Maximizing Efficiency Of Solar Panel with Plataforma Solar De Almería (PSA) Algorithm Through PLC

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ABSTRACT
The increasing demand for energy, the continuous reduction in existing sources of fossil fuels and the growing concern regarding environment pollution, have pushed mankind to explore new technologies for the production of electrical energy using clean, renewable sources, such as solar energy, wind energy, etc. Among the non-conventional, renewable energy sources, solar energy affords great potential for conversion into electric power, able to ensure an important part of the electrical energy needs of the planet. While the output of solar cells depends on the intensity of sunlight and the angle of incidence, it means to get maximum output; the solar panels must remain in front of sun during whole day. But due to rotation of earth, panels cannot maintain their position always in front of sun. This problem results in decrease of their output. Thus to get a constant output, an automated system is required which should be capable to constantly rotate the solar panel to receive maximum solar energy. The work is carried out to built automated sun tracking system using Programmable Logic Controller (PLC); sun’s apparent position is calculated using Plataforma Solar de Almería (PSA) algorithm with input as geographical latitude, longitude, year, month, day, and time. With sun angles obtained by PSA algorithm, stepper motor adjusts solar panel so that to obtain maximum output. Programming in PLC is carried out in Ladder Diagram (LD) for stepper motor drive sequence and for calculation of solar angles Function Block Diagram (FBD) is used. It is observed that there is increase in power of 35.75% by tracking than fixed pane.

Keywords: Solar energy tracking system, PLC, LD, FBD, PSA.

NOMENCLATURE

PLC: Programmable Logic Controller.
PSA: Plataforma Solar de Almería.
LD: Ladder Diagram.
FBD: Functional Block Diagram.

I. INTRODUCTION
Solar energy is the most readily available and free source of energy since prehistoric times. It is estimated that solar energy equivalent to over 15,000 times the world’s annual commercial energy consumption reaches the earth every year. India receives solar energy in the region of 5 to 7 kWh/m² for 300 to 330 days in a year. This energy is sufficient to set up 20 MW solar power plants per square kilometre land area. Solar energy can be utilised through two different routes, as solar thermal route and solar electric (solar photovoltaic) routes. Solar thermal route uses the sun’s heat to produce hot water or air, cook food, drying materials etc. Solar photovoltaic uses sun’s heat to produce electricity for lighting home and building, running motors, pumps, electric appliances, and lighting [6].

As the range of applications for solar energy increases, so does the need for improved materials and methods used to harness this power source. There are several factors that affect the efficiency of the collection process. Major influences on overall efficiency include solar cell efficiency, intensity of source radiation and storage techniques. The materials used in solar cell manufacturing limit the efficiency of a solar cell. This makes it particularly difficult to make considerable improvements in the performance of the cell, and hence restricts the efficiency of the overall collection process. Therefore, the most attainable method of improving the performance of solar power collection is to increase the mean intensity of radiation received from the source. There are three major approaches for maximizing power extraction in medium and large scale systems. They are sun tracking, maximum power point (MPP) tracking or both. Thus, project work is carried out for solar tracking to increase efficiency of power generation using Programmable Logic Controller.
II. SOLAR TRACKERS

The output of solar cells depends on the intensity of sunlight and the angle of incidence, it means to get maximum output; the solar panels must remain in front of sun during the whole day. A good sun-tracking system must be reliable and able to track the sun at the right angle even in the periods of cloud cover. Over the past two decades, various types of sun tracking mechanisms have been proposed to enhance the solar energy harnessing performance of solar collectors. Taking into consideration of all the reviewed sun-tracking methods, sun trackers can be grouped into one-axis and two-axis tracking devices. Figure 1 illustrates all the available types of sun trackers in the world. For one-axis sun tracker, the tracking system drives the collector about an axis of rotation until the sun central ray and the aperture normal are coplanar. There are three types of one-axis sun tracker:

1. **Horizontal-Axis Tracker** – the tracking axis is to remain parallel to the surface of the earth and it is always oriented along East-West or North-South direction.

2. **Tilted-Axis Tracker** – the tracking axis is tilted from the horizon by an angle oriented along North-South direction, e.g. Latitude-tilted-axis sun tracker.

