Improve dual axis solar tracker algorithm based on sunrise and sunset position

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This paper presents sensorless dual axis solar trackers based on sun position using sunrise and sunset database. The database created from exact calculation of solar azimuth and elevation based on Terrestrial Dynamical Time (TDT)system with parameters input: local date, time, geographic location, altitude and timezone. By using linear interpolation the sun position in direction of α and β angles for other time can be obtained during a day. The solar panel move based on sun position in direction of α and β angles. The prototype solar tracker consists of digital electronics circuit and mechanical construction has been functioning as expected, especially for small-sized of solar panel. The measurement of the electrical power output of solar power between a flat position compared to the upright position of sunlight has resulted in a greater power. For seven hours energy captured by flat posistion was 166.4 Watthour. However by used solar tracker increased to 225.05 Watthour. Thus the solar tracker algorithm has increased output power of Solar Power Generation and it's efficiency 26 %. This technique independent from weather conditions, although cloudy, panel position remains consistent with the maximum illumination when the weather is sunny back later. By this way, the solar panel always absorbs maximum sunlight as well as generate maximum electricity.

Keywords: Dual axis solar tracker; Solar panel; Sunrise and sunset database; Linear interpolation.

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1. Introduction

The solar radiation varies according to the orbital variations. The total solar radiation output from the sun in all frequencies at a distance R from the sun centre [1] is equal to $4\pi R^2$ Q(R). If the radiation flux per unit area at a distance R represented by Q(R) and the earth approximately 150x106 km away from the sun. Hence, the total solar output is about 3.8 x 1026 W. Since, the surface area of the earth is 4πr2; the amount of solar radiation per unit area on a spherical planet becomes as 340 W/m2 [1]. Therefore the solar energy has a large potential for future renewable energy sources.

Solar energy is one of the new and renewable energy being actively developed in Indonesia as a tropical country. Indonesia solar energy potential is huge around an average of 4.8 kWh / m2 / day, equivalent to 112,000 GWp, but which has been used only about 10 MWp [2]. In conventional applications of solar panels has many shortcomings, especially on the relatively low output efficiency. There are several factors that affect the electric power generated by solar panels, such as material type solar cells, the level of light intensity and temperature of the working of solar panels.

The performance of solar panels is dependent upon sunlight it receives. In general, the sun will rise from the east toward the west in seconds, minutes and hours. As well as the sun will slight change in position from south to ward the north in monthly. Generally, solar panels installed permanently (fixed) on the stand. For subtropical countries generally

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exposes the panels towards the south or to the north [3]. Meanwhile, a tropical country installation is done tends to be flat. Installation techniques like this will cause the light of the morning sun and afternoon are not in the right position against the direction of the sun. As a result, the amount of electrical energy that can be raised to a little more than it should [4]. Tracking the sun during the day in order to maximize the amount of collected energy. It is possible to gain a significant amount of energy when mounting PV systems on trackers. This gain depends on location, but will generally be 20-35% for a two-axis tracking system [5].

2. Notation

The notation used throughout the paper is stated below.

TD	Terrestrial dynamical
UT	Universal time
Transit	Transit time in hour
TZ	Time zone in hour
L	Longitude (degree)
EqT	Time equation
Jd	Julian day
β_t	β angle for t
T_t	Long time t
β_{sr}	Sunrise time β angle.
T_0	Transit long time (angle 0°)
T_{sr}	Sunrise long time
α_t	α angle for t.
α_{sr}	Sunrise time α angle.
α_{ss}	Sunset time α angle.
T_{ss}	sunset time long

3. Solar Tracker based on sun's position

3.1 Solar Tracker

One of the factor that can improve the efficiency of the photovoltaic system [6] is availability of solar tracking mechanism in the system. There are typically two types of solat tracker designs available i.e. one and dual axis solar tracker [7]. The one axis solar tracker consist of a horizontal-axis tracker which always oriented along East-West or North-South direction; tilted-axis tracker which is tilted from the horizon by an angle oriented along North-South direction; and vertical-axis tracker also known as an azimuth sun tracker. The dual axis solar tracker consist of azimuth-elevation and tilt-roll sun tracking systems, follow the sun in the horizontal and vertical plane.

A solar tracker is a device that orients a solar panel toward the sun. The solar tracker techniques can be used a sun tracking algorithm or light tracing sensors. The sun tracking algorithm independent from weather conditions, although cloudy, panel position remains consistent with the maximum illumination when the weather is sunny back later. This paper focused on sensorless dual axis solar trackers based on sun position using sunrise and sunset.

