

Design and Construction of Photovoltaic Charger Optimization Using Temperature Control Based on Proportional Integral Derivative Controller

Elsa Marcela Candra Devi¹, Slamet Hariyadi^{2*}, Dwiyanto³, Hana Catur Wahyuni⁴

^{1,2,3}Politeknik Penerbangan Surabaya, Jl. Jemur Andayani 1 No. 73, Surabaya, Indonesia

⁴Universitas Muhammadiyah Sidoarjo, Indonesia

*Correspondent Author, Email : slamethariyadi396@yahoo.com

Article Info	ABSTRACT
Article history: Submitted: June 15, 2024 Final Revised: June 25, 2024 Accepted: June 25, 2024 Published: June 30, 2024	
Keywords: Water Treatment Plant Water Clustering ESP32 Water pH Sensor DS18B20 Sensor Turbidity Sensor Fuzzy Logic Thingspeak Website	This research designs and builds a photovoltaic charging system optimized with temperature control using PID (Proportional Integral Derivative). This system aims to improve charging efficiency and extend service life by controlling the temperature that affects the performance of the photovoltaic charger. Solar cells are used to convert solar energy into electricity, which is then regulated by the solar charger controller before going to the battery. Arduino controls the temperature of the solar cell by activating the air pump based on the PID algorithm and displays temperature, voltage, and current data on the LCD. As a result, this system is able to improve charging efficiency and maintain the temperature within the desired limits, thereby extending the service life of the charger.

1. INTRODUCTION

The demand for energy, especially electricity, continues to increase along with population growth in Indonesia. Dependence on fossil resources such as natural gas, coal, and oil that are increasingly depleted and have significant environmental impacts is driving the acceleration of the transition to renewable energy. One promising alternative is solar energy, which has shown rapid growth both globally and nationally.

In an era where conventional energy resources are increasingly limited and the impact on the environment is increasingly felt, the development of renewable energy is very important at this time. Especially solar energy, which has great potential as a reliable and environmentally friendly renewable energy source.

Photovoltaic technology offers an environmentally friendly solution to generate electricity from sunlight. Photovoltaic chargers are used to convert solar energy into electrical energy that can be stored in batteries for use in various electronic devices, such as mobile phones and remote monitoring systems. By optimizing the charging system on photovoltaic batteries by utilizing proportional integral derivative-based temperature control, it is hoped that it can increase the efficiency of renewable energy use and reduce our dependence on conventional resources.

Indonesia's energy demand is projected to rise by 70% in the next decade, with electricity comprising 32% of this demand. Fossil fuels accounted for 86% of electricity generation in 2018, contributing significantly to national CO2 emissions, Zahari, T. N., & McLellan, B. C. (2023). Indonesia has an estimated solar energy potential of 207.8 GW, making it a key player in renewable energy development, Pambudi, N. A., & Ulfa, D. K., (2024). The implementation of photovoltaic systems, especially with optimized charging systems, can significantly improve energy efficiency, Marhatang, M., AM, S. Y., Muhammad, R. D., Rifaldi, A., & Winarty, C., (2023). Strategies to enhance energy security and sustainability are essential for the successful adoption of renewable energy in regions like North Halmahera, Perdana, A. A., Wijaya, M. E., & Ichsan, I., (2022).

Based on several reasons above, it was decided to conduct a study with the title "DESIGN AND CONSTRUCTION OF PHOTOVOLTAIC CHARGER OPTIMIZATION USING TEMPERATURE CONTROL BASED ON PROPORTIONAL INTEGRAL DERIVATIVE CONTROLLER".

2. LITERATURE REVIEW

2.1. Solar Energy

Solar radiation, as an infinite energy source, has become the focus of intensive research in the development of renewable energy technology. The abundant potential of solar energy, especially in tropical areas such as Indonesia, has encouraged the diversification of primary energy sources. The conversion of solar energy into electrical energy through photovoltaic technology and solar thermal power plants are the most common examples of applications. In addition, the integration of solar architecture and the exploration of artificial photosynthesis open up new opportunities to increase the efficiency of solar energy utilization. The formation of a p-n junction creates an internal electric field, facilitating the movement of excited electrons, which generates an electric current, Jasim Hasan AlTimimi, M. (2023). The intensity and spectrum of sunlight directly affect energy conversion rates, Sharma et al., (2022).

