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# Optimizing the position of photovoltaic solar tracker panels with artificial intelligence using MATLAB Simulink

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**ABSTRACT**

This research aims to apply an artificial intelligence (AI) system to control the position of photovoltaic (PV) panels to maximize the use of solar energy using the solar tracker. The implementation of AI algorithms to achieve optimal panel orientation, considering factors such as sunlight intensity and sun position is also discussed. The simulation results using matrix laboratory (MATLAB) Simulink can be observed on the scope, displaying the position control graph of the solar panel from sunrise to sunset. By employing proportional integral derivative (PID) control, the error is likely to be minimal, ensuring that the panel will continue to follow the sun until it sets at the maximum point of 4:00 PM. After that, the panel can be adjusted back or reset to the initial position at 6:00 AM for the following day. In a full-day simulation, the solar panel will follow the sun's movement from sunset to sunrise. At the basic level, sunrise occurs in the first hour at position 1.0, which is 6:00 AM in the minimum point at the bottom left corner of the curve, and sunset occurs in the afternoon at position 5.25, which is 4:00 PM at the maximum point in the top right corner of the curve.



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## 1. INTRODUCTION

To achieve the goals of national self-reliance and energy resilience, as stipulated in the primary regulation governing energy issues in Indonesia, namely Government Regulation Number 79 of 2014 concerning the national energy policy, the Indonesian government promotes the utilization of renewable energy and restrains the use of fossil energy sources. The policy sets a target for the mix of renewable energy from 2020 to 2050 [1]. Additionally, regulations regarding the use of renewable energy in Indonesia are outlined in Presidential Regulation Number 112 of 2022 concerning the acceleration of renewable energy development for electricity supply [2]. Renewable energy is indeed becoming a primary focus in efforts to reduce the impact of climate change and dependence on fossil fuels [3]-[5]. Many artificial intelligence (AI) technologies are employed in modeling and analyzing renewable energy systems to enhance efficiency, reliability, and performance [6], [7].

Global efforts to find sustainable energy solutions have sparked increased interest in solar energy technologies in the last few decades [8], [9]. As one of the most promising renewable resources, solar energy has significant potential to make a substantial contribution to the world's energy needs [3], [10], [11]. In this context, photovoltaic (PV) panels, serving as the core of the solar energy conversion system into electricity, are receiving special attention [12], [13]. Figure 1 is the solar energy generation by region measured in terawatt-hours (TWh).

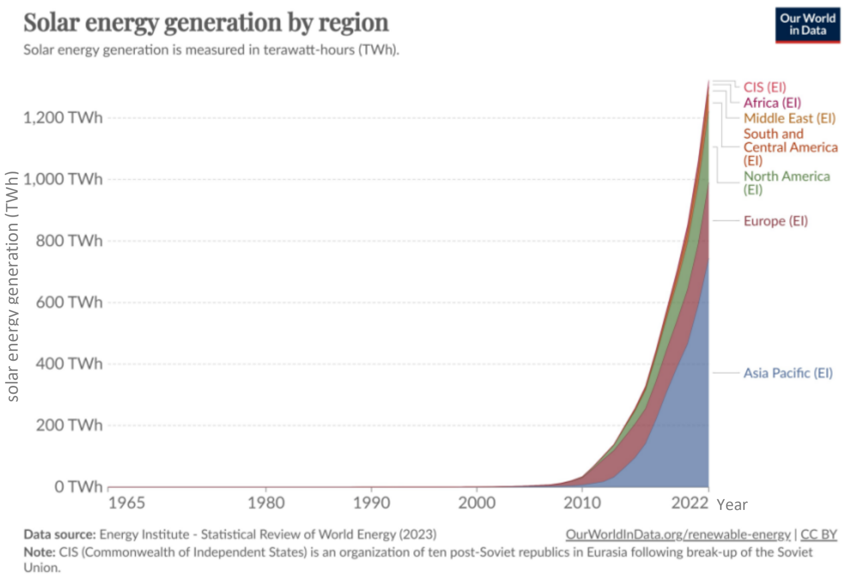



Figure 1. Global solar energy generation [14]

However, challenges associated with the variability of sunlight intensity and the changing position of the sun throughout the day affect the energy output generated by PV panels [15]. Therefore, optimizing the orientation of panels towards sunlight becomes crucial to enhance the efficiency of the PV system [16]. The global development of AI with various applications is illustrated in Figure 2. Where annual patents obtained globally exceeded 30,000 patents for the period from 2018 to 2020.

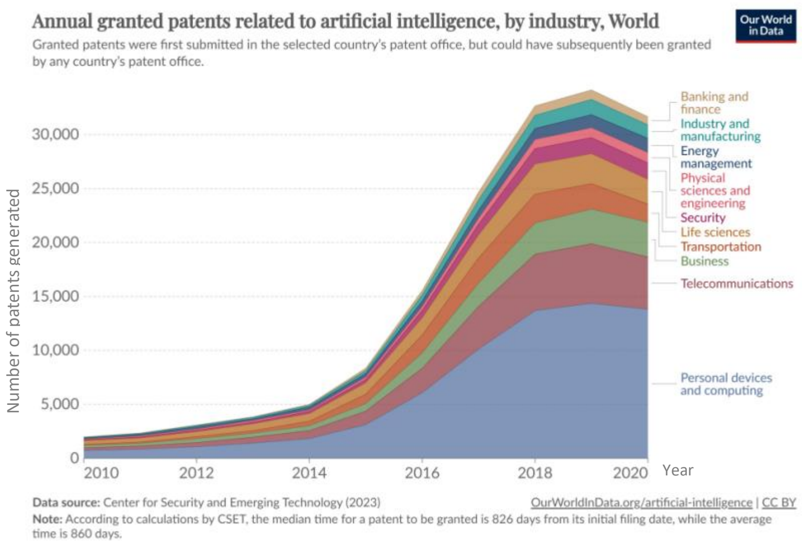



Figure 2. The global development of AI [17]

Integrating AI with the control of PV panel positions presents an innovative solution to various challenges. AI allows the system to learn from past experiences and improve its performance over time. It can adapt to changing environmental conditions, ensuring optimal positioning of the panels. This dynamic optimization maximizes the utilization of solar energy, enhancing overall efficiency.

To understand and implement this solution, this article explores concrete applications of AI in controlling the position of PV panels using the matrix laboratory (MATLAB) Simulink simulation environment. The advantages of MATLAB Simulink in integrating physical models and AI algorithms make it an ideal platform for developing intelligent control solutions for the positioning of PV panels. Through the understanding and implementation of this solution, it is expected that this research can contribute to the discovery of innovative solutions that not only enhance solar energy efficiency but also pave the way for the development of more environmentally friendly and sustainable energy technologies.

