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Designing an Efficient PV Tracking System Analyzing Solar Incident Angles

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***Abstract*—In this paper, we propose an effective and efficient model of PV tracking system using solar incident angle. Position of the sun determines how much sunlight would fall directly on a PV surface. This phenomenon affects the amount of energy that would be converted into electricity. Aligning the PV panel to a suitable angle would increase the rate of conversion of sunlight to electricity. Determining solar incident angles helps in aligning a PV panel properly. In this following model, we have calculated the solar incident angle for a longitude and latitude. Calculated incident angles are grouped into twelve months by taking their average value for each month. Then, these values are used in an Arduino based microcontroller to align the PV panel to a particular angle at different times of the day. The calculated annual average enhancement of incident solar radiation has been found to be 22%.**

***Keywords*— PV Tracking, incident angle, solar radiation, Arduino, microcontroller**

I. INTRODUCTION

Recently the research on renewable energy gets more and more attention due to the continuous diminution of fossil fuel as well as awareness among people regarding environmental concern. The solar power is one of the most important of all the available renewable energy sources. The solar panel converts the sunlight into the electric power via photo-voltaic effect. This conversion depends on the amount of the sunlight that is incident on the solar panel [1].

In Bangladesh most of the solar panels are installed on the rooftop with a fixed position without any tracking system. Keeping the panel fixed is only effective to get maximum sunlight from 11 a.m. to 2 p.m. in a day [2] which is not an effective way to achieve maximum output from a PV system. Thus, rotating the panel according to the sun's position will receive more sunlight and solar power than the fixed ones.

The rotation will make sure that the sunlight will be incident perpendicularly on the solar panel all day long. However, to track the panels automatically, a motor driven sensor-based system is necessary.

Tharamuttam and Ng proposed a microcontroller based automated solar tracking system that can utilize solar position using sensors. The system also uses the sun's azimuthal and elevation angle. 3-4% more efficiency was gained by the researchers [3]. Karimov et al. proposed an automated PV tracking system. It has a base of pyramidal stand and panels are installed on top of the base. This proposed model can track the sun using solar position [4]. Saravanan et al. designed a solar tracking system using a three-phase motor, Light Dependent Resistor (LDR). A feedback and corrective system ensure the right positions of the solar panels. The model can get around 25% to 30% efficiency with a very low-cost implementation [5]. Bozkrut and Bas¸ proposed a system for utilization of maximum sun rays. The proposed tracking system uses a time-based circuit, sensors and servo motor. This model provides a review of performance on PV panels [6]. Xiaodi et al. have designed a novel solar boiling water system containing a holistic solar funnel concentrator. The researchers analyzed the performance of the novel solar tracking system. They have achieved 20% more efficiency comparing to static PV panels [7]. In most of the cases, sensors detect the intensity of the sunlight and using a microcontroller, the motor can continuously rotate the panel to track the position of the sun. Though this type of system is efficient, but it is costly and requires regular maintenance as uneven accumulation of dust on the sensors can cause erroneous reading of light intensity.

In this work, a simple tracking system has been proposed that does not use any sensors to track the sun continuously. Rather, the incident angle of the radiation has been calculated from morning till evening for 365 days. Then the monthly average of hourly incident angle has been calculated. This value is used in the Arduino microcontroller to rotate the motor every hour from morning to evening. This way collection of radiation can be improved significantly compared to fixed PV system as well as avoiding continuous tracking using sensor-based system.

II. THEORY

Solar panels are positioned in an angle towards the sun in a way so that the panels would produce maximum energy. But fixed panels are not capable of utilizing the maximum energy of the sun as it cannot accumulate all the solar energy available throughout the day. The relative rotation of earth to sun dictates that incident radiation from the sun at a certain place on earth varies every second. Equation (1) shows the incident angle of direct radiation from the sun on a position [8].

$$\theta = \cos^{-1}\begin{pmatrix} \sin\delta\sin\varphi\cos\beta\ - \\ \sin\delta\cos\varphi\sin\beta\cos\gamma + \\ \cos\delta\cos\varphi\cos\beta\cos\omega + \\ \cos\delta\sin\varphi\sin\beta\cos\gamma\cos\omega \\ + \cos\delta\sin\beta\sin\gamma\sin\omega \end{pmatrix} \qquad (1)$$

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TABLE I. HOUR ANGLE FOR DIFFERENT HOURS(IN DEGREE)

Time	**6 AM**	**7 AM**	**8 AM**	**9 AM**	**10 AM**	**11 AM**	**12 PM**	**1 PM**	**2 PM**	**3 PM**	**4 PM**	**5 PM**	**6 PM**
HA	-90	-75	-60	-45	-30	-15	0	15	30	45	60	75	90

Legend: HA- Hour Angle

Where θ is the angle of incidence which is the angle between the beam radiation on a surface and normal to the surface. The declination angle is denoted by δ, determines the angular position of the sun at solar noon from directly above the equator. Cooper et al. calculated this angle mathematically by the following "(2)" [8].

