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PID Controller Simulation on Single Axis Solar Tracking System

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ABSTRAK

Efisiensi yang rendah pada solar cell dipengaruhi oleh beberapa factor yaitu tingkat radiasi, suhu, dan sudut instalasi. Penelitian ini membahas upaya meningkatkan performa solar panel yaitu dengan menggunakan sistem pelacak surya sumbu tunggal. Dalam penelitian sistem pelacak surya sumbu tunggal ini dimodelkan dengan menggunakan PID controller pada software Matlab Simulink. Dalam metode tracking system, solar cell disimulasikan pada sumbu tunggal yang berorientasi pada sudut elevasi, sebagai masukan dan pengoptimasian kontrol posisi yang tepat terhadap arah pergerakan matahari pada pukul 07.00 – 17.00 wib. Hasil simulasi didapatkan penggunan kontrol PID pada perancangan single axis solar tracking system menunjukkan hasil yang baik, dimana kontroler yang dirancang dapat mendeteksi arah pergerakan matahari dengan cukup akurat. Sudut elevasi terendah yaitu 1,7 derajat dan tertinggi 68,21 derajat. Solar tracking system memiliki potensi menyerap lebih banyak radiasi matahari untuk mendapatkan output lebih baik yang dihasilkan dari solar cell.

Kata kunci: *solar cell, sumbu tunggal, tracking system, PID controller, Simulink Matlab*

ABSTRACT

The low efficiency of the solar cell is influenced by several aspect, namely radiation levels, temperature, and tilt angle. This research discusses improving solar panels' performance using a single-axis tracking system. This research modelled a single-axis of solar cell tracking system using a PID controller in Matlab Simulink software. In the tracking system method, the solar cell is simulated on a single axis oriented to elevation angle as input and optimization of precise position control to direct the sun's movement at 07.00 – 17.00 WIB. The simulation results shown that using a PID control in designing a single-axis of solar cell tracking system shows significant results, where the controller design can accurately detect the direction of the sun's movement. Furthermore, the lowest elevation angle is 1.7 degrees, and the highest is 68.21 degrees. Furthermore, solar tracking systems have the potential to absorb more radiation for a greater output of solar cells.

Keywords: *solar cells, single axis, tracking system, PID controller, Simulink Matlab*

1. INTRODUCTION

The development of renewable energy now increasingly popular. It has a regeneration of the energy supply needed by the public, which requires for development of technology in sector renewable energy to sustainably produce clean electrical energy without fossil fuel emissions **(Jamroen et al., 2020)**. Producing electrical energy sourced from renewable energy, it's a step to keep the environment continuously **(Amelia et al., 2020)**. Solar energy utilizes solar radiation, called clean energy, because it pollutes the climate and environment the least **(Racharla & Rajan, 2017)**. Solar energy sources have a considerable potential on Indonesia island, up to 4,8 kWh/m^2/day or around 112,000 GWP, which can be generated and distributed **(Sukmajati & Hafidz, 2015)**.

The employment of sunlight by using solar cells as a power plant has begun to be developed to decrease the use of fossil fuels. One way to convert sun energy into electrical energy is to use solar cell devices or photovoltaic (PV) modules **(Mane et al., 2018)**. Developing the solar panel industry can increase energy supply from fossil fuels to renewable energy sources and support sustainable development to reduce carbon emissions **(Jamroen et al., 2021)**. The output potential of solar cells is affected by several factors: temperature, radiation level, and angle of tilt of solar panels **(Pulungan et al., 2021)**. The efficiency of solar panels can be increased by including supporting components such as a cooling system, maximum power point tracking (MPPT) system, and sun tracking system **(Ocłoń et al., 2020)**.

One way to improve the performance of solar panels is to use a solar tracking system which aims to keep solar panels parallel to the direction of the sun track and increase the intensity of sun radiation that falls on the surface of solar panels **(Aung, 2019) (Halder et al., 2021)**. An estimated solar tracking system on solar panels increases output power by 40 – 50% **(Hanwate & Hote, 2018)**. Solar tracking systems can be divided into two categories single-axis and dual-axis **(Batayneh et al., 2019)**. One axis is oriented at varying azimuth or elevation angles in the single-axis tracking system method. In contrast, the dual-axis solar tracking system uses both axes synchronously combined **(Sabir & Ali, 2016)**. The single-axis tracking system is widely usaged in its implementation because it is cheap and easy to apply. Solar cells are driven using a controlled dc motor **(Banik et al., 2021)**. Solar cells were then designed using Matlab Simulink PID control to optimize the exact position between a solar cell and the sun **(Setiawan et al., 2013)**. This study evaluates the performance of the solar cell control system using the PID Controller to obtain optimization on the solar cell through simulation on the Matlab Simulink software.