Several related studies conducted by previous researchers provide a synthesis of key studies in this field, highlighting methodologies, findings, and research contributions. Shinde *et al.* [18] investigated the integration of proportional integral derivative (PID) controllers adapting to maximum power point tracking (MPPT) for a solar array. Ali *et al.* [19] finded that the Bat Algorithm (PID-BA) performs the best in terms of settling time and overshoot for the sun tracking system on photovoltaic panels. on dual-axis tracking optimization for solar cells using the imperialist competitive algorithm (ICA). Live *et al.* [20] conducted a simulation study of fuzzy auto-tuning PID controllers using MATLAB. Masrur *et al.* [21] explored the optimal tilt angle to maximize PV yields. Mosalam [22] evaluated the operation of an integrated PV system with buildings. Oufettoul *et al.* [23] analyzed the performance of PV module positions in a solar PV array under partial shading conditions. Qais et al. [24] stated that the research utilizes the Three-Diode Model (TDM) for photovoltaic modules, where its optimality is determined by the optimization algorithm used, such as the Circle Search Algorithm (CSA), which provides highly accurate results and lower absolute current error compared to other algorithms. Fahmida *et al.* [25] simulated the maximum power point position of PV using MATLAB simscape. Ikhwan *et al.* [26] applied model predictive control to dual-axis solar trackers using MATLAB Simulink simulations. Ganesan *et al.* [27] focused on modeling and simulating the incremental conductance algorithm for solar MPPT. The distinction of this research from similar studies lies in creating a unique approach to optimizing the position of PV panels and considering the real-time variability of sun position changes. This study utilizes different variables in the PID controller, panel, and motor parameters that will impact MATLAB Simulink simulations.

This research has several objectives that detail its focus and contributions to the understanding and development of solar energy technology. Firstly, the research aims to comprehend the concept of PVs, a crucial process in converting heat energy into electricity. With a profound understanding of this process, the research is expected to provide better insights into the energy conversion mechanism in PV panels.

Next, the research targets an understanding of the movement of the sun solar tracker system, a vital element in energy efficiency for solar panels. This goal includes an analysis of how the movement of solar panels can be optimized to enhance the efficiency of solar energy collection throughout the day. Another key objective is to understand and optimize the movement of solar panels as quickly as possible towards the optimal sun position. A deep understanding of the dynamics of this movement forms the basis for designing a system that is responsive and adaptive to changes in the sun's position.

In addition to the technical aspects, this research has a significant impact on the development of AI to optimize the position of PV panels. By leveraging AI, this research opens the potential to improve the efficiency of solar energy utilization and reduce dependence on conventional energy sources. The benefits of this research include reducing operational costs of power plants through the optimization of renewable energy use, as well as making a positive contribution to the overall development of renewable energy technology. Thus, this research not only aims to deepen the understanding of PV technology but also seeks to provide practical solutions to enhance efficiency and sustainability in solar energy utilization.

## 2. METHOD

The research methodology applied in this project consists of several stages outlining the steps of system development and data analysis. Firstly, the system design involves creating a circuit for the PID controller, panel, and motor. Next, variable determination involves using variable values in the PID controller, panel, and motor simulations to ensure the precision and accuracy of the results. The following are parameter variables for the PV panel and motor set to determine the optimal limits of PID control for the PV position concerning the sun's orientation.

PV Panel:

- Damping coefficient (Kd): the value Kd=5 refers to the damping coefficient in motion control, affecting how quickly the solar panel movement will reach the desired position without significant overshoot.
- Inverse of moment of inertia (1/J): the value 1/J=8.6 indicates the inverse of the moment of inertia of the solar panel, influencing the panel's response to changes in motion.

Motor:

- Motor gain (Kg): the value Kg=2,000 reflects how effectively the motor can transfer electrical energy into mechanical motion.
- Friction coefficient (Kf): the value Kf=0.0700 represents the friction coefficient in the motor, affecting how easily or difficulty the motor can move.

- Torque constant (Kt): the value Kt=0.0700 refers to the torque constant of the motor, related to how much torque the motor generates based on the current passing through it.
- Inverse of inductance (1/L): the value 1/L=1.0000e-05 indicates the inverse of the motor's inductance, affecting the motor's response to changes in current.
- Resistance (R): the value R=10 is the motor's resistance, influencing how efficiently electrical energy is converted into mechanical energy by the motor.

The next step involves the development of an AI model with the design of an adaptive algorithm. This algorithm considers environmental variables to optimize the panel's position relative to the orientation of the sun. Afterward, the integration of AI with the PV panel control system is carried out using MATLAB Simulink, ensuring the alignment and performance of the system.

Simulation and testing are the implementation stages of the PV panel orientation system model into the simulation. This is done to test the system's response to environmental changes and ensure that the system can adapt dynamically. The analysis of results is the final step, involving the evaluation of system efficiency and response in various environmental conditions. Furthermore, the parameter variables on the PV panel and motor are set to determine the optimal limits of PID control for the PV position concerning the sun's orientation. For the PV panel, the variables involve damping coefficient: and inverse of moment of inertia, while for the motor, the variables include motor gain, friction coefficient, torque constant, inverse of inductance, and resistance. The values of these variables are carefully chosen to achieve an optimal balance between system response and energy efficiency.

## 3. RESULTS AND DISCUSSION

### 3.1. Energy conversion in solar panels

Solar power generation with a PV panel system is the predominant type of solar power generation in Indonesia. Its main advantage lies in a more efficient process, making the installation costs more affordable. This power generation system converts solar energy directly into electrical energy through the PV concept.

Based on the Figure 3, a solar cell is an electronic component made of semiconductor material that is sensitive to light. The main component used in the manufacture of solar cells is a photodiode, an electronic component that is responsive to light. This sensitivity allows solar cells to capture sunlight and direct it to the next system to be converted into electrical energy. The basic principle of the PV or PV effect concept is to directly convert sunlight into electricity through the use of solar cells.

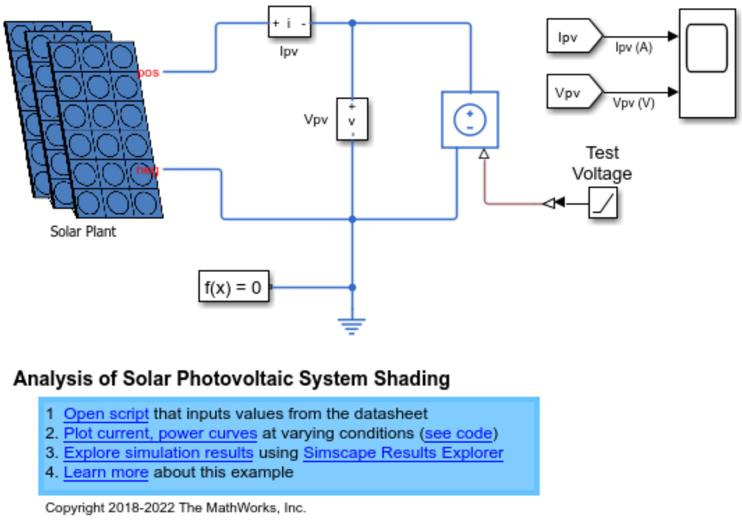



Figure 3. Schematic diagram of PV system

In this concept, solar cells function as a tool to capture light, which contains photons from the sun. Photons are the basic units of solar energy that can be captured by solar cells and then converted into electrical power. Solar cells operate on the principle opposite to light emitting diodes (LEDs), which convert electrical energy into light or can be considered similar to photodiodes in the p-n junction relationship. When photons with higher energy than the energy gap arrive, the semiconductor absorbs these photons to form electron-hole pairs as charge carriers. Subsequently, electrons and holes move sequentially towards the p and n semiconductor layers, creating a potential difference and photocurrent, which is the current generated by light. When photons collide with the solar cell's wall, a process of generating electric current occurs. This process begins when a photon hits the semiconductor wall, causing the loss of an electron in the wall conductor atom. The atom that loses this electron is called a hole. Electrons have a negative charge, while photons have a positive charge. This difference in charge creates an electric current. In a solar cell, voltage and current arise when two connected electrodes are in a solid and liquid system. When the connected electrode receives light from the sun, the voltage and current will automatically appear.

