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Development of an Automated Biaxial Solar Photovoltaic Tracking System

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ABSTRACT

This paper presents and describes a prototype product code-named SolT2A which is a system that tracks the position of the sun automatically across the celestial vault in two axes. This kind of system is typically used in a solar photovoltaic (PV) system in terrestrial applications to provide electrical power. It is designed and fabricated due to Malaysia's location near the equator, thus the solar altitude crosses the zenith and the azimuth reverses direction during the year. Thus the use of a static PV system is not maximised during half of the year. This situation can be addressed by using a two-axes solar tracking system. So far, Malaysia has not implemented such power-tracking systems. Thus SolT2A has been designed and fabricated to address the problem by using a combination of electro-mechanical devices with an element of programming ingenuity and intelligence. Basically SolT2A measures solar irradiance at four points and makes comparisons in terms of the intensity received. These data are then analysed and processed by a controller before being sent to a DC motor that ensures the maximum amount of solar irradiance received on the PV panels all the time. Thus SolT2A is a system that maximises the power output of the PV panels to obtain the highest

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power output continuously. Based on field data, the maximum output open circuit voltage produced by the SolT2A tracking system and that with a static PV system is as much as 82 %. The overall increase in open circuit voltage production is between 15 to 20 % daily. With the technical know-how and proven prototype, Malaysia can look into joining the small and limited but niche pool of expertise in this area. This will not only give immediate socio-economic impact to the population, but will give an upgrade to Malaysia as a country with expertise in the area. This concept could also be applied to defence systems. With further testing and improvement, SolT2A system can be further upgraded to reach a commercial stage. This will definitely be of commercial interest to the country.

Keywords*: solar photovoltaic system, two-axes tracking system, prototype, field performance*

Basics of Solar Photovoltaic Geometry

A solar photovoltaic (PV) module converts the sun's energy to electricity directly. The generation of electricity is directly proportional to the amount of solar radiation the module receives. The highest PV output is obtained when the direct solar radiation is normal to the surface of the module. But as the sun charts its daily path across the hemispherical vault, static PV arrays work less optimally since the amount of energy received varies continually.

The angle at which the solar beam strikes the surface is called the incident angle as shown in Figures 1 and 2.

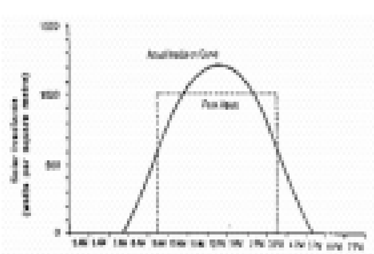

Figure 1: A Typical Solar Irradiance vs Time Plot for a Low Latitude Region [1]

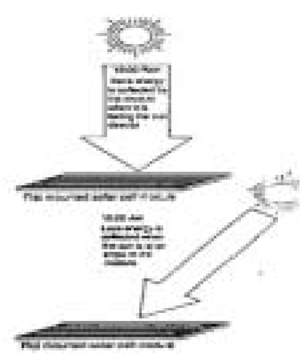

Figure 2: The Angle Between the Module and the Sun [1]

Thus, it becomes evident that the maximum PV output is obtained if a solar module is turned to face the sun throughout the day. This practice is called tracking. Examples of a manual tracking PV system are shown in Figures 3 and 4 [2].

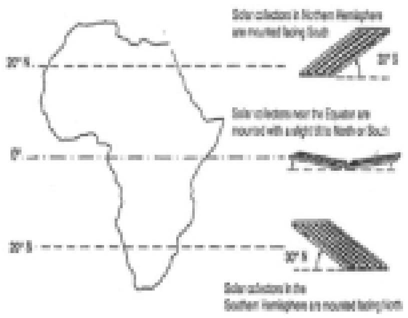

Figure 3: Mounting Angles for Static Solar Collectors [1]

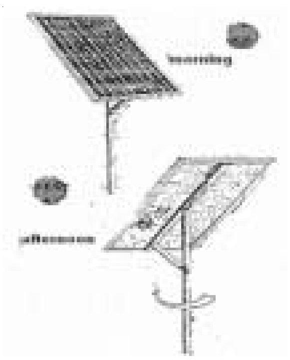

Figure 4: Manual Tracking System using a Rotatable Pole Mount [1].