3. **Vertical-Axis Tracker** – the tracking axis is collinear with the zenith axis and it is known as azimuth sun tracker.

![Types of sun tracker](http://ijrar.com/)

Figure 1: Types of sun tracker [9].

There are two types two-axis sun tracker, they are:

1. **Azimuth-elevation and**

2. **Tilt-roll sun trackers,**

These sun trackers track the sun in two axes such that the sun vector is normal to the aperture as to attain 100% energy collection efficiency. Azimuth-elevation and tilt-roll (or polar) sun tracker are the most popular two-axis sun tracker employed in various solar energy applications. In the azimuth-elevation sun-tracking system, the solar collector must be free to rotate about the azimuth and the elevation axes. The primary tracking axis or azimuth axis must parallel to the zenith axis, and elevation axis or secondary tracking axis always orthogonal to the azimuth axis as well as parallel to the earth surface. The tracking angle about the azimuth axis is the solar azimuth angle and the tracking angle about the elevation axis is the solar elevation angle. Alternatively, tilt-roll (or polar) tracking system adopts an idea of driving the collector to follow the sun-rising in the east and sun-setting in the west from morning to evening as well as changing the tilting angle of the collector due to the yearly change of sun path. Hence, for the tilt-roll tracking system, one axis of rotation is aligned parallel with the earth’s polar axis that is aimed towards the star Polaris. This gives it a tilt from the horizon equal to the local latitude angle. The other axis of rotation is perpendicular to this polar axis. The tracking angle about the polar axis is equal to the sun’s hour angle and the tracking angle about the perpendicular axis is dependent on the declination angle. The advantage of tilt-roll tracking is that the tracking velocity is almost constant at 15 degrees per hour and therefore the control system is easy to be designed [9].

III. SUN POSITION ALGORITHM

A. Sun position algorithms review:

The solar literature contains a wide range of papers referring to the calculation of the Sun position. These calculations can be classified into two groups. The first is a group of relatively simple formulae and algorithms that, given the day of the year, estimate basic Sun-position parameters, such as the solar declination or the equation of time (Cooper, 1969; Lamm, 1981; Spencer, 1971; Swift, 1976). The second consists of more complex algorithms (Michalsky, 1988; Pitman and Vant-Hull, 1978; Walraven, 1978) that, given the precise location and instant of observation, compute the position of the Sun in ecliptic (ecliptic longitude, obliquity), celestial (declination, right ascension), and/or local horizontal coordinates (zenith distance and solar azimuth).

Usually, a solar tracking system needs to know the local horizontal coordinates of the Sun at the system location (specified by its geographic longitude and latitude) at any given instant of time (specified by the date and the universal time). From this point of view, none of the reported algorithms are complete.
their input is more specialized (i.e., the input values to the algorithm are not the geographical longitude and latitude, date and universal time) or their output falls short of what is required (i.e., the algorithm does not provide the local horizontal Sun coordinates as the result), or both. Table 1 shows the variables calculated by each of the different algorithms analyzed [2].

Even though the all algorithms mentioned above may be considered good enough for most solar tracking applications, its accuracy, computing efficiency, and ease of use can still be improved. These tasks have been undertaken and, as a result, a new algorithm called the PSA algorithm was developed.

Table 1: Solar parameters calculated by different authors [2].

<table>
<thead>
<tr>
<th>Reference</th>
<th>Declination Right</th>
<th>Azimut Zenith</th>
<th>Distance or elevation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooper, 1969</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Spencer, 1971</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Swift, 1976</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Pitman and Vant-Hull, 1978</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Walraven, 1978</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Lamm, 1981</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Michalsky, 1988</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

B. Plataforma Solar de Almeria (PSA) algorithm:

Following are characteristics of PSA algorithm:

1. Its ease of use has been improved by incorporating an efficient method of computing the Julian Day from the calendar date and Universal Time.

2. Memory management has been improved by controlling the scope and life span of variables.

3. Speed and robustness have been improved by eliminating unnecessary operations and using simple robust expressions for calculating the solar azimuth, which are valid for both hemispheres.

