Single Axis Solar Tracker

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Abstract— **The Single Axis Solar Tracker is created to track the maximum sun daily. This project is invented especially to prevent wasting energy during sunrise to sunset. This project is needed because it can increase maximum power produced daily using photo-voltaic. Nowadays there are many trackers available in market but most of them cost a lot, wasting so much energy such as wasting energy on motor since the power require to rotate the photo-voltaic module is high and very complicated design. The operation of this project is the tracker will move automatically from east to west daily. To completely specify the position of the sun it is necessary to specify three coordinates. However, if one assumes the distance from the sun to the Earth to be constant, the position of the sun can be specified using two coordinates. Two common choices are the solar altitude and the azimuth. The purpose of this project is to compare the power output produced by using tracker and fixed angle. This project use programmable interface controller (PIC) for controlling the tracker,**

Keywords— single axis solar tracker, fixed angle, altitudes and azimuth, programmable interface controller (PIC)

I. INTRODUCTION

Electricity has become the most important things in human life not just for living things, but commonly all equipment need electricity. This is because much equipment needs an electricity to operate. Commonly in the world there are many ways to produce electricity but most of it is not green environment such as fossil fuel (coal, oil, and natural gas), water power and nuclear power. Now days, many pollution happen either water or air pollution. To reduce it several actions can be taken by produced the project that applying the concept of green environment. Solar cells operate by converting sunlight directly into electricity using the electronic properties of a class of material as known as semiconductors. This project focuses on sunny day only. This project is one alternatively best solution among others because it use solar to generate electricity. The cost for initial set up is a little bit expensive because the costs include acquisition costs, maintenance costs and replacement costs. [1]

Extracting useable electricity from the sun was made possible by the discovery of the photoelectric mechanism and subsequent development of the solar cell – a semi conductive material that converts visible light into a direct current. By using solar arrays, a series of solar cells electrically connected, a DC voltage is generated which can be physically used on a load. Solar arrays or panels are being used increasingly as efficiencies reach higher levels, and are especially popular in remote areas where placement of electricity lines is not economically viable. This alternative power source is continuously achieving greater popularity especially since the realisation of fossil fuels shortcomings. Renewable energy in the form of electricity has been in use to some degree as long as 75 or 100 years ago. Sources such as Solar, Wind, Hydro and Geothermal have all been utilised with varying levels of success. The most widely used are hydro and wind power, with solar power being moderately used worldwide. This can be attributed to the relatively high cost of solar cells and their low conversion efficiency.

Solar power is being heavily researched, and solar energy costs have now reached within a few cents per kW/h of other forms of electricity generation, and will drop further with new technologies such as titanium oxide cells. With a peak laboratory efficiency of 32% and average efficiency of 15-20%, it is necessary to recover as much energy as possible from a solar power system. [2] This includes reducing inverter losses, storage losses, and light gathering losses. [3] Light gathering is dependent on the angle of incidence of the light source providing power (i.e. the sun) to the solar cell's surface, and the closer to perpendicular, the greater the power. [4] Level ground, it is obvious that over the course of the day the sunlight will have an angle of incidence close to 90°in the morning and the evening. At such an angle, the light gathering ability of the cell is essentially zero, resulting in no output. As the day progresses to midday, the angle of incidence approaches 0°, causing a steady increase in power until at the point where the light incident on the panel is completely perpendicular, and maximum power is achieved. [5]

As the day continues toward dusk, the reverse happens, and the increasing angle causes the power to decrease. From this background, to maintain the maximum power output from the panel by maintaining an angle of incidence as close to 0° as possible. By tilting the solar panel to continuously face the sun, this can be achieved. This process of sensing and following the position of the sun is known as Solar Tracking. It was resolved that real-time tracking would be necessary to follow the sun effectively, so that no external data would be required in operation. [6]

This projects has several problem will be occur during operating. Even a small amount of shade on a photo-voltaic module can significantly reduce the module output voltage. It is thus of paramount importance to select a site for a photo-voltaic system where the photo-voltaic array will remain unshaded for as much of the day as possible. This is easy if there are no objects that might shade the array, but it is probably more likely that a site will have objects nearby that shade the array at some time of the day on some day of the year. The scope of the project is to develop the tracker that can find the maximum sun daily. This can produced maximum output voltage on photo-voltaic. The other scope of project is to compare the maximum power output from fixed angle and tracker. Other than that the function of photo-voltaic and its operation can be known.

