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The Design and Implementation of Hybrid Automatic Solar Tracking System

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Abstract: A solar tracking system is the device for orienting solar photovoltaic modules and solar thermal collectors toward the sun. This study presents a microcontroller based energy efficient hybrid automatic solar tracking system with a view to assess the improvement in solar conversion efficiency. The two-axis solar tracking system is constructed with both hardware and software implementations. The proposed tracking system uses a new solar sensor position with an adaptive feature. The economical analysis of the solar tracking systems is an important element of this reaearch. A comparative analysis was performed using three systems, i.e., hybrid, dual-axis tracking, single-axis and stationary module. The results showed that the use of the dual-axis tracking system produced 18% gain of power output, compared with a single-axis tracking system. The gain of output power with the dual-axis tracking system was much higher (54%) when compared with a stationary system inclined at 23.5° to the horizontal which is reasonable. Considering the state of the art of the technology, successful strategy, robust control philosophy and the potential added benefit of this research can be employed on a large scale in sustainable manner.

Key words: Sun tracking system, solar photovoltaic energy, position sensor, microcontroller, technology, output

INTRODUCTION

Industrial and domestic reliance on the use of fossil fuel is today facing challenges in demand and environmental consideration. Faced with a possibility of scarce oil resources and increasing concern about its harmful byproducts such as toxic pollution, global climate change and acid rain, awareness of using renewable energy is growing. So, the green energy also called the renewable energy has gained much attention now a days. Green energy can be recycled, much like solar energy, micro hydro power, wind power, biomass energy, terrestrial heat, temperature difference of sea, sea waves, morning and evening tides (Bull, 2001; Rahman, 2003). Solar energy technology is one of the promising sources of future energy supplies because it is clean and remarkably abundant. Solar energy can be converted into electricity through the solar cells. So far the efficiency of generating power from solar energy is relatively low. Thus, increasing the efficiency of generating power of solar energy is very important. There are three main ways to make photovoltaic cells more efficient. One method is to improve the materials design; the other one is maximum power point tracking due to nonlinear I-V characteristic of PV array and the final one is to optimize the output by installing the solar panels on a tracking base that follows the sun. This research employed the last method. The amount of current a PV panel produces has a direct correlation with the intensity of light the panel is absorbing.

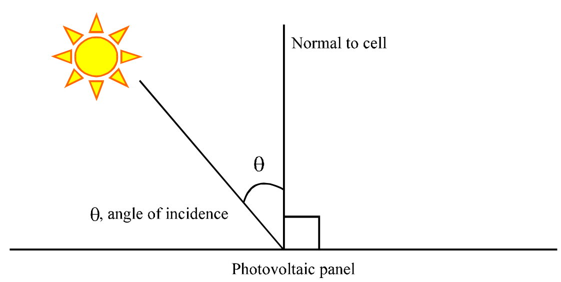

Fig. 1: Angle of incidence to solar panel

The normal to the cell is perpendicular to the cell's exposed face as shown in Fig. 1. The sunlight comes in and strikes the panel at an angle. The angle of the sunlight to the normal is the angle of incidence (θ) (Pritchard, 1983). Assuming the sunlight is staying at a constant intensity (λ) the available sunlight to the solar cell for power generation (W) can be calculated as:

$$W = A\lambda \cos\theta \quad (1)$$

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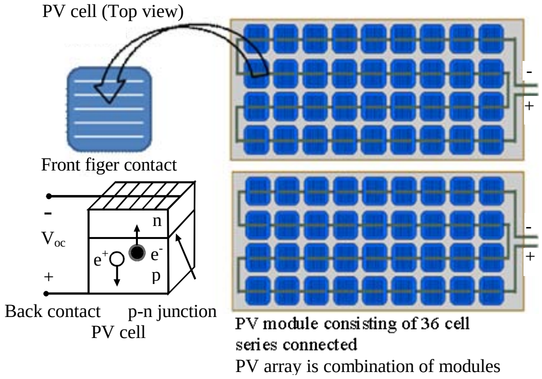

Fig. 2: PV cell structure, module and array

Here, A represents some limiting conversion factor in the design of the panel because they cannot convert 100% of the sunlight absorbed into electrical energy. By this calculation, the maximum power generated will be when the sunlight is hitting the PV cell along its normal and no power will be generated when the sunlight is perpendicular to the normal. With a fixed solar panel, there is significant power lost during the day because the panel is not kept perpendicular to the sun's rays. A tracking system can keep the angle of incidence within a certain margin and would be able to maximize the power generated. Many researchers have proposed different methods for tracking the sun (Konar and Mandal, 1991). A fixed flat-photovoltaic panel can be a set to collect a high proportion of available noon-time energy, significant power is available in the early mornings and afternoons when the misalignment with a fixed panel becomes excessive to collect a reasonable proportion of the available energy. Thus, the primary benefit of a tracking system is to collect solar energy for the longest period of the day and with the most accurate alignment as the sun's position shifts with the seasons. Today researchers use single-axis and duel axis tracking system. But hybrid solar tracking system can provide more power and also efficient service than other tracking system.