4. Accuracy has been improved by modifying the simplified equations of the Nautical Almanac used by Michalsky with the introduction of new coefficients and new terms, and including parallax correction.

Description of PSA algorithm: The input to the PSA Algorithm is time and location. The time for the instant under consideration is given as the date (year, month, and day) and the Universal Time (hours, minutes and seconds). The location is given as the longitude and latitude of the observer in degrees. Latitude is considered positive to the North and longitude to the East.

The Julian Day, jd, is computed from the input data by the following expression [2]:

\[
j_d = \left[\frac{1461 \times (y+4800 + \frac{m-16}{12})}{4} + \frac{367 \times (m-2-12 \times \left\lfloor \frac{m-16}{12} \right\rfloor - 1)}{12} - \frac{3 \times (\Omega + \varepsilon)}{100} \right] + \frac{d - 32075}{24} + 0.5 + \text{hour} \times \frac{1}{24}
\]

where \( j_d \) is the Julian day, \( m \) is the month, \( y \) is the year, \( d \) is the day of the month and hour is the hour of the day in Universal Time in decimal format, i.e., it includes the minutes and seconds as a fraction of an hour, and all divisions except the last are integer divisions.

The ecliptic coordinates of the Sun are computed from the Julian Day, by the following set of equations (all angles in radians):

\[
n = j_d - 2451545
\]

where ‘\( n \)’ is difference between the current Julian Day and Julian Day 2451545.0 (noon 1 January 2000)

\[
\Omega = 2.1429 - 0.0010394594 \times n
\]

\[
L(\text{mean longitude}) = 4.8950630 + 0.017202791698 \times n
\]

\[
g(\text{mean anomaly}) = 6.2400600 + 0.0172019699 \times n
\]
\( l(\text{ecliptic longitude}) = L + 0.03341607 \times \sin g + 0.00034894 \times \sin 2g - 0.0001134 - 0.0000203 \times \sin \Omega \ldots \) (6)

\[
ep (\text{Obliquity of the ecliptic}) = 0.4090928 - 6.2140 \times 10^{-9} \times \pi + 0.0000396 \times \cos \Omega \ldots (7)
\]

The conversion from ecliptic to celestial coordinates is accomplished using the standard trigonometric expressions

\[
ra (\text{right ascension}) = \tan^{-1} \left( \frac{\cos \ep \times \sin l}{\cos l} \right) \ldots (8)
\]

\[
\delta (\text{Declination}) = \sin^{-1} \left( \frac{\sin \ep \times \sin l}{\cos l} \right) \ldots (9)
\]

\[
gmst (\text{Greenwich mean sidereal time}) = 6.6974243242 + 0.0657098283 \times n + \text{hour} \ldots (10)
\]

\[
lmst (\text{Local mean sidereal time}) = (gmst \times 15 + \text{Long}) \frac{\pi}{180} \ldots (11)
\]

where Long is geographical longitude

\[
\text{hour angle (}\omega\text{)} = \text{lmst} - \text{ra} \ldots \ldots (12)
\]

\[
\theta_z (\text{Zenith distance}) = \cos^{-1} \left[ \cos \phi \cos \omega \cos \delta + \sin \delta \sin \omega \right] \ldots (13)
\]

\[
\gamma (\text{Solar azimuth}) = \tan^{-1} \left( \frac{-\sin \omega}{\tan \delta \cos \phi - \sin \phi \cos \omega} \right) \ldots (14)
\]

\[
\text{parallax} = \frac{\text{Earth mean radius}}{\sin \theta_z} \ldots (15)
\]

\[
\theta_z = \theta_z + \text{parallax} \ldots \ldots (16)
\]

where the mean radius of the Earth and distance to the Sun considered are given by

Earth Mean Radius = 6371.01 km

Astronomical Unit = 149597890 km

IV. Programmable Logic Controller (PLC)

A programmable logic controller, also called a PLC or programmable controller, is a computer-type device used to control equipment in an industrial facility. In a traditional industrial control system, all control devices are wired directly to each other according to how the system is supposed to operate. In a PLC system, however, the PLC replaces the wiring between the devices. Thus, instead of being wired directly to each other, all equipment is wired to the PLC. Then, the control program inside the PLC provides the “wiring” connection between the devices. The control program is the computer program stored in the PLC’s memory that tells the PLC what’s supposed to be going on in the system. The use of a PLC to provide the wiring connections between system devices is called soft wiring.

