Optimization of parabolic photovoltaic and solar thermal tracker model systems using heat transfer fluid

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ABSTRACT

Renewable energy sources such as photovoltaic (PV) and solar thermal (T) used in tropical Indonesia are still not optimal in converting electrical energy. This is caused by the movement of the sun which is not centered on the surface of the photovoltaic/thermal (PV/T). Based on this, PV/T technology was developed with a parabolic tracker system combined with T control with the aim of optimizing electrical energy conversion. The testing technique was carried out using an experimental method by comparing the installation of PV/T technology with a parabolic tracker system and a flat PV position. In the PV/T parabolic tracker, the supporting components use aluminum foil technology and heat transfer fluid (HTF) to reduce excess heat on the panel surface. The parabolic tracker system is implemented through a centralized system following the sun and aluminum foil and HTF technology function to keep the surface temperature stable. The results of PV performance testing at peak loads carried out at 10:00 am-3:00 pm, the installation of flat PV produced an average DC power of 71.68 Wp and the parabolic tracker system produced an increase in average DC power of 84.57 Wp, while with an increase in power of 17.98% during fluctuating weather conditions.

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1. INTRODUCTION

The use of renewable energy power plants using solar energy in Indonesia has great potential based on tropical regions with quite high levels of solar intensity [1], [2]. Therefore, support the Indonesian government's program to continue to make breakthroughs in reducing greenhouse gas (GHG) emissions or CO_2e and carbon emissions in reducing global warming with the aim of later being able to encourage an energy transition in the use of environmentally friendly renewable energy [3], [4]. The benefits that will be felt from the installation of renewable energy, especially in Indonesia, will be able to reduce dependence on the use of fossil fuels and can increase the use of energy efficiency with the profit of being able to reduce the cost of energy use in the long term. This program will later become a priority as a solution to the crisis problem in increasing the portion of renewable energy generation that continues [5]. Then, considerations and important issues regarding the operation and installation of renewable energy, namely the many remote areas that do not yet have electricity, especially underdeveloped areas, will be a solution to the current energy problem [6]. Based on this, the use of development and implementation of renewable energy installations is very necessary for electricity suppliers in industry, residential homes and especially for 3T (frontier, outermost, and underdeveloped) areas [7]–[9].

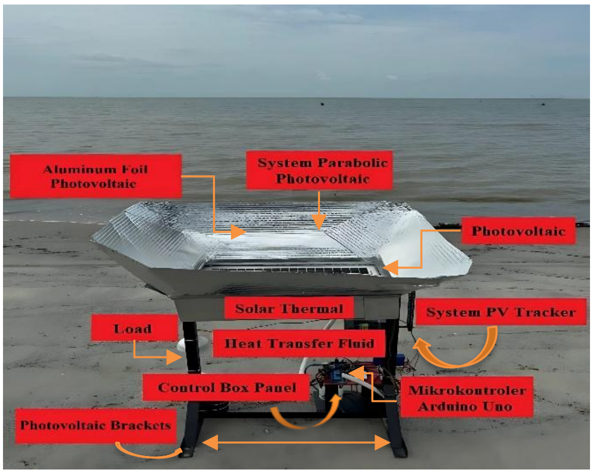
The North Sumatra region has the intensity of sunlight and quite potential if renewable energy power plants are installed, especially photovoltaic (PV) and solar thermal (T) technology [10]–[12]. Based on the potential for installing and operating renewable energy power plants for the North Sumatra region, the weather forecast is that the temperature will be sunny at 23-33 ºC and the most efficient lighting will reach 11 hours/day during the equinox event, which of course is very profitable for building solar-powered power plant installations [13]. However, erratic weather fluctuations in the Medan city area cause energy conversion from renewable generators to be less than optimal. This greatly influences the output from the use of PV and solar T technology to convert solar energy to the maximum [14]–[16]. The first problem that will be developed is that the movement of the sun which is not concentrated on the photovoltaic/thermal (PV/T) surface is not able to convert energy to the maximum. The application of PV to be used to generate new energy still uses a static (conventional) system where the solar panels installed on the object are static or do not move, this is a problem because the energy source from the sun as an object always moves from east (rising) to west (setting), This causes the reception of solar energy from solar panels to not be optimal or optimal [17]–[19]. The instability of the power produced by PV is very dependent on the intensity of the sun received [20]–[22]. Then the problem that often occurs is that excess heat in the PV system is not efficiently received by the T system, so that PV performance electricity production does not increase [23], [24]. Increasing PV cell temperature also reduces electrical power efficiency [25], [26]. Therefore, a system for increasing energy conversion by utilizing PV/T by regulating water circulation in the system can streamline the PV/T output flow and heat can be resolved. Heat is known to directly affect the performance of PV cells, therefore water circulation in PV/T systems and reuse of heat collected in PV cells are very necessary.