2. RESEARCH METHODOLOGY

This study discusses the use of tracking systems on solar panels using numerical and Simulink simulation modelling methods in the software Matlab R2021a. This study's type of solar tracker system is single-axis solar tracking. Simulation modelling is done by previewing the specifications of solar cells used. The type of solar panel module used in this simulation is the LUMINOUS model LUM150P polycrystalline solar panel, which has a Standard Test Condition (STC), spectrum AM1.5, 25°C cell temperature and the irradiance of 1000 W/m^2. In addition, this solar panel has several characteristics, including having positive tolerance to ensure higher output and good performance under weak light conditions. For more detailed specifications, see Table 1.

Table 1. Solar Panel Spesification

Description	Value
Solar Panel Model	LUM150P
Power Maximum (Pmax)	150 W
Power Voltage Maximum (Vmp)	18,2 V
Power Current Maximum (Imp)	8,25 A
Open–Circuit Voltage (Voc)	22,1 V
Short–Circuit Current (Isc)	8,83 A
Efficiency of Module	15,24%
Temperature of Operation	-40°C to + 85°C
System Voltage Maximum	1000 Vdc
Maximum Series Fuse Rating	15 A
Tolerance of Power	0~+5 W
NOCT	46°C±2°C
Temperature Co-efficient of Pmax	-0.398%/°C
Temperature Co-efficient of Voc	-0.34%/°C
Temperature Co-efficient of Isc	0.0576%/°C

The angle of the tilt solar cell varies between 0 – 90°. Thus the solar cells need to adjust every month. For solar panels with an orientation facing north, angle adjustments need to be made between 0 – 40° from March to September, While solar panel with an orientation facing south adjusts the tilt angle between 0 - 30° from October to March **(Handoyo et al., 2013)**. In this study, 4 series of solar panels are connected in parallel with an angle of tilt is 30°.

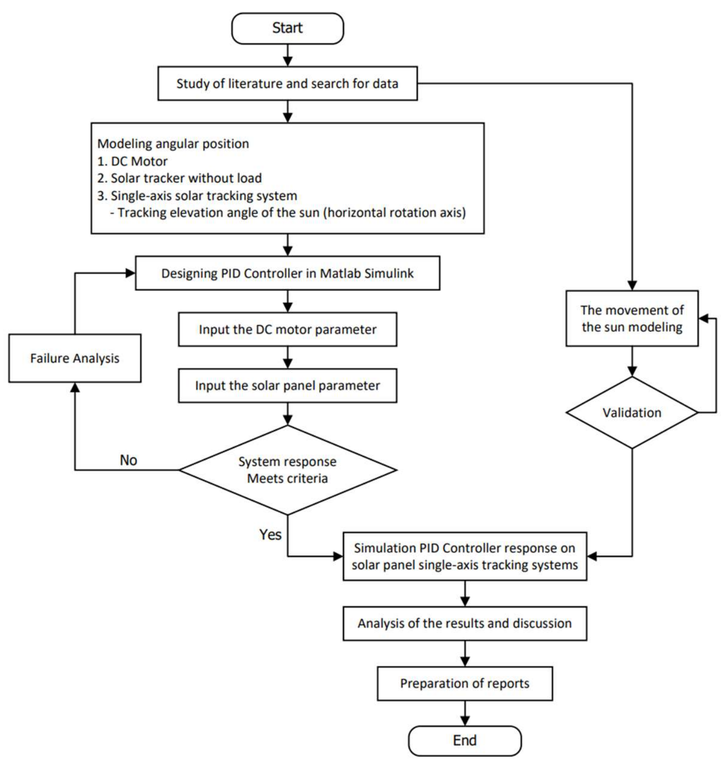

Figure 1. Flowchart of The Design of PID Controller Solar Cell Tracking System

In the flow diagram of the single-axis solar tracking system, a model of the movement of the dc motor and solar panels is made in Matlab Simulink. First, the modelling data used are categorized into two according to each subsystem. The next stage is to design a PID control with parameters (Kp, Ki, Kd). Then both are modelled according to the input data, namely the sun's position and time angle, and verified to get the appropriate solar tracking system on the solar panel. If the resulting response does not meet the criteria for the control system, it can be reviewed by evaluating the steps taken. And the last step is to make an analysis and a final drafting report.