Background to the Research

The mounting structure of PV modules in existing applications worldwide has mostly been of the static type [1, 3-5]. Automated tracking solar PV systems are already established in the developed regions of the world [3, 6-8]. In Malaysia, despite the thousands of PV systems installed, there is yet to exist a tracking PV system on a single axis, let alone a biaxial system [9, 10]. There are three main categories of solar tracking systems in popular use:

- an electromechanical system using an automated electronically-sensing and controlling mechanism.
- a passive mechanical system using a phase-change material
- a computer-controlled system using mathematical models.

There are many advantages and disadvantages of each system and they have been reported in various publications [3, 11]. The focus of this project is on the first type.

Problem Identification

At the present moment, all of the PV power systems in Malaysia are of the static type. If the PV modules are tracking in a single axis, the energy yield is estimated to increase. It is anticipated that if the tracking is biaxial, the yield will increase even more. Thus this project proposes to study an automated solar photovoltaic biaxial tracking system since there is none yet available in the country.

Objectives

The objectives needs in this research were to:

- Design a suitable automated PV biaxial solar tracking system.
- Fabricate and testing of the tracker in laboratory conditions.
- Monitor the performance of the system in operational field conditions.

The goal of the research area was to produce a Malaysian-made prototype two-axes solar PV tracking system.

Significance of Project

The automated solar PV biaxial tracking system shall be the first of its kind to be developed indigenously. In addition to having a prototype, the knowledge attained from this project will provide a wealth of information in terms of biaxial automated solar PV tracking systems in operating Malaysian field conditions. Therefore, this project will help UiTM develop further expertise in the short to medium terms. The long-term importance would be to develop local expertise and locally designed and fabricated product in the area of PV and related technology, to meet the challenges in the globalisation era.

Scope of the Research

The proposed project shall cover the following parts:

- Simulation of the complete system.
- Laboratory fabrication and testing of a prototype.
- Field performance monitoring.

The first part comprises of simulations of the biaxial tracking system. At the same time an electromechanical sensing and controlling tracking system shall be designed on the computer, taking into consideration various parameters such as components, sensors, sensing and controlling mechanisms and gearing system.

The second part comprises of activities to fabricate a prototype system that will be tested in the laboratory. Results from the lab tests will guide refinement works on the final prototype.

The third part comprises of installation and performance monitoring of the prototype system in the field.

Methodology

The design of the system consists of the following parts:

- Software design
  Main controller that controls the tracking system via programming.
- Electronic circuit design
  Includes all the electronic parts such as controller, driver circuit, and etc.

Mechanical structure design Includes all mechanical parts such as frame, gear, motor, and etc.

The methodology used is summarized in Figure 5.

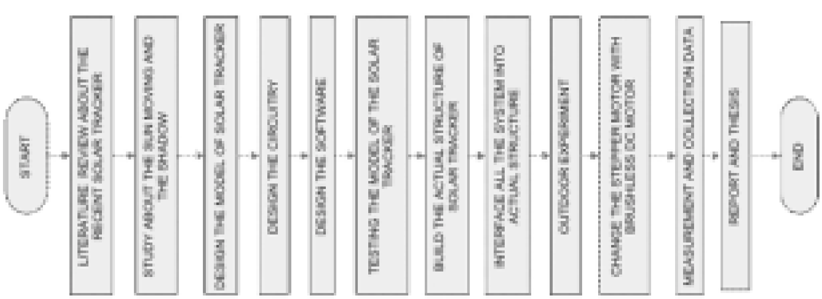

Figure 5: Methodology Flowchart

Design Principles

Analemma Phenomenon

There are two factors that describe the position of the sun: the tilt of the earth on its axis and the elliptical shape of the earth's orbit. These two factors when combined, form the figure eight shape as shown in Figure 6, which is known as "analemma" [12].

