Dual Axis Sun Tracking System with PV Panel as the Sensor, Utilizing Electrical Characteristic of the Solar Panel to Determine Insolation

Freddy Wilyanto Suwandi

Abstract—**This paper describes the design and implementation of a novel two axis sun tracking system which utilizes no external light sensors to make PV cell facing in the direction of maximum irradiation to promote system efficiency. The novelty lies in the practical utilization of solar panels as the sensors. The solar cell's electrical attributes is used to determine insolation parameter. The positioning of the PV cell in the tracking system is driven by two stepper motors which could position the PV cell almost perpendicular to the sun during the day time. Meanwhile, the search algorithm is implemented using adaptive step perturbation method. The paper will first highlight and elaborate the concept. Then experimental results will be included to prove the effectiveness of the system.**

Index Terms- Sun Tracking System, PV Cell, Dual Axis, Insolation and Solar cell's electrical attributes.

INTRODUCTION

Driven by the increasing energy consumption and the need for more renewable energy resources, the amount of solar energy harvesting has increased rapidly in the recent years. In the large scale solar power plant, one-axis and two-axis sun tracking system are often utilized to substantially improve the daily energy production of the PV cells. Indeed, the energy gain is nearly 28 % in middle Europe [1] and even more than 50 % in north Europe [2]. One and two axis solar tracking system only represent 27 % of the total power plant capacity worldwide in 2008 [3]. If the installation and running costs of these tracking systems are reasonable, there will be a possibility of increasing the energy yield per unit area of the solar plant. Currently, the mechanical parts are still relatively cheaper than the PV module itself; hence the sun tracking system will increasingly be used in the solar power plant.

In the recent years, statistical and geometrical sun tracking approach, in which time is the input to the system to determine the tilt angle of the PV-panel has become very popular. However, the system is not adaptive and versatile. Hence, a better dynamic system, dual axis PV-panel tilts angles sun tracking system with automatic adjustment facility and closed loop control, is proposed to improve the tracking performance.

The conventional sun tracking includes light sensors on the PV panel platform to sense the solar irradiance. When the light sensors give the same output, it means PV panel is facing the sun and has optimum insolation at the corresponding position. However, the initial proofreading and correcting of light sensors are time consuming and the devices properties are easily varied under different operational conditions. In order to overcome the aforementioned drawbacks, this paper will discuss an active sun tracking scheme without light sensors. The property of the open-circuit voltage and short circuit current of PV modules will be the indication of the corresponding irradiation in tracking the sun.

The objective of the project is to optimize the solar energy harvesting through maximizing the available insolation from the sun. This is achieved through the development of the novel sun tracking system using Agilent Technology Data Acquisition and VEE pro programming environment.

This paper is organized in the follow way. Section I discusses the design and implementation of the sun tracking system and followed by the discussion on the operating principle and the working algorithm in section II. Section III will discuss about the additional functions of the sun tracking system. The experimental results obtained using the tracking system will then be discussed in section IV.

I. DESIGN AND IMPLEMENTATION OF THE SUN TRACKING SYSTEM

A. *Structural Design – Rotate and Tilt*

Rotate and Tilt structure is chosen for a smoother movement on dynamic search system. This structure is friendly to the base motor. It does not stress the first level structure through unnecessary load torque from the structure above it. This design involves first rotating the PV panel to the desired direction and then tilting it to the desired tilt angle in order to get maximum irradiance.

Rotate and tilt system has a rotational structure at the base platform and the tilting structure at the second level. To make sure the structure is stable and the load torque is constant for the rotational motor, the centre of gravity of tilting structure is aligned at the rotating centre.

Figure 1 shows the idea and implementation of rotate and tilt system.

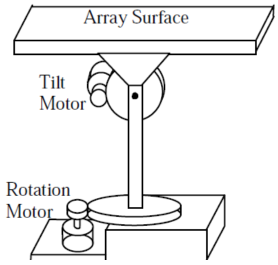

Fig. 1. Rotate and Tilt Mechanism Structure

B. *PV Cell as sensor*

In this sun tracking system, small polycrystalline PV cells are used as the sensors to determine the solar irradiance. The very important electrical characteristic of the solar panel used is the short circuit current, I_{SC}.

