Automated Dual-axis Solar Tracking System Using Fuzzy Logic Control

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Abstract

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Abstract:

Utilization of solar powered system as renewable energy alternatives plays a dominant role in generating electricity. Throughout the years, solar tracking system has been continuously improved by researchers globally to maximize the power efficiency of a system. In this paper, a Fuzzy Logic Controller (FLC) is integrated into a large scale solar tracking system with photovoltaic (PV) panels to optimize the system's performance. In this project, a dual-axis solar tracking based on light intensity comparison using Fuzzy Logic Control method is utilized. Arduino Uno microcontroller is used as the main controller of this system and Light Dependent Resistors (LDR) are used to sense the light intensity at different altitude angles and sun azimuth. Two NEMA 34 stepper motors are used to actuate the Photovoltaic (PV) system. FLC is utilized to help the microcontroller to decide which direction and position of the PV panel should rotate to or stay. From the experiment conducted, it was observed that the developed system has an increase of output power efficiency of 96% when compared to the conventional solar tracking system.

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***Abstract*—Utilization of solar powered system as renewable energy alternatives plays a dominant role in generating electricity. Throughout the years, solar tracking system has been continuously improved by researchers globally to maximize the power efficiency of a system. In this paper, a Fuzzy Logic Controller (FLC) is integrated into a large scale solar tracking system with photovoltaic (PV) panels to optimize the system's performance. In this project, a dual-axis solar tracking based on light intensity comparison using Fuzzy Logic Control method is utilized. Arduino Uno microcontroller is used as the main controller of this system and Light Dependent Resistors (LDR) are used to sense the light intensity at different altitude angles and sun azimuth. Two NEMA 34 stepper motors are used to actuate the Photovoltaic (PV) system. FLC is utilized to help the microcontroller to decide which direction and position of the PV panel should rotate to or stay. From the experiment conducted, it was observed that the developed system has an increase of output power efficiency of 96% when compared to the conventional solar tracking system.**

Keywords—Solar tracking system, Fuzzy Logic Controller (FLC), Arduino Uno, Light Dependent Resistors (LDR), Photovoltaic, Dual-axis controller.

I. INTRODUCTION

In the era of globalization, electricity power is one of the most essential infrastructures in maintaining people's daily life. Most people are born into a life filled with electricity and often take it for granted. Unrenewable energy source such as fossil fuel is the main energy used for electricity generation. In fact, the diminishing fossil fuel resources are expected to be exhausted within the next hundred years [1].

In Malaysia, coal is the main energy source used to generate electricity. According to the statistic, total electricity generated in Malaysia in 2020 was approximately 162.93 billion kWh. In recent years, electric power generation using renewable energy sources has begun to take on a dominant role in fulfilling the demand of electric energy [2]. In countries like Malaysia where a warm climate is dominant, solar energy is determined as one of the predominant energy resources since they are costless, accessible, plentiful and safe [3]. A solar photovoltaic (PV) panel system is often used to capture solar energy for electricity generation. Solar irradiance is the quantity of solar energy that falls on a solar PV panel over a period of time. A solar tracker is always used to optimize the PV panels system [6]. It has been recorded that an increase in the efficiency of energy production of 35% per year has been achieved by solar tracking systems [4].

Currently, solar energy generation has relatively low efficiency [5]. However, the limitation of PV panels is that their solar irradiance is highly dependable on the sunlight intensity and ambient temperature. Hence, a solar tracking system is introduced to solve these problems. With a solar tracker, the PV panels can be controlled so that their position are always perpendicular to the direction of the sunlight to maximize their solar irradiance and adjusts its direction when there is a decrease in solar irradiance intensity. Using a suitable control algorithm the solar PV system can be greatly optimized [9]. Therefore, in this project, a dual-axis solar-tracking control system with fuzzy logic control based on Arduino Uno is designed and developed to maximize the load (solar irradiance) on PV solar panels.

In this paper, a dual-axis solar tracking system is designed and developed based on light intensity comparison between four LDR sensors. Fuzzy logic algorithm is designed to give the best accuracy in positioning the solar PV panels [7,8]. In addition, the power efficiency of solar irradiance on the PV panels between solar-tracking [12] and non-tracking mode are compared under the same location and environment.

II. RESEARCH METHODOLOGY

A. Hardware Development

The solar tracking system consists of an Arduino UNO microcontroller board, four LDR sensors, a DM 860A motor driver, two NEMA 34 stepper motors, and a MPPT charger controller. FLC is implemented in the system through Arduino programming. The overall system architecture can be referred to Fig. 1.