$$\delta = 23.45 \sin\{360(284+n)/360\} \quad (2)$$

Here, n is the specific day of the year. n = 1, 2, 3, 4...,364, 365. θ is positive for the angles north to the equator and negative for the angles south to the equator. Latitude, ϕ, the angular location north or south of the equator, north is positive [8]. Slope, β, the angle between the plane of the surface in question and the horizontal. β value above 90° means the surface has a downward facing component [8]. Surface Azimuth Angle, γ, is the deviation of the projection on a horizontal plane of the normal to the surface from the local meridian, with zero due to south, east negative and south positive [8]. Hour Angle, ω, The angular displacement of the sun east or the west of the local meridian due to the rotation of the earth on its axis 15 degree per hour. Morning is considered negative and afternoon positive [8]

III. CALCULATIONS

Using equation (1) we can calculate the incident angle, θ, for a place. In this paper, we have calculated the solar incident angle for Dhaka, Bangladesh. The latitude and longitude of Dhaka is 23.84° N and 91.41° E. To calculate incident angle θ, values for ω, γ, β and ϕ are to be calculated first. The slope is taken to be the same as latitude, 23°. The panels are south facing; therefore, surface azimuth angle has been considered 0°. Hour angle is a variable parameter. From sunrise to sunset it changes every hour. For a single day, the changes of hour angles are shown in Table I.

Declination angle, δ can be calculated by using equation (2), where n changes for every day of the year as n = 1,2,3.............364, 365. We can calculate incident angle for different hours using equation (1). Latitude, slop and surface azimuth angle are considered as mentioned before. The hour angle is taken from Table I. In this way, from 7am to 5pm incident angles for every hour is calculated.

IV. RESULT

Variation of the incident angles takes place throughout the year. These values are periodic as expected. It also indicates that over a 30 days span, the values are increasing or decreasing gradually. For every hours of the day, we also got similar periodic variation. So, for a month we grouped their values by taking their average. Table II shows the monthly average incident angle for every hour from 7 a.m. to 5 p.m. Each hourly value has been calculated by averaging 30 values of the whole month. This grouping is done for the twelve months.

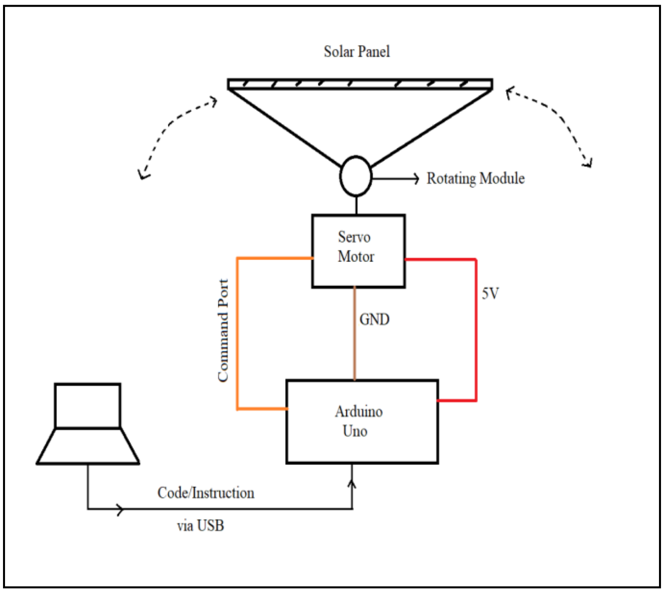

Fig. 1. Circuit Diagram for the implementation of PV panel using Arduino and servo motor

Values obtained from Table II will be used in Arduino microcontroller program so that it can move the motor in a regular interval. The following code shows the part of the arduino program. The values of the angle will be stored in myArray[]. The program will take data from this array and will move the motor. Function delay() is used to maintain the position of the motor as well as defining the interval time between two successive movements.

```
void position(float myArray[], int days)
{
int i = 0;
while(i < days)
{
for(int pos = 0; pos < 11; pos++){
myservo.write(myArray[pos]); //tell servo to read the angle
from array
delay(60*60*1000); // holds the position 1 hour
}
delay(12*60*60*1000); //after running the code for a single
day it would wait for next day
i = i+1;
}
}
```

Fig. 1 shows the schematic diagram of the system. It shows the interaction of various components of the system. Coding instructions are sent to the Arduino board. Servo motor is attached to a rotating module which moves the PV panel according to the commands. Once program is uploaded to the microcontroller, the PV system can be used independently without being controlled.

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TABLE II. AVERAGE INCIDENT ANGLES FOR DIFFERENT HOUR (IN DEGREE)