2.1 Solar Cell Characteristics

Solar cells output characteristics are in the shape of a non–linear curve affected by temperature and sun radiation levels **(Revati & Natarajan, 2020)**. Characteristics of solar panels can be seen in the graphical modelling of the relationship between current (I) and voltage (V) and the graph of a relationship between power (W) and voltage (V). The solar panel temperature graph is 25°C with variations in the level of solar radiation; it is 400 W/m^2, 600 W/m^2, 800 W/m^2, and 1.000 W/m^2.

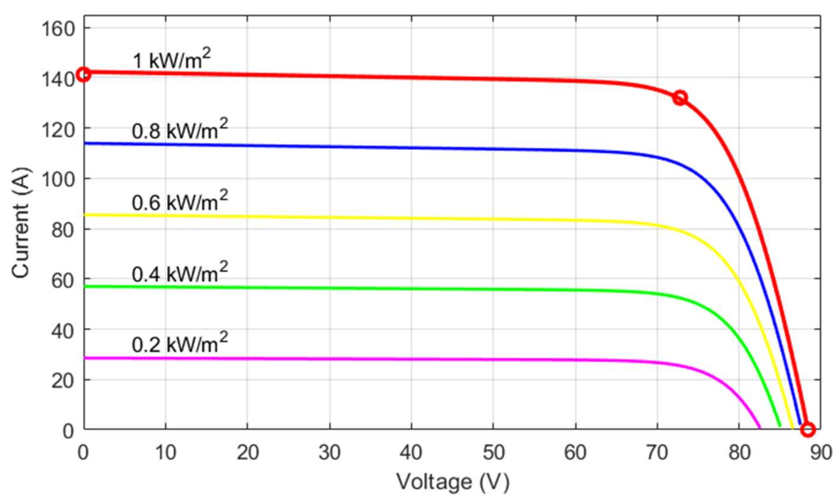

Figure 2. Solar Cells I-V Characteristics

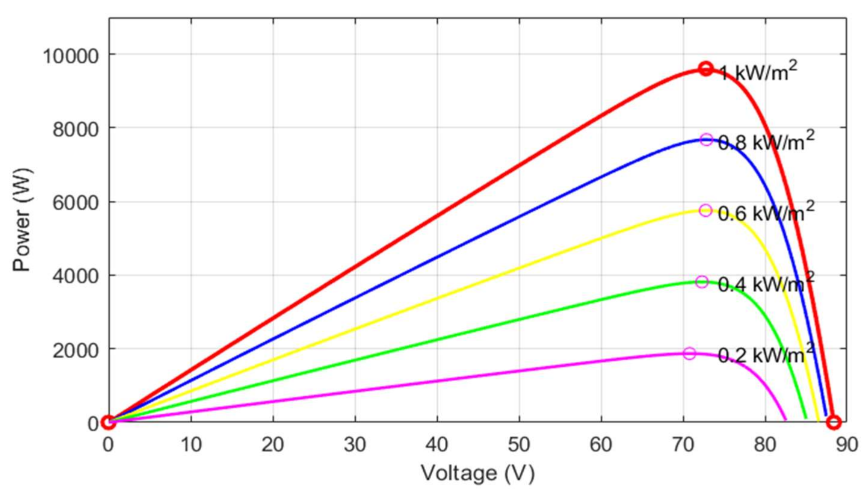

Figure 3. Solar Cells P-V Characteristics

Figures 2 and 3 show that the current (I) remains constant with increasing voltage up to the maximum point, but it's getting longer and less. In this case, it is stated that solar radiation's intensity significantly affects the solar panel's output performance.

2.2 Tracking System of Solar Cell

A system of solar tracking is an automatic control system on solar panels that detect sun motion to get optimal light intensity. To improve the performance of the solar tracking system, the angle of tilt and orientation of solar panels is set perpendicular to the direction of the sun's rays, aiming to produce an optimal amount of radiation each year **(Singh et al., 2016)**. Solar tracker systems are classified into single-axis and dual-axis solar tracker systems. Single axis tracking system is a single-axis sunlight tracking system control that usually follows the direction of the sun's motion from sunrise to sunset. While dual-axis solar tracking system uses dual axes with different degrees so that each axis can rotate well from east to west (zenithal) and north to south (azimuth) **(Hafez et al., 2018)**.