There is limitation for this project such as this project just focused for consumer in Malaysia only. The photo-voltaic module only operates in sunny day. This project will function 24 hours. The tracking will be operating 12.27 hours a day since we set it according to the data that we obtained from sun position. The main source that must have in these projects is sunrise. These are because the power can be generated due sunrise receive to photo-voltaic module and restore it in battery. Whenever no sunrise receives this project will stop working and in the evening (around 7.00 a.m.) the photo-voltaic module is start at initial condition and will repeat until 30 days. After 30 days, user must restart the tracker since the sun position is different every month.

II. METHODOLOGY

A. Mechanical Part

The mechanical part showed the orientation the photo-voltaic module for single axis solar tracker. Several factor must be consider due to designing the tracker such as the material that been used, the strength of tracker, the weight and the torque required to drive the photo-voltaic module including the weight of the tracker. To calculate the torque required, force of the solar tracker is need to obtain first by using this formula:

$$F = mg$$
$$F = ma$$

where,

> **F** is the force vector or the magnitude of the force
> **m** is the mass of the subject
> **a** is the acceleration of subject
> **g** is the acceleration due to gravity

Torque is the tendency of a force to rotate an object about an axis, fulcrum, or pivot. Just as a force is push or a pull, a torque can be thought of as a twist. To calculate torque for this project, equation below can be used. [7]

$$\mathcal{T} = Fr$$

where,

> $\mathcal{T}$ is the torque vector or the magnitude of the torque
> **r** is the displacement vector or radius
> **F** is the force vector or the magnitude of the force

In this project, torque is needed to calculate first to know either the motor is capable to rotate the modules since the modules is very heavy. Torque is higher during starting until the peak sun hour (PSH) and after peak sun hour (PSH) until afternoon. [8] This is because; during the peak sun hour the tracker is in equilibrium condition. The torque for both sides is equal with each other. During peak sun hour (PSH) until afternoon the torque is less compared to during starting until peak sun hour (PSH). This is because due to the gravity force to drag both solar modules down. The torque for the solar module to rotate to the initial position is same as the starting torque. The torque required for starting is:

> Weight pv-module = 1.03kg x 20 = 20.6kg
> Weight tracker = 5.3kg
> Acceleration due gravity = 9.81 m $s^{-2}\approx 10$
> Force pv-module = 17.86 x 10 = 206N
> Force tracker = 5.3 x 10 = 53N
> Total Force = 259N
> Gear Radius = 40mm = 0.04m
> Torque due to starting = 10.36Nm

A worm gear is used in this design because it very suitable with this project. A worm gear consist of a cylinder with a spiral groove mounted on shaft, this is generally referred to as worm shaft and a gear which normally referred to as the worm wheel. The gear than meshes with the spiral groove on the cylinder and so when the cylinder rotates it causes the gear to rotate as well. The worm always drives the worm wheel around it is not reversible so the worm wheel can't drive the worm to increase the speed. If it's attempted the system will normally jam or lock. [9] So this gear is suitable for this project because this project design had an effect of wind. The design for worm gear is shown in figure 1 and actual designs are in figure 2.