The parabolic trough PV/T system is designed to be able to concentrate sunlight into a focal point to produce very high heat temperatures [27]–[29]. Utilizing a parabolic trough design to focus sunlight along a copper pipe through which heat transfer fluid (HTF) flows to absorb heat and circulate through an automatic pump connected to the Arduino Uno microcontroller. In addition, the electrical efficiency of the system must be evaluated through the analytical positioning of the PV cells which must consider optimizing the exposure of the cells to sunlight without minimizing the amount of solar reflection onto the copper pipes. Utilization of cooling techniques such as the use of heatsinks must be applied to PV cells to improve electrical performance. The intensity of sunlight received by solar panels can be maximized by installing the installation at the right tilt angle so that maximum output power is obtained. Optimize the tilt angle of the solar panel that will be used on the device using an active sun tracking system [30], [31]. Effective optimization is carried out by taking the theta angle (θ) on the negative x-axis using the angle 45º, 90º, and 135º [32]. Then in the design of an integrated T system, the PV module and cooling box flow are combined to achieve T and electrical conversion efficiency from the PV/T system by utilizing the fluid flow rate. The advantage of designing a hybrid PV/T system is that it has great potential in generating solar energy and harvesting heat and electrical energy simultaneously. This technology design is integrated using PV/T system technology with a parabolic model supported by automatic tracker technology with Arduino microcontroller settings to achieve optimum values in following the movement of the sun from the system installation so that it is more centered.

2. METHOD

The system design that will be built is environmentally friendly technology in upscaling the conversion of electrical energy from solar energy through optimizing the parabolic tracker model system which will be integrated with PV and solar T using HTF assisted by Arduino Uno microcontroller technology. PV/T power plants can absorb maximum electrical energy using fluid circulation and the use of compound parabolic collector (CPC) type solar collectors. Apart from that, the components that will be used include PV to form a parabolic system with a polycrystalline panel type. Other supporting components consist of a battery, wattmeter, control box panel, linear actuator, DC watt meter and Arduino microcontroller. PV/T operating system by activating the Arduino Uno connected to the tracker so that the angle 45º, 90º, and 135º can work optimally looking for PV concentrated points in sunlight. Then the Arduino Uno microcontroller acts as a center for commanding the sensor connected to the pump to circulate water so that the temperature on the surface of the panel becomes stable. Alumunium foil technology is useful in reducing excess heat on the PV surface. To support optimal test results, a comparison was made based on the flat PV installation system based on Figure 1(a) and the parabolic PV/T tracker installation system based on Figure 1(b), the data will later be processed using the double exponential method to support the analysis of data accuracy values because it has fluctuating data output. The overall design of the system model for PV with a flat position and PV/T parabolic tracking system model is shown in Figure 1.