3.2 Sun's Position Algorithm

A sun's position algorithm used to determines the position of the sun at any given time for a specific location. The position of the sun relative to the earth is affected by the revolution and rotation of the earth. Therefore, the sun position depends on the time, date and geographic location: longitude (0 to 180°) and latitude (0 to ±90°). The calculation of the sun's position by using the equation of time on the Universal Time Coordinated system or UTC also need altitude and timezone.

The orbital positions of the Sun are calculated using Terrestrial Dynamical Time (TD) because it is a uniform time scale. However, world time zones and daily life are based on Universal Time (UT) [8]. In order to convert eclipse predictions from TD to UT, the difference between these two time scales must be known. The parameter delta-T (ΔT) is the arithmetic difference, in seconds, between the two as:

$$\Delta T = TD - UT \tag{1}$$

The sunrise occurs when the upper limb of the Sun disc is visible at the horizon, towards east, at a location whose elevation is reduced to the sea level, while the sunset occurs in the same circumstances, but in the opposite direction, towards the western horizon [9]. Here is the exact calculation of solar azimuth and elevation as well as sunrise and sunset position [10-12]:

1. Input these parameters:
    1. Local date, time
    2. Timezone
    3. Location (Latitude and Longitude)
    4. Altitude
2. Conversion of UTC time into TDT
3. Calculate the angle of declination :

$$D = \text{arc}\,\sin(\sin(22.439 - 0.00000036.\ (Jd - 2451545))\ .\ \sin(L)) \tag{2}$$

4. Calculate sun transit

$$Transit = 12 + TZ - (L/15) - EqT \tag{3}$$

The time equation can be used:

$$EqT = q/15 - RA \tag{4}$$

where:

$$RA = \text{arc}\,\tan(\cos(22.439 - 0.00000036.\ (Jd - 2451545)).\ \sin(L) / \cos(L)) / 15 \tag{5}$$

5. Conversion transit time from UTC into TDT
6. Using the declination angle of the sun and the transit time, the sunrise and sunset times can be obtained.

4. Methodology

Tracking of solar systems can be made in a number of different ways. The two-axis trackers have used in this research to ensure that the solar panel absorbs maximum sunlight to generate maximum electricity. Position of solar panel move based on sunrise and sunset databased created from sun position website of our previous work [10,11]. The overall procedure of dual axis solar tracker based on sunrise and sunset database shown in flowchart Figure 1. The read geographic location, altitude, timezone process, and create database of sunrise and sunset only did one time as inisialisation during first time tracker installed.