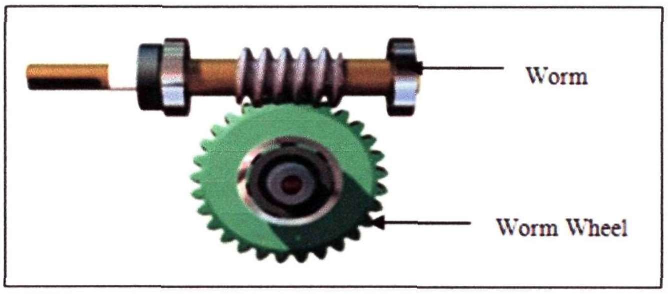

Figure 1: 3D Design

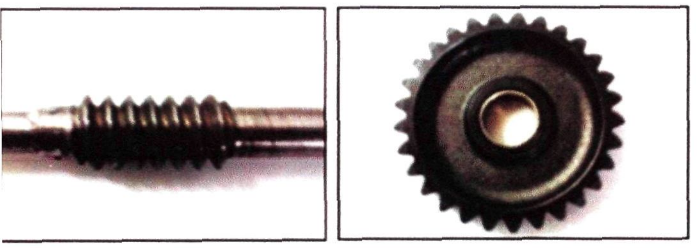

Figure 2: Actual Design

B. Electrical Part

The moveable solar module is located on the rotor driving by 24V dc motor with motor controller. For this project brushless dc motor (VEXTA) is been used since this motor are high efficiency, low maintenance and long life, low noise, control simplicity, low weight, and compact construction. [10] In order to rotate solar module effectively at the same time, therefore balance oriented design is created. This circuit is design to be compitible on many application of time operates. Solar module will work automaticly when it power up in the morning (7.00 a.m). Figure 3 below are completed circuit design for this project. The design for solar panel module also must be consider for this project. This project is suitable for standalone project. The type of photo-voltaic that been choose for this project is compatible with the purpose that want to use it. Load profile calculation had been made to know how many photo-voltaic module array is needed for this project. Figure 4 below is the suitable configuration for this project.

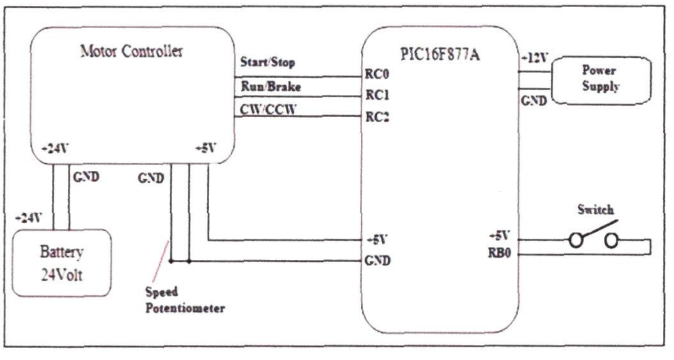

Figure 3: Circuit Diagram for Controller the Tracker

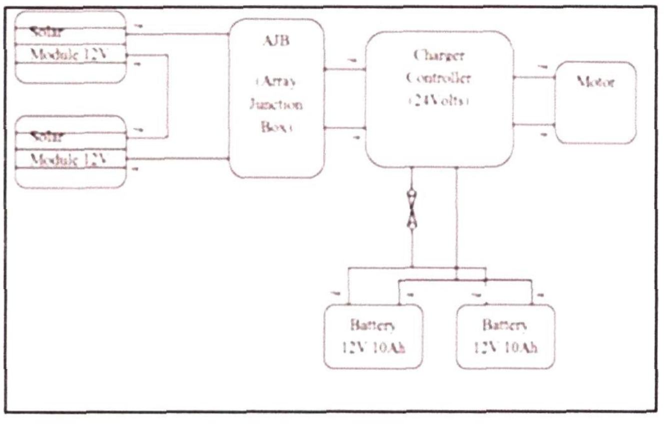

Figure 4: Standalone Solar Design

C. Software Design

Microcontroller acts as brain of the whole solar tracking system. It will operate after we switch on the circuit. The microprocessor will send the signal to motor to move the solar panels to right direction that been obtain in algorithm. The programming part is the most crucial part in this project. There are two types of programming language which are C language and assembly language. The C language is selected for programming Microcontroller Solar Tracking Control because it is easier and faster to learn with compared to assembly language. For programming in C language, the MPLAB IDE for PIC software is chosen as it has all necessity of programming a PIC microcontroller unit. The Table 1 below is a sample the azimuth angle and latitude angle of sun position on September 2010. [11].

