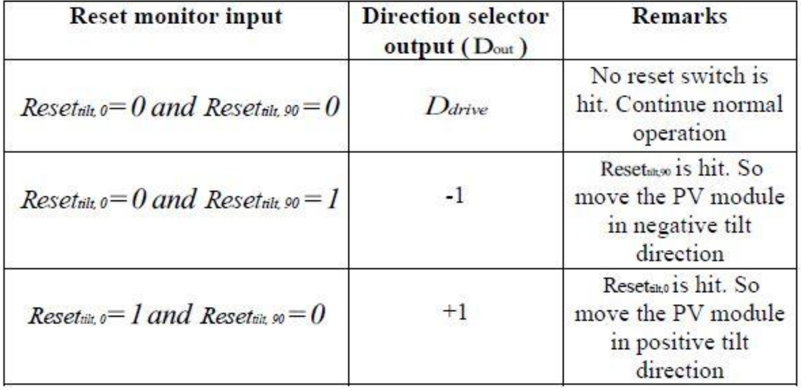
In case of tilt motion, it will generate logical input 1 at direction 0 and 90˚when the PV module hits those reset switches. So the control mechanism when each reset switches are hit can be explained as follows.

- *Reset tilt, 0* : When a *Reset tilt, 0* has logical input 1 then the PV module should rotate in the positive direction until it hits the *Resettilt, 90* and then should continue the tracking process. When it hits the *Resettilt, 90* , the current position of the motor should be set as 90˚.
- *Resettilt, 90* : When a *Resettilt, 90* has logical input 1 then the PV module should rotate in the positive direction until it hits the *Reset tilt, 0* and then should continue the tracking process.

This reset control is done by the reset monitor block and a direction selector.

The I/O from the Reset monitor maps with the direction selector as in Table 2.

Table 2 Signal mapping between direction selector and reset monitor



Reset monitor input	Direction selector output (D_{out})	Remarks
$Reset_{tilt,0}=0$ and $Reset_{tilt,90}=0$	D_{drive}	No reset switch is hit. Continue normal operation
$Reset_{tilt,0}=0$ and $Reset_{tilt,90}=1$	-1	$Reset_{tilt,90}$ is hit. So move the PV module in negative tilt direction
$Reset_{tilt,0}=1$ and $Reset_{tilt,90}=0$	+1	$Reset_{tilt,0}$ is hit. So move the PV module in positive tilt direction

3.7.1.5 Motor signal generator

It's function is to generate the control signals to control the direction of the tilt slewing drive. It's flow chart is given below in Figure 3.7.5. From the flow chart below we can see that it has basically Positive, Negative and Stop states. The A, B, C, D are the control signals for H-bridge switches.

The 'ε' denotes the absolute error threshold value between the slewing drive angle and the input tilt angle. When given position is reached, the position reached flag (*Xtilt* in case of tilt) is set as '1' for the tilt controller.

The Dout can be negative, positive or zero based on the current position and the required position of the motor.

The generated control signals for H-bridge switches A, B, C, D will be passed to the H-bridge and the H-bridge will either rotate the motor is positive, negative direction or it will apply brake to the motor to fix its current position

