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Optimising Energy for Automatic Plant Watering Using Dual Axis Solar Tracking

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***Abstract*— The dual-axis solar tracker is designed to optimize sunlight absorption by solar cells, enhancing energy efficiency through a dynamic framework that allows solar panels to follow the sun's movement throughout the day. The system employs light-dependent resistor (LDR) sensors to detect sunlight intensity, with four LDR modules strategically placed around the solar cell surface. The tool is powered by two actuators for vertical and horizontal adjustments, controlled by a 5-volt 4-channel relay activated by an Arduino based on signals from the LDR modules. The findings from the study demonstrate that the dual-axis solar tracker significantly improves power output compared to static solar panels. Specifically, the solar tracker system increased the power generation of solar cells by 47% in the first test and 55% in the second test, demonstrating a substantial enhancement in energy collection. This improvement is influenced by factors such as optimal positioning, increased light intensity capture, and adaptation to varying environmental conditions like temperature and humidity. The dual-axis tracking system ensures that solar panels are consistently oriented towards the sun, resulting in more efficient battery charging. The optimized charging process provides a stable supply of electrical energy, which is essential for powering water pumps and maintaining an automatic plant irrigation system. This continuous supply of energy not only supports sustainable agricultural practices but also reduces dependency on conventional power sources, thereby promoting energy efficiency and resource conservation.**

***Keywords*— Solar tracker dual axis, LDR sensor, Actuator, Arduino, Water pump, Plant watering.**

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I. INTRODUCTION

A. Background

Indonesia is an agrarian nation, with the majority of its population engaged in agricultural activities for their livelihood. A variety of plants are cultivated in Indonesia, including strawberries. Strawberries represent one variety of subtropical fruit crops that are commonly cultivated in the highlands. Strawberry plants are highly dependent on the climate of their surrounding environment. One of the most appropriate climate requirements is a rainfall intensity of 600-700 mm per year. Furthermore, strawberry plants require a minimum of eight to ten hours of sunlight per day [1]. Water is also a crucial element for their growth and development. Deprivation of water can impede the growth and development of these plants. To ensure optimal growth and development, it is essential to provide sufficient and regular irrigation.

The majority of plant watering is currently conducted manually by farmers, which presents a significant challenge in terms of time management and labour efficiency. Consequently, there is a clear need for research into the potential of automatic plant watering systems to address these issues. The operation of automatic plant watering devices necessitates the input of electrical energy, which enables the functioning of the plant watering tool. Furthermore, this research employs the use of solar cells, which represent an environmentally friendly technology that can be utilised as a source of electricity in the development of automatic plant watering tools. The advantages of solar power include the absence of emissions, the ability to obtain energy without reliance on external sources, ease of maintenance, and the capacity to function effectively in a variety of lighting conditions. However, solar cells are not without limitations, particularly in terms of their sensitivity to sunlight intensity [2].

The maximum energy output of a solar cell is achieved when the sun is perpendicular to the surface of the cell. The position of the Sun will invariably shift from east to west on a daily basis. However, the majority of solar panel installations are currently positioned in a single direction, which results in the optimal energy absorption process only occurring temporarily, specifically when the sun is perpendicular to the solar cell. In order to optimise the utilisation of solar panels, a system has been developed that is capable of obtaining full sunlight. This is achieved by creating solar cells that are able to follow the sun's movement perpendicularly [3]. In this context, the objective of this research is to design solar cells with a dual-axis solar tracker system with the aim of optimising the absorption of sunlight for the generation of electricity for water pumps, particularly for the irrigation of plants, including strawberries

B. Problem Formulation

In light of the aforementioned background, several key problems have emerged, which can be summarised as follows:

1. How might the conversion of solar energy into electrical power be optimised using a Solar Tracker Dual Axis system?
2. How can the power produced by solar cells with the Solar Tracker Dual Axis system and static solar cells be compared?

C. Purpose

This research aims to develop a dual-axis solar tracker tool with the following objectives:

1. The aim is to ascertain how sunlight can be most efficiently transformed into electricity using solar cells in conjunction with the Dual Axis system.
2. The objective is to ascertain the comparative output of power generated by solar cells in conjunction with the Solar Tracker Dual Axis system.