2.2. Solar panels

Solar cells, silicon-based semiconductor devices, operate on the principle of converting light energy into electrical energy. The interaction between solar photons and the silicon crystal structure results in the splitting of electron-hole pairs. The p-type and n-type semiconductor layers that are connected form a p-n junction, creating an internal electric field. When photons are absorbed, electrons are excited throughout the p-n junction, producing an electric current. The energy conversion efficiency of solar cells is greatly influenced by the properties of the semiconductor, cell structure, and the intensity and spectrum of solar radiation. Solar energy technologies can significantly reduce reliance on fossil fuels, potentially avoiding millions of tons of CO₂ emissions annually, Kumar et al., (2023). The integration of solar energy into various sectors, including agriculture and industry, highlights its versatility and potential for sustainable development, Obaideen et al., (2023).



2.3 Battery

Batteries in solar cell systems act as electrical energy storage. The reversible electrochemical process allows batteries to convert electrical energy into chemical energy during charging and vice versa into electrical energy during discharging. The redox reactions that occur at the electrodes and electrolytes are the basis of this energy conversion process. Secondary batteries, which can be recharged many times, are commonly used in solar cell systems because of their efficiency and small size.



Figure 2. Solar Cell Battery Construction

2.4 Proportional Integral Derivative (PID)

For instance, in DC motor control, the P component helps regulate rotor speed effectively, achieving a settling time of approximately 0.68 seconds, Setyawan, R. T. (2024). In load frequency control systems, the I component is crucial for maintaining stability in power generation and demand balance, Jangiri, S., & Jones, K. O. (2024). In solar tracking systems, the D component smooths the actuator's movement, enhancing the accuracy of solar panel positioning, Widyaningrum, V. T., Romadhon, A. S., & Safitri, D. (2023). While PID controllers are widely used for their simplicity and effectiveness, they may struggle in highly dynamic or non-linear environments. Advanced optimization techniques, such as genetic algorithms, are being explored to enhance PID performance in these complex scenarios, Joykutty, L., & Caulkins, J. (2023).

Proportional Integral Derivative (PID) is a controller that optimizes the precision of an instrumentation system through feedback that takes into account the error between the desired value and the actual output to produce a precise control signal. Each PID component has a specific function:

- a. Proportional
Proportional action provides an immediate response to changes in error but cannot eliminate steady-state error.
- b. Integral
Integral action gradually reduces steady-state error but can cause overshoot if not properly adjusted.
- c. Derivative
Estimates future error trends by considering the current rate of change of error, producing a control signal that dampens rapid changes, ensuring a smooth response.

2.5 Solar Cell Cooling System

A cooling system is designed to regulate the temperature of a system by moving heat energy from a hotter area to a cooler area. This cooling process can be done through various mechanisms, such as convection, conduction, and radiation. A cooling fluid, such as water or air, is generally used as an intermediary medium to absorb heat.

2.6. DC Water Pump

A DC (Direct Current) water pump is a pump that is powered by direct current electricity, usually from a limited resource such as a battery or solar panel. This pump is more efficient in energy use than an AC water pump because it does not require an inverter to convert alternating current to direct current. In addition, DC water pumps can operate at low voltages, making them ideal for off-grid applications and in remote locations that are difficult to reach.



Figure 3. DC water pump

2.7 ESP32

ESP32 is equipped with internal flash memory. In addition, this module also supports connections to external flash, allowing for larger data storage. ESP32 has an internal RTC that allows the device to track time in real time, even when in power-saving mode, Wijaya, P. M., Kusuma, A. P., & Romadhona, R. D. (2024). This is useful in applications that require scheduling or time recording.



Figure 4. ESP32

2.8. Solar Charge Controller

A solar charge controller is an electronic device that plays a crucial role in a solar power system. This device functions to regulate the flow of electric current from the solar panel to the battery with high precision. Through sophisticated control mechanisms, this controller ensures that the battery is charged safely and efficiently, and prevents damage from overcharging or over-discharging. Two types of controllers commonly used are PWM and MPPT. PWM controllers regulate the charging rate by modulating the pulse width, while MPPT controllers actively track the maximum power point of the solar panel to maximize system efficiency.