Time (24hr)	Azimuth Angle	Altitude Angle
7:00	81°	-3°
7:15	81°	1°
7:30	81°	5°
7:45	81°	8°
8:00	82°	12°
8:15	82°	16°
8:30	82°	19°
8:45	82°	23°
9:00	82°	27°
9:15	82°	31°
9:30	82°	34°
9:45	81°	38°
10:00	81°	42°
10:15	81°	45°
10:30	80°	49°
10:45	80°	53°
11:00	79°	56°
11:15	78°	60°
11:30	77°	64°
11:45	75°	67°
12:00	73°	71°

Table 1: Azimuth and Altitude Angle on September 2010

From the table tabulated above, for single axis solar tracker the azimuth angle is not applicable for this project. Altitude angle can be assuming approximately 15^0 per hour. An algorithm has to be developed to make the microcontroller to read the input and respond accordingly. From the testing that had been made, founded that when the motor rotates 850ms is approximately 15^0. Since the motor rotates clockwise 12 times a day, therefore motor will rotates counter clockwise 10200ms to set it to initial position. Therefore, the algorithm is established and represented by a flowchart in figure 5. These flowcharts are then translated into C language and compiled using MPLAB IDE and burn into integrated circuit using UIC00B. [12]

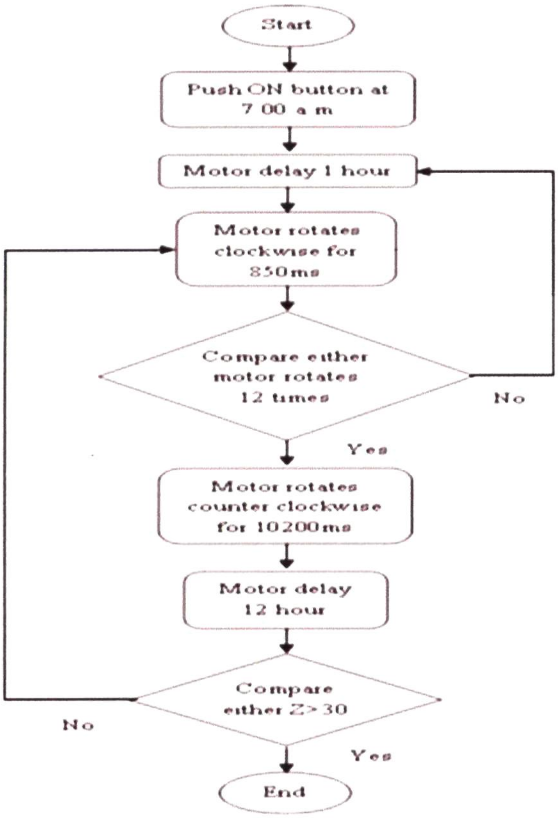

Figure 5: Flow Chart Programming

D. Hardware Design

Figure 6 shows how the circuit is connected. The circuit above is the complete design for this project. To design the tracker, several factor are been consider such as stability, flexibility and strength. For the base of the tracker, mild steel material is been choose since mild steel is very heavy compared to mother material. Base need to be strong to support the weight of photo-voltaic module. Aluminium is choose for the rest of the design since aluminium is very light, strong enough compared to others. Figure 10 are mechanical design for this project. To rotate the photovoltaic module, battery is needed to power up the motor. Each battery is 12 volt and 10Ah, so the combination of two batteries together as the power supply which is 24 volt and 10Ah.