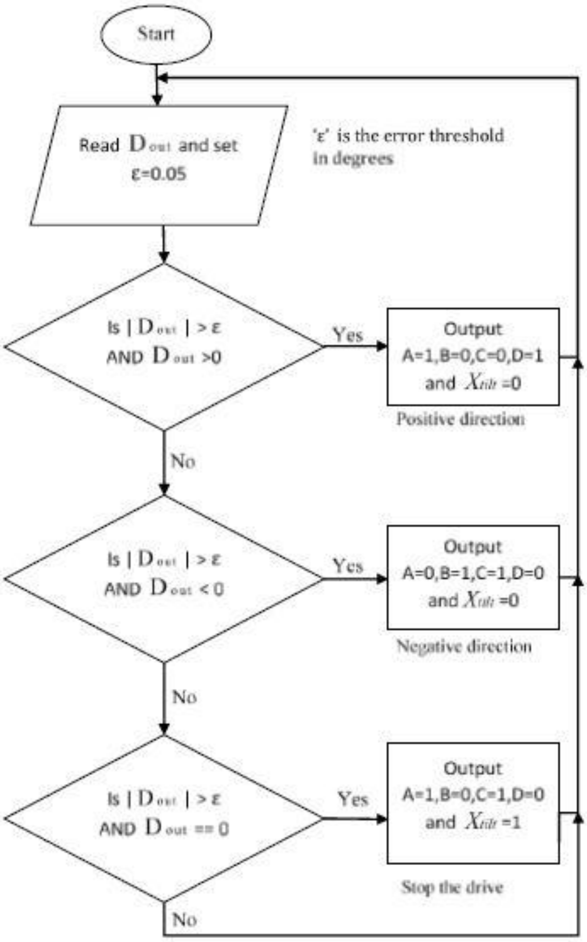


Figure 3.7.5 Flow chart of motor signal generator

3.7.1.6 Protection During Storm

When the wind speed is too high, It causes a lot more load to the PV panel. In case of storm the PV module is at high risk of mechanical damage. So in order to protect the PV system, a storm input is kept in the tilt motor controller block.

The main concept of dealing with storm would be to set the PV panel is such a way that it has minimum surface area. That could only be achieved if we set the PV panel parallel to the ground (i.e. when the *Tiltmodule* equals to 0˚).

So if the tilt motor controller receives a logical 1 input in wind flag then it sets the PV panel at 0˚ (parallel to horizontal plane) tilt until it receives a logical 0 input.

3.7.2 Azimuth motor controller

This block controls the movement of the slewing drive in azimuthal direction.

The block diagram of this system is shown below in Figure 3.7.6.

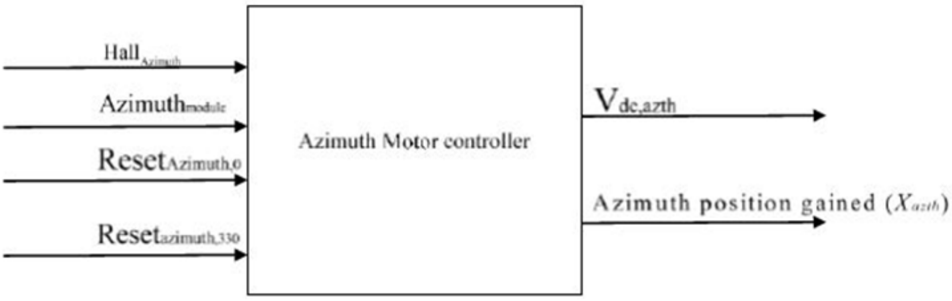


Figure 3.7.6 Azimuth motor controller

3.7.2.1 Block Diagram of Azimuth Motor Controller

The block diagram of the azimuth motor controller is given below in Figure 3.7.7. The model as well as the operation of this block is almost same as that of Tilt motor controller . The Only difference is it has 2 reset switches in 0° and 330°. And it does not have storm flag. It is not needed to change PV panel azimuthal position during storm. The reset mechanism can be explained as follows:

- *ResetAzimuth, 0* : When it hits the *ResetAzimuth, 0* , the current position counter is set to 0° and then it moves in the positive direction until it hits the *Resetazimuth, 330* switch. Then the normal operation progresses.
- *Resetazimuth, 330* : When this switch is hit, the PV module is moved in negative direction until *ResetAzimuth, 0* is hit. Then the current position counter is set to 0° and the normal operation is progressed.