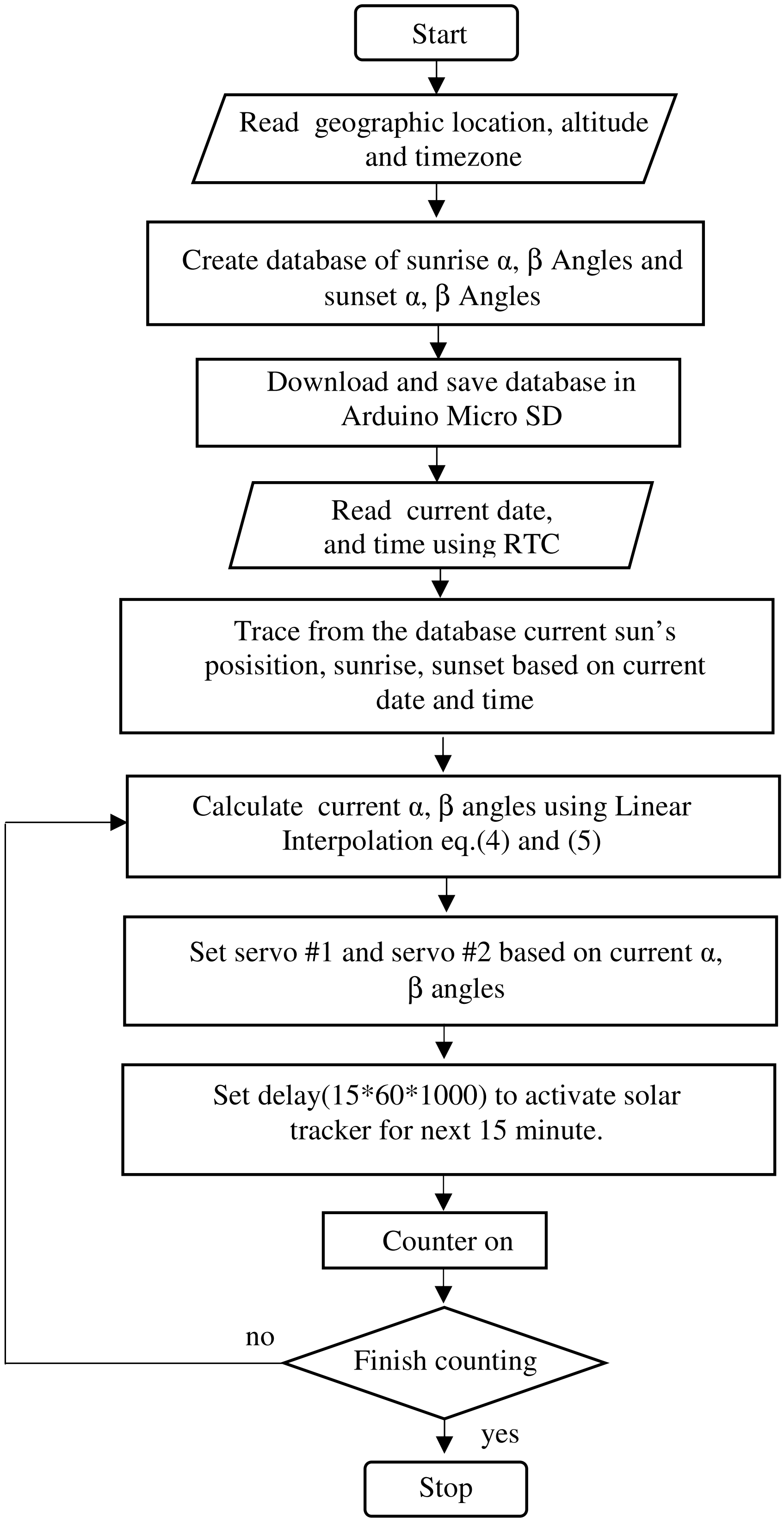

Figure 1 Dual Axis Solar Tracker Algorithm

The dual axis solar tracker is based on the calculation of the sun's position given by two important angles as shown in figure 2. They are the α angle from zenith to north or south direction and β angle from zenith to west or east direction.The other α angle and β angle can be calculated using interpolation equation (6) and (7).

$$\alpha_t = \alpha_{sr} + \frac{T_t - T_{sr}}{T_{ss} - T_{sr}}(\alpha_{ss} - \alpha_{sr}) \tag{6}$$

$$\beta_t = \beta_{sr} - \frac{T_t - T_{sr}}{T_0 - T_{sr}}\beta_{sr} \tag{7}$$

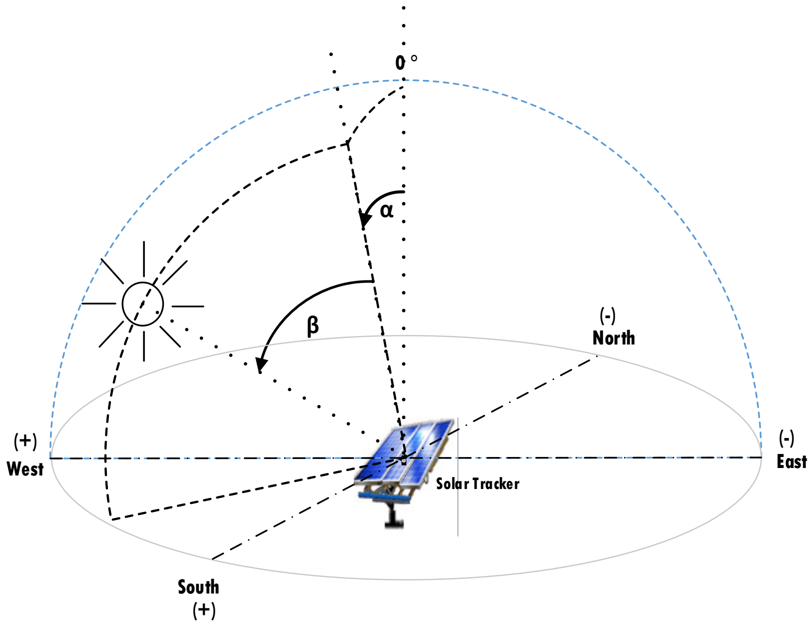

Figure 2 The solar tracker α, β angel

Based on these pair values per day sunrise and sunset using interpolation the sun position in α angle and β angle for other time can be obtained for one day. Then two servo motor set the solar panel position to spherical coordinat (α, β) as shown in figure 2.