2.3 PID Controller System Design

In this study, the PID controller is applied to optimally control the solar cell's position according to the sun's path based on the movement of elevation angle and azimuth angle using Matlab Simulink. PID control consists of three constant parameters, including proportional value, integral value, and derivative value. By adjusting these three parameters, the control can be designed as a stage of a particular process.

2.3.1 Proportional Control (K_p)

Proportional control (K_p) is a simple control that amplifies the drive error signal to accelerate system output to reach a set point. Where is formulated as follows:

$$U(t) = K_p \, e(t) \tag{1}$$

The connection between input controller U(t) and the error signal e(t) can be seen in Figure 4. The proportional control block diagram below:

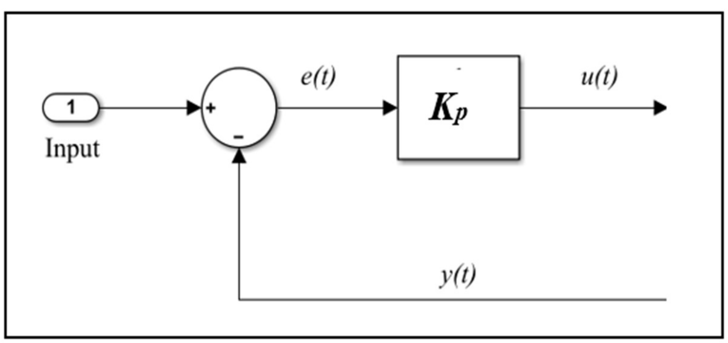

Figure 4. Block Diagram Of Proportional Control (K_p)

Figure 4 explains that the input will be summed with feedback, and then the error signal generated from summation is multiplied by the proportional constant (K_p), producing controller input U(t).

2.3.2 Integral Control (K_i)

Integral control (K_i), in principle, aims to eliminate the offset error usually generated by proportional control (K_p). Integral control could be formulated as follows:

$$U(t) = K_p\, e(t) + \frac{K_i}{\tau} \int_0^t e(\tau)\, d\tau \tag{2}$$

The relationship between integral control output U(t) and error signal e(t) can be seen in Figure 5. The integral control block diagram below:

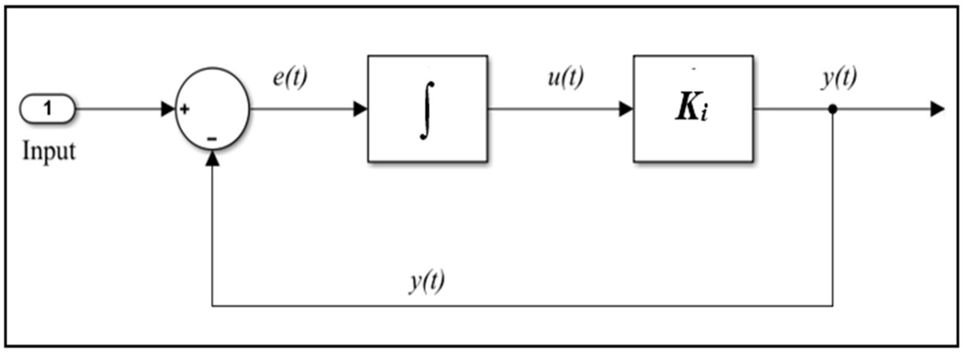

Figure 5. Block Diagram Of Integral Control (K_i)

2.3.3 Derivative Control (K_d)

Derivative control (K_d) can also be called speed controller, and this is because the controller's output is proportional to the rate of change of the error signal. Derivative control can be formulated as follows:

$$u(t) = K_d \frac{de(t)}{dt} \tag{3}$$

The relationship between derivative control output (K_d) and error signal e(t) can be seen in Figure 6. below:

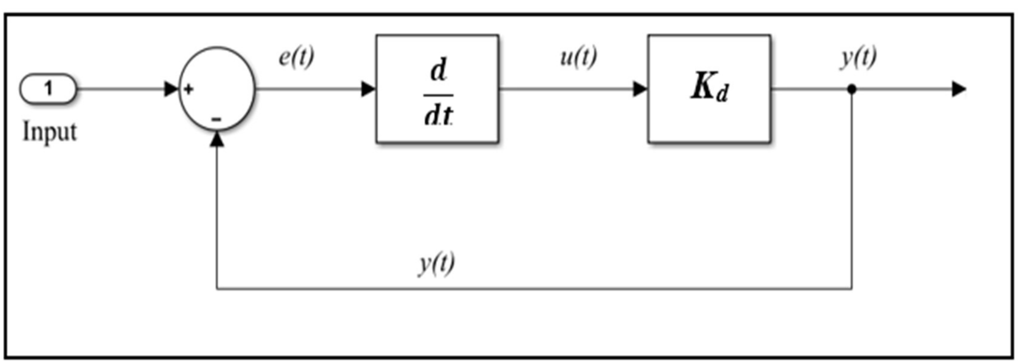

Figure 6. Block Diagram Of Derivative Control (K_d)