Photovoltaic array model: The photovoltaic array is an arrangement of several modules connected in series/parallel to get a suitable power and voltage. The basic element of the photovoltaic array is the solar cell which usually uses a p-n junction diode in a physical configuration to produce photovoltaic electricity. Solar cell is basically a p-n junction fabricated in a thin wafer or layer of semiconductor as shown in Fig. 2. Being exposed to the sunlight, photons with energy greater than the band-gap energy of the semiconductor are absorbed and create some electron-hole pairs proportional to the incident irradiation as shown in Fig. 2. Under the influence of the internal electric fields of the p-n junction, these carriers are swept apart and create a photocurrent which is directly proportional to solar insolation (Messenger and Ventre, 1999). PV system naturally exhibits a nonlinear I-V and P-V characteristics which vary with the intensity of sunlight exposed and cell temperature.

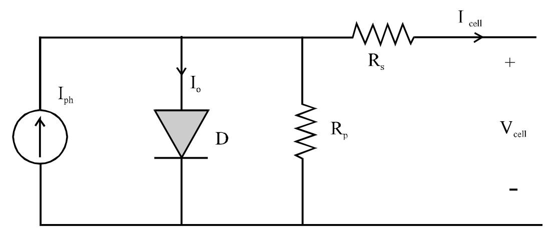

Fig. 3: Simplified equivalent circuit of a solar cell

A PV cell is represented by a simplified equivalent circuit as the one shown in Fig. 3 and by an Eq. 2:

$$V_{cell} = \left(\frac{nkT_c}{q} \ln \frac{I_{ph} + I_o - I_{cell}}{I_o} - R_s \times I_{cell} \right) \quad (2)$$

Where:

- q = Charge of electron
- n = The ideality factor of cell which depends on the PV technology
- k = Boltzmann constant (1.38×10-23)
- I_{cell} = Cell output current
- I_{ph} = Photocurrent which is a function of cell operating temperature and solar irradiance
- I_o = Reverse saturation current of diode
- R_s = Series resistance of cell
- T_c = Cell operating temperature
- V_{cell} = Cell output voltage

Photocurrent mainly depends on the solar insolation and cell's working temperature which:

$$I_{ph} = [I_{sc} + K_1(T_c - T_0)]G \quad (3)$$

Where:

- I_{sc} = The short circuit current at 25°C temperature (reference) and 1 kW m^{-2} irradiance
- K_1 = Cell's short circuit current temperature co-efficient
- G = The solar insolation in kW m^{-2}
- T_0 = The cell's reference temperature

Also, the cell's saturation current varies the cell's operating temperature which may expressed as:

$$I_s = I_{so}\left(\frac{T_c}{T_o}\right)^3 \exp\left[qE_g\left(\frac{1}{T_o}-\frac{1}{T_c}\right)/kn\right] \quad (4)$$

Where:

I_{so} = The cell's reverse saturation current at reference temperature and solar radiation 1 kW m^{-2}

E_g = The bang-gap energy of the semiconductor used in the cell

I_{so} can be found from Eq. 5:

$$I_s = I_{so}/\left[\exp\left(\frac{qV_{oc}}{nkN_sT_o}\right)-1\right] \quad (5)$$

Where:

V_{oc} = The open circuit voltage under standard condition

N_s = The no. of cells connected in series

An even more exact mathematical description of a solar cell which is called the double exponential model is derived from the physical behavior of solar cell constructed from polycrystalline silicon. This model is composed of a light-generated current source, one diode, a series resistance and a parallel resistance (Phang *et al*., 1984; Islam *et al*., 2010). However, there are some limitations to develop expressions for the V-I curve parameters subject to the implicit and nonlinear nature of the model. A photovoltaic panel which was the power source was shown in Fig. 4. The shunt resistance R_p is inversely related with shunt leakage current to the ground. In general, the PV efficiency is insensitive to variation in R_p and the shunt-leakage resistance can be assumed to approach infinity without leakage current to ground. On the other hand, a small variation in R_s will significantly affect the PV output power.