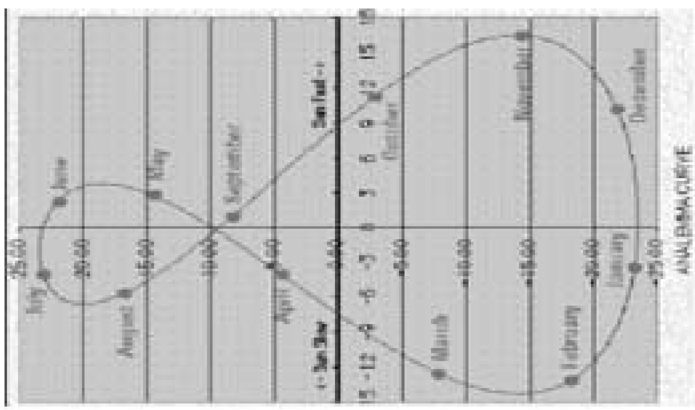

Figure 6: The Figure Eight Shape for Analemma Phenomenon (Analemma.com, 2006)

Generally, a solar tracker is built to track all positions of the sun across the hemispherical vault [13-16]. Typical sunpath charts for Malaysia are shown in Figures 7 to 10.

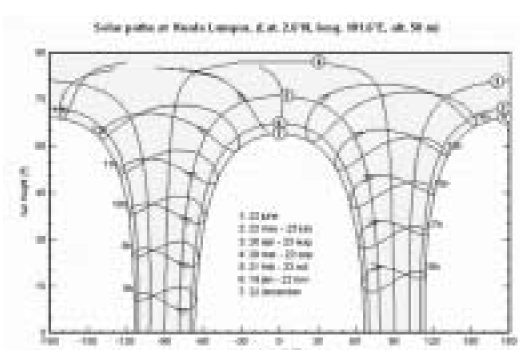

Figure 7: Sunpath Chart for Kuala Lumpur using Civil Time in Cartesian Coordinates

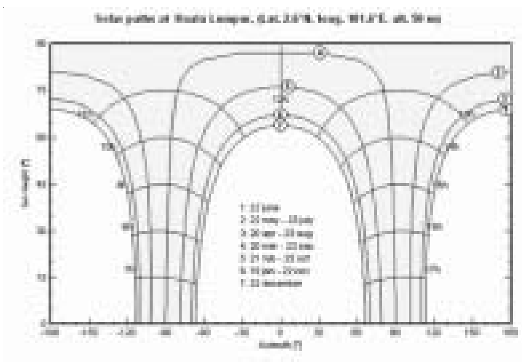

Figure 8: Sunpath Chart for Kuala Lumpur using Solar Time in Cartesian Coordinates

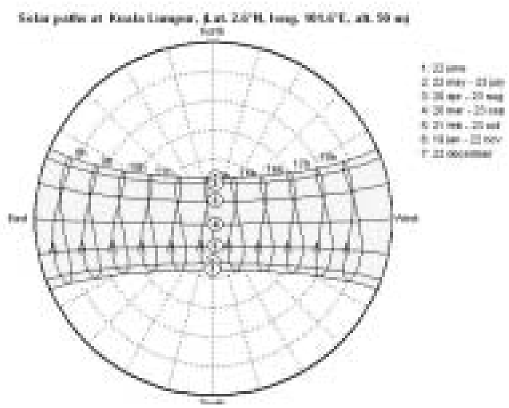

Figure 9: Sunpath Chart for Kuala Lumpur using Civil Time in Polar Coordinates

Basic Tracking Concept

The product from this project is code named SolT2A. Its main tracking concept is based on the use of the shadow. This is achieved by placing two similar sensors that detect light levels. If one sensor is lighted and the other is shadowed, a difference in voltage outputs arises. These are amplified and a suitable electro mechanical system is designed to make them equal. Subsequently, a programme then instructs the DC motors to operate until both sensors give equal outputs, at which the motors stop. As the sun continuously moves, both sensors again receive different light levels, and the process repeats. This concept is shown in Figures 11 and 12.