5. Results and Discussion

5.1 Result of α and β angle for one day

The Andalas University geographic location with latitude -0.9145° and longitude 100.4595° are chosed in this research. The altitude 280 m and 7 timezone are used to create sun posistion database. These parameters entered to the sun position simulator [11] that can be accessed at http://planetbiru.com/apps/trisula3d/. The result for transit time is shown as figure 3. This value used to calculate sunrise and sanset after added or subtracted with day length. The sunrise and suset time have varied followed the transit time curve. The α and β angle are measured base on vertical position of solar panel as 0°. The sunrise and sunset database for α and β angle created as shown in figure 4 and firgure 5 repectively.

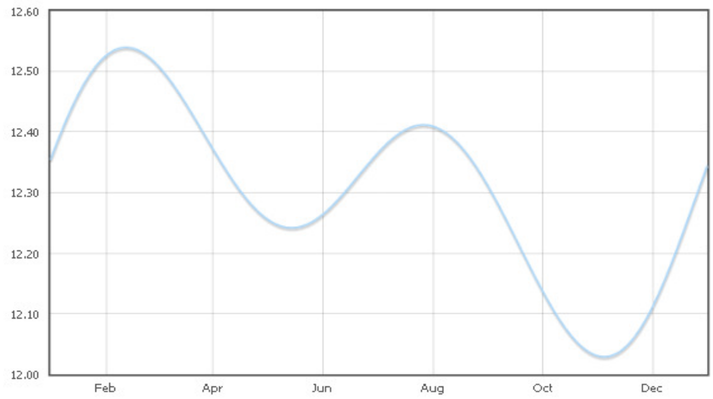

Figure 3 Transit time for one year

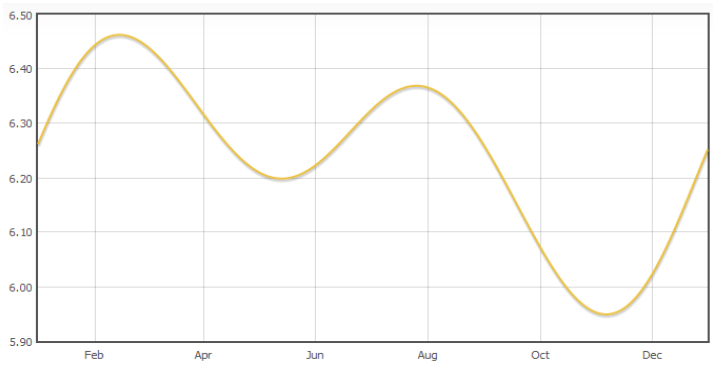

Figure 4 Sunrise database for one year

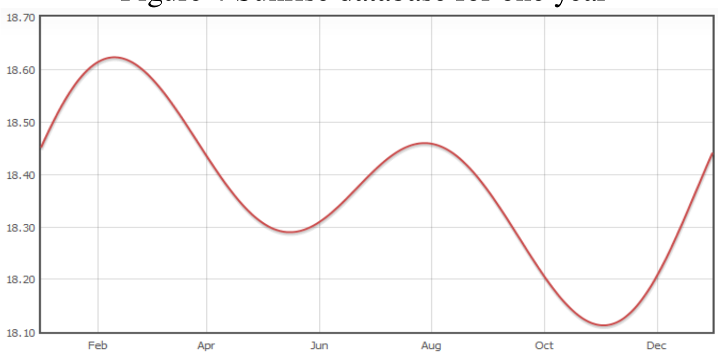

Figure 5 Sunset database for one year

The α and β angle for sunrise and sunset database created are shown in figure 6 and firgure 7 repectively.