Taxonomy of solar tracker: Solar tracker is a rack or plate for photovoltaic modules that move to point at or near the sun throughout the day. In other words, a solar tracker is a generic term used to describe devices that orient various payloads toward the sun trackers add to the efficiency of the system, reducing the sizeand the cost per kWh. According to the movement of the axis of rotation, there are three types solar tracker those are available.

First one is Single-Axis Tracker (SAT) then the second one is Dual-Axis Tracker (DAT) and a simple scheme as in Fig. 5. Single-axis tracker acts as an axis of rotation.

There are several implementations of single-axis trackers these include Horizontal Single-Axis Trackers (HSAT), Vertical Single Axis Trackers (VSAT), Tilted Single-Axis Trackers (TSAT) and Polar Aligned Single-Axis Trackers (PSAT). Dual-axis trackers have 2 df that act as axis of rotation.

There are some common implementations of dual axis trackers (Krachong *et al*., 2008; Koyuncu and Balasubramanian, 1991). They are classified by the orientation of their primary axis with respect to the ground.

Two common implementations are Tip Tilt Dual-Axis Trackers (TTDAT) and Azimuth Altitude Dual-Axis Trackers (AADAT) (Garrison, 2002). Dual-axis trackers allow for optimum solar energy levels due to their ability to follow the sun vertically and horizontally.

Dual-axis trackers are typically used in smaller residential installations and locations with very high government feed in tariffs. On the other hand, hybrid trackers move on three axes to point directly at the sun, taking maximum advantage of the sun's energy. It has two racks one moves North and South an other moves East and West side.

Thus, the primary benefit of a tracking system is to collect solar energy for the longest period of the day and with the most accurate alignment as the sun's position shifts with the seasons.

Fig. 4: PV module in the renewable energy lab of CUET

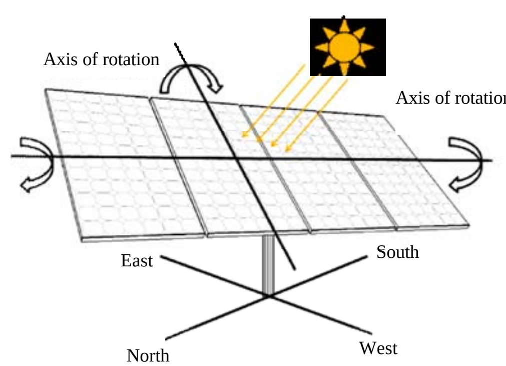

Fig. 5: Dual-axis solar tracker combines two motions while tracking

MATERIALS AND METHODS

Here, a microcontroller operated hybrid two-axis sun tracker which works efficiently in all weather conditions regardless of the presence of clouds for long period. A comparative analysis was performed using three systems, i.e., dual axis tracking, single axis tracking and stationary based on the experimental prototype. Generally, one PV module has been used. But researchers can use two PV module in this structure in addition, the greater the level of concentration employed the more important accurate tracking becomes because the proportion of energy derived from direct radiation is higher and the region where that concentrated energy is focused becomes smaller. The selection of tracker type is dependent on many factors including installation size, electric rates, government incentives, land constraints, latitude and local weather (Popat, 1998; Berenguel *et al*., 2004). Appropriate spacing can maximize the ratio of energy production to cost this being dependent upon local terrain and shading condition sand the time-of-day value of the energy produced. For fixed collector, the projection of the sun beam on the PV cell which is oriented perpendicularly to the radiation direction is equal and the angle $S = S_0 \cos\theta$ and the angle θ is changing in the interval ($\pi/2$, $-\pi/2$) during the day where S_0 is the collector area. The angular velocity of the sun moving across the sky is equal $\omega = 727 \times 10^{-5}$ sec^{-1} and the differential of the falling energy is equal $dW = IS_0\, dt$. When it does not consider the atmosphere influence and can calculate the energy which is fallen on the collector area $S_0 = 1$ m^2 during 1 day (Sarker *et al*., 2010):

$$W = \int_{-2100}^{+2100} IS_0 \cos\omega t dt = IS_0 \left[\frac{\sin\omega t}{\omega}\right]_{-2100}^{+2100} = \frac{2IS_0}{\omega} = 303\times10^7 \text{ W} \quad (6)$$

For the tracking collector which is all the time optimally oriented to the sun: When it is not considered the atmosphere influence, it can be calculated the energy which is fallen on the collector area $S_0 = 1$ m^2 during 1 day:

$$W = IS_0 t = 475\times10^7 \text{ W} \quad (7)$$

Comparison Eq. 6 and 7 show the energy surplus 57% when it is not considered the atmosphere influence. It would be really obtained this surplus for example on the moon surface (Fig. 6).