### 3.2. The impact of sunlight intensity

The level of sunlight radiation received directly by solar cells directly affects the voltage and current generated from the PV concept. Under conditions where sunlight radiation intensity remains constant, an increase in environmental temperature can lead to a decrease in voltage on solar panels. Conversely, the electric current generated by solar cells will increase. Changes in temperature on solar cells can be influenced by several factors, including air temperature, cloud conditions, and wind speed around the location of solar panel placement. It is important to understand that fluctuations in sunlight intensity and changes in environmental temperature can have a significant impact on the system's response. Therefore, parameter adjustments on the panel and motor, such as damping coefficient and inverse of moment of inertia, should consider variations in sunlight intensity and temperature changes that may occur. By incorporating these factors into the analysis, this research can provide deeper insights into the performance of the PV system in dynamically responding to environmental variations.

### 3.3. Improvement of efficiency

The efficiency of solar panels can be enhanced through the use of reflectors or concentrators. Reflectors or concentrators shaped like mirrors serve as reflectors and focus sunlight onto the solar cell panels. This reflection of sunlight increases the concentration of light on the solar cell panels, resulting in a significant increase in the generated electrical energy. Studies show that the addition of reflectors or concentrators can increase the power output of solar cell panels by up to approximately 46%. Although this method provides improved performance, it should be noted that concentrating light intensity can lead to a rapid increase in the temperature of the solar cell panels.

The increase in the temperature of solar cell panels can negatively affect the power output. In fact, every 1 ˚C increase in the temperature of solar panels, especially from the standard temperature of 25 ˚C, can cause a decrease of about 0.5% in the total power generated. Therefore, optimizing the efficiency of solar cell panels not only involves increasing light intensity but also considering effective temperature control. High air temperatures can also be a performance-reducing factor for solar panels. Additionally, the presence of shading obstacles can reduce the output of solar panels, and bypass diodes can be implemented as a solution to address this issue. By considering the influence of variables such as light intensity, temperature, and shading, this research leads to a more holistic understanding of the factors that affect the efficiency and performance of solar panels.

### 3.4. Solar tracker

Solar power plants are one of the forms of renewable energy power plants that are increasingly being implemented in Indonesia, especially in areas that are not yet covered by the electricity grid. This system relies on sunlight as the main source of energy and converts it into electricity through the use of solar panels. The power capacity generated by solar panels is determined by the number of solar cells in the panel, as well as the temperature and sunlight radiation that affect these solar panels.

It is known that the orientation of sunlight changes with the axis of the earth's rotational rotation. The intensity of sunlight hitting the surface of the semiconductor diode layer of the solar panel causes electrons in the diode layer to generate a voltage and current difference due to the PV effect. With the voltage and current difference, potential electrical energy is formed, which will be directed to the electrical storage source.

Two strategies can be applied to achieve the maximum power output from solar panels. First, power output control can be done by adjusting the output voltage using a power converter known as MPPT. The schematic diagram of solar tracker is shown in Figure 4 and the simulation is shown in Figure 5. In addition, the power output of solar panels can also be increased by maximizing the sunlight radiation reaching the surface of the solar panel.

To increase the sunlight radiation reaching the solar panel, it can be achieved by adjusting the position of the panel to always be perpendicular to the direction of the sun. This is because the position of the sun changes throughout the day from east to west. Therefore, solar panels need to be able to move in line with the movement of the sun to optimize radiation at all times. This system is known as a solar tracker. The forces on a PV panel are generally related to solar energy and light waves. Changes in frequency or wavelength can affect the amount of energy received by the solar panel.