Figure 5. Solar charger controller

3. RESEARCH METHOD

3.1. Research Design

This research design has been visualized in the form of a flowchart. A flowchart is a graphical representation that uses special symbols to describe the sequence of steps in a process. Thus, this flowchart serves as a clear and structured roadmap for the implementation of this research.



Figure 6. Research Flow Diagram

3.2. Tool Design

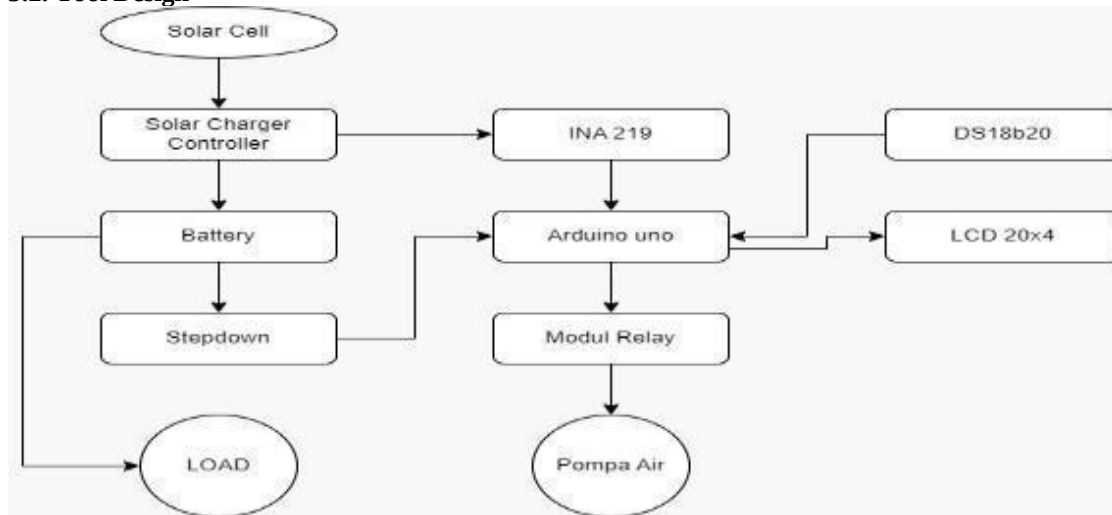


Figure 7. Tool Block Diagram

From the solar cell to the SCC to regulate the current and voltage produced by the solar panel, then into the battery to charge the battery. From the battery supply the load and kr stepdown module to lower the voltage and then used to supply the Arduino. Arduino will read the voltage and current data from the ina219 sensor and the temperature from the ds18b20 sensor and then display it on the LCD20x4. Arduino will also control the relay module that goes to the pump to activate and deactivate the pump with the PID algorithm based on the temperature input that is read to regulate the temperature of the solar cell with water media through water spray from the pump.

4. RESEARCH RESULTS AND DISCUSSION

4.1. Solar Panel Testing

The author uses a 20 WP solar panel. This component is the main object that will be the generator to charge the battery voltage and receive the cooling system work process.



Figure 8. Tool Design



Figure 9. Polycrystalline Solar Panels

Table 1. Solar Panel Test Results

4.2. INA 219 Sensor Testing

INA 219 Sensor Testing must be carried out to determine whether the installed sensor is working according to its function or not. This test is important because a sensor that is not functioning properly can cause errors in measurement and data analysis. Testing is carried out using a hair dryer as a tool to provide a heat load on the system, thus allowing verification of the accuracy of current and voltage measurements by the INA219 sensor.