I_{SC} increases with the increase in the irradiance. To put it more accurate, I_{SC} is proportional to the irradiance in the cosine function of the angle between a normal to the collector face and the incoming solar beam radiation. Figure 2 illustrates the angle described above.

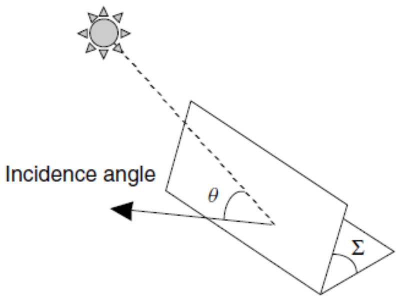

Fig. 2. The incidence angle □ between a normal to the collector face and incoming solar beam radiation

$$I_{sc}\ \alpha\ solar\ beam\ radiation * \cos(\theta) \quad (1)$$

Solar cell can hence be tilted around while short circuit current is being measured. The maximum current will indicate the best insolation when the incident angle is zero degree. This property of solar cell was confirmed in the experiment. Table I shows the tabulated result and figure 3 is the plotted result.

This property has been extended to another electrical characteristic of the solar panel, open circuit voltage, V_{OC}. In the derivation of V_{OC}, it is found that V_{OC} is proportional to natural logarithmic of I_{SC},

$$V_{oc} = \frac{k\,T}{q}\ln\left(\frac{I_{sc}}{I_o} + 1\right) \quad (2)$$

The relation between I_{SC} and V_{OC} will be more clearly illustrated in figure 4.

Table I

Correlation between Solar irradiance and I_{SC}

incidence angle	experimental irradiance	expected irradiance
0	55	55
5	54	54.7907084
10	54	54.16442642
15	53	53.12592045
20	51	51.68309414
25	49	49.84692829
30	47	47.63139721
35	44	45.05336244
40	41	42.13244437
45	38	38.89087297
50	35	35.35331853
55	31	31.546704
60	26	27.5

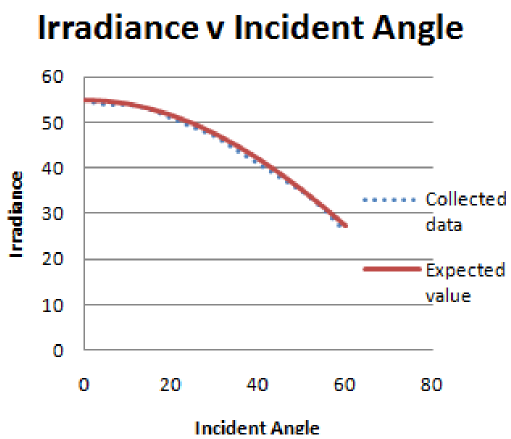

Fig. 3. Graph of irradiance vs incident angle. This Graph closely follows the cosine function.

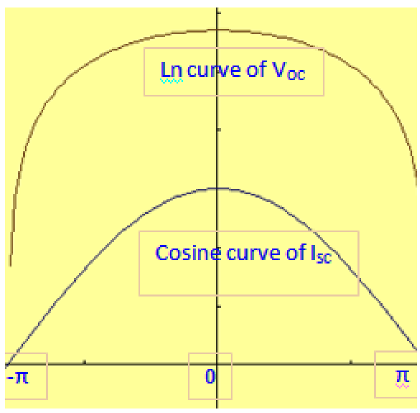

Fig. 4. Overlay of graph of Voc and Isc vs agle □.

From figure 4, it can be deduced that V_{OC} is way bigger than I_{SC} in the PV cell used for the experiment. This is an advantage to the system because larger V_{OC} value is easier to measure compared to the small I_{SC}. This will increase the precision of measurement hence will be able to determine the insolation more accurately than I_{SC}.