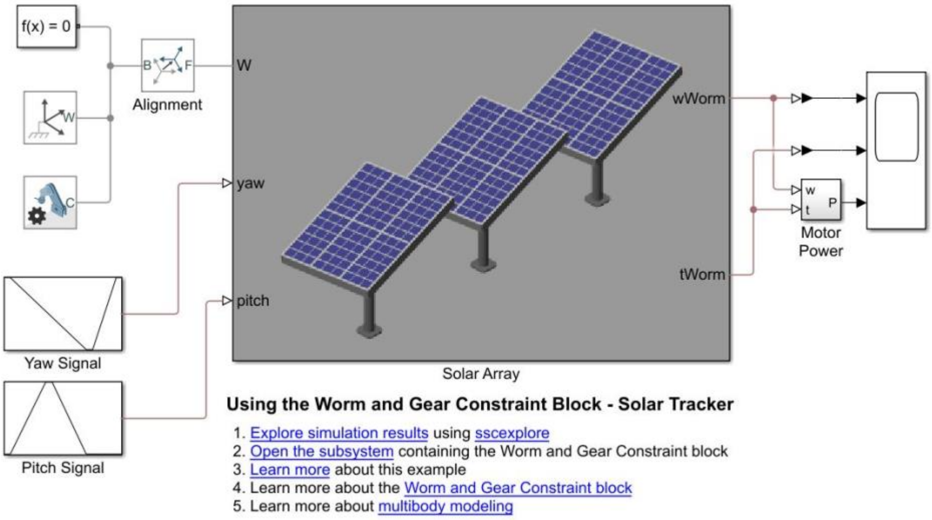



Figure 4. Schematic diagram of solar tracker

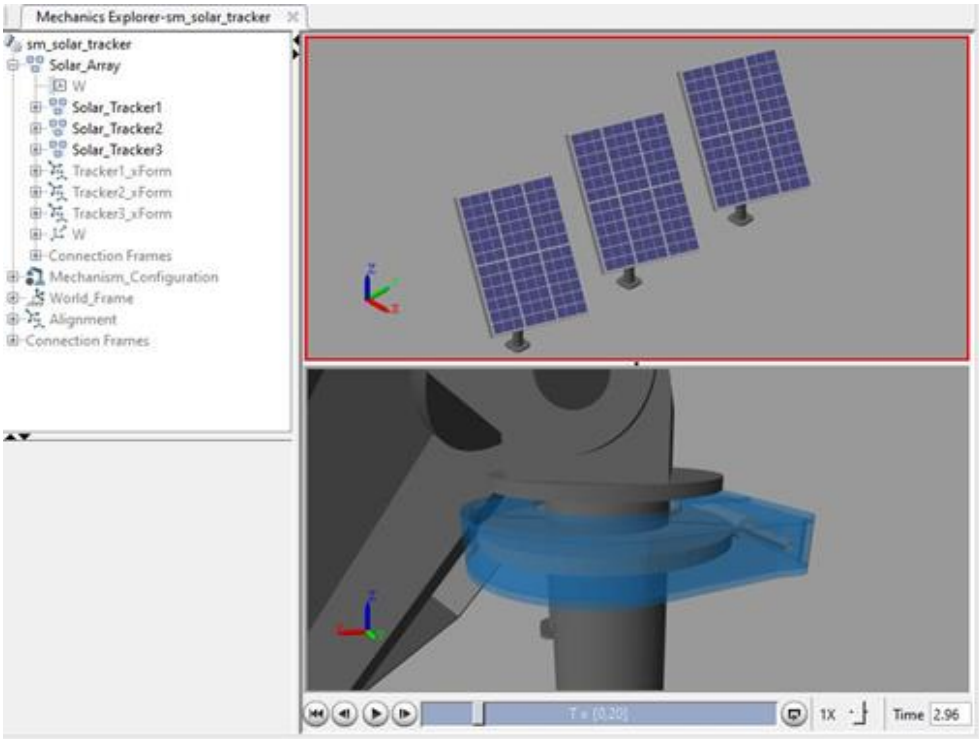



Figure 5. Solar tracker simulation

Based on the Figure 6, when the curve of the PV movement input signal increases, it can reflect a situation where the PV system receives additional energy or signals. This can be caused by factors such as an increase in sunlight intensity, changes in the angle of illumination, or an improvement in the efficiency of solar panels. In this context, an increase in the signal curve can indicate that the PV system is receiving more power or energy, potentially enhancing its performance and electrical output.

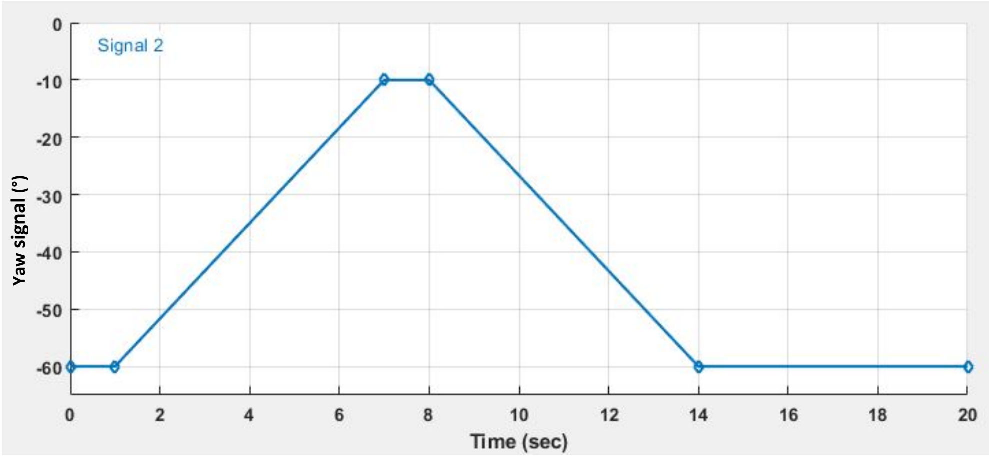



Figure 6. Curve of solar tracker input signal (up)

On the contrary, in Figure 7, a decrease in the PV input signal curve can reflect a condition where the energy or signal received by the PV system is decreasing. Factors that may cause this decrease could include cloud cover, reduced sunlight intensity, or technical issues with solar panels. The decrease in the signal curve may indicate that the PV system is generating less energy or power, which can affect its performance and electrical output.

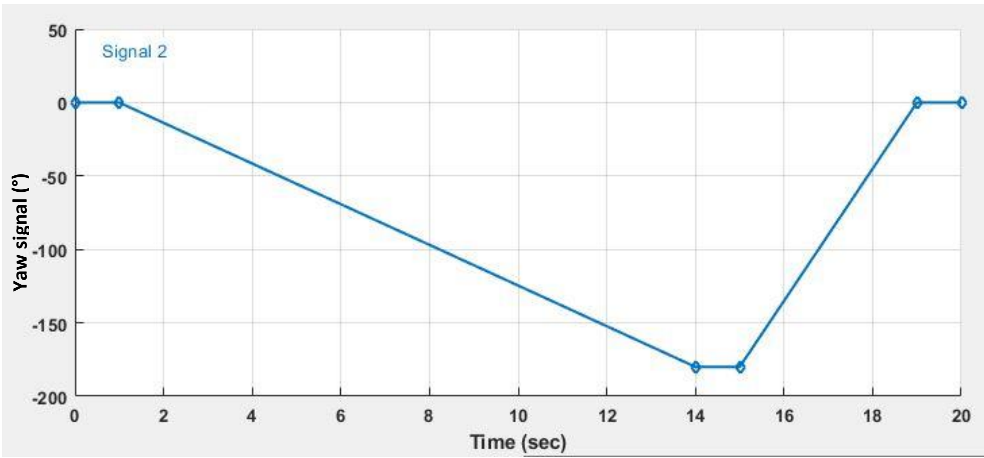



Figure 7. Curve of solar tracker input signal (down)

Figure 8 demonstrates a maximum worm angular velocity of 2245 deg/s, indicating the system's capability for rapid adjustments. The solar tracker also exhibits a maximum motor torque of 0.2 Nm, highlighting its mechanical strength. Additionally, the maximum motor power of 3.85 kW showcases its energy efficiency. The system's response to changes in the signal curve illustrates its ability to react swiftly to fluctuations in the operational environment.

The high maximum angular velocity of the worm at 2245 deg/s indicates the system's ability to respond quickly and accurately to changes in the sun's position. This is crucial for maximizing the efficiency of solar energy collection. The maximum motor torque of 0.2 Nm indicates the motor's ability to move the solar tracker system with sufficient power to overcome resistance and potential loads during operation.

The high maximum motor power of 3.85 kW suggests that the motor can supply sufficient power for efficient operation of the solar tracker system. This level of power ensures the motor can drive the system effectively. Adequate motor power is crucial for achieving the necessary speed and torque. Consequently, it supports the system's ability to track the sun accurately and reliably.