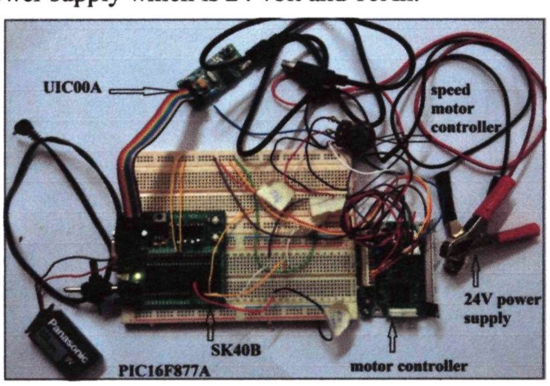

Figure 6: Hardware Circuit

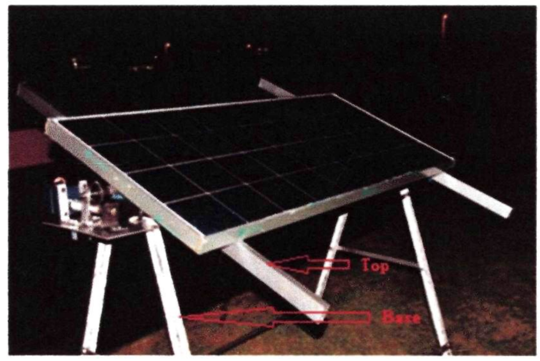

Figure 7: Mechanical Design

III. Results And Discussions

This experiment applies two photo-voltaic modules. Photo-voltaic module is connected in series as a set. Photo-voltaic module can be composed of many small sets by both series and parallel connections. When sets are in a series connection, the output DC voltage of the solar generating power system will be raised. While sets are in a parallel connection, the output DC current of the solar generating power system will be raised. Therefore, series and parallel connections can be used as is suitable to produce desired output DC voltage and current. Since solar cells are difficult to be produced, every solar cell panel has its own characteristics. In addition, environmental factors such as dust, clouds, etc., may cause different voltages and currents in different sets. Two result are been measure for fixed angle and tracker. The reason is to compare the power output from the tracker and fixed angle. Figure 8 below show the tracker and fixed angle.

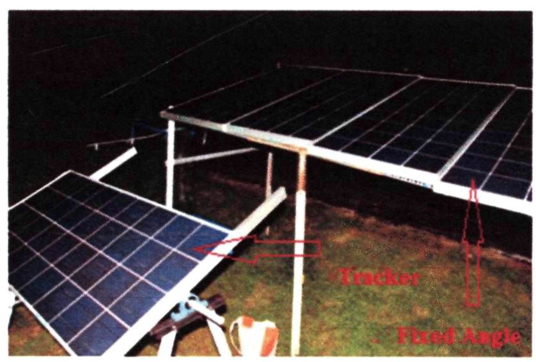

Figure 8: The proposed solar tracking system placed by a fixed angle type system.

Type of Solar Module = UniSolar 11 Watt Flexible Solar Module					
P_{mp}	10.3	Watt (W)	Time of Day	1.00 P.M - 5.00 P.M
V_{oc}	23.8	Volt (V)	Latitude	3 8'N
V_{mp}	16.8	Volt (V)	Longitude	101 42'E
I_{sc}	0.78	Amp (A)	Name of Location	Photovoltaic Monitoring Centre (PVMC)

Table 2: Data Sheet and Site Information

Time	Solar Irradiance, G	Fixed Angle			
		O/C Voltage, V	Voltage with Load, V	S/C Current, A	Power, W (Voltage with Load * S/C Current)
1.00 P.M	612	19.898	3.0011	0.4321	1.29677531
1.15 P.M	597	19.808	2.9811	0.4191	1.24937901
1.30 P.M	603	19.813	2.9891	0.4232	1.26498712
1.45 P.M	720	20.101	3.2311	0.4671	1.50924681
2.00 P.M	713	20.011	3.2202	0.4432	1.42719264
2.15 P.M	643	20.008	3.1931	0.4221	1.34780751
2.30 P.M	623	19.878	2.8021	0.3431	0.96140051
2.45 P.M	591	19.767	2.7231	0.3201	0.87166431
3.00 P.M	693	19.756	2.7965	0.3233	0.90410845
3.15 P.M	543	19.323	2.5421	0.3105	0.78932205
3.30 P.M	531	19.214	2.3451	0.3321	0.77880771
3.45 P.M	674	19.534	2.2572	0.3841	0.86699052
4.00 P.M	711	19.598	2.4972	0.4147	1.03558884
4.15 P.M	621	19.432	2.4927	0.3651	0.91008477
4.30 P.M	576	19.231	2.3241	0.3431	0.79739871
4.45 P.M	531	19.103	2.1201	0.3501	0.74224701
5.00 P.M	571	19.002	2.3212	0.3001	0.69659212