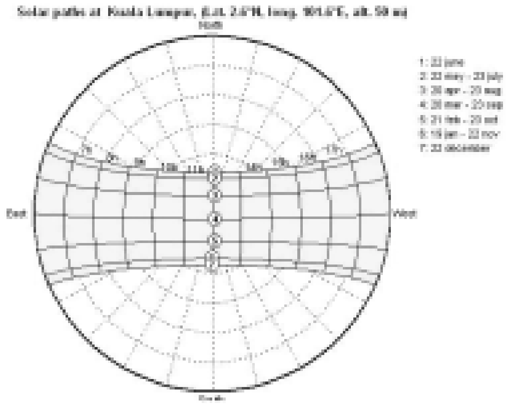

Figure 10: Sunpath Chart for Kuala Lumpur using Solar Time in Polar Coordinates

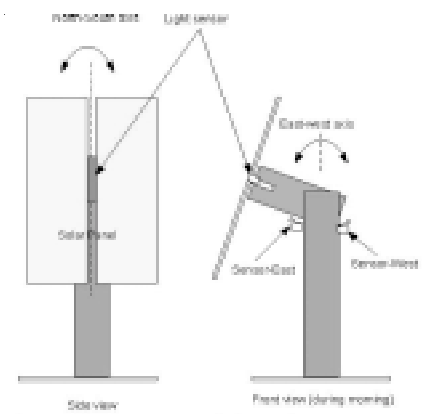

Figure 11: Structure of the SolT2A system

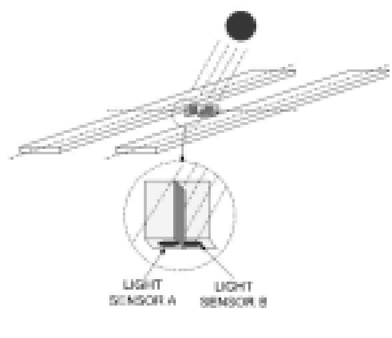

Figure 12: Shadow Formation Showing One Sensor in light and One Sensor in Shadow

General Flowchart and Explanation of the System

The main program flow chart of the controller of SolT2A is shown in Figure 13.

Firstly, the programme checks the status of the start button and present time. If the start button is pressed or present time is 7.30 am, the DC motor rotates the PV panel until it faces East. The limit switch sensor-east will limit the position of panel. Now SolT2A is ready to track the