A. Block diagram of PLC: A PLC consists of following components; CPU (central processing unit), Input module, Output module, Power supply unit and memory unit. Figure 2 shows block diagram of PLC. In the diagram, arrows between block indicates information and power flow direction.

a. CPU: It is the brain of PLC system. It consists of the microcontroller, Memory IC and necessary circuit to store and retrieve information from the memory. The Job of CPU is to monitor status or state of input device, scan and solve the logic of a user program and control ON or OFF state of output device.

b. Memory: The type of RAM (Random Access Memory) normally used is CMOS (Complementary Metal Oxide Semiconductor) to store the program.

c. Input/output: Input is the one through which signal is send and result is observed at the Output.

![Figure 2: Block diagram of PLC](image)
• All of its components – built into, one self contained unit.
• All input and output screw terminals are built into PLC package, and not removable.
• Also called packaged controller.

➢ Modular PLC
• The modular PLC comes as separate pieces.
• A handful of different assemblies, called racks.
• Specific pieces are selected based on the need of control situation.

b. PLC Operation :

A PLC works by continually scanning a program, scan cycle as consisting of 3 important steps: checking input status, executing the program, and updating output status.

Step 1—Check input status—The PLC takes a look at each input to determine if it is on or off.

Step 2—Execute program—The PLC executes your program one instruction at a time.

Step 3—Update output status—finally, the PLC updates the status of the outputs based on which inputs were on during the first step and the results of executing your program during the second step. After the third step, the PLC goes back to step one and repeats the steps continuously. Figure 3 shows operation cycle of PLC.

B. Rexroth Bosch PLC:
In market, many PLCs are available such as ABB, Siemens, Schneider, etc., Rexroth Bosch PLC is basically from German Company - INDRA WORKS and it is a leading Industrial Drive and Control company. Rexroth Bosch PLC are available in three categories; they are a. Indra Logic L-10, b. Indra Logic L-20 and c. Indra Logic L-40.

These PLCs differ in technical data, processor, memory, local I/O extension and performance. In this project Indra Logic L-10 PLC is used as per requirement of application. All PLCs contain general applicable elements and designs such as data types, variable, configuration, resource and task. Program Organization Unit (POU) of all PLC contains function, function block and program, which help user to program in different way for different application.

Programming in Rexroth Bosch PLC

Rexroth Bosch provides different languages for programming, so as provide easier platform for user to program. Programming languages in Indra Logic is classified into two categories; they are as follows [11]:

1. Graphical programming languages
2. Textual programming languages

Graphical programming languages contain following languages

a. Sequential Function Chart (SFC):

The Sequential Function Chart (SFC) is graphically oriented languages which make it possible to describe the chronological order of different actions with in a program. For this actions are assigned to step elements and the sequence of processing is controlled by transition elements. Figure 4 shows example of sequential function chart.

Figure 3: Operation cycle of PLC.

Figure 4: Sequential Function Chart (SFC).
b. Function Block Diagram (FBD):

The Function Block Diagram (FBD) is a graphically oriented programming language. It works with a list of networks whereby each network contains a structure which represents either a logical or arithmetic expression, the call of a function block, a jump, or return instruction. Figure 5 shows example of Function Block Diagram (FBD).

![Function Block Diagram (FBD)](

Figure 5: Function Block Diagram (FBD).

c. Ladder Diagram (LD):

The Ladder Diagram (LD) is also a graphics oriented programming language which approaches the structure of an electric circuit. It consists of a series of networks. A network is limited by a left and right vertical current line. In the middle is a circuit diagram made up of contacts, coils and connecting lines. Figure 6 shows Ladder Diagram.

![Ladder Diagram](

Figure 6: Ladder Diagram (LD).