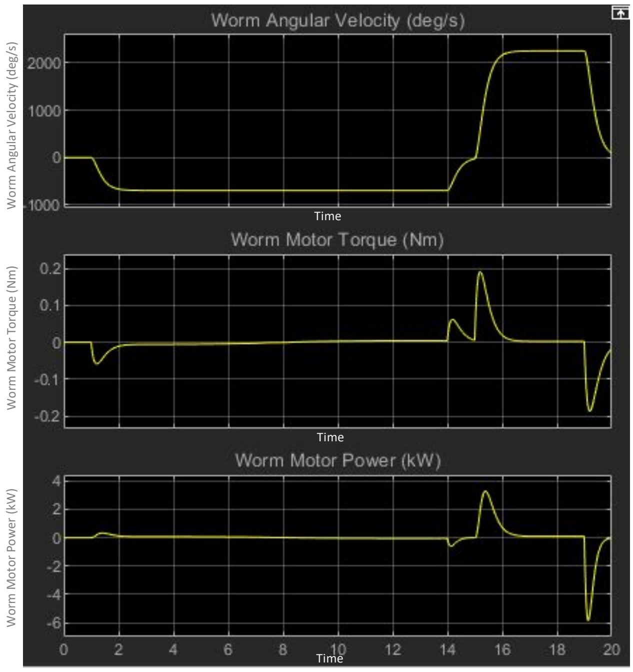



Figure 8. Graphs of worm angular velocity, motor torque, and motor power

### 3.5. Solar panel control using proportional integral derivative

The sun, as an energy source, undergoes movement that must be tracked by solar panels to generate energy optimally. Solar panels need the ability to track the sun's movement, which occurs continuously due to the earth's rotation on its axis. Typically, solar panels are installed without adjusting their position to follow the sunlight, resulting in suboptimal output voltage.

To address this issue, devices are used to adjust the tilt of solar panels, allowing them to dynamically follow the sun's position. This continuous adjustment maximizes sunlight exposure throughout the day. As a result, the output voltage of solar panels is significantly enhanced. Panels with this dynamic scheduling perform better compared to those without it.

A controller is needed to regulate the movement of solar panels, and in this paper, the design of a controller using the PID method is carried out to control the position of solar panels optimally along the sun's path. Modeling and simulation are done using Simulink in MATLAB, an interactive environment for numerical calculations, visualization, and programming. The use of MATLAB enables data analysis, algorithm development, and the creation of models and applications.

PID control, as one of the control methods, is employed to improve the system's response. Proportional control amplifies the error signal, speeding up the system's output towards the setpoint. The relationship between the controller input u(t) and the error signal e(t) in Figure 9 is described in (1) [18].

$$u(t) = Kp\, e(t) \tag{1}$$

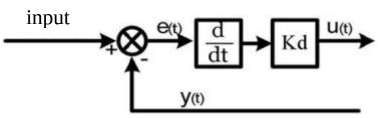



Figure 9. Block diagram of proportional control

The input signal will be summed with the feedback signal, and the error generated from this summation operation will be multiplied by the proportional constant (Kp) to produce the controller input u(t). The integral control function (Ki) is essentially designed to eliminate offset errors that often arise from proportional control. The relationship between the integral control output u(t) and the error signal e(t) based on Figure 10 is described in (2) [18].

$$u(t) = Ki \int_0^e e(t)\, d(t) \tag{2}$$

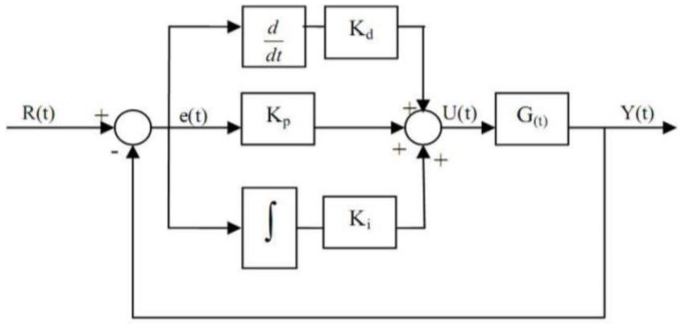



Figure 10. Block diagram of integral control

Description:
u(t): PID controller output signal
Kp: proportional constant
Ki: integral constant
Kd: derivative constant
e(t): error signal
d(t): disturbance

Derivative control is often referred to as a speed controller because its output is directly proportional to the rate of change of the error signal. The block diagram of derivative control is shown in Figure 11. The relationship between the derivative control output u(t) and the error signal e(t) is described in (3) [18]. This control method helps improve the system's response to changes in the error signal.

$$u(t) = Kd\, \frac{d(e)t}{dt} \tag{3}$$

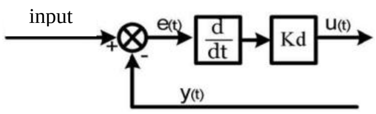



Figure 11. Block diagram of derivative control

The combination of the three controllers forms a PID controller. PID controllers are commonly used in control processes and systems. The equations for a PID controller are provided, and Figure 12 shows the block diagram of the PID controller [18].

$$u(t) = Kp\, e(t) + Ki \int_0^e e(t)\, d(t) \tag{4}$$

Explanation:
u(t): PID controller output signal
Kp: proportional constant
Ki: integral constant
Kd: derivative constant
e(t): error signal
d(t): disturbance

The creation of the PID controller system consists of several subsystems, including the motor and the control panel, as shown in Figure 13. Initially, the researcher designs the motor movement system. Next, the researcher develops the control panel. Finally, these two subsystems are integrated into a single PID controller solar tracker system.

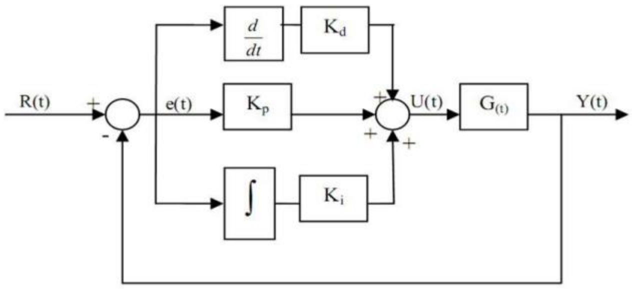



Figure 12. Block diagram of derivative control PID

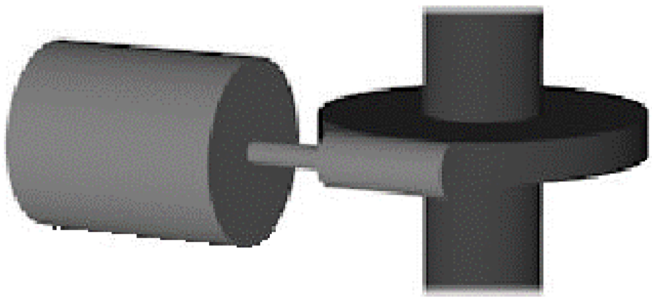


Figure 13. Control motor

The first subsystem designed is the motor control, as illustrated in Figure 14. This subsystem includes the equations for the motor that generates torque to rotate the solar panel. These equations describe the electromagnetic motion necessary for the system's operation [18].

$$\frac{di}{dt} = \frac{1}{L}\left(V - K_g K_f \frac{d\theta}{dt} - R_i\right) \tag{5}$$

Explanation:
di/dt: derivative of current with respect to time, depicting the change in electric current in the motor
L: motor inductance
V: motor input voltage
Kg: gear ratio constant
Kf: friction constant
dθ/dt: derivative of rotation angle with respect to time, depicting the angular velocity of the motor
R: motor resistance.