D. Problem Restriction

To ensure the integrity of research findings, it is essential to define the problem boundaries at the outset. This enables the research to remain focused on the specific issues outlined in the title and to avoid unanticipated challenges.

The following section outlines the limitations of the issues that have been identified in this study.

1. The research employs 100 Wp solar cells.
2. The utilisation of an LDR sensor module for the purpose of tracking sunlight.
3. The mechanical system of the solar tracker employs the use of an actuator motor.
4. The utilisation of Accu/Aki for the purpose of energy storage.
5. The load is a water pump.
6. The text makes no mention of automatic plant watering systems

II. METHODS

This research employs a literature review methodology, whereby interviews are conducted with strawberry farmers, and previous journal research on dual-axis solar trackers for plant watering is also considered.

A. Tool Planning

The objective of this tool is to create a dual-axis solar tracker design, with the aim of optimising solar energy absorption. This energy is subsequently converted into electricity by solar cells, which can then be used for automatic plant watering. The tool utilises two actuators as a drive, with specifications of the first actuator pertaining to vertical motion and those of the second to horizontal motion. The Arduino Mega 2560 microcontroller is employed as the tool system controller, with a maximum of four Light-Dependent Resistors (LDRs) permitted within the LDR modules. The solar panel utilised is a 100 Wp monocrystalline model, accompanied by a 35Ah wet battery with storage capabilities. The battery safety system employs a 10-ampere solar charger controller. A water pump is utilised to irrigate the plants. It is equipped with a rain sensor and regulated by a real-time clock (RTC) module, which controls the lifespan of a 5-volt, one-channel relay. The relay acts as a switch to activate the pump. Accordingly, the water pump will be operational according to the settings of the RTC module, which has been configured to activate at 9 am and 3 pm with an active relay for one minute when watering is required. During this period, the water pump will remain inactive, as the rain sensor detects moisture and sends a signal to the microcontroller, thereby preventing the relay from becoming active. Additionally, an I2C LCD serves as a display for time and watering instructions when the designated watering interval has been reached.

B. Tool Planning

The operational principle underlying the mechanism can be discerned in the block diagram illustrated in Figure 1. The design of the system is intended to provide an overview of the tools manufactured and to illustrate the operational principle of each component. This can be observed in Figure 1, which is a system planning block diagram that provides the following details:

1. LDR module: A light-dependent resistor (LDR) is a specific type of resistor whose resistance value is influenced by the intensity of light it receives. The function of the LDR is to facilitate the flow of electric current when light levels are high, and to impede this current when light levels are low. Given that the resistance value of the LDR is low when the light intensity is high, the voltage that passes through the LDR will also be high. Conversely, when light intensity is reduced, the resistance value of the LDR rises, thereby reducing the voltage that passes through the LDR [5]. This research employs four KY018 LDR modules with operational voltage parameters of 3.3V to 5V.