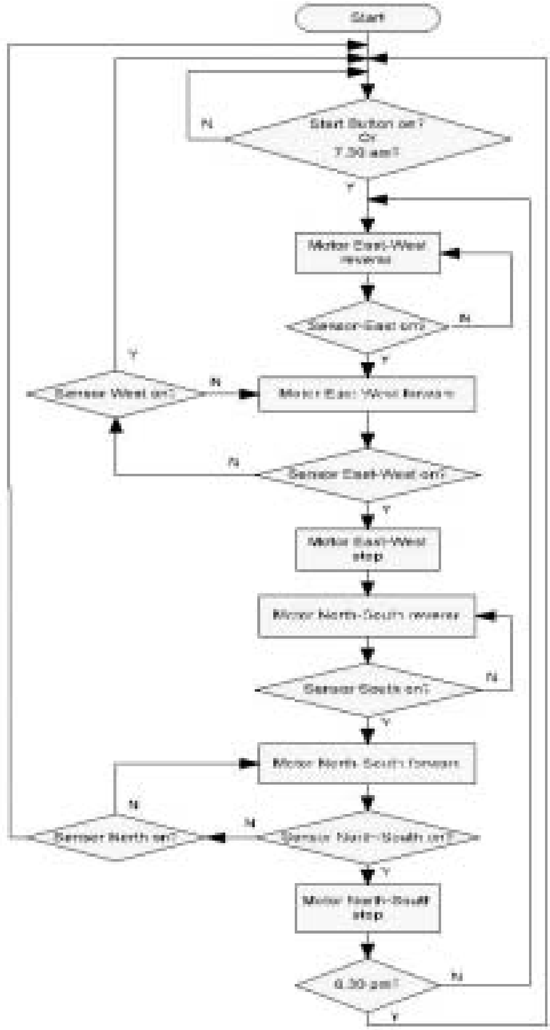

Figure 13: General Flowchart of the Controller

sun. The DC motor turns the PV panel slowly to West until it faces the sun's beam directly. Similarly, the other DC motor starts to rotate the PV panel along the North-South direction (analemma). Both motors track the sun until SolT2A reaches the limit switch sensor-west. When the structure hits the limit switch or the present time is 6.30 p.m., the system stops. The system is automatically activated again the next day at 7.30 a.m. and the process repeats.

Experimental Results

A field test was done in the parking lot in front of the S&T tower in UiTM, Shah Alam. The performance of SolT2A was evaluated by measuring the open circuit voltage of the PV panel. For comparison, a static PV panel was placed near the SolT2A. A sample result of the voltage output was then plotted against time as shown in Figure 14.

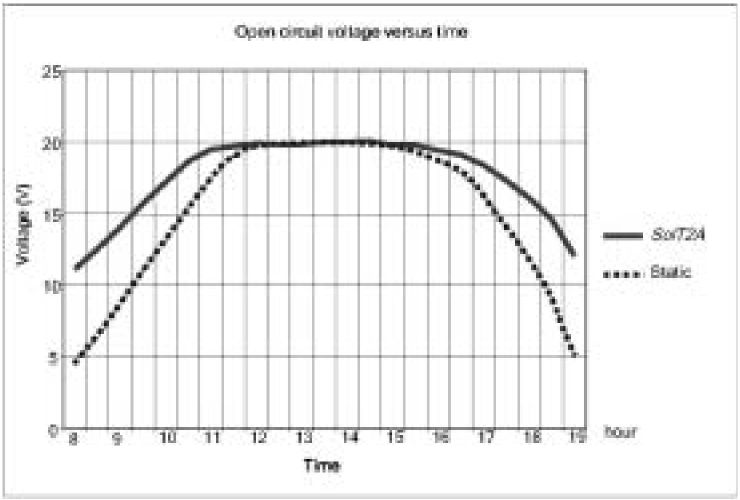

Figure 14: Results form Field Test of the SolT2A Showing the Open Circuit Voltage vs Time

From the results shown in Figure 14, it is evident that the SolT2A tracking system produces a higher output compared to the static PV system. Note that the voltage output on the SolT2A system exceeds that of the static system by a maximum difference of about 82 % both in the beginning hours in the morning and ending hours in the evening. The differences in production tapers as a function of time and the output from both systems are the same at about 12 to 15 hours daily. This easily represents about 15 to 20 % increase of system production voltage.

Conclusions

Based on the experiments and field tests conducted, it can be concluded that the SolT2A was able to fully utilise the sunlight by tracking the movement of the sun. This was shown by the higher voltage output produced by the SolT2A compared to the static PV system. The light sensors were placed in a special casing to enhance the shadow formation for optimum performance. The interfacing software was successfully done and the structure performed as designed.

Recommendations

The recommendations for further improvement of the system are:

- Obtaining field data for extended periods.
- Using four solar PV modules in a basic array string.
- Installing a detailed monitoring system with actual load for system performance.
- Better grade for the gearing, circuitry and their casings.
- Using radio frequency (RF) for data monitoring.

Acknowledgement

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