UNIVERSITI PUTRA MALAYSIA

AUTOMATED DUAL-AXIS SOLAR TRACKING SYSTEM BASED ON ASTRONOMICAL EQUATION AND GLOBAL POSITIONING SYSTEM

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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I wish to dedicate this thesis to Allah, his messenger Muhammad S.A.W. and my beloved family

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

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December 2015

Chairman : Assoc. Prof. Wan Zuha B Wan Hasan, PhD
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Currently, solar power generation brings many long term benefits such as low operating cost due to no fuel needed and environmental friendly. In solar technology, the sun energy is captured by using photovoltaic (PV) panel and converts the solar radiation into electricity. To maximize a solar module's power output the module needs to receive as much direct sunlight as possible. A dual axis solar tracker allows a mounted PV panel to remain perpendicular to incident sunlight, thus maximizing power output. In this research, works are focused to overcome the weaknesses in the current tracking system especially for portable and mobile application. Therefore, this study focuses on designing and developing a portable dual-axis solar tracking system that focuses on portable and mobility purpose. Furthermore, this study proposed an electronic control system with embedded sun's path trajectory algorithm purposely for maximizing the power generated from the attached PV panel. The tracking system utilizes the GPS module and a digital compass sensor for determining the location and the heading feedback of the system respectively. Moreover, the microcontroller based tracking system is embedded with a PID controller for which will increase the PV positioning accuracy by using the feedback signal of the absolute encoder. Furthermore, the research also analyses and compares the output performance between the fixed-tilted PV panel and the developed portable solar tracking.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
Sebagai memenuhi keperluan untuk ijazah Master Sains

SISTEM PENJEJAK SOLAR DWI PAKSI AUTOMATIK BERASASKAN PERSAMAAN ASTRONOMI DAN SISTEM PENENTU KEDUDUKAN GLOBAL

Oleh

MOHD HASIMI BIN MOHD SIDEK

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Pengerusi : Assoc. Prof. Wan Zuha B Wan Hasan, PhD
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Kini, penjanaan kuasa solar membawa banyak manfaat jangka panjang kerana kos operasi yang rendah tanpa kebergantungan kepada bahan api dan kuga mesra alam sekitar. Dalam teknologi solar, tenaga suria ditukarkan kepada tenaga elektrik dengan menggunakan panel fotovolta . Untuk memastikan tenaga yang dijana oleh modul solar berada pada tahap maksimum, modul fotovolta yang digunakan perlu sentiasa menerima cahaya matahari sebayak mungkin. Penjejak solar dwi paksi membolehkan panel fotovolta yang dipasang sentiasa kekal serenjang dengan cahaya matahari, sekali gus memaksimakan kuasa keluaran. Kajian ini banyak tertumpu untuk mngatasi kelemahan-kelemahan dalam sistem penjejak solar yang sedia ada terutamanya pada aplikasi mudah alih dan senang untuk dibawa kemana-mana. Oleh itu, kajian ini memberi tumpuan kepada merekabentuk dan membangunkan sistem penjejak solar dwi paksi mudah alih bagi tujuan mudah alih. Disamping itu, kajian ini mencadangkan satu algoritma laluan trajetori matahari yang dibenamkan ke dalam sistem kawalan elektronik bagi memaksimakan janaan kuasa daripada panel fotovolta. Sistem penjejak solar ini menggunakan module GPS dan juga penderia kompas digital bagi menentukan lokasi serta memberi arah petunjuk untuk sistem ini. Selain itu, sistem penjejak yang berasakan mikropengawal ini mengandungi pengawal PID yang mana akan meningkatkan ketepatan penentududukan panel fotovolta denagan mengunakan insyarat suapan balik oleh penderia pengekod mutlak. Tambahan pula, kajian ini juga menganalisis dan membandingkan prestasi tenaga yang dijana oleh panel fotovolta yang dipasang pada sistem tetap condong dan sistem penjejak solar mudah alih.