System software operation: The assembly language was utilized in this study. It was more than adequate to satisfy design objectives while enhancing level of understanding of the programming language. Software operation can be divided into four main parts. The first part is initial positioning. Prior to powering up the system the photocell must be manually set to a starting point (East and North, here tracker has two starting point because its two panel to move) once manually positioned, the tracking sensor will move one 3.75° step sec^{-1} the clockwise direction until a value of light intensity greater then the preset threshold is measured. The threshold has been set as a constant in program code to equal a voltage level of 4.60 V. This level was selected to correspond to what was measured with the shielded photocell pointed directly at the sun. This level ensures that the tracker will seek out only an extremely bright source of light. The second part of the system code deals with light tracking. This is the heart of the program. Once the tracker has set its initial position to a bright source of light (sun), it is ready to align itself more precisely and continue tracking the light. The tracker first measures light intensity at its present location. It then moves counter clockwise (left) by one 3.75° step and takes another measurement. Next, it moves clockwise (right) two 3.75° steps and takes a final measurement.

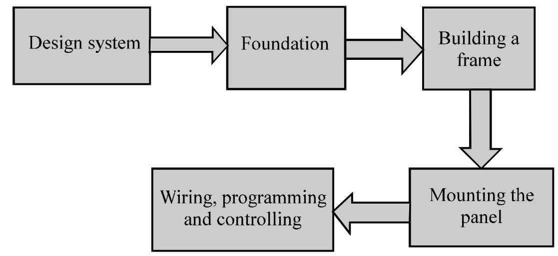

Fig. 6: Flow diagram of implementation of the entire project

The software comparison subroutines compare these values and position the tracker at the point of greatest measurement. If any of the values are equal, the tracker will return to the center position and check again later. The tracker will wait 3 min before checking the three positions again. The 3 min interval is based on the fact that the sun moves 1° every 3 min.

Low light detection is the third portion of the software routine. This work in conjunction with the tracking routine discussed before. If light intensity below the low light threshold level, the tracker will keep measuring at whatever position it is at until the threshold is reached. The threshold for this portion has been assigned a constant in software equal to 3.70 V. This level corresponds to what was measured with the shielded photocell during daytime overcast conditions. The last portion of the software routine allows the tracker to reset itself at the end of a day. After every motor movement, a register is incremented or decremented so that the net position of the tracker can be known at any shown time. The driver circuit is shown in Fig. 7 and 8.

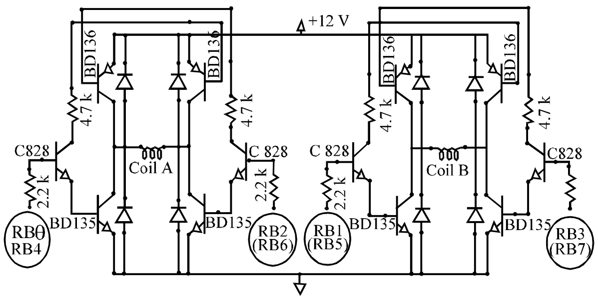

Fig. 7: Full bridge driver circuit for stepper motor

Once the tracker has moved 180° light intensity is checked. If light intensity is >3.70 V threshold, the tracker will return to its starting point and enter sleep mode. The overall software control flow is shown in Fig. 9. If above,