A combination of three controllers will be used as PID control. This PID control is usually widely used in process control or control systems. For example, the blow is an equation and block diagram of PID control in Figure 7 **(Wang, 2020)**.

$$U(t) = K_p\, e(t) + \frac{K_i}{\tau} \int_0^t e(\tau)\, d\tau + K_d \tau_D \frac{de(t)}{dt} \tag{4}$$

Keterangan :
U(t) : Controller Output Signal PID
Kp : Constant Proportional
Ki : Constant Integral
Kd : Constant Derivative
e(t) : Error Signal

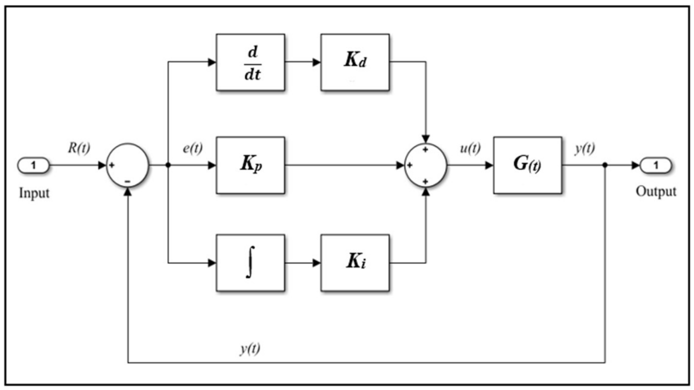

Figure 7. Block Diagram PID (Proportional Integral Derivative) Controller

3. RESULT AND DISCUSSIONS

3.1 Simulink Solar Panel Without Tracking System

This study uses a simple Matlab Simulink scheme, where the solar panel input data consists of irradiance level and temperature. The input data used is variation in the irradiance level at an average temperature of 26,7°C in Depok city in early July 2022 at 07.00 – 17.00. Simulink design can be seen in Figure 8 below.

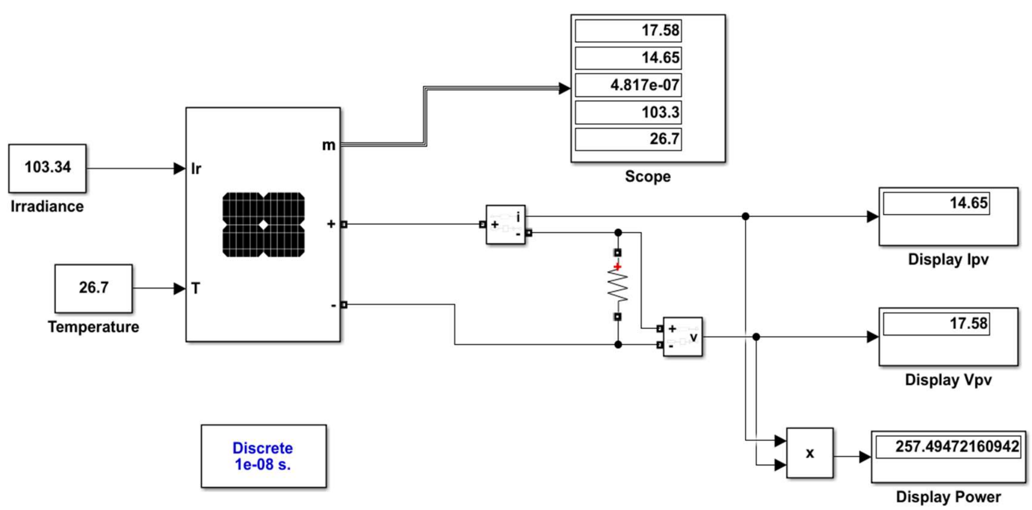

Figure 8. Simulink Solar Panel Testing Without Tracking System

Results of the Simulink solar cell test without a tracking system with variations in irradiance and the average temperature in Depok city in early July 2022 are shown in Table 2 below.