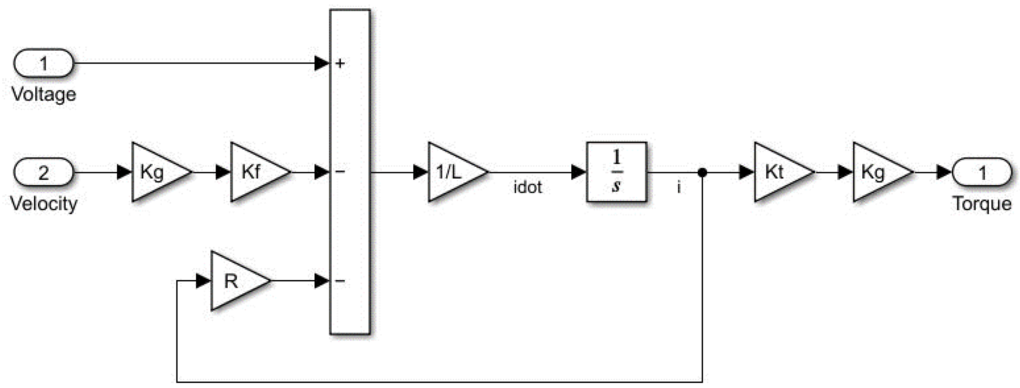



Figure 14. Control motor sub system

Motor torque equation [18]:

$$T = K_g K_t I \quad (6)$$

Explanation:
T: Motor torque produced
Kg: Gear ratio constant
Kt: Motor torque constant
I: Motor current

In (5) reflects the electromagnetic motion equation, explaining the relationship between voltage, current, and torque in the motor. In (6) describes the relationship between current and motor torque. Both equations are essential in modeling and controlling the motor in a solar tracker system.

The second subsystem designed is the solar panel controller as shown in Figure 15. This subsystem in Figure 16 describes the motion equation for the solar panel rotating on its central axis. The rotation of the solar panel is influenced by the torque generated by the motor. The motion equation is expressed as follows [18].

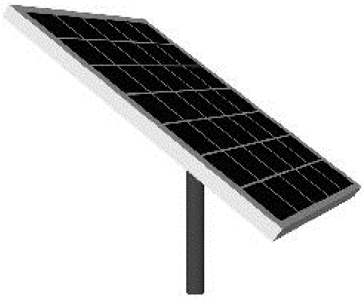


Figure 15. Controller panel

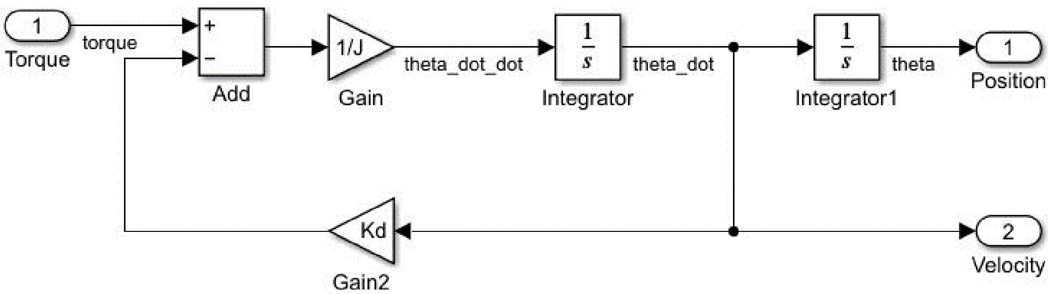



Figure 16. Controller panel subsystem

$$\frac{d^2\theta}{dt^2} = \frac{1}{J}\left(T - K_d \frac{d\theta}{dt}\right) \quad (7)$$

Explanation:
*T*: torque generated by the motor.
*$dt^2/d^2\theta$*: angular acceleration of the solar panel with respect to time, describing the change in angular velocity.
*J*: moment of inertia of the solar panel.
*T*: torque generated by the motor.
*Kd*: damping coefficient in the angular motion of the panel.
*$dt/d\theta$*: angular velocity of the solar panel with respect to time, describing the change in the rotation angle.

In (7) explains how the solar panel responds to the torque applied by the motor. It shows how the panel's angular motion is influenced by the moment of inertia and the damping coefficient. This equation is crucial for accurately modeling the dynamics of solar panel rotation. Understanding these dynamics is essential for optimizing the performance of a solar tracker system.

After the motor subsystem and the panel controller subsystem are created, these two subsystems are integrated into one PID controller solar tracker system. In this model, the controller outputs voltage to the motor to rotate the solar panel to the desired position. The reference signal is a step unit. Constant voltage is applied to the motor.

To increase the exposure of solar radiation on solar panels, it can be achieved by adjusting the position of the panel surface to always be perpendicular to the direction of the sun. The sun moves throughout the day from east to west. Therefore, solar panels need to be able to move to follow the changing position of the sun to receive maximum radiation at all times. This system is known as a solar tracker.

The forces on PV panels are generally related to solar energy and light waves. Changes in frequency or wavelength can affect the amount of energy received by the solar panels. To create a solar tracker, researchers first initiate motor movement by raising steps considered as the input signal, as shown in the schematic diagram in Figure 17, to change the position of the sunlight. With the step set to 1 and the simulation time running for 10 seconds in Simulink, a graph of the position and speed of the solar panel is generated, as shown in Figure 18.