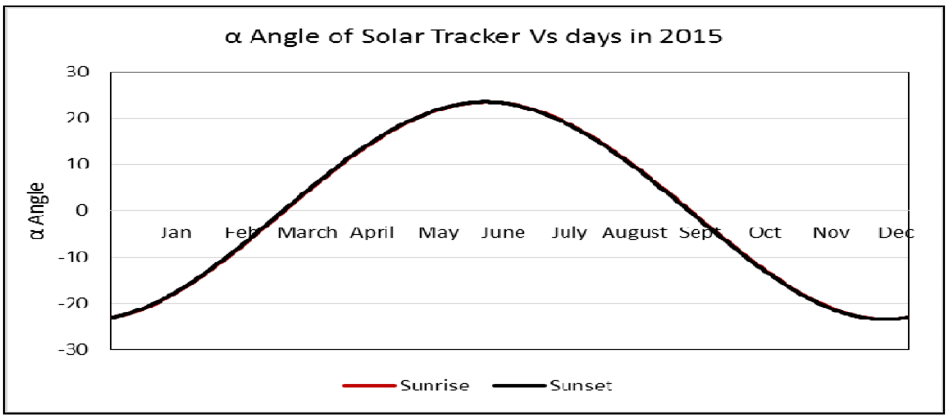

Figure 6. α Angle of Solar Tracker for sunrise and sunset

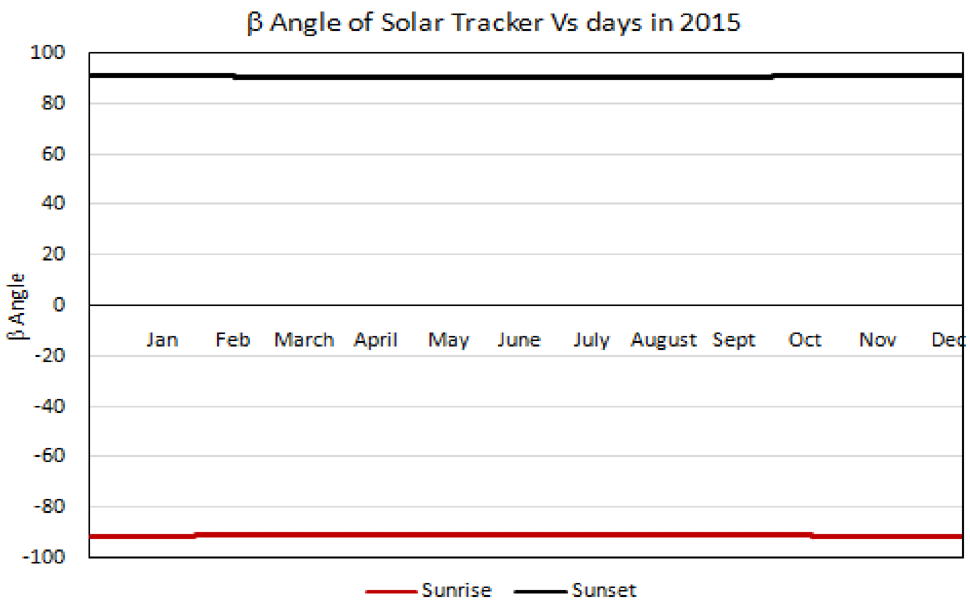

Figure 7 β Angle of Solar Tracker for sunrise and sunset

The α angle of sunrise near the same as α angle when sunset for daily movement. However the β angle of sunrise more different with β angle when sunset around 180° as shown in figure 7. Therefore the solar panel move around 180° in the west-east direction for daily track.

5.2. Solar Tracker Prototype

The electronic circuit of solar tracker consist of Real Time Clock (RTC), Micro SD and Arduino Mega 2560 as shown in figure 8. The circuit will read real time date and time using RTC and compared them to date and time of sun position database to determine latitude and longitude angle. Then these angles used as arduino input to set servo motor directed solar panel always follow the sun position or perpendicular to the sun in order to produce maximum energy conversion.