Table 3: Data for Fixed Angle

Time	Solar Irradiance, G	Tracker			
		O/C Voltage, V	Voltage with Load, V	S/C Current, A	Power, W (Voltage with Load * S/C Current)
1.00 P.M	612	20.017	3.1231	0.4401	1.37447631
1.15 P.M	597	19.898	2.9931	0.4371	1.30828401
1.30 P.M	603	20.002	3.0912	0.4398	1.35950976
1.45 P.M	720	20.105	3.5931	0.5321	1.91188851
2.00 P.M	713	20.056	3.5231	0.5121	1.80417951
2.15 P.M	643	20.041	3.3011	0.4692	1.54887612
2.30 P.M	623	20.038	3.2323	0.4601	1.48718123
2.45 P.M	591	19.818	2.8262	0.4331	1.22402722
3.00 P.M	693	20.049	3.4012	0.4832	1.64345984
3.15 P.M	543	19.683	2.5091	0.4111	1.03149101
3.30 P.M	531	19.677	2.4927	0.4102	1.02250554
3.45 P.M	674	20.043	3.3491	0.4732	1.58479412
4.00 P.M	711	20.051	3.4257	0.4909	1.68167613
4.15 P.M	621	20.022	3.1921	0.4512	1.44027552
4.30 P.M	576	19.713	2.6251	0.4212	1.10569212
4.45 P.M	531	19.677	2.4928	0.4105	1.0232944
5.00 P.M	571	19.694	2.5718	0.4147	1.06652546

Table 4: Data for Tracker

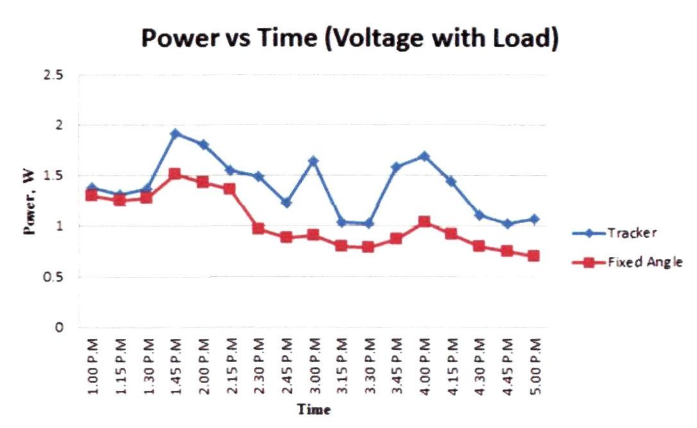

Figure 9: Comparison power produced Fixed Angle and Tracking System (voltage with load)

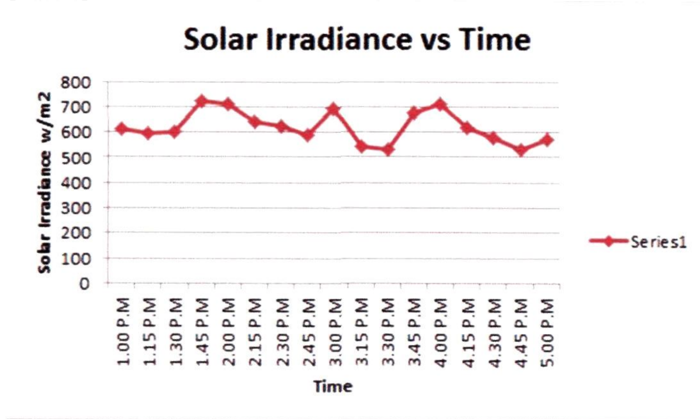

Figure 10: Solar Irradiance during testing

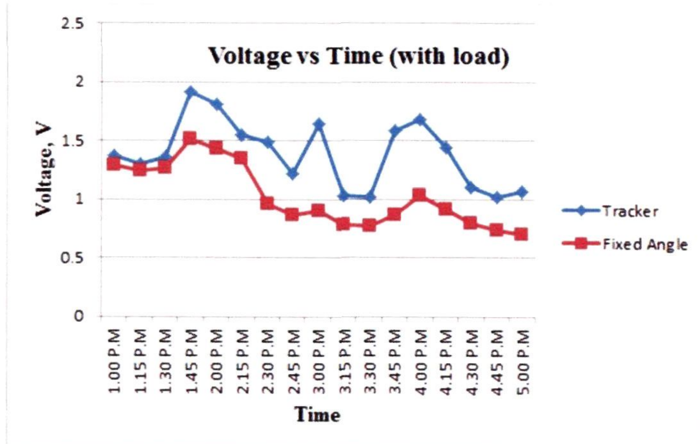

Figure 11: Comparison voltage produced Fixed Angle and Tracking System (with load)