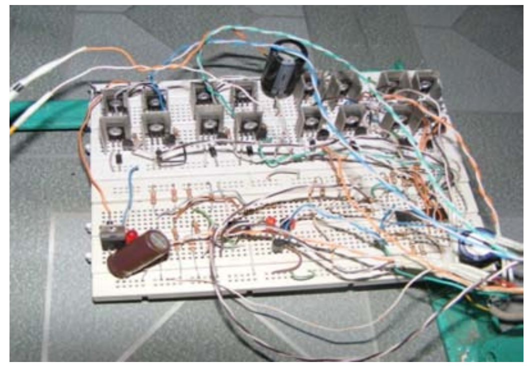

Fig. 8: Breadboard assembly of circuit components

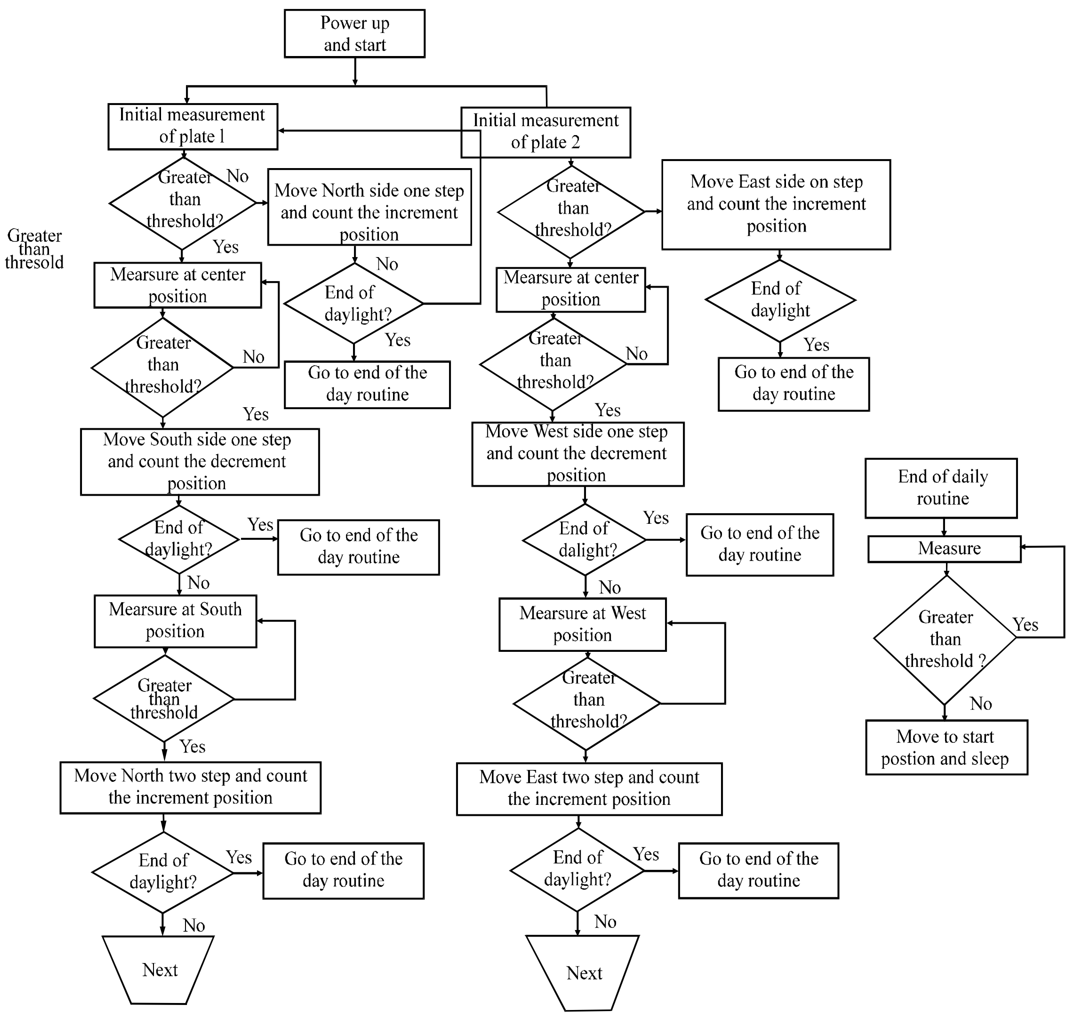

Fig. 9: Software flow diagram

it will keep checking until the measurement drops below the threshold. Once the tracker enters sleep mode, it can be reset manually with a momentary switch.

RASULTS AND DISCUSSION

Performance improvement analysis: Final experiment was setup as in Fig. 10. To determine the percentage difference in power output between modules in stationary position (30° to the horizontal) on single-axis, dual-axis and hybrid tracker. The data in Table 1 was shown the difference of power output based on the comparison of the three systems, stationary, single and dual-axis tracker.

Even with minor variations due to climate changes, the average power output was greater in favor of the hybrid solar tracker that of dual and single-axis tracker and stationary system.

Regardless the time period of linear increasing or decreasing of output power, the period of time was chosen between 11 a.m. to 17 p.m. Average increase by employing hybrid dual-axis tracker was calculated to be 20.79 and 54.88% over the single-axis tracker and stationary one, respectively (Fig. 11).