Table 2. Solar Cell Test Results Without Tracking System

No	Hours	Irradiance (W/m^2)	Temperature (°c)	Ipv (A)	Vpv (V)	WattPeak (Wp)
1	07.00	43,12	26,7	6,13	7,36	45,21
2	08.00	228,35	26,7	32,09	38.50	1235,53
3	09.00	354,13	26,7	49,26	59,11	2911,69
4	10.00	440,46	26,7	58,95	70.74	4170.30
5	11.00	463,20	26,7	64,31	77.17	4963.87
6	12.00	447,77	26,7	59,50	71,41	4248,91
7	13.00	418,23	26,7	56.97	68,37	3894,83
8	14.00	353,21	26,7	49,14	58,96	2897,28
9	15.00	262,46	26,7	36,79	44,15	1624,43
10	16.00	174,19	26,7	24,57	29,48	724,39
11	17.00	103,34	26,7	14,65	17,58	257,49

From the observations in simulation at a constant temperature of 26,7°C, it can be shown in Figure 9 that the highest output value of solar panel power is located at around 11.00, with an irradiance of 463,20 W/m^2 and produces a power output of 4.963,87 Watt peak (Wp)/hour. On the other hand, the lowest power output value is at 07.00 with an irradiance of 43,12 $W/m^{2,}$ and the resulting power output is 45,21 Watt peak (Wp)/hour, and at 17.00 with an irradiance of 103,34 W/m^2 and an output of 257,49 Watt peak (Wp)/hour.

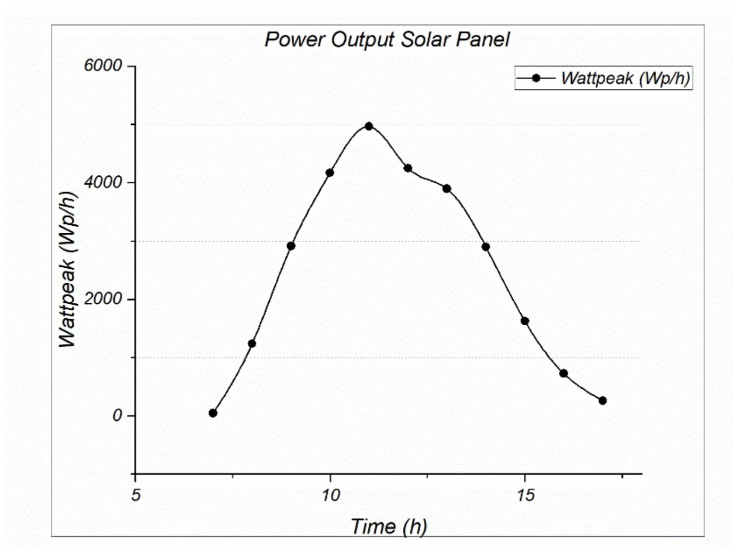

Figure 9. Solar Panel Power Output Chart Without Tracking System

3.2 Drive DC Motor Subsystem

The solar panel tracking system course requires a driving motor to move and position the solar panel following the sun's rays. The driving motor subsystem controls movement in the appropriate direction at the desired speed.

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

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

The following are parameters used in the DC motor subsystem driving the solar tracking system.

Table 3. DC Motor Drive Subsystem Parameters

Motor Parameter	Value	Unit
Error discriminator (Kg)	2000	V/rad
Amplifier gain (Kf)	0.0700	V/V
Servo amplifier (Kt)	0.0700	V/V
Inductance (L)	1.0000e-5	Kg.m^2/rad
Resistance (R)	10	Ohm

In Table 3, it is stated that the data parameters inputted to the PID control, such as error discriminator (Kg), amplifier gain (Kf), Servo amplifier (Kt), inductance (L), and Resistance (R). Then the parameters are summed and verified by analyzing the system response, as shown in Figure 10. Finally, the reliability of the PID control is determined by inputting the unit value reference into the solar tracker system and observing the resulting response.