Nevertheless, the use of V_{OC} does come with limitations. V_{OC} of a panel is dependent on temperature, hence the performance may be affected at high temperature operation condition. Moreover, V_{OC} of a panel has a maximum rating. This means in the region of maximum rating, the value of V_{OC}- does not give an appreciable increase with the increase in solar irradiance. Therefore, V_{OC} alone is not a good enough indicator to be used to track the solar irradiance. However, the fact that V_{OC} is larger than I_{SC} is still useful under low intensity irradiance. In this operating condition, normally associated with cloudy weather, the change in V_{OC} measurement due to the change in irradiance is about 60 times the change in the value of I_{SC}. Figure 5 and 6 will show the performance of I_{SC} under this working condition.

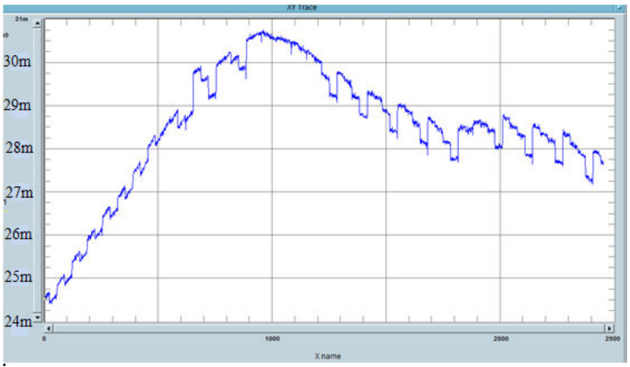

Fig. 5. Measurement of voltage across a small load (5.3Ω) to approximate I_{SC} under low solar irradiance. The tracked value is from 25mV to 31mV. This equivalents to 6 mV difference.

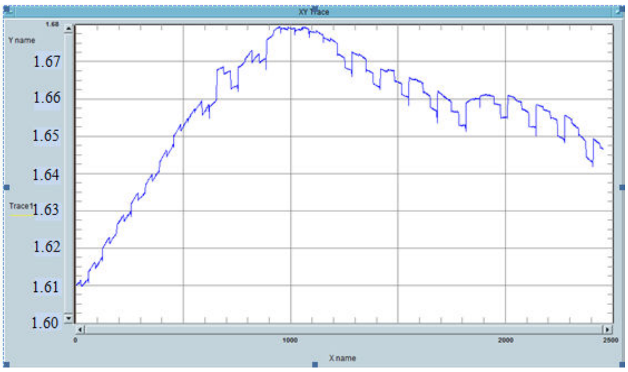

Fig. 6. Measurement of V_{OC} under low solar irradiance. The tracked value is from 1.61V to 1.68V. This equivalent to 70mV difference.

II. Operating Principle and Working Algorithm of the Dynamic Sun Tracking System

The proposed dual axis sun tracking system can tracked the sun in two axes- horizontal and vertical. The first motor will rotate the solar panel to track the sun in the horizontal axis. Once it has established the correct direction of the sun, it will start tracking in the vertical axis to get the best tilt angle. The working principle of the tracking system is based on the V_{OC} of solar cell used under the correct conditions. The search system implements step perturbation method in searching for the maxima location. In short, the system will take a step in an arbitrary direction and sense the change in the voltage of the solar cell. If a negative response is obtained from the feedback of the sensor, the system will turn around and move in the opposite direction until it reaches the maxima point as illustrated in figure 4. To prevent the system from oscillating at the maxima region, a small minimum change in intensity is required before a further step is taken.

Besides the algorithm, searching conditions need to be specified to anticipate the changing environment condition such as movement of cloud over the sun which causes a variation in the intensity of solar irradiance. Without these searching conditions, the sun tracking system will be searching nonstop to react to the changing intensity. The conditions of interest are as follow:

- Search trigger and its frequency

The system can search whenever there is a specified change in the solar intensity. This condition can be used in the indoor experiment where the light intensity can be closely controlled. However, in the unpredictable outdoor environment, this condition could not be applied because the fluctuation in solar intensity due to moving cloud is prevalent. Therefore, to tackle this problem, a periodical search is more appropriate. Since the movement of the sun could be estimated about 15^{o}/hour, an appropriate user predefined search cycle of 5, 10, 15 minutes can be chosen to track the sun pretty accurately.