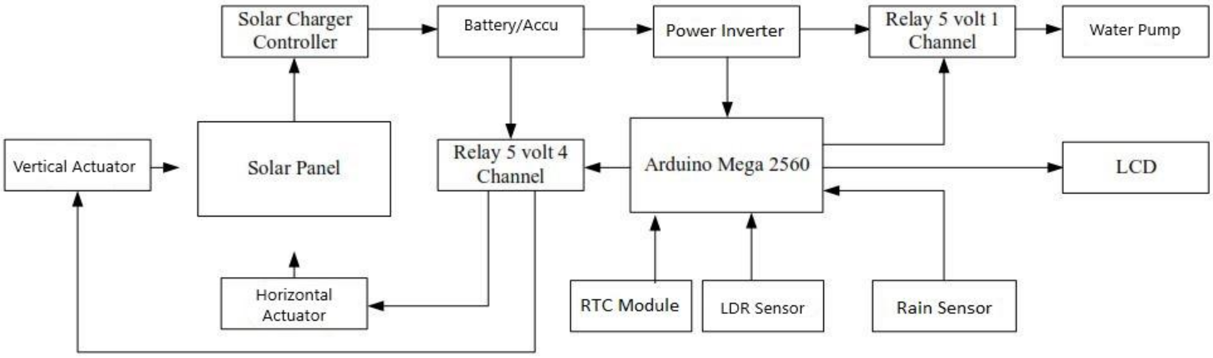

FIGURE 1. Block Diagram of System Planning

2. Solar Charge Controller: A solar charge controller is an electronic apparatus that is utilised for regulating the direct current which is charged into the battery and subsequently discharged to the load. The function of the solar charge controller is to regulate overcharging (excessive charging due to the battery becoming fully charged) and excess voltage from solar panels. Excessive voltage and charging will reduce the lifespan of the battery [4]. The SCC employs a pulse width modulation (PWM) type with a maximum capacity of 10 A.
3. Battery: A battery is defined as a device that functions as a converter of chemical energy into electrical energy, exhibiting a diversity of shapes and sizes. The battery consists of two poles: the positive pole (anode) and the negative pole (cathode). The classification of batteries is based on their type, and they are thus divided into two main categories: primary batteries and secondary batteries. Additionally, batteries can be classified as either wet or dry batteries [6]. In this design, a 12-volt wet battery with a capacity of 35 Ah will be employed.
4. The actuator is a mechanical device that can convert electricity into mechanical energy. Actuators are mechanical devices that facilitate the conversion of electrical energy into mechanical motion, whereas electromagnet devices are capable of producing kinetic energy. The kinetic energy will be employed to operate a mechanism or system [4]. The function of the actuator is to operate as a system driver within a mechanical controller. The actuator is driven by an electric motor. The linear actuator, designated HARL + 3618, is a brand matrix type with a DC input voltage of 12 volts. It is employed in the design of the tool, comprising a total of two pieces that serve as the driver for the solar tracker frame.
5. The Arduino Mega 2560 was employed in this instance. It serves as a microcontroller for the regulation of the tool system. The Arduino Mega 2560 is an ATmega2560 microcontroller board, the technical specifications of which are detailed in the datasheet. It comprises 54 digital input/output pins (15 of which may be utilised as PWM outputs), 16 analogue inputs, 4 UART (serial port hardware), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. The aforementioned device contains all the necessary components to support the microcontroller. To establish a connection, simply connect the device to a computer via a USB cable. Alternatively, users may opt to power the device with either an AC-DC adapter or battery [7].
6. 5 volt relay: A relay is an electromechanical component that is operated by an electrical current and comprises two primary components: an electromagnet (or coil) and a set of mechanical switches or switch contacts. The relay employs the electromagnetic principle to facilitate the movement of the switch contacts, thereby enabling the delivery of highvoltage electricity with a relatively low electric current. The tool employs two distinct channel types. The first comprises a four-channel relay, which serves as both a connector and a breaker for two actuators. The second is a five-volt, singlechannel relay, which controls the water pump switch.
7. The Real Time Clock (RTC) module is comprised of the following components: A real-time clock (RTC) comprises a single integrated circuit with the function of storing time and date data. The RTC DS3231 is a real-time clock (RTC) that is capable of storing a multitude of temporal data, including seconds, minutes, hours, dates, months, days of the week, and years, with a projected lifespan until 2100. The RTC DS3231 is an integrated circuit with a parallel data line and a two-wire serial interface (I2C). I2C communication utilises two ports, namely the Serial Data (SDA) and Serial Clock (SCL) ports [8].
8. The rain sensor is a vital component in the overall system. The circuit designed to detect rainfall is a straightforward one, comprising a sensor installed on a domestic roof. The rain detector circuit operates by establishing a connection between the sensor terminal and the surrounding rainwater, which allows the circuit to detect rainfall. The water sensor in this rain detector circuit can be constructed using a printed circuit board (PCB) and designed in such a way that the principle of the connection between the two terminals when exposed to water is fulfilled [9].

9. The water pump is responsible for draining the water. It employs a National brand pump that has a power rating of 125 watts.
10. The function of the inverter is to convert the direct current (DC) input voltage into a balanced alternating current (AC) output voltage with the desired magnitude and frequency, as detailed in [4]. In this study, an inverter with a power output of 1500 watts, manufactured by Hinomaru, was utilised.
11. I2C LCD: The LCD module serves the function of displaying the output value of the microcontroller. The module contains 192 stored characters, arranged in 16 lines of 2 characters each. Furthermore, a programmable character generator is available. The LCD can be assigned an address in two different modes: a 4-bit mode and an 8-bit mode [10].