Table 2 above show the data sheet and site location where the result is be taken. Different type of photovoltaic module and site of location choose may affect the result. The result is taken from 1.00 P.M until 5.00 P.M had been tabulated in table 3 and 4. From the result that obtain from table 3 and table 4, it can be seen that the voltage output is different time by time. This is because the voltage and current produced by the solar module is not depend how hot that day or what, the voltage and current is depend on how many photons that produced by sun or in other words how many irradiance produced by sun on that day. The performance of a photo-voltaic array is dependent upon sunlight. Climate conditions (e.g., clouds, fog) have a significant effect on the amount of solar energy received by a photo-voltaic array and, in turn, its performance. Most current technology photo-voltaic modules are about 10 percent efficient in converting sunlight. Figure 9 shows the different power produced between fixed angles and tracking system for voltage with load. Figure 10 shows the irradiation during the testing. Different irradiation produced had an effect of power produced. Figure 11 shows the different voltage produced between fixed angles and tracking system (with load).

IV. CONCLUSION

This paper has presented a means of controlling a sun tracking array with an embedded microcontroller system. Specifically, it demonstrates a working software solution for maximizing solar cell output by positioning a solar array at the point of maximum light intensity. This project presents a method of searching for and tracking the sun. While the project has limitations, particularly in hardware areas, this provides an opportunity for expansion of the current project in future years. Upon completion, it can be concluded that the project has successfully met all the objectives such as:

- A single axis solar tracking system had been build to obtain maximum output power.
- There are proving that tracking system produced more power compared to the fixed angle.
- A microcontroller solar array that actively tracks the sun maximum solar panel output had been successfully built.
- A design that can locate the sun's position at any instance, and aligning the array using the microcontroller so that all incident rays are normal to the array surface has been built.

V. FUTURE WORK AND RECOMENDATION

The goals of this project were purposely kept within what was believed to be attainable within the allotted timeline. As such, many improvements can be made upon this initial design. That being said, it is felt that this design represents a functioning miniature scale model which could be replicated to a much larger scale. The following recommendations are provided as ideas for future expansion of this project:

- Increase the sensitivity and accuracy of tracking by using a light sensor. A phototransistor with an amplification circuit would provide improved resolution and better tracking accuracy/precision.
- Utilize a dual-axis design versus a single-axis to increase tracking accuracy.
- High powered battery is necessary for solar tracking performing outdoor chore especially when multiple motor is used.
- Implementing heat management system to cool solar panels for improved efficiency, as it was found during the design stage and testing that the efficiency of the cells varies considerably with varying heat conditions
- Used software Adam View or other suitable software to collect the data since the irradiation is change every second. The data will be moiré accurate compared taking it by using multimeter.

REFERENCES

[1] Alan l. Fahrenbruch and Richard H. Bube, "Photovoltaic Solar Energy Conversion 1st Edition", Academic Press INC. London 1983

[2] Fahrenburch, A. and Bube, R. 1983, Fundamentals of solar cells, Academic Press, New York.

[3] Partain, L.D. 1995, Sollar Cells and their applications, John Wiley & Sons. New York.

[4] John A. Duffie & William A. Beckman, "Solar Engineering of Thermal Process 2nd Edition", John Wiley & Sons, INC. 1991

[5] Roger A. Messenger and Jerry Ventre, "Photovoltaic Systems Engineering, 2nd Edition", CRC Press, Boca Raton 2004.

[6] Duryea S, Syed I, Lawrence W, An Automated Battery Management System for Photovoltaic Systems, International Journal of Renewable Energy Engineering, Vol 1, No 2, Aug 1999

[7] E. Wernekinck, A. Kawamura, and R. Hoft, "Mechanical Engineering Design and Stimulations,", Fluids and Mechanics, Vol. 6, No. 3, 1991, pp. 364-370.

[8] M. F. Khan and R. L. Ali (2005), "Automatic sun tracking system," presented at the All Pakistan Engineering Conference, Islamabad, Pakistan.

[9] T. Yoshida, O. Shizuka, and O. Miyashita, and K. Ohniwa, "Speed Control and Gearing Systems,", McGraw-Hill Publishing, Vol. 15, No. 6, pp. 1118-1123.

[10] Ali Emadi, "Energy-Efficient Electrical Motor 3rd Edition, revised and expanded", Marcel Dekker, INC 2005

[11] Sunposition.info

[12] John A. Duffie & William A. Beckman, "Solar Engineering of Thermal Process 3rd Edition", John Wiley & Sons, INC. 2006