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I certify that a Thesis Examination Committee has met on 4 December 2015 to conduct the final examination of Mohd Hasimi Bin Mohd Sidek on his thesis entitled "Automated Dual-Axis Solar Tracking System Based On Astronomical Equation And Global Positioning System" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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I hereby confirm that:

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LIST OF ABBREVIATIONS

PV	Photovoltaic
PWM	Pulse Width Modulation
USNO	United States Naval Observatory
NMEA	National Marine Electronics Association
IC	Integrated Circuit
MCU	Microcontroller Unit
PLC	Programmable Logic Controller
LDR	Light-Dependent Resistor
LT	Local Time
LST	Local Solar Time
LSTM	Local Standard Time Meridian
TC	Time Correction
GMT	Greenwich Mean Time
Eot	Equation of Time
CFC	Chlorofluorocarbon
PVC	Polyvinyl chloride
ASCII	American Standard Code for Information Interchange
GPS	Global Positioning System
2D	Two dimension
3D	Three dimension
RE	Renewable Energy
DC	Direct Current
AC	Alternating Current
UART	Universal Asynchronous Receiver/Transmitter
I2C	Inter-Integrated Circuit
PID	Proportional, Integral Derivative
GUI	Graphical User Interface
NGDC	National Geographical Data Centre
OS	Overshoot

CHAPTER 1

INTRODUCTION

1.1 Research Overview

In the years ahead, the demand for energy will escalate, whereas the conventional fossil fuel energy will deplete in a rapid pace. Henceforth, harvesting the power from a renewable energy source is vital in order to fulfill the growing energy needs. Among all the available renewable energy sources, solar energy is the most abundant and available all year-round with a global capacity of 40GW [1]. Other than solar, wind, geothermal, hydro, and ocean wave energy are solution for reducing the carbon footprint [2].

In solar technology, energy from the sun is captured by using photovoltaic (PV) panel and converts the solar radiation into electricity. Additionally, PV technology is a fast growing technological progress that requires very little maintenance with zero carbon foot-print. The performance of a PV panel is not only dependent upon the solar irradiance power, whether condition and the ambient temperature, but it also depends on the solar radiation's incidence angle to the PV panel [3]. During the day, the sun appears to move through the sky from east to west, therefore the angle between sun and a fixed PV surface is continually changing. Thus, the power density on a fixed PV module is less than that of the incident sunlight.

Lately, there are many works which have been taken in order to maximize the power extraction from the PV panel. Solar tracking system offers a practical technology solution to improve the power efficiency generated by the PV panel. In theory, the direct sun power incident, I_{DN} on a solar panel depends not only on the power contained in the sunlight, but also on the angle between the solar panel and the sun, θ. During the day, the sun appears to travel from the east to west, and the sun also appears to move up and then down in the sky as well. Therefore the incident angle received by the flat collector varies throughout the day. Since the power generated from a PV system depends on the sun's incidence angle, the solar-array system must be altered or adjusted so that the array is always aligned towards the sun in order to produce maximum power [4].

Generally, solar tracker is a device used for aligning a PV panel towards the sun. In this context, there are three types of solar tracking system, namely passive tracker, active tracker and open-loop tracker. Passive tracker uses two canisters filled with compressed gas fluid that placed each in the east and west of the tracking. However, this gas tracker rarely points the PV panel direct to the sun due to the unpredictable ambient temperature.

Yet, as the advancement of sensor technology, light sensor is used in the active sun tracker system and it is placed at various locations at the tracker to determine the best sun position, which is done by tilting the PV panel using actuators. Nevertheless, cloud and shadow effects are the major drawbacks of the system. This consequence brings disadvantages because power is wasted to drive the tilting actuator back and forth for during its searching mode.

Other than that, open-loop tracker is also commonly used for tracking the sun path. The tracker uses pre-determined astronomical database to determine the sun position for any given time and location's coordinate by using any embedded controller. In addition, the open-loop tracker is based on the altitude and the azimuth position of the sun, therefore, this system is not dependent to either ambient temperature or weather. This circumstance gives great advantages, such that it will not eliminate unwanted power dissipation and sensory complexity [5-7].

1.2 Problem statement

Although the open-loop tracker is simpler and cheaper than the closed-loop tracker, however it does not observe the output of the processes that it is controlling. Consequently, an open-loop system does not have the ability to compensate any external disturbances applied to the system, especially the azimuth heading reference which will introduce azimuth angular offset to the tracking system. As we all know, every location has its unique sun's path trajectory.