In accordance with the block diagram depicted in Figure 1, the device is operational when the solar panel or solar cell is illuminated by sunlight, thereby undergoing the photovoltaic effect and transforming solar energy into electrical energy. The electrical energy thus generated is then stored in the battery (accumulator). The solar charge controller is the component through which the electrical energy passes before being stored in the battery. The function of the solar charge controller is to regulate the voltage entering the battery, thereby preventing overcharge. It is imperative that the solar charge controller is connected to the battery in a primary position prior to the solar cells. The solar charge controller in use operates at a voltage of 12 Volts with a current limit of 10 Amperes.

To enhance the efficacy of solar energy absorption, the system is furnished with a solar tracking apparatus comprising two actuators, which derive their 12-volt power source from the battery. The actuators are operated in accordance with the input from the Light-Dependent Resistor (LDR) sensor. The light-dependent resistor (LDR) sensor in the dual-axis solar tracker system is utilised to ascertain the intensity of sunlight from diverse directions, thus enabling the solar cells to consistently face the most optimal sunlight direction. The system is equipped with four light-dependent resistor (LDR) sensors, which are positioned around the solar cells in a configuration that allows for the detection of light intensity from a range of directions. These sensors are located at the top left, top right, bottom left, and bottom right positions, respectively. The light-dependent resistor (LDR) sensors are responsible for measuring the intensity of light at their respective positions, subsequently generating a voltage that is dependent on the quantity of light received.

The Arduino microcontroller is programmed to read the analogue values of the four light-dependent resistor (LDR) sensors and to perform a comparative analysis of the light intensity in each direction. The Arduino program subsequently calculates the mean value of the LDR pairs in each axis (up-down and left-right), and then performs a comparison of the resulting differences. Should the discrepancy between the light intensities detected by the LDRs surpass a specified threshold, the Arduino microcontroller will then initiate the activation of the corresponding relays in order to direct the actuators in the desired manner. To illustrate, should the light intensity at the upper LDR be greater than at the lower LDR, the programme will initiate the activation of a relay, prompting a movement of the actuator in an upward direction. The same principle applies in reverse. This process is repeated continuously, ensuring that the solar cell maintains alignment with the sun and receives maximum illumination throughout the day.

To illustrate, during the east position of the solar zenith, the LDR sensor will track the sun and transmit a signal to the Arduino Mega. The Arduino then issues a command to the 5 Volt relay connected between the actuator and the battery, thereby placing the relay in an operational state and enabling the transfer of power from the battery to the actuator. The actuator will then move in the appropriate direction (up or down) in order to adjust the position of the solar cell in line with the movement of the sun. The actuator will cease to function once the LDR sensor is positioned perpendicular to the sunlight.

The system employs a battery-powered water pump as a load, which is converted from direct current to alternating current via an inverter to provide the necessary power. In the case of automatic plant watering, the operation is dependent on the input from the RTC and rain sensors. The pump is set to activate automatically at 9:00 am and 3:00 pm, as programmed in the Arduino code for the RTC sensor. In the event of precipitation at the designated times, the device will not operate.