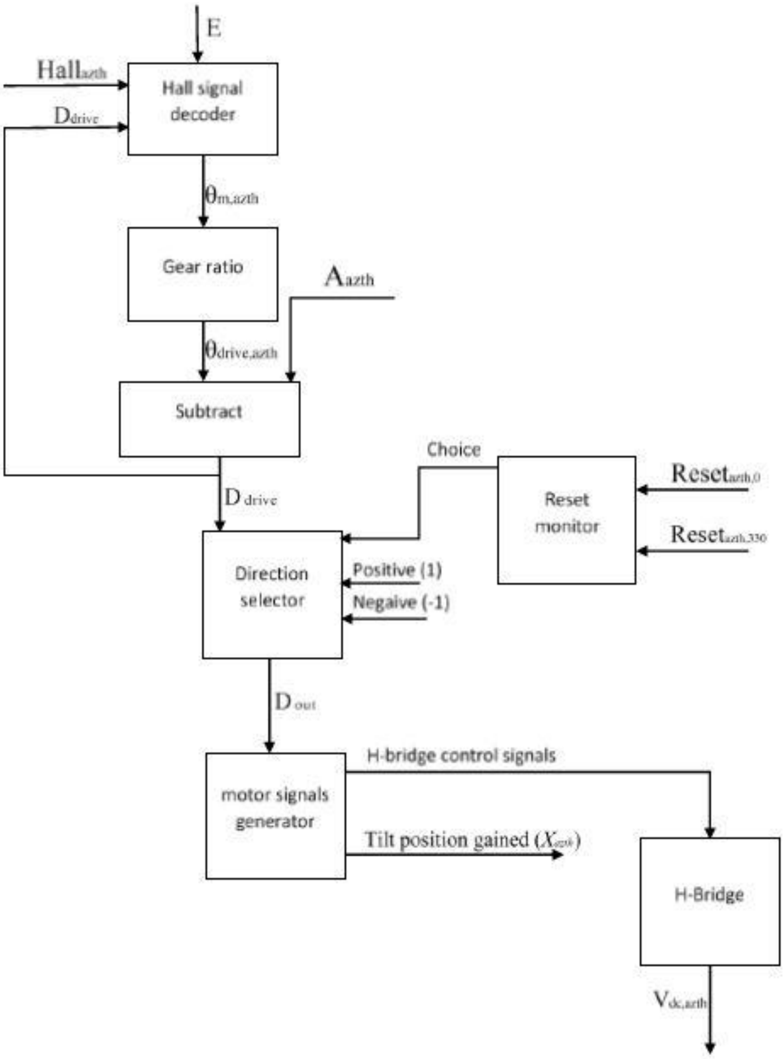


Figure 3.7.7 Block diagram for Azimuth motor controller

3.8 Orientation of PV Panel When the System Starts

When the system starts the PV panel should be facing 90° in tilt direction and 0° in azimuth direction. One big question is how to orient the PV panel in the correct tilt and azimuth direction when the system starts for the first time or after a power failure? To solve this problem the reset button can be used.

- In tilt direction : The system Should be given a logical 1 pulse to the input *tilt, 0 Reset* . Then the reset routine follows and PV panels moves in positive direction until the *tilt, 90 Reset* is hit and sets current position as 90°.
- In azimuth direction: Same as in case of tilt direction but the logical 1 pulse should be given to the input , *330 azimuth Reset* . So that the PV module moves in negative azimuthal direction until it reaches the 0° in azimuth direction.

IV. CONCLUSION

In conclusion; for optimization many techniques could be used to solve the problem for Solar Panel Tracking System. This paper was aims to present the optimum sizing and location of DG in power system by showed the literature review that using Particle Swarm Optimization (PSO). Particle swarm optimization (PSO) is a population-based optimization method first proposed by Kennedy and Eberhart in 1995, inspired by social behavior of bird flocking or fish schooling. The PSO as an optimization tool provides a population-based search procedure in with individuals called particles change their position (state) with time. In a PSO system, particles fly around in a multidimensional search space. During flight each particle adjusts its position according to its own experience (This value is called Pbest), and according to the experience of a neighboring particle (This value is called Gbest), made use of the best position encountered by itself and its neighbor. Finally this paper demonstrate solar panel starting from installation till controlling.

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