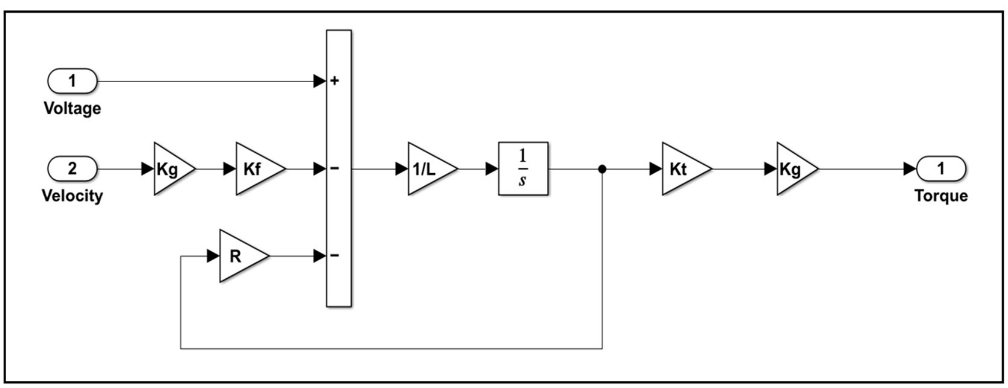

Figure 10. Drive DC Motor Subsystem

3.3 Solar Panel Subsystem

Solar cell subsystem is made as the direction of position solar cell to sun motion by changing torque from DC motor to motion of controlling change in the position of solar cell. Direction is a way of positioning solar cells to the sun's motion by changing torque from the DC motor to control the position change of solar cell.

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

The following are parameters used in the solar panel subsystem, as shown in Table 4.

Table 4. DC Motor Drive Subsystem Parameters

Solar Panel Parameters	Value	Unit
Torque constant (Kd)	5	Nm/A
Inertia moment (J)	8,6	$Kg.m^2$

In the solar panel subsystem, the input value used is the result of the summing of the DC motor driving subsystem, which is based on the parameter data in Table 4. In addition, verification is carried out to observe and analyze the response generated by the solar panel subsystem in Figure 11.

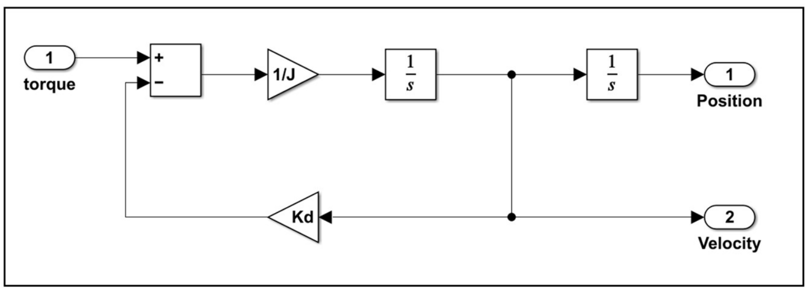

Figure 11. Solar Panel Subsystem

3.4 PID Controller Solar Tracking System Analysis

Design model of solar tracker system using PID controller is to integrate each subsystem, it is driving DC motor and solar panels, and then PID control and scope are made from simulation results in form plots of position and velocity, as can be seen in Figure 12 below.

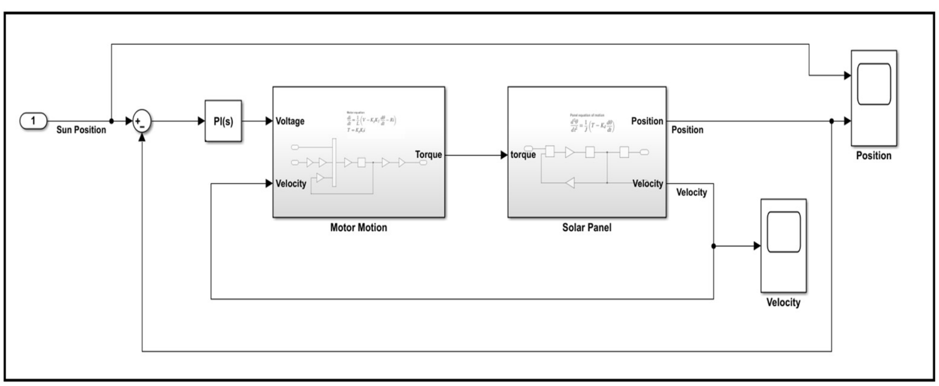

Figure 12. Simulink Solar Tracking System With PID Controller

When the Simulink program is run, it can be seen in the results of the plot position, where the yellow line is an indicator of the sun position and the blue colour is an indicator of the position solar panel. It is assumed that the sun's position will be constant in its orbit, and the solar panel's position will follow its direction. Still, there is an overshot on the graph, which is indicated by the presence of 1 amplitude slightly deviating from the sun's direction. But it will slope and immediately position the solar cell suitable to the point facing the sun and follow its position's direction, as shown in Figure 13 below.