C. Circuit Plan

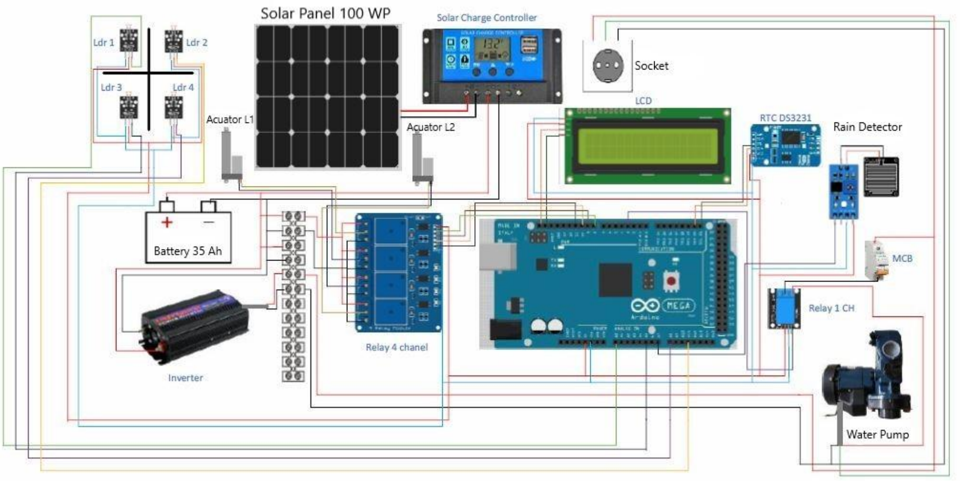

FIGURE 2. Wiring Circuit of the Appliance

The Arduino Mega 2560 serves as the plant watering system's primary controlling device, integrating input from a rain sensor and a Real Time Clock (RTC) module. Its 5-volt, 1-channel relay output is utilized for the water pump switch, while the Arduino also oversees the solar cell solar tracker system, employing a Light Dependent Resistance (LDR) module with a Linear Actuator (LA) driver. The latter facilitates the switching on and off of the actuator power source's connectivity to the battery. The control system for the two linear actuators—one for vertical movement and one for horizontal movement—is comprised of a 4-channel relay module, which is operated via an Arduino Mega microcontroller. The power supply for this module is derived from a battery, as illustrated in Figure 2.

The circuit scheme commences with the positive (+) battery terminal being connected to the common (COM) terminals of relays 1 and 3, while the negative (-) battery terminal is linked to the COM terminals of relays 2 and 4. In the configuration involving a vertical linear actuator, the positive terminal of the actuator is connected to the common point (COM) terminal of relay 3; meanwhile, the negative terminal of the actuator is connected to the COM terminal of relay 4. Conversely, in the case of horizontal linear actuators, the positive terminal of the actuator is connected to the common point (COM) terminal on relay 1, while the negative terminal is connected to the COM terminal on relay 2. The relay module is connected to the Arduino by means of a VCC pin connection to the 5V pin on the Arduino and a GND pin connection to the GND pin on the Arduino. The input control pin of relay 1 is connected to digital output pin 11 of the Arduino, the input control pin of relay 2 is connected to digital output pin 10, the input control pin of relay 3 is connected to digital output pin 8, and the input control pin of relay 4 is connected to digital output pin 9. This configuration enables the Arduino to regulate the flow of power from the battery to each linear actuator in an independent and controlled manner. This configuration enables the system to control the vertical and horizontal movements of the actuators with a high degree of precision.

D. Planning of Dual Axis Solar Tracker

Prior to the fabrication of a tool, it is essential to devise a dual-axis solar tracker design and to establish the specifications of the intended tool. The objective is to facilitate both the process of tool fabrication and the selection of components to be employed in said process. Figure 3 illustrates a dual-axis solar tracker tool design created using the Prisma 3D Android application. Two panel boxes are provided, the upper one for circuit control components and the lower one for battery/battery storage.