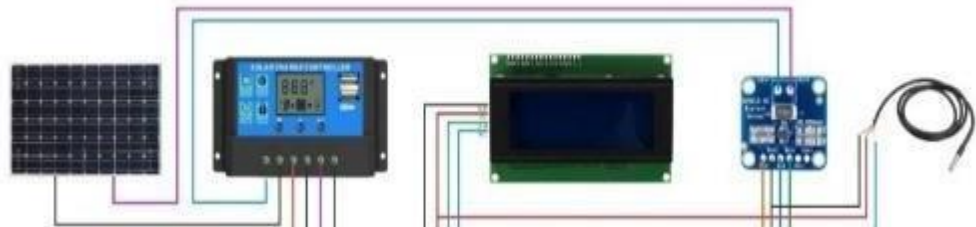


Figure 10. INA219 Sensor Circuit

Table 2. INA219 Test Result

No	Voltage	Current	AVO	LCD
1	13,74	0,05		
2	13,70	0,05		
3	13,91	0,116		

No	Measurement (V)	Appearance LCD (V)	Difference (V)	Error (%)
1	13,6	13,5	0,1	0,735%
2	16,3	16,2	0,1	0,735%
3	17,0	16,8	0,2	1,176%
4	17,2	17,1	0,1	0,735%
5	17,3	17,2	0,1	0,735%
6	12,4	12,3	0,1	0,735%
7	13,2	13,1	0,1	0,735%

Overall, the error that occurs in the INA219 sensor measurement is relatively small, ranging from 0.578% to 1.176%. This shows that the difference between the values measured by the measuring instrument and those displayed on the LCD is quite small and can be considered accurate for practical purposes. The average error obtained is around 0.75%, which indicates that this sensor has quite good reliability in voltage measurement.

4.3. Temperature Sensor Testing

In this study, the DS18B20 temperature sensor is used to measure the surface temperature of the solar panel. This sensor is an electronic device that is sensitive to temperature changes. The analog output signal from the sensor is then processed by the microcontroller to obtain accurate temperature data.

The use of sensors can be determined through comparative calculations between the DS18B20 sensor and the digital thermometer by looking at the error value, and if the error value is known, then the sensor can be declared feasible and accurate so that it can be calculated for the error comparison using the following formula:

$$e = \frac{|X_o - X_s|}{X_o} \times 100\%$$

Information:

E = Error (%)

X_O = Actual Data

X_S = Sensor Data

Table 3. Temperature Measurement Results

No	Sensor Ds18B20	Thermogun	Selisih	Error (%)
1	32,75°C 	32,20°C 	0,50	0,50%
2	36,81°C current 	36,60°C 	0,20	0,57%
3	40,44°C	39,30°C	1,14	2,91%

No	Sensor Ds18B20	Thermogun	Selisih	Error (%)
				

4.4. Testing Solar Panel Output Voltage

This study aims to identify the effect of watering on the output voltage produced by solar panels.

Table 4. Solar cell solar panel output voltage results

No	(Time)	Temp start °C	Set Point temp	Volt Output start	Temperature end °C	Output end (VOLT)
1.	11.00	38,2°	32°	19,5	34,2°	13,6
2.	11.15	39,7°	32°	20,6	35,1°	13,6
3.	11.30	39,8°	32°	20,6	35,4°	13,6
4.	12.05	39,6°	32°	20,3	34,0°	13,4
5.	12.45	39,7°	32°	19,8	34,5°	13,4
6.	13.00	38,6°	32°	20,7	33,9°	13,2

4.5. Air Flow Testing on Solar Cell Cooling System

This study aims to determine the air flow rate required during the solar panel cooling process through watering. The test was carried out by filling a 3000ml bucket with air and connecting it to a DC water pump. The airflow data obtained:

Table 5. Water Debit Testing Result

No	Start Temperature °C	Volt Output start (Volt)	Fill Debit Water start (ML)	End temperature °C	Volt Output end (Volt)	Fill Debit water end
1	38,2°	19,5	3000	34,2°	13,6	2600
2	39,7°	20,6	2600	35,1°	13,4	2200
3	39,8°	20,6	2200	35,4°	13,6	1800
4	39,6°	20,3	1800	34,0°	13,3	1400
5	39,7°	19,8	1400	34,5°	13,2	1000
6	38,6	20,7	1000	33,9°	13,2	750

4.6. PID Testing

PID Control works by calculating the error value by comparing the actual output value with the desired value.