Textual languages contain following

a. Instruction List (IL): It consists of a series of instructions. Each instruction begins in a new line and contains an operator and, depending on the type of operation, one or more operands separated by commas. Figure 7 shows example of Instruction List.

![Instruction List](

Figure 7: Instruction List.

b. Structured Text (ST): it consists of a series of instructions which determined in high level languages, or in loops can be executed. Figure 8 shows example of Structured Text.

![Structured Text](

Figure 8: Structured Text.

V. Methodology

The common ways used to solar tracking are photoelectric detection and solar trajectory tracking modes. The former uses a photoelectric sensor to monitor the solar movement, and then it controls the mechanisms to track the sun. This mode has high sensitivity, but it is easy to be interfered by the weather and miscellaneous light. The latter controls the mechanisms of tracking by calculating the solar trajectory. This mode doesn't subject to environment, thus in this project both tracking methods are used to reduce error and improve accuracy.

Photoelectric detection tracking: Figure 9 shows general block diagram for photoelectric detection
tracking, which consists of two duplicate photo resistances, motor, Programmable Logic Controller (PLC) and solar panel.

When two photo resistances receive same sunlight their values are equal, if there is change in resistance value with sunlight then sensor will give signal to PLC to run the motor until two photo resistance values are equal. This method may be affected by weather conditions thus solar trajectory tracking is also included to improve the tracking performance.

Fig 9: The composition system block diagram [1].

Solar trajectory tracking:

This tracking method includes determining sun position by calculating solar azimuth, solar elevation and other angles by algorithms. There are several algorithms for calculating the position of the sun based on the date and time provided by an auxiliary clock and geographical data (longitude and latitude of the point used to estimate the position of the sun). This work used the PSA algorithm, developed by the Plataforma Solar de Almeria, which has improved the calculation of universal time as well as the treatment of leap years and which also makes the calculation more quickly and robustly.

Proposed system for project:

Figure 10 shows combination of both tracking system. In figure 10, u represents the position (azimuth and elevation) the tracking system assumes is the location of the sun. It can be seen that this estimated position of the sun is obtained by adding two values: ū, which is the position obtained from the equations that model the sun’s movement, and ũ, which is a correction of that position based on the estimated position of the sun, Y. There are several algorithms for calculating the position of the sun based on the date and time provided by an auxiliary clock and geographical data. They are Cooper, Spencer, Pitman and Vant-Hull, Michalsky algorithm and Plataforma Solar de Almeria (PSA) algorithm.

A. Study of PSA Algorithm: To compute solar vector, Plataforma Solar de Almeria (PSA) algorithm is used which combines these two characteristics of accuracy and simplicity. Following are characteristics of algorithm:

5. Its ease of use has been improved by incorporating an efficient method of computing the Julian Day from the calendar date and Universal Time.
6. Memory management has been improved by controlling the scope and life span of variables.
7. Speed and robustness have been improved by eliminating unnecessary operations and using simple robust expressions for calculating the solar azimuth, which are valid for both hemispheres.
8. Accuracy has been improved by modifying the simplified equations of the Nautical Almanac used by Michalsky with the introduction of new coefficients and new terms, and including parallax correction.

B. Programming in PLC: Ladder diagram for photoelectric detection tracking is written in Indralogic Rexroth bosch PLC.

Description: Two motors for two axis rotation (horizontal and vertical) will be operated when respective photo resistances value differs. Figure 11 shows sequence operation block diagram. Monitoring screen for tracking project is written in Indralogic’s visualization section. Coding of PLC is shown in figure 12.
VI. Conclusion

Sun tracking strategy reduces error, and improves power. Thus sun tracker with both photoelectric detection tracking and solar trajectory tracking will be combined to reduce error of tracking. PLC is used for controlling and monitoring; as it is advanced tool and it suits for all weather conditions. Photoelectric detection tracking ladder diagram is build and it is compared with the solar trajectory for given time and location, so that panel is set perpendicular to sun rays to generate maximum power. Improving the efficiency of solar photovoltaic power generation is an important path which can deal with the global energy crisis at present.

References:

Papers:


Manual:
Website:
[9] Sun position calculator by pveducation.org