Time	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
7:00 AM	76.31	75.63	75.13	75.07	75.55	75.89	75.72	75.23	75.23	75.4	76.13	76.57
8:00 AM	62.48	61.14	60.21	60.26	61.47	62.25	61.87	60.71	60.71	60.71	62.13	62.99
9:00 AM	49.05	46.85	45.33	45.52	47.65	48.99	48.34	46.32	46.32	46.13	48.46	49.86
10:00 AM	36.5	33.02	30.53	30.93	34.51	36.64	35.62	32.32	32.32	31.85	35.57	37.74
11:00 AM	26.19	20.63	16.08	16.9	23.26	26.58	25.01	19.52	19.52	18.55	24.78	28.04
12:00 PM	21.67	14.17	5.43	6.91	17.97	22.24	20.26	12.46	12.46	10.69	19.89	23.94
1:00 PM	26.19	20.63	16.08	16.9	23.26	26.58	25.01	19.52	19.52	18.55	24.78	28.04
2:00 PM	36.5	33.02	30.53	30.93	34.51	36.64	35.62	32.32	32.32	31.85	35.57	37.74
3:00 PM	49.05	46.85	45.33	45.52	47.65	48.99	48.34	46.32	46.32	46.13	48.46	49.86
4:00 PM	62.48	61.14	60.21	60.26	61.47	62.25	61.87	60.71	60.71	60.71	62.13	62.99
5:00 PM	76.31	75.63	75.13	75.07	75.55	75.89	75.72	75.23	75.23	75.4	76.13	76.57

A. Efficiency Enhancement by Solar Tracking PV System:

Sun light does not fall perpendicularly all the time on a fixed PV panel. So, by tracking the panel towards the sun will increase the intensity of the incident radiation by an amount of $I\cos\theta$.

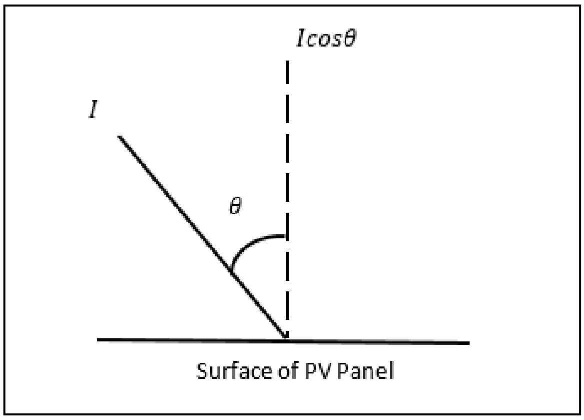

Fig. 2. Absorbed sun ray at a certain angle and 90°

Where I is the incident beam radiation, falling on the surface of a PV panel at an angle θ. If the sun ray would fall directly on the surface of a PV panel, that ray would be denoted by $I\cos\theta$ (Fig. 2). So, calculating $I/I\cos\theta$, we would find the efficiency enhancement of the proposed system compared to the fixed PV panel. As the average value of incident angle, for every hour (from 7 a.m. – 5 p.m.) is already calculated for 12 months, using that value from Table II, we would find the average efficiency enhancement for every hour of the 12 months. Following Table III shows the average efficiency enhancement of every month which is generated by calculating $I/I\cos\theta$.

From Table III, we can see that pointing directly to the sun increases efficiency significantly. Due to the position of the sun at 7 a.m. and 8 a.m., diffuse solar radiation is significantly

higher than direct solar radiation. So, the values of average efficiency enhancement at 7 a.m. and 8 a.m. are not taken into consideration. This phenomenon is also applicable at 4 p.m. and 5 p.m. So, the enhancement values of 4 p.m. and 5 p.m. are not considered. Considering the values from 9 a.m. to 3 p.m., we can find out that the efficiency increases from 1% up to a maximum of 55%. Between 9 a.m. and 3 p.m., the average increase of efficiency for a year is 22%.

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TABLE III. AVERAGE EFFICIENCY ENHANCEMENT

EE of Time	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
7:00 AM	4.23	4.03	3.9	3.89	4.01	4.1	4.05	3.92	3.87	3.97	4.17	4.3	4.03
8:00 AM	2.16	2.07	2.01	2.02	2.09	2.15	2.12	2.04	2	2.04	2.14	2.2	2.08
9:00 AM	1.53	1.46	1.42	1.43	1.48	1.52	1.5	1.45	1.42	1.44	1.51	1.55	1.48
10:00 AM	1.24	1.19	1.16	1.17	1.21	1.25	1.23	1.18	1.16	1.18	1.23	1.26	1.2
11:00 AM	1.11	1.07	1.04	1.05	1.09	1.12	1.1	1.06	1.04	1.05	1.1	1.13	1.08
12:00 PM	1.08	1.03	1	1.01	1.05	1.08	1.07	1.02	1	1.02	1.06	1.09	1.04
1:00 PM	1.11	1.07	1.04	1.05	1.09	1.12	1.1	1.06	1.04	1.05	1.1	1.13	1.08
2:00 PM	1.24	1.19	1.16	1.17	1.21	1.25	1.23	1.18	1.16	1.18	1.23	1.26	1.2
3:00 PM	1.53	1.46	1.42	1.43	1.48	1.52	1.5	1.45	1.42	1.44	1.51	1.55	1.48
4:00 PM	2.16	2.07	2.01	2.02	2.09	2.15	2.12	2.04	2	2.04	2.14	2.2	2.08
5:00 PM	4.23	4.03	3.9	3.89	4.01	4.1	4.05	3.92	3.87	3.97	4.17	4.3	4.03
Average efficiency enhancement of a year (without considering values of 7 AM, 8 AM, 4 PM, 5 PM)													1.22

Legend: EE–Efficiency Enhancement of; Avg– Average.