Currently, solar tracker developers, researchers and contractors set their open-loop tracker sun's trajectory database manually for specific location. As a result, this current method is not practical for mobile solar tracking system. If the tracking system is uploaded with wrong sun's trajectory database, the PV modules attached to the tracking system will surely not always aligned towards the sun. The offset and misalignment of the PV module will absolutely reduce the power generation efficiency.

To overcome the current system disadvantages, an open-loop solar tracking system with an automatic global sun's path trajectory database generator is proposed. Moreover, the tracking system will have the ability to eliminate the tracking azimuth angular offset. For the azimuth and altitude positioning integrity, PID controller algorithm will also be embedded in the tracking system. On top of that, the research will fuse and combine all the developed sub-system into a single free-interface and easy to set-up solar tracking system controller board.

1.3 Research Objectives

The aim of this research is to design and develop a system that is capable to maximize the power generation from the PV panel globally regardless of the system's deployment location. Furthermore, minimizing the power consumption of the system's electronics and actuators is also a vital requirement. In order to fulfill the research goal, these are the main objectives:

1. To design and develop an open-loop dual-axes solar tracker controller system for mobile application.
2. To develop an algorithm for generating annual sun's path trajectory database automatically at any location.
3. To compare the power produced from solar tracker with the power produced from fixed solar collector.

1.4 Scope and Limitation of Work

This research focuses on the design and construction of a portable dual-axis solar tracker that can be deployed anywhere on the surface of the earth. Therefore, the solar tracker structure is assembled using standard cylindrical aluminum hollow and customs Polyuthrene (PE) for the main structure and the joints respectively. For the mobility and the ease of transportation, these materials are chosen due to its lightweight, economical and durability.

Other than that, the research also stresses on maximizing the PV power generation by minimizing the solar incidence angle towards the panel with 1 degree accuracy. Since every location has its unique solar path, the ability to track the sun in different location also becomes the focal point in the research whereby this feature is very important for the sake of the system's mobility and portability. In this research, the experiment was performed at the parking lot located at the Engineering Faculty, Universiti Putra Malaysia with the coordinate of 3.00 North and 101.72 East.

Generally, solar tracking system consumes extra power used for driving the system's mechanism and also its electronic system; therefore in this work, the proposed solar tracking system will be powered by a high capacity independent rechargeable Lead Acid based battery. Other than that, the tracking driving system is equipped with two low power and high efficient actuators for tilting and rotating the attached PV module. On top of that, low power and highly reliable microcontrollers, electronic components and sensors are also used for the proposed solar tracker electronic systems.

There are also few factors that could influence and limit the experimental data during conducting the research. First, the shadow effect which is due to the natural structure and buildings that blocks the sun irradiance towards the PV panel especially during the dawn and dusk. Again, the experiment was carried out in an outdoor environment, which means that haze, wind and other weather-related variables could not be controlled and could influence the data integrity.

1.5 Significance of the Research

In this research, maximizing the solar power generation is very important especially when the unhealthy and expensive fossils energy is going to deplete soon. Although there are several ways to increase the solar power generation, this research only focuses on improving the amount of solar radiation collection towards the PV panel for maximizing the energy generation based on the astronomical algorithm. The mobility of the system is suitable for big or small independent and rural electrification. All in all, the system accuracy on tracking the sun's trajectory path gives a greater power generation that can encourage more research on generating clean energy especially in solar power system in Malaysia.

1.6 Thesis Outline

This thesis starts with Chapter 1 which presents a general introduction to the subject and the problem statement. It also introduces the aims, objectives, significance of the study and a brief summary of the structure of the thesis.

Next, Chapter 2 provides a literature review on related field of this study. It includes the equations related throughout this study, the interrelated technology and literature in photovoltaic and solar tracking.

Then, Chapter 3 describes the research methodology that is carried out to achieve the objectives, the design in mechanical structure, the selection of components and motors used in its driving and control systems, the flow of the program and electromechanical system of the tracking system.

Subsequently, Chapter 4 presents the results, discussion and comparison to validate the approached method.

Finally, Chapter 5 gives a summary and conclusion according to the findings of this research. Suggestions and recommendations for further extension of research in this area are also presented in this final chapter.

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