- Condition for searching

With the predetermined searching cycle, the system still needs another condition for starting the search. This condition will be able to handle the current fluctuation in the solar intensity. The system will sample the solar intensity every second for a period of four seconds. The results are analyzed to check whether the peak to peak variation is less than a user predefined value of 5 mV. If the condition is satisfied, the system will start the search. This condition could increase the possibility of getting constant intensity during the search, but it cannot guarantee the unpredicted future outcome. To ease the concern over this matter, the search is made in the shortest time possible. Normally it will take about 1-2 seconds provided it does not start from a fresh search.

The whole working algorithm is summed up in the flow chart shown in figure 8.

With the algorithm being defined, sun tracking system will start tracking from sun rise. As the sun moves, the system will use the roll-stepper motor to track the movement in azimuth plane and tilt-stepper motor to track the movement in the altitude plane to get the best tilt angle. Both motors will track the sun every 10 minutes until sunset.

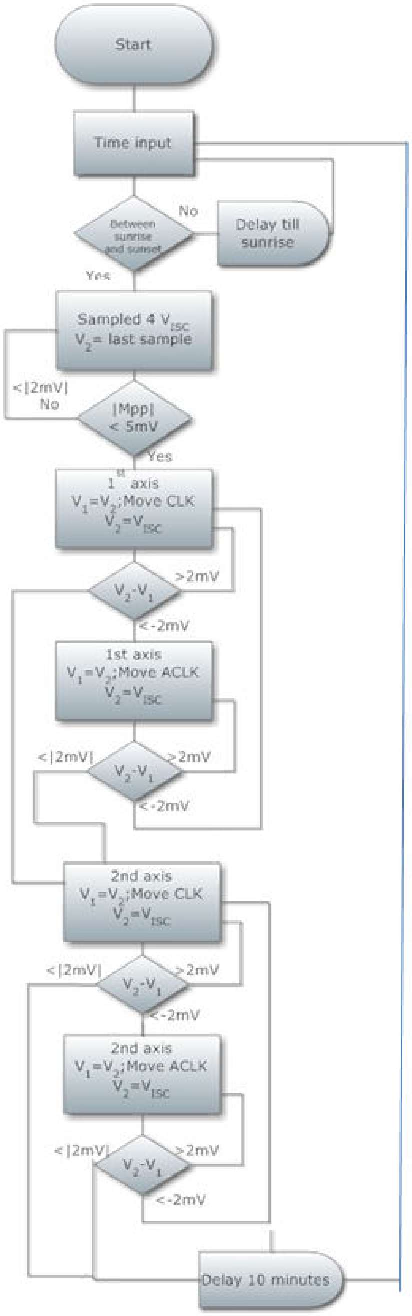

Fig. 8. Flowchart of sun tracking searching algorithm utilizing electrical characteristics of the solar panel and other initial searching conditions.

III. ADDITIONAL FUNCTIONS OF SUN TRACKING SYSTEM

Besides tracking the sun, this sun tracking system has two other value added sub systems, namely temperature and cooling system and data logging with real time performance monitoring system.

A. Temperature and Cooling System

Temperature does affect the performance of the PV panel and excessive heat may results in damage to the cell due to lattice vibrations that create defects in the crystalline material. Therefore, this sun tracking system is designed to provide an alarm and actuating signal to prevent the PV panel being damaged by heat. To demonstrate the capability of this actuating signal, the sun tracking system is equipped with a DC fan which will be activated by the actuating signal generated by the system. The cooling system can be customized in a way to prevent permanent damage as well as maintain a lower temperature environment for the PV panel. This will depends on the threshold temperature preset by the user. For damage prevention, the threshold can be set at 57^{o}C and 60^{o}C, whereas for low working temperature, the threshold can be set at 37^{o}C and 40^{o}C. Figure 9 shows the flowchart of the ON-OFF control cooling system.