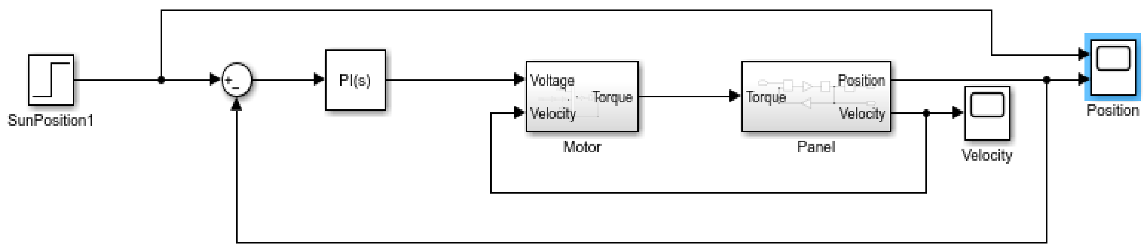



Figure 17. Schematic diagram of PI panel control

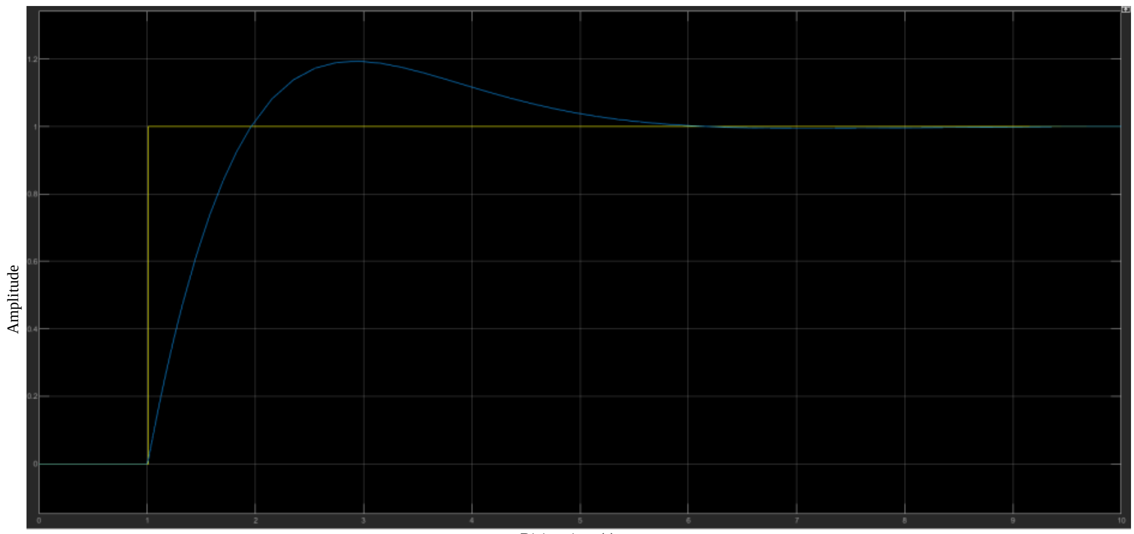



Figure 18. Graph of solar tracker position against solar orientation

It can be observed from the graph in Figure 18 that in the simulation over 10 seconds, the controller panel takes a considerable amount of time, specifically 2 seconds, to adjust itself until it reaches the overshoot point. Then, the position of the controller panel will return to normal, following the normal position of sunlight. This forms the basis for the panel movement if controlled using a PI controller.

When the sun's position is set using a step with a square wave signal amplitude increased by 1A, the panel position will follow its maximum point. However, there is an overshoot that causes the panel position graph to differ or there is an error from the actual sun position. Nevertheless, over time, this overshoot will decrease and return to normal relative to the sun's position. This makes the motor return to the maximum sun position. Figure 19 is the simulation result of proportional-integral motor control.

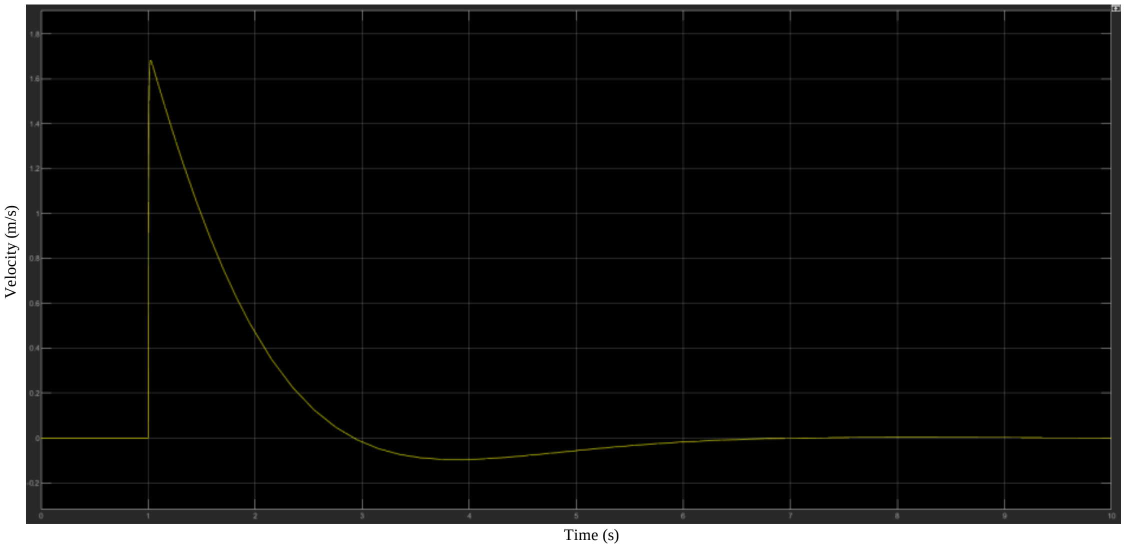



Figure 19. Graph of solar tracker speed against solar orientation

It can be observed from the graph in Figure 19 that the rotational speed of the panel will increase in the first second. When the rotation of the solar panel motor is heading towards the maximum point of sunlight, the curve will drop to 0, indicating that the motor has stopped. In the second experiment, the motor position initially moves, as indicated by the curve rising from 0 to 1.6 A. Then, there is a decrease from 1.6 A to 0 A, which means that the sun has been followed by the solar panel and is in a good position.

To make this solar tracker system more precise and accurate, the researcher simulated the control of the solar panel in real time by inputting data on the position and time of solar orientation, as shown in Figure 20. MATLAB Simulink must recognize the position and time data through the use of sunPositionData and sunTime to create more realistic simulation results. Afterward, a comparison can be made between the position and time based on the Figure 21.