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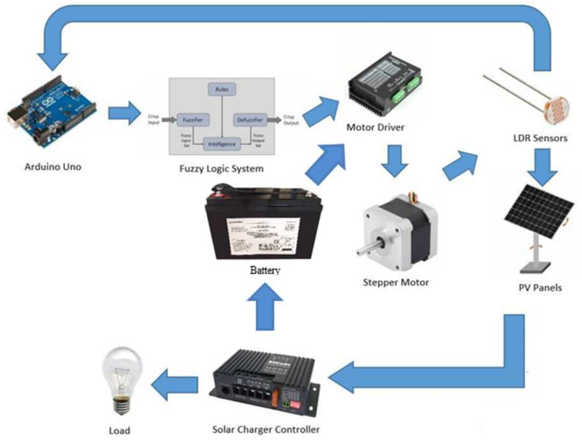

Fig. 1. Overall Solar Tracking System Architecture with FLC

The PV system can be categorized into two parts which are the tower and the controller box. The tower consists of a base, a pillar, two NEMA 34 stepper motors two PV panels, four LDR sensors and two NEMA 34 stepper motors. Fig. 2 shows the overall PV system.

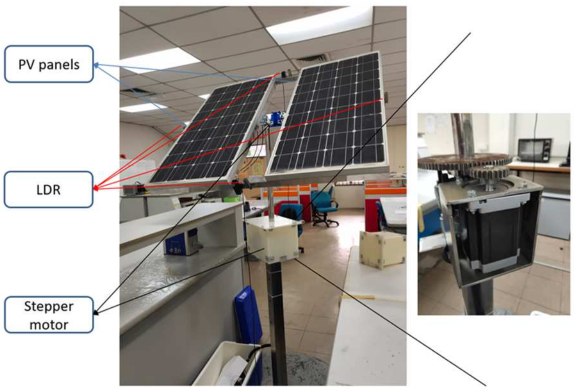

Fig. 2 PV System

The Arduino Uno R3 microcontroller board is supplied by a 5V battery. Four LDRs are connected to the analog input of the Arduino board. Two NEMA 34 stepper motors are connected to DM860A motor drivers, and the drivers are connected to the digital output of the Arduino board. The motor drivers need a 12V power supply.

B. Software Development

Software development is started by designing an FLC system on MATLAB using fuzzy toolbox. Then, Arduino programming is written by implementing FLC algorithm into it using Arduino IDE. The Arduino programming starts with the fuzzification part, followed by the control rules and rules evaluation. Lastly, defuzzification part is written using the centroid method to give the crisp output.

The first step to design an FLC algorithm is to identify the input and output variables of the system. In this project, there are two sets of input and output, where each output is controlled by one input. Each input comes from the difference between the analog values of the two LDR sensors at X-axis and Y-axis respectively. First output will rotate horizontally based on its input while the second output will rotate vertically based on its input.

Fuzzifcation converts the input or output signal from crisp value into a number of fuzzy values or fuzzy sets. This project utilizes two inputs and two outputs of membership function as shown in Fig. 3. Each membership function represents the degree of difference of two LDRs on X-axis and Y-axis respectively and they are quantized as shown in TABLE I.

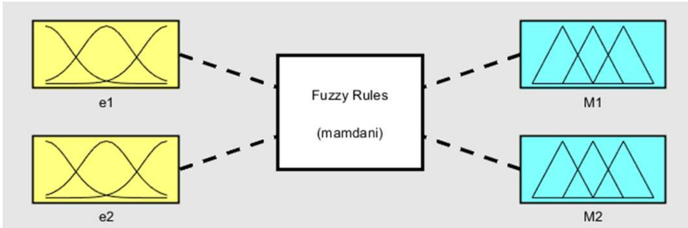

Fig. 3 Membership Functions for the Input and Output Fuzzy Sets

TABLE I QUANTIZATION OF FUZZY SET

Linguistic Term	Label
Negative Big	NB
Negative Medium	NM
Negative Small	NS
Zero	ZE
Positive Small	PS
Positive Medium	PM
Positive Big	PB

The knowledge base of a FLC consists of data base and a rule base [10,11,12]. The fuzzy control rules are written based on the fuzzy model of the project process which mean the fuzzy control rules IF-THEN are generated in order to track the maximum sunlight intensity. Due to the nonlinearities of the sun movement, there are 14 fuzzy rules written to yield a better performance.

Defuzzification involves the conversion from fuzzy value back to crisp value that is required to actuate the motor to rotate the PV panel. There are several methods of defuzzification such as center of gravity (COG), mean of maximum (MOM), and center average methods. In this project, the center of gravity (COG) or known as centroid method is used because this method is the most prevalent and physically appealing of all defuzzification methods. The equation of centroid method is shown in equation (1) below:

$$x^* = \frac{\sum u_x(x).x}{\sum u_x(x)} \quad (1)$$

Where x is the output variable, $x^*$is the deffuzified output and $u_x(x)$ is the aggregated membership function.