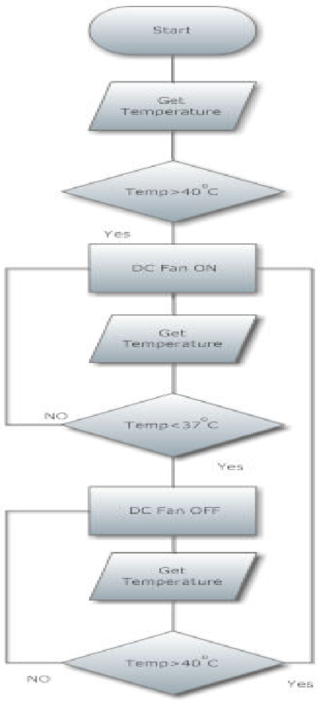

Fig. 9. Flow chart of cooling system.

B. Data Logging and Real Time Monitoring

Data logging system has also become another key point to make the proposed system standing out from the rest of the sun tracking systems. This data logging system is able to give a real time monitoring of system performance as shown in figure 5 and 6. The measured data is exported together with a time stamp to a file for any post processing steps to further analyze the performance of the solar cell. The various raw data collected from the solar cell are as follow:

- Temperature of solar cell
- Potential drop across the load
- Current flowing through the load
- V_{OC} of solar cell

The implementation of data logging function is straight forward because the tracking system is implemented on a portable Agilent data acquisition device.

IV. Experimental Result and Performance Analysis of the Sun Tracking System

The first part will analyze the power generated by the solar cells with and without dynamic tracking system. The second part analyzes the performance of the cooling system.

A. Effectiveness of Tracking System

The effectiveness and reliability of the dynamic sun tracking system employing solar panel characteristics as sensor is verified by experimental results. For a comparison, a static PV cell and a PV cell with a dynamic tracking system are tested under the together under the same condition. Both the PV cells are of the same electrical characteristics- max V_{OC} 2.2V and max I_{SC}=0.1A. The measured power conversions of the cells are the basis for performance comparison. The effectiveness of the system were tested under two conditions: sunny and cloudy day.

1. Result From Sunny Day

TABLE III
EXPERIMENT CONDITIONS

Weather	Sunny
Starting Time	(17/3/2010 2:42:14 PM)
Ending Time	(17/3/2010 6:09:17 PM)
Duration	2 hours 42 mins

TABLE IV
EXPERIMENT RESULTS

Type	Dynamic Tracking system	No Tracking system
Load	5.3Ω	5.3Ω
Average Voltage	0.8899V	0.5938 V
Average Current	0.1679 A	0.1120 A
Improvement	49.87%	NA
Average Power	0.14944 W	0.066529W
Improvement	124.6%	NA

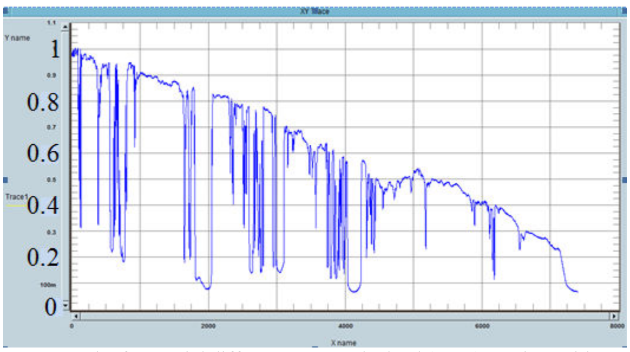

Fig. 10. Graph of Potential difference across the load (5.3Ω) vs Time with no tracking system (Sunny)