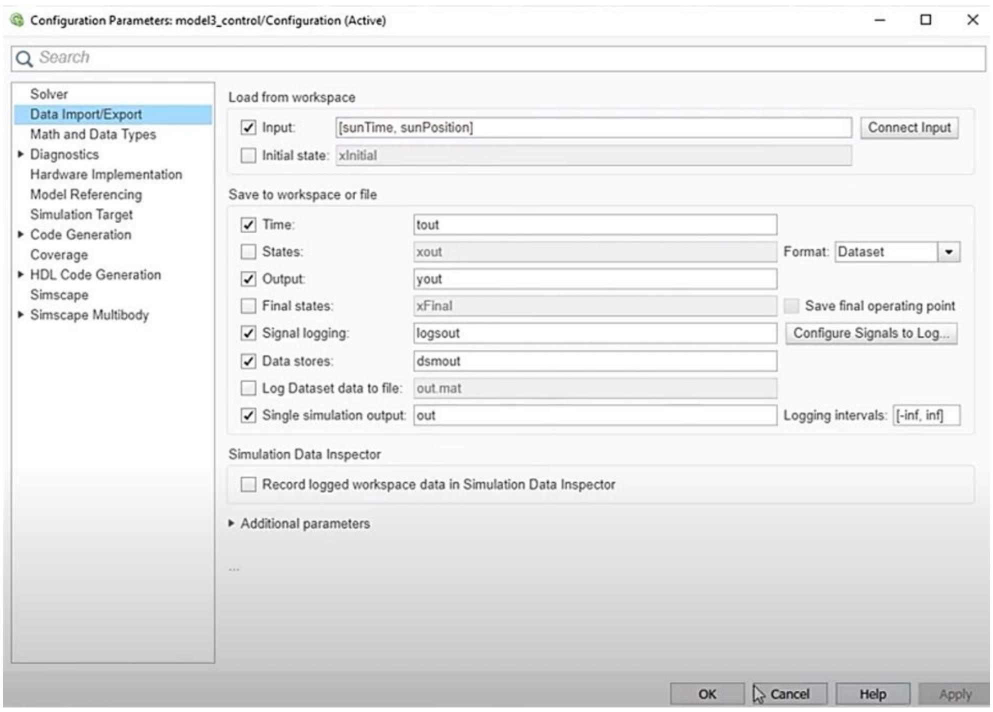



Figure 20. Input of sunPositionData and sunTime

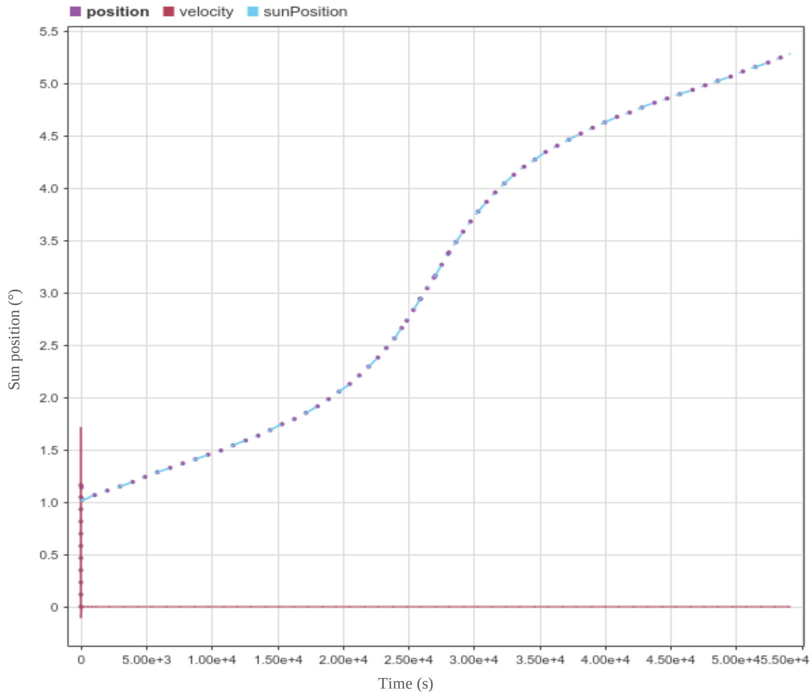
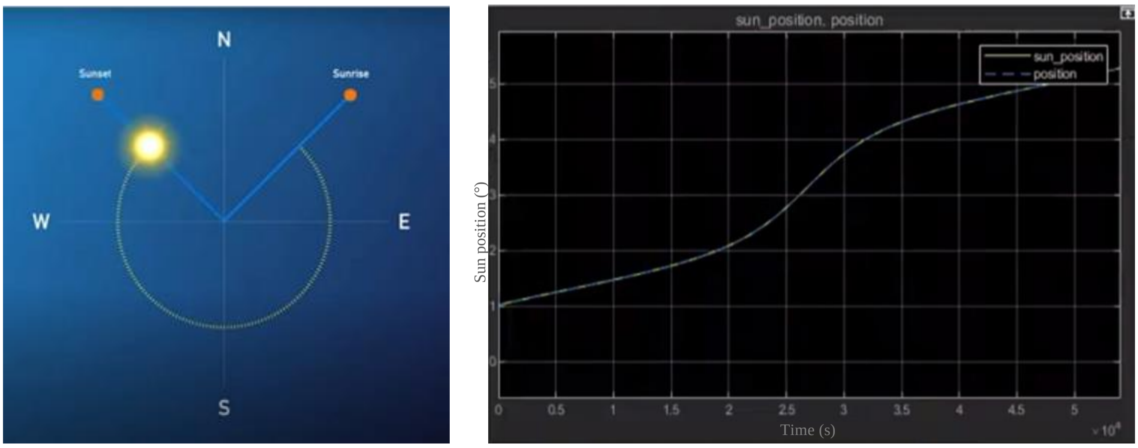



Figure 21. Graph of solar tracker position and speed according to solar orientation

Figure 22 shows the graph of the solar tracker position according to the solar orientation. In a full-day simulation, the solar panel follows the movement of the sun from sunrise to sunset, as depicted in Figure 22(a). At the basic level, sunrise occurs in the first hour at position point 1.0, which corresponds to 06:00 AM at the minimum point at the bottom-left corner of the curve. Sunset occurs in the afternoon at position point 5.25, which corresponds to 4:00 PM at the maximum point at the top-right corner of the curve in Figure 22(b). The panel will rotate for a total of 10 hours in this MATLAB Simulink simulation.




(a) (b)

Figure 22. Graph of the solar tracker position according to the solar orientation on the scope (a) illustration of the movement of the sun and (b) the slope position based on the movement of the sun

The simulation results can be observed on the scope, displaying the position control graph of the solar panel from sunrise to sunset. The yellow line represents the sun's position, while the dashed blue line indicates the panel's movement. By using PID control, the error is likely to be minimal, so on the graph, the panel will continue to follow the sun until it sets at the maximum point at 4:00 PM. After that, the panel can be adjusted back or reset to the initial position at 6:00 AM for the next day.

Although our research provides valuable insights based on the research findings, it is not without limitations. One limitation is the scope of the experimental setup, which may not fully reflect real-world conditions. Future research could explore more diverse scenarios and incorporate additional variables to enhance the applicability of the findings. Furthermore, investigating the long-term performance and durability of optimized solar panel systems would provide valuable information for practical implementation.

## 4. CONCLUSION

Increasing the efficiency of solar panels can be achieved by using reflectors or concentrators that reflect and focus sunlight onto the solar cells. While adding reflectors can enhance power output, the risk of increased solar panel temperature must be considered, requiring a careful balance between output improvement and potential temperature rise. Solar tracking systems, or solar trackers, provide an effective solution for enhancing solar panel efficiency through PID control, involving proportional, integral, and derivative components, to optimally adjust the position of solar panels. Modeling and simulation using PID methods in MATLAB allow for in-depth analysis of the system's response to changes in sun position, representing a tangible effort to maximize sunlight reception by solar panels. Incorporating motors and PID control, solar trackers address overshoot and adapt to changes in sun position according to simulation results. The next step involves integrating AI into panel positioning control through MATLAB Simulink. While challenges related to AI implementation are acknowledged, this approach offers potential advancements for intelligent and adaptive PV systems. Simulation results in MATLAB Simulink display the position control graph of the solar panel from sunrise to sunset. By employing PID control, the error is minimized, ensuring the panel follows the sun until it sets at 4:00 PM, after which it can be reset to the initial position at 6:00 AM for the following day. In a full-day simulation, the solar panel follows the sun's movement from sunrise to sunset, with sunrise at 6:00 AM at the minimum point on the curve and sunset at 4:00 PM at the maximum point.

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