C. Experimental Setup

In order to analyse and compare the output power efficiency of the dual-axis solar tracking system between tracking mode and non-tracking mode, an experiment is set up to achieve the objective of this problem. The experiment is done outside Process Control Laboratory, P10, Universiti Teknologi Malaysia, Johor. Fig. 4 shows the dual-axis solar tracking system in operation. A multimeter is used to measure the voltage and current output from the PV panel in order to calculate its output power.

Fig. 4 Dual-axis Solar Tracking System in Operation

By using Ohm's Law, the output power can be calculated using the following equation $P(W) = VI$ where I is the output current from the PV panel while V is the output voltage from the PV panel.

The experiment is carried out by taking measurement every one hour interval from 9.00 a.m. to 4.00 p.m. (1.00 p.m. is excluded) for three days. Measurements are taken for both tracking mode and non-tracking mode to compare their output power and power efficiency.

III. Result and Discussion

The findings focus on analyzing the output power obtained from the developed dual-axis solar tracking system implemented with FLC with tracking mode and non-tracking mode. A comparison was made between the two modes to determine whether the efficiency of solar energy collection was enhanced when applied with FLC.

A. Simulation Results and Discussions

A simulation was performed by using fuzzy logic toolbox in MATLAB software to show the output of FLC based on the control rules. The simulation result can be shown in rule form and surface form. The result in rule viewer form for X_axis and Y_axis are shown in Fig. 5 and Fig. 6 respectively. On the other hand, the result in Surface Viewer form for X_axis and Y_axis are shown in Fig. 7 and 8 respectively. From the result, if the input value between the two sensors (error) is larger, the steps done by the stepper motor is higher. Inversely, if the error is smaller, the steps done by the stepper motor is lower. If the error value is positive, the stepper motor rotates in CW direction and vice versa. This theory is applied for both horizontal and vertical movement of PV panel.

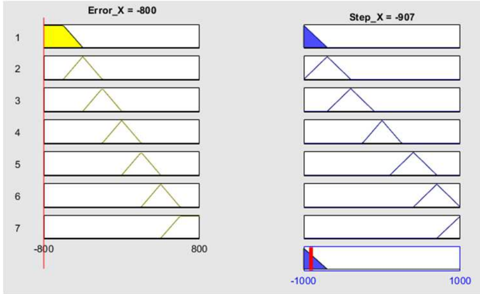

Fig. 5 Rule Viewer Result in Rule Form for X_axis

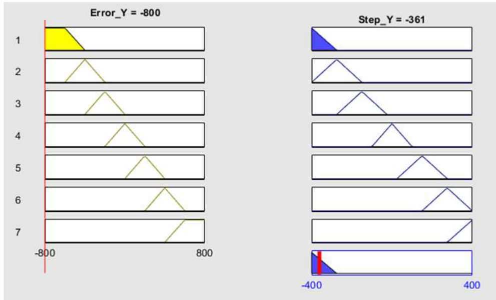

Fig. 6 Rule Viewer Result in Rule Form for Y_axis

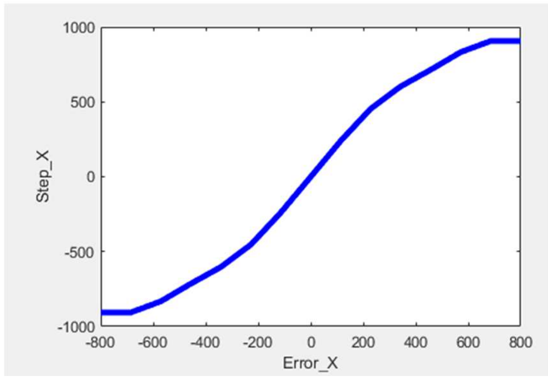

Fig. 7 X_axis Surface Viewer Result

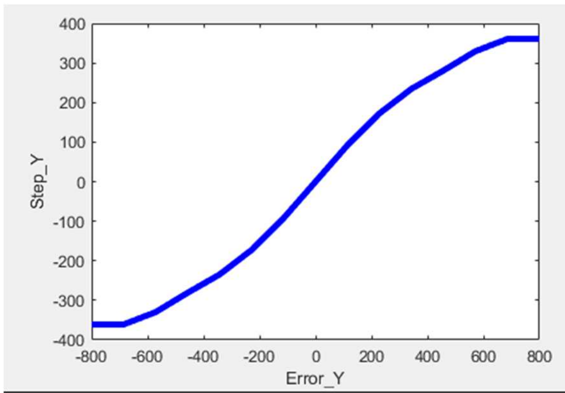

Fig. 8 Y_axis Surface Viewer Result

An experiment is carried out by comparing the output power produced by the dual-axis solar tracking system between its tracking mode and non-tracking mode. Main parameters measured for this experiment are Voltage (V) and Current (A). Output power (W) and power efficiency (%) is then calculated using the following equation:

$$\eta_{Power}(\%) = \frac{P_T(Total)}{P_{Expected}} \times 100\% \quad (2)$$

$$P_{Expected} = \frac{1000W}{m^2} \times (1.2 \times 0.54)m^2 \quad (3)$$

Where $1000\ W^{m^{-2}} = Irradiance$ and $1.2 \times 0.54\ m^2$ is the area of the PV panel. The output powers (W) of the dual-axis solar tracking system between the tracking mode and non-tracking mode are plotted into graphs as shown in Figure 9, 10 and 11. It can be observed that, the output power from the system with the tracking mode is almost higher than the output power from the system with non-tracking mode.

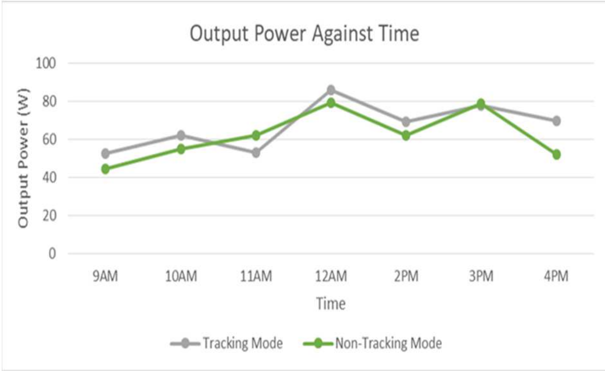

Fig. 9 Output Power of the system on 12th June 2023

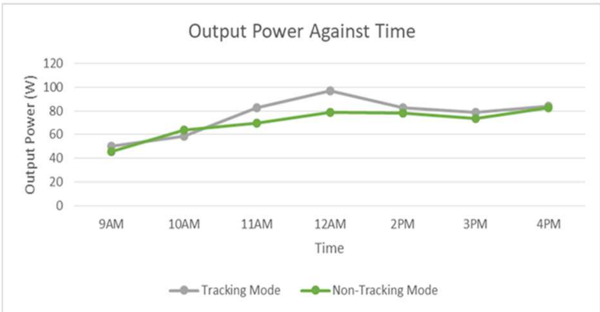

Fig. 10 Output Power of the system on 13th June 2023

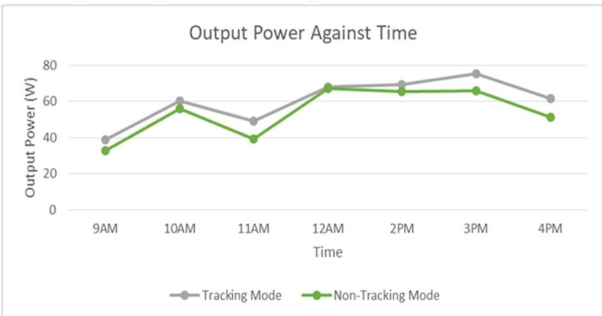

Fig. 11 Output Power of the system on 14th June 2023

In order to determine the output percentage difference between the system in tracking mode and non-tracking mode, Power Difference, P_{diff} (%) and Efficiency Difference, η_{Diff} (%) are calculated with the following equations:

$$P_{diff}(\%) = \frac{P_{Track} - P_{Non-Track}}{P_{Non-Track}} \times 100\% \quad (4)$$

$$\eta_{diff}(\%) = \frac{\eta_{Track} - \eta_{Non-Track}}{\eta_{Non-Track}} \times 100\% \quad (5)$$

From TABLE II, it is proven that a solar tracking system with FLC has an increase of output power efficiency (%) of 9.63% in average compared to its non-tracking mode

.

TABLE II Power Difference And Efficiency Difference

Date	Power Difference (%)	Efficiency Difference (%)
12th June 2023	8.28	8.28
14th June 2023	8.92	8.92
15th June 2023	11.69	11.69
Average	**9.63**	**9.63**

IV. Conclusion

With the trend of going green, specifically on Sustainble Development Goal 7 (SDG7) on *Affordable and Clean Energy,* solar energy has emerged as one of the most efficient alternative energy sources for electricity generation due to its abundant availability and cost-effectiveness. A PV panel system is often used to generate electricity by capturing solar energy and convert it into electric energy. However, the problem of the system is that its output power efficiency or solar irradiance become low when the panel is not aligned with the sun.

In this paper, an automated dual-axis solar tracking system, using FLC is developed. The developed system is able to maximize the output power efficiency (solar radiance) when the PV panel is aligned with the sun. From the results obtained, when compared to the stationary system, it was observed that the overall efficiency and output power of the developed system is increased by 9.63%.

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