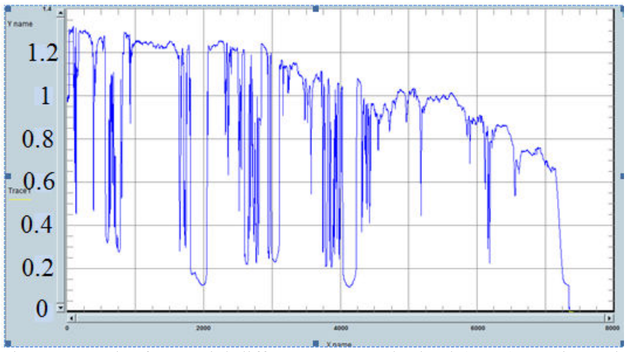

Fig. 11. Graph of Potential difference across the load (5.3Ω) vs Time with tracking system (Sunny)

2. Result From Cloudy Day

TABLE V
THE PARAMETERS OF THE PV CELL

Weather	Cloudy
Starting Time	(16/3/2010 3:46:28 PM)
Ending Time	(16/3/2010 6:13:26 PM)
Duration	2 hours 27 mins

TABLE VI
EXPERIMENT RESULTS

Type	Dynamic Tracking system	No Tracking system
Load	5.3Ω	5.3Ω
Average Voltage	0.03482 V	0.019535 V
Average Current	0.00695 A	0.003686 A
Improvement	88.54%	NA
Average Power	0.000256 W	0.000072 W
Improvement	255.5%	NA

From both experimental results, it shows that the tracking system is doing a great job in tracking the sun during afternoon and morning time when the offset form vertical direction is greater. The effectiveness of the tracking system will be less during noon time because both the PV cells are facing the same direction.

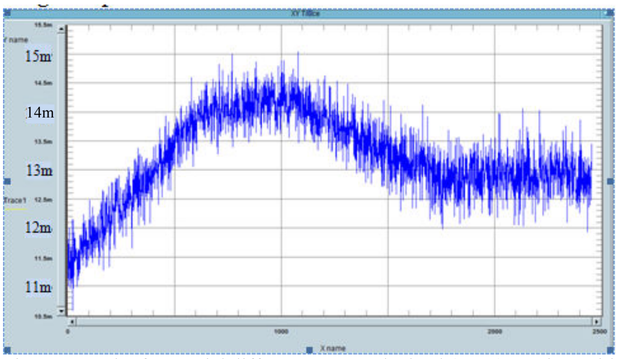

Fig. 10. Graph of Potential difference across the load (5.3Ω) vs Time with no tracking system (Cloudy)

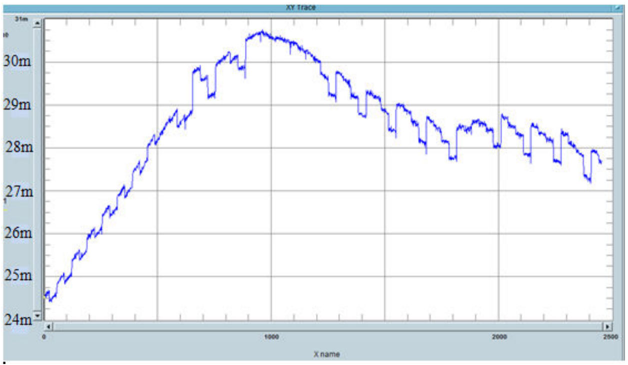

Fig. 11. Graph of Potential difference across the load (5.3Ω) vs Time with tracking system (Cloudy)

B. *Cooling System*

In the controlled experiment, under room temperature, the cooling system could reduce 10°C to 20°C depending on the temperature difference between PV cell and the surrounding. Two results were obtained during the experiment.

TABLE VII
EXPERIMENTAL RESULTS

	TEMP 1	V_{OC} 1	TEMP 2	V_{OC} 1
COOLING SYSTEM	43°C	2.12V	50°C	*NA*
NON COOLING SYSTEM	53°C	1.90V	70°C	1.80V

V. CONCLUSION

Based on the experimental results, it can be concluded that the novel sun tracking system is not only capable of maintaining optimal tilt angles for the PV cells, but also capable of giving actuator signals for panel protection from excessive heat and logging data with real time performance monitoring.

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