Error value = actual value – setpoint value

After obtaining the error value, the controller will try to minimize the error value at all times by adjusting the control variables that can be changed to k_p , k_i , and k_d values. The PID controller will calculate the output based on the difference between the current temperature (process variable) and the desired temperature (setpoint). The output of the PID is a value that usually regulates the speed or intensity of the control, but in this case, the author will use it to control the duration of the pump on/off time.

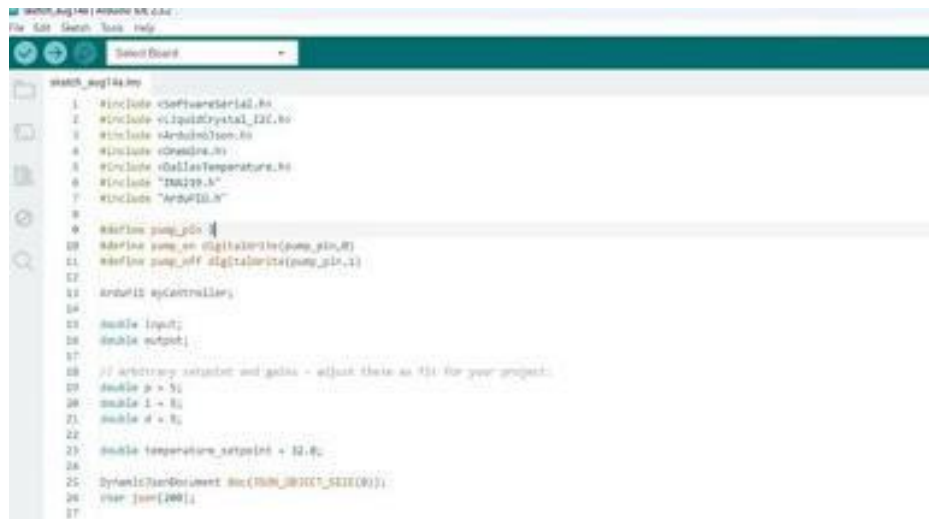


Figure 11. PID Program

In the above program, the PID controller calculates the error value as the difference between the setpoint and the actual value. In this project, the PID system set is Kp, Ki, and Kd of:

Kp : 5 Ki : 5 Kd : 5

Another coefficient that is set for the temperature setpoint is 32 degrees. The PID process will be used to calculate the PID control. The PID output limit is between 0 and 30 to ensure the output value remains within the acceptable range of the system. Furthermore, after finding the results of the cooling system test, determine the error in the PID using the following formula.

Error = Temperature – Set Point

P = Kp x Error

I = Ki x (Total Error + Past Error)

D = Kd x (Error – Past Error)

$$PID = P + I + D$$

Table 6. PID Test Result

Time	Timer	Temperature	Set Point	Error	P	I	D	PID
1	30s	34°	32	2	10	25	-5	30
2	28s	33°	32	1	5	15	-5	15
3	22s	32°	32	0	0	5	-5	0
4	21s	32°	32	0	0	5	-5	0

RESULTS AND DISCUSSION

Based on the discussion of the Design of Optimization of Photovoltaic Charger Using Temperature Control Based on Proportional Integral Derivative Controller, several conclusions can be drawn as follows:

1. The intensity of sunlight has a direct correlation with the power generated by the solar panel. The lower the light intensity, the lower the power generated, and vice versa.
2. This automatic watering system allows precise regulation of the surface temperature of the solar panel so that the cooling process can be carried out as needed.
3. The surface of the solar panel affects the output of the solar cell, especially before and after watering the surface.
4. The addition of IoT is very effective because the solar panel can be monitored remotely

From the research that has been carried out, there are several suggestions so that further similar research can produce good data, including:

1. Temperature sensors on the surface of the solar cell can make temperature measurements more accurate.
2. Selection of temperature sensors based on sufficient accuracy and can be easily integrated with microcontrollers such as Arduino.
3. Selection of solar panels with slightly rough or textured surfaces to increase light absorption and reduce dirt and water buildup.