The average increase by employing hybrid tracker was also calculated to be 28.79% over the dual-axis tracker. Gain from trackers is much greater during the long days of Summer than in Winter. There is strong sun for many additional hours, including the utility's peak use hours (noon to 6 p.m). If the system is connected to the grid and utility has time-of-day metering, the tracker' ability to capture all the afternoon sun.

Time-of-day metering means that utilities purchase excess power during peak hours in summer at a significant premium, adding even more value to a tracker system. On off-grid systems however a tracker may not add as much value if a stationary array will produce all the power researchers need in Summer. Researchers can see gaining power from three different types of tracker.

However, researchers can see better performance of these types of tracker. Power was acquired more from hybrid tracker than both single and dual-axis tracker as shown in Fig. 12. Finally, one thing can say for getting the full advantage of the tracking system. Then, hybrid tracker can give better performance than any kind of tracker.

Fig. 10: Laboratory prototype of hybrid solar tracker

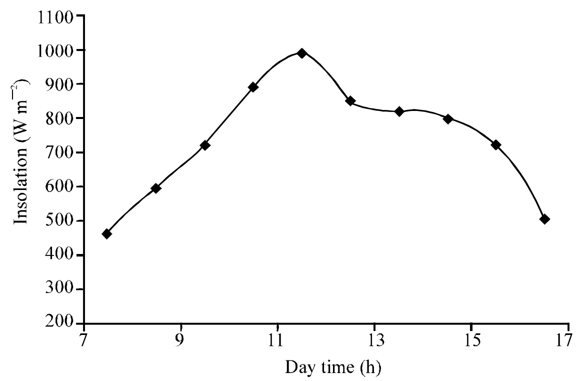

Fig. 11: Hourly insolation variation per square meter 08, August, 2011

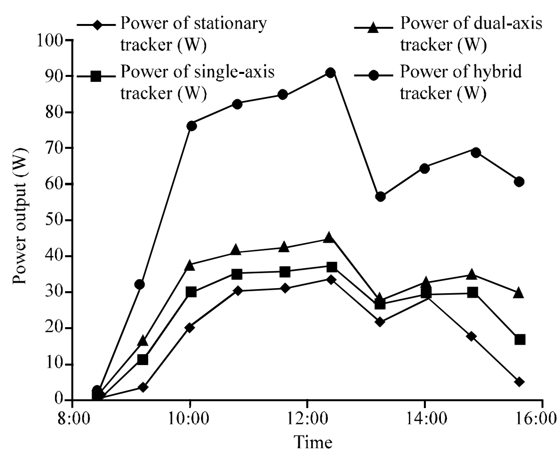

Fig. 12: Performance assessment of hybrid, dual, single-axis solar tracker

Table 1: Mono crystalline PV modules (8/09/2011)

Time	Pw of stationary (W)	Pw of single-axis (W)	Pw of dual-axis (W)	Pw of hybrid (W)	Difference between St and DA (%)	Difference between SA and DA (%)	Difference between SA and hybrid (%)
8:00	0.06	0.06	0.06	0.06	3.74	1.75	2.43
9:00	3.87	11.24	16.48	31.23	326.13	46.60	89.50
10:00	20.38	30.90	38.15	47.34	87.23	23.48	24.10

Table 1: Continue

Time	Pw of stationary (W)	Pw of single-axis (W)	Pw of dual-axis (W)	Pw of hybrid (W)	Difference between St and DA (%)	Difference between SA and DA (%)	Difference between SA and hybrid (%)
11:00	30.53	35.09	41.43	48.57	35.73	18.06	17.23
12:00	30.90	35.88	42.51	49.13	37.60	18.48	15.57
13:00	34.00	37.64	45.44	49.79	33.64	20.73	9.57
14:00	21.66	27.02	28.23	45.96	30.34	4.48	62.81
15:00	28.94	29.39	32.82	43.21	13.41	11.69	31.65
16:00	17.94	30.62	34.98	44.76	95.00	14.23	27.95
17:00	5.22	16.51	30.01	42.45	475.05	81.82	41.45
Average percent difference between 10:00 and 17:00					54.88	20.79	28.79

CONCLUSION

This study presented a solar-tracking system which is an efficient system. It can be manipulated anywhere such as house-hold activities in office even in industrial purposes. The cost of the implementation of this research is low. It is a micro-controller based research.

Today world is now facing acute power crisis. Researchers need to find new resource and also need to boost efficiency the production of power from other renewable energy sources. Researchers need also a better power system to give service those people who live in remote area. Under this circumstance, type of research can give a good result when energy crisis is one of the most vital issue in the world.

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