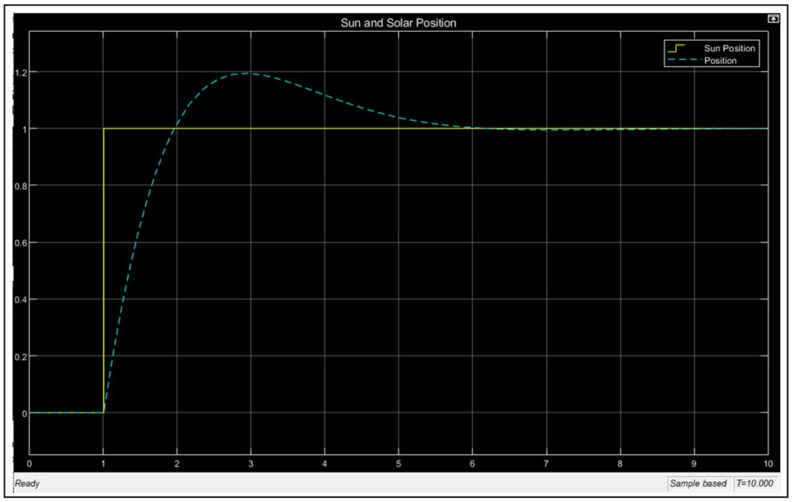

Figure 13. Plot Design Solar Tracking System With PID Controller

The speed of the solar cell can be shown in scope velocity, where the speed of the solar cell will increase in the first second. DC motor will move solar cells according to the sun's direction; if appropriate, it could be said that the solar tracker system is working correctly.

3.5 Result Analysis of Solar Tracking System

Testing of the tracking system on the solar cell was carried out using data on the position of the sun according to the elevation angle of the sun in the Depok City area at latitude (-6.40719°) and longitude (106.815835°) in early July 2022 starting at 07.00 - 17.00 WIB. The lowest elevation angle is at 07.00, which is 1,7 degrees, and at 17.00, which is 23,68 degrees. In comparison, the highest elevation angle is 12.50 at 68,21 degrees.

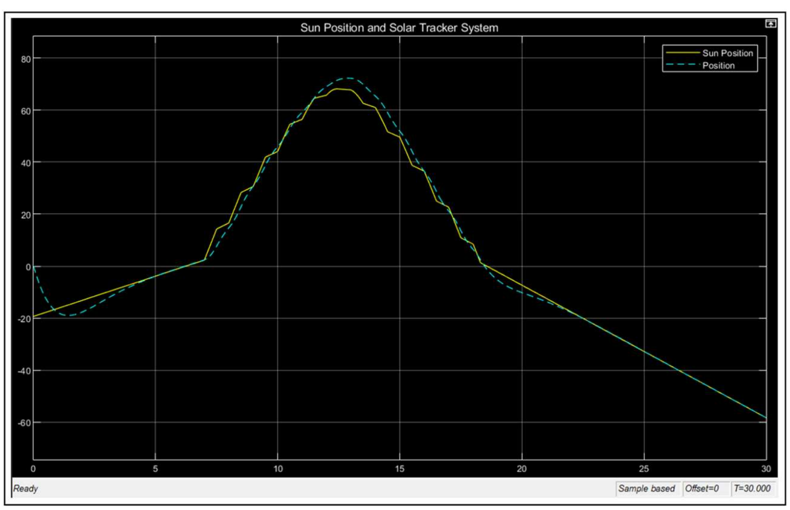

Figure 14. Plot Result Solar Tracking System With PID Controller On Elevation Angle

Furthermore, test data is integrated with Simulink on Matlab R2021a as input data in tracking modelling solar system simulation, as seen in Figure 14, seen in the graph of simulation results using Matlab Simulink software using PID control. Where can be seen in the graph, the level of error in the positioning of a solar panel is smaller than before. Therefore, the solar cell tracking system will work following the sun's rays from morning to afternoon, and when it reaches its maximum point, the solar panel can be set back to its first position for the next day.

4. CONCLUSIONS

The implementation of solar panels as a source of clean electrical energy sourced from solar energy has a significant output if it is developed optimally. From the research that has been done, it can be concluded that the solar tracker system can potentially increase power output in the application of solar cells. The use of PID control in the model of a single-axis solar tracker system shows good results, where the controller that has been designed can detect the direction of the sun's movement quite accurately. Furthermore, this solar tracking system can absorb more solar radiation than a passive solar panel system, where the greater irradiance obtained will be proportional to the output produced by a solar cell.

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