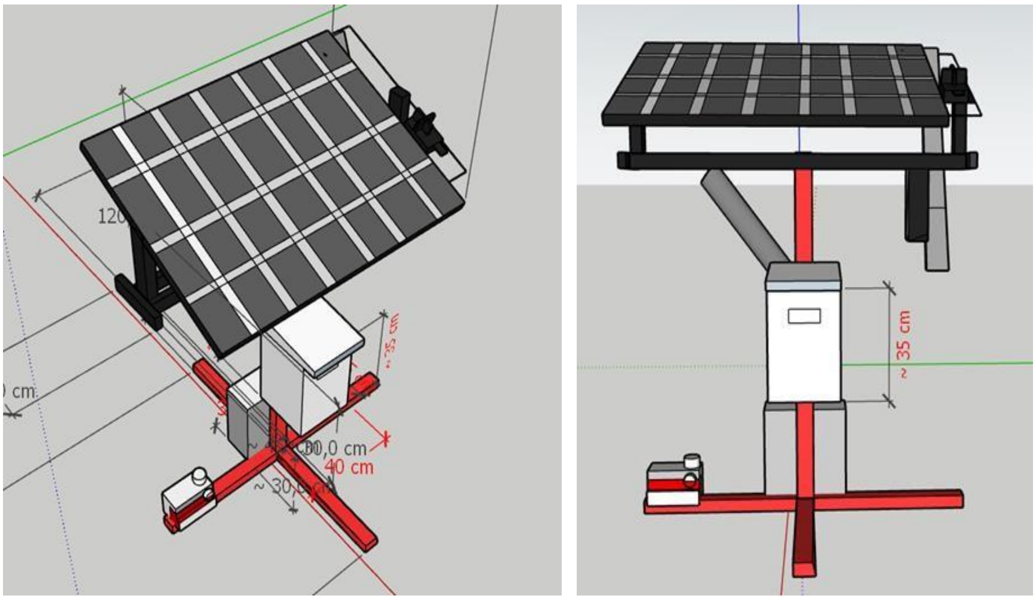

FIGURE 3. Planning of Dual Axis Solar Tracker Device

E. Formula of Calculation

The objective of this tool is to enhance the absorption of solar energy, which will then be converted to electrical energy through solar cells. The dual-axis solar tracker is designed to position the solar cells directly opposite the sun, facilitating rapid battery charging and a continuous supply of power to the water pump.

The data collected in this study presents a comparison of the output characteristics of solar cells with and without a dynamic solar tracker system. The current and voltage obtained will be used to calculate the power generated, using the following formula:

$$Power = Voltage \times Current \qquad (1)$$

The calculation of the power generated in both the dynamic system and the static system can be determined using the following equation:

$$Increased\ Power = \frac{Average\ Power\ (dynamic\ system) - Average\ Power\ (static\ system)}{Average\ Power\ (static\ system)} \times 100\% \qquad (2)$$

III. RESULT OF THE SOLAR CELL TESTS

A. Tool Design Results

The design of this tool has resulted in the creation of a dual-axis solar tracker with a water pump load, which is intended for use as a plant watering mechanism. In order to track the solar cell system, a framework that can be moved in all directions is required. The framework of the dual-axis solar tracker employs angle iron and holo iron, which are capable of supporting the weight of solar panels. The solar tracker system necessitates the utilisation of two actuators for the purpose of moving the frame, with input derived from the LDR sensor. This sensor has been programmed by the Arduino Mega microcontroller with a 5-volt 4-channel relay output, thereby facilitating the activation of the aforementioned actuator.

The uppermost part of the framework is where the solar cell is located. Adjacent to it is a box containing four light-dependent resistor (LDR) modules, which are constrained by plywood. Additionally, there is a rain sensor that serves as a rain detector. Furthermore, the tool is furnished with a panel box, which serves as a repository for Arduino Mega components, inverters, RTC sensors (utilised for the automated irrigation of plants), 5-volt relays (used as connectors and breakers for actuators), batteries (for energy storage derived from solar cells) and voltage sources for actuators. Additionally, an LCD is positioned on the panel box door, functioning as a indicator of the safe watering tool's operational status. Further details of the tool as a whole can be found in Figure 4.

FIGURE 4. Tool Design Results

A. Results of The Solar Cell Tests

The objective of this experiment is to evaluate and contrast the performance of solar cells with and without a tracking system (dynamic position) in terms of voltage, current, and power. The initial test was conducted on 6 August 2024. The test results are presented in Table 1 of the test report.

TABLE I
First Test Results

No	Time	Dynamic Solar Cells			Static Solar Cells		
		Voltage (V)	**Current (I)**	**Power (P)**	**Voltage (V)**	**Current (I)**	**Power (P)**
1	08:00	22.3	3.4	75.82	19.5	2	39
2	08:30	22.5	3.5	78.75	19.6	2.2	43.12
3	09:00	22.4	3.6	80.64	20.8	2.4	49.92
4	09:30	23.1	4	92.4	22.5	3.2	72
5	10:00	23.3	4.1	95.53	22.4	3.2	71.68
6	10:30	22.9	4.2	96.18	22.3	3.3	73.59
7	11:00	23	4.2	96.6	22.3	3.3	73.59
8	11:30	23.2	4.3	99.76	23	3.4	78.2
9	12:00	22.7	4.1	93.07	22.6	2.5	56.5
10	12:30	22.8	4.3	98.04	22.6	2.8	63.28
11	13:00	22.5	4.2	94.5	22.2	2.6	57.72
12	13:30	22.5	1.6	36	21.8	1.2	26.16
13	14:00	21.5	0.9	19.35	19.8	0.6	11.88
Average		**22.67**	**3.57**	**81.28**	**21.65**	**2.52**	**55.13**