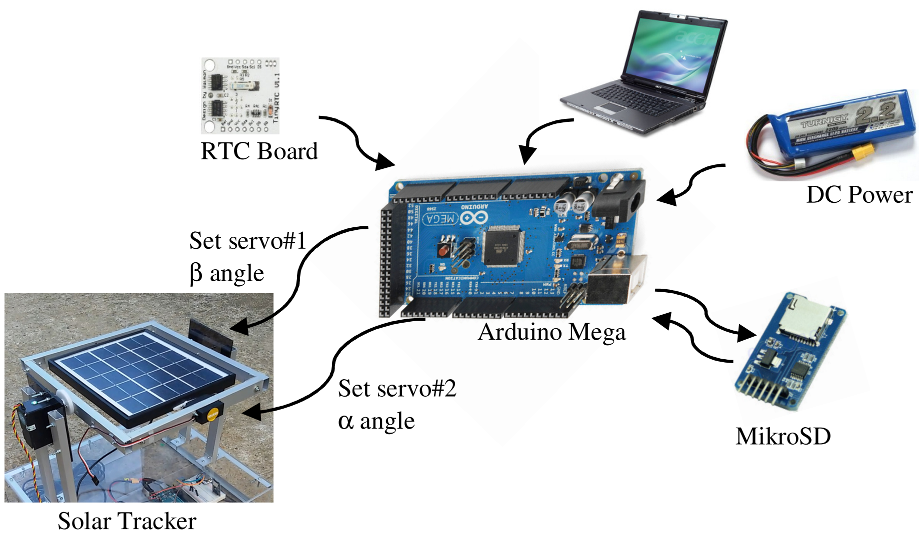

Figure 8 The electronic circuit of solar tracker

The solar tracker algorithm which download to arduino mega is state below:

```
1. Read current date and time from RTC
RTCval = RTChour*60+RTCminute;
2. SD.open to read database of sun position.
3. Compare RTC date and time with database date and time to get sunrise, sunset time and its latitute and longitute.
4. Calculate current latitute and longitude using Linear Interpolation eq.(4) and (5).
5. Set servo #1 based on current latitude.
6. Set servo #2 based on current longitude.
7. SD.close(file) to close database.
8. Set delay(15*60*1000) to activate solar tracker for next 15 minute.
```

The mechanism of electro-mechanical displacement consists of two servo motors, one for altitude and the other for longitude displacements. The functionality of solar tracker mechanism have tested using small solar panel 4 Wp which mechanical costruction as shown in figure 8. The solar tracker have moved based on sun position derived from sunrise and sunset database created from sun position website of our previous work [10,11].

5.3. Test on the 180 Wp Solar Panel

Then function of solar tracker mechanism tested using real 185 Wp solar panel. The mechanical construction of solar panel can move in two direction which east and west direction 180° for daily movement and ± 25° for north and south direction for six monthly movement. The solar panel was used Sharp NU 185 A1H which maximum pawer in STC 185 Watt, 30.2 Volt. The system test on Thuesday 14 May 2015 with databased:

```
5,14,6,12,18,16,19.59,-90.59,19.71,90.59
```

The meaning of these values are: sunrise time 6:12, with α angle 19.59° and β angle -90.59° (in east direction) and sunset time 18:18, with α angle 19.71 and β angle 90.59. The other α angle and β angle can be calculated using interpolation equation (4) and (5). The results summerized as table 1 below:

Table 1: α and β angle for one day

Time	Hour*60+minute	β angle	α angle
6:12	372	-90.59	19.59
8:00	480	-62.48	19.61
9:00	540	-46.86	19.62
10:00	600	-31.24	19.63
11:00	660	-15.62	19.64
12:00	720	0	19.65
13:00	780	14.46	19.66
14:00	840	28.91	19.67
15:00	900	43.37	19.68
16:00	960	57.82	19.69
17:00	1020	72.28	19.70
18.16	1096	90.59	19.71

The prototype solar tracker which consists of digital electronics circuit and mechanical tracker construction has been functioning as expected, especially for small-sized of solar panel. As for the solar panel with large size need motor with high power from DC motor types.

The electrical power generated by solar panel have measured for two condition of solar panels positions mounted flat and by moving perpendicular of solar lighting. The measurement of the electrical power output of solar power between a flat position compared to the upright position of sunlight has resulted in a greater power. For seven hours energy captured by flat posistion is 166.4 Watthour. However by used solar tracker 225.05 Watthour. Thus the method of solar tracker without sensor has increased output power of Solar Power Generation (PLTS) and it's efficiency 26 %. For the cloudy wheather the effect of solar tracker not so significant, cause of sun light near the same for any other direction. However by using sensorless solar tracker based on sun position have maximized the amount of collected solar energy.

5. Conclusion

An accurate solar tracker based on sun position have been developed. Position of solar panel move based on sunrise and sunset database created from sun position website of our previous work. The prototype solar tracker which consists of digital electronics circuit and mechanical construction has been functioning as expected, especially for small-sized of solar panel. The measurement of the electrical power output of solar power between a flat position compared to the upright position of sunlight has resulted in a greater power. For seven hours energy captured by flat posistion is 166.4 Watthour. However by used solar tracker increased to 225.05 Watthour. Thus the method of solar tracker without sensor has increased output power of Solar Power Generation and it's efficiency 26 %. For the cloudy wheather the effect of solar tracker not to significant, cause of sun light near the same for any other direction. However by using sensorless solar tracker based on sun position have increased the amount of solar energy collected.

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