4. In the context of IoT for monitoring solar panels, connection range is very important, especially if the solar panels are in remote locations or have geographical challenges. By choosing the right connectivity technology, it can be ensured that the IoT system can be accessed and managed effectively.
5. In a study, it is necessary to train instincts in running test equipment or measuring instruments to support the implementation of the research.
6. It is expected that each study is based on a strong understanding to support the implementation of the research.

REFERENCES

- [1] Jangiri, S., & Jones, K. O. (2024). *Optimizing an intelligent fuzzy-hybrid Proportional-Integral-Derivative (PID) controller for Load Frequency Control systems*. 1–4. <https://doi.org/10.1109/infotech63258.2024.10701332>
- [2] Jasim Hasan AlTimimi, M. (2023). Solar Energy. IntechOpen. doi: 10.5772/intechopen.106155
- [3] Joykutty, L., & Caulkins, J. (2023). Comparison of Machine Learning Algorithms for DC Motor PID Control with Genetic Algorithm. *Journal of Student Research*, 12(1). <https://doi.org/10.47611/jsr.v12i1.1936>
- [4] Kumar, Ch., Singh, S. K., Gupta, M. K., Nimdeo, Y. M., Raushan, R., Deorankar, A. V., Kumar, T. M. A., Rout, P. K., Chanotiya, C. S., Pakhale, V. D., & Nannaware, A. D. (2023). Solar energy: A promising renewable source for meeting energy demand in Indian agriculture applications. *Sustainable Energy Technologies and Assessments*, 55, 102905. <https://doi.org/10.1016/j.seta.2022.102905>
- [5] Marhatang, M., AM, S. Y., Muhammad, R. D., Rifaldi, A., & Winarty, C. (2023). Prototype of AC Microgrid Solar Power Plant with Off-Grid System. *INTEK: Jurnal Penelitian*, 10(1), 64-69.
- [6] Obaideen, K., Olabi, A. G., Swailmeen, Y. A., Shehata, N., Abdelkareem, M. A., Alami, A. H., Rodríguez, C., & Sayed, E. T. (2023). Solar Energy: Applications, Trends Analysis, Bibliometric Analysis and Research Contribution to Sustainable Development Goals (SDGs). *Sustainability*, 15(2), 1418. <https://doi.org/10.3390/su15021418>
- [7] Pambudi, N. A., & Ulfa, D. K. (2024). The geothermal energy landscape in Indonesia: A comprehensive 2023 update on power generation, policies, risks, phase and the role of education. *Renewable and Sustainable Energy Reviews*, 189, 114008.
- [8] Perdana, A. A., Wijaya, M. E., & Ichsan, I. (2022). ACCELERATING RENEWABLE ENERGY DEVELOPMENT TOWARD ENERGY SECURITY. *Jurnal Kebijakan Publik*, 13(4), 404-412.
- [9] Setyawan, R. T. (2024). An Optimizing the Control of DC Motors in CNC Machines by Enhancing the Parameters of the Proportional-Integral-Derivative (PID) system. *Jurnal Teknik Mesin Mechanical Xplore*. <https://doi.org/10.36805/jtmvx.v4i2.6141>
- [10] Sharma, V. K., Singh, R., Gehlot, A., Buddhi, D., Braccio, S., Priyadarshi, N., & Khan, B. (2022). Imperative Role of Photovoltaic and Concentrating Solar Power Technologies towards Renewable Energy Generation. *International Journal of Photoenergy*, 2022, 1–13. <https://doi.org/10.1155/2022/3852484>
- [11] Widyaningrum, V. T., Romadhon, A. S., & Safitri, D. (2023). *Solar Tracking System Dual Axis using Proportional Integral Derivative (PID) Controller*. 1–5. <https://doi.org/10.1109/itis59651.2023.10420258>
- [12] Wijaya, P. M., Kusuma, A. P., & Romadhona, R. D. (2024). Prototype of a Warehouse Shoe Lamp Automation System Using Motion Sensors Based on the Internet of Things (IoT). *JOSAR (Journal of Students Academic Research)*, 9(2), 63-73.
- [13] Zahari, T. N., & McLellan, B. C. (2023). Review of policies for Indonesia's electricity sector transition and qualitative evaluation of impacts and influences using a conceptual dynamic model. *Energies*, 16(8), 3406.