The first test results in Table 1 show the difference in voltage, current and power between dynamic solar cells and static solar cells. Where the value produced between dynamic solar cells and static solar cells has a different value every hour. Dynamic solar cells get higher voltage, current and power values than static solar cells. This is because dynamic solar cells use a dual axis tracker to optimise the absorption of sunlight on the solar cells. From the results of the first test, we can find the value of the power produced by the solar cells every hour by calculating with the power increase formula (2).

$$Increased\ Power = \frac{Average\ Power\ (dynamic\ system) - Average\ Power\ (static\ system)}{Average\ Power\ (static\ system)} \times 100\%$$

$$Increased\ Powrer = \frac{81.28-55.13}{55.13} X 100\%$$

$$Increased\ Power = 47.43\%\ or\ 47\%$$

From the calculation results obtained by 47% increase in power by using a dynamic solar cell system. The second test was conducted on 7 August, the results of which are presented in Table 2.

TABEL 2.
Second Test Results

No	Time	Dynamic Solar Cells			Static Solar Cells		
		Voltage (V)	Current (I)	Power (P)	Voltage (V)	Current (I)	Power (P)
1	08:00	23.2	3.3	76.56	22.3	1.4	31.22
2	08:30	22.6	3.7	83.62	22.5	2.0	45.00
3	09:00	22.3	3.6	80.28	21.6	2.2	47.52
4	09:30	21.5	1.1	23.65	19.3	1.0	19.30
5	10:00	22.4	3.7	82.88	22.2	2.1	46.62
6	10:30	22.9	4.8	109.92	22.1	2.7	59.67
7	11:00	21.8	1.3	28.34	21.5	0.7	15.05
8	11:30	21.6	1.2	25.92	21.7	0.8	17.36
9	12:00	22.0	1.0	22.00	21.9	0.9	19.71
10	12:30	22.0	2.2	48.40	22.1	2.0	44.20
11	13:00	22.0	1.5	33.00	21.6	1.3	28.08
12	13:30	22.8	2.7	61.56	22.7	2.3	52.21
13	14:00	21.5	1.0	21.50	21.3	0.9	19.17
14	14:30	22.0	0.8	17.60	21.5	0.6	12.90
15	15:00	21.3	0.3	6.39	20.5	0.3	6.15
Average		**22.13**	**2.15**	**48.11**	**21.65**	**1.41**	**30.94**

In Table 2 there are differences in voltage, current and power between the dynamic solar cell systems and the static solar cells, where in the first test with the second test there are different values of voltage, current and test power. In the second test, the voltage, current and power values were lower than in the first test, due to cloudy weather conditions, so the sun's illumination of the solar cells was less than optimal. From the test results, the power increase for solar cells of average power can be calculated as follows.

$$Increased\ Power = \frac{Average\ Power\ (dynamic\ system) - Average\ Power\ (static\ system)}{Average\ Power\ (static\ system)} \times 100\%$$

$$Increased\ Powrer = \frac{48.11-30.94}{30.94} X 100\%$$

$$Increased\ Power = 55.49\%\ or\ 55\%$$

From the calculation results obtained by 55% increase in power by using a dynamic solar cell system. The increase in power generated between the first and second tests is due to the fact that in the second test in cloudy conditions, the sunlight absorbed by the solar cells is less than optimal, so there is little competition between the dynamic and static solar cells, so the power increase in the second test is higher than in the first tester. A comparison of the performance of the dynamic and static solar panels in the first and second tests can be seen in Figure 5.

Figure 5, based on Table 1 and Table 2, shows the power comparison between dynamic and static solar panels. Based on the figures and tables presented, it can be seen that in the first test the power generated by dynamic and static solar panels is higher than the power generated in the second test, where the average power generated by dynamic and static solar panels in the first test is 81.28 watts and 55.13 watts, the difference between the power generated in the first and second test is due to different weather conditions at the same time on different days. In the second test, the average power generated by the dynamic and static solar panels was 48.11 watts and 30.94 watts respectively, but the difference between the power generated in the first and second tests was due to different weather conditions at the same time on different days. Due to cloudy weather conditions, the sunlight absorbed in the second test was less than optimal and the power generated was not as high as in the first test

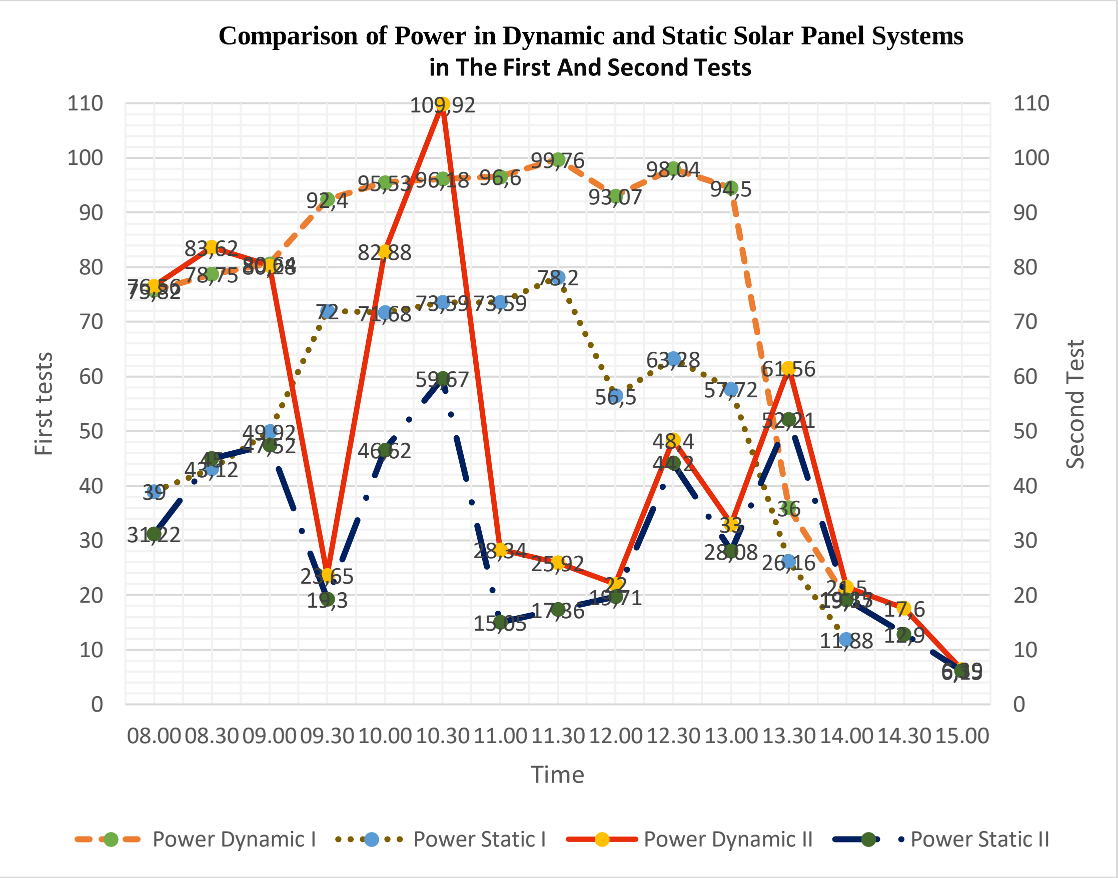

FIGURE 5. Comparison of Power in Dynamic and Static Solar Panel System in The First and Second Tests

IV. CONCLUSION

The results of the tool, namely the dual-axis solar tracker, indicate that it is an effective means of optimising energy for the automatic watering of plants. This is achieved through the use of an LDR sensor, which enables the tool to follow the sun's movement. Furthermore, the tool has the potential to enhance the power generation of a dynamic system in comparison to a static system. The results of the initial trial demonstrated an increase in power generation by dynamic solar cells and static systems by 47%, while the subsequent trial exhibited a 55% increase. The enhanced power generation by the dynamic system or solar tracker system has the capability to expedite battery charging at a faster rate than static solar cells. Consequently, this enables the continuous operation of the water pump for plant irrigation.

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