(a)



(b)

Figure 1. System model design for PV and PV/T; (a) flat PV design model and (b) PV/T parabolic tracking system model using HTF

To support power optimization, the maximum power point tracking (MPPT) algorithm tracking efficiency equation is needed to be evaluated based on tracking efficiency, energy loss when searching for the maximum power point (MPP), estimated maximum power point (EMPP), and actual MPP tracking time of the PV array tMPP. Fast and responsive tMPP determination is important to maximize energy production from solar power systems. The shorter the time required to reach MPP, the more efficient MPPT is in optimizing overall solar power system performance. The tracking efficiency of the controller is determined by (1):

$$\eta = \frac{P_{\text{MPP}}}{P_{\text{MPP(max)}}} .100, \% \tag{1}$$

where MPP or peak maximum power point (PMPP) is the output power value of the PV string, which is tracked by the controller, and PMPP (max). PMPP refers to the point at which a solar panel or solar panel array produces maximum power under certain conditions, such as specific sunlight intensity and panel temperature are the maximum available power values. The loss of energy can be expressed in (2):

$$E_{\text{MPP}} = \int_0^{t_{\text{MPP(max)}}} (P_{\text{MPP(max)}} - P_{\text{MPP}}^k). dt, J \tag{2}$$

Then in determining PkMPP, namely the value of the current PV panel power in the MPP search process. The actual tracking time of the PV array MPP can be represented based on (3):

$$t_{\text{MPP}} = \frac{\left|P_{\text{MPP}} - P_{\text{MPP}}^k\right|}{P_{\text{MPP}}} .100 < 1\% \tag{3}$$

3. RESULTS AND DISCUSSION

Tracking technology is a system that allows solar panels to follow the movement of the Sun from east to west throughout the day, thereby maximizing sunlight reception and energy efficiency. The measurement and data analysis processes described in connection with the use of this technology usually include several key steps and parameters. The results of the reliability system analysis and test evaluation were carried out using a feasibility test where this tool can operate in coastal areas where there are no shadows in the surrounding environment. High surface temperatures can lower the surface temperature of solar panels by adding aluminum foil to the solar panels. The parabolic model around the solar panels functions as a centralized concentration so that sunlight automatically focuses on the panel point, then to minimize the spread of excess heat or reduce the temperature is coated with aluminum foil as a system that can improve the performance of solar panels. Aluminum foil is designed using T conductivity consisting of aluminum to increase cooling efficiency on the panel surface area. Then the tracker which is controlled using an Arduino Uno is able to find the central point of the photon effect which is an elementary particle so that it is more concentrated on the panel surface. The HTF performance in fluid flow circulation, namely heat transfer, aims to validate the T, exergy and overall performance in minimizing excess heat. With the help of designed technical experiments, short circuit current Isc, open circuit voltage Voc, output power, and PV surface temperature with a tracker system and also a parabolic system. This temperature measurement records measurements from 7:00 am to 6:00 pm to observe the effect of temperature on the PV module throughout the day. In the experiment of installing a reflector using parabolic without using a circulating cooling system, the surface temperature of the PV module continued to increase, increasing from 28.7 °C morning afternoon reached 48.7 °C in the afternoon. However, with the help of alumunium foil and water circulation for the cooling system, the surface temperature of the PV module is stable 32.6°C in corner conditions 90^{o}. The addition of system cooling fluid, the surface temperature of the PV module makes the energy conversion more stable with temperature 28-35 °C. Testing of the parabolic PV/T system design will also determine the estimated intensity of solar radiation and determine the size of the T collector, T insulation, fluid type, and heat pipe filling ratio. Analysis can include monitoring daily performance, comparing it to historical data, and identifying patterns and anomalies that may impact system efficiency. The results of real data in the field by carrying out experimental testing of the overall system design can be shown in Figure 2.

Results of no-load and load power graphs under the conditions in Figure 2(a). DC output data for PV/T performance when under load, the voltage Vmp (V) reaches 17.68 V when the sun is hot or at 12.00 pm and at no load the Voc (V) reaches 20.8 V, Figure 2(b) graph of the DC current produced when the panel is under load, namely Imp (A) reaches 0.89 A, the current Isc (A) reaches 1.12 A, and Figure 2(c) accumulated DC power when under load, namely Pmp (W) reaches 15.7 Wp and the accumulated DC power output when not under load or in terms of Idle power (W) reaches a maximum of 23.2 Wp. This condition is in sync with environmental conditions that are free from shadow effects so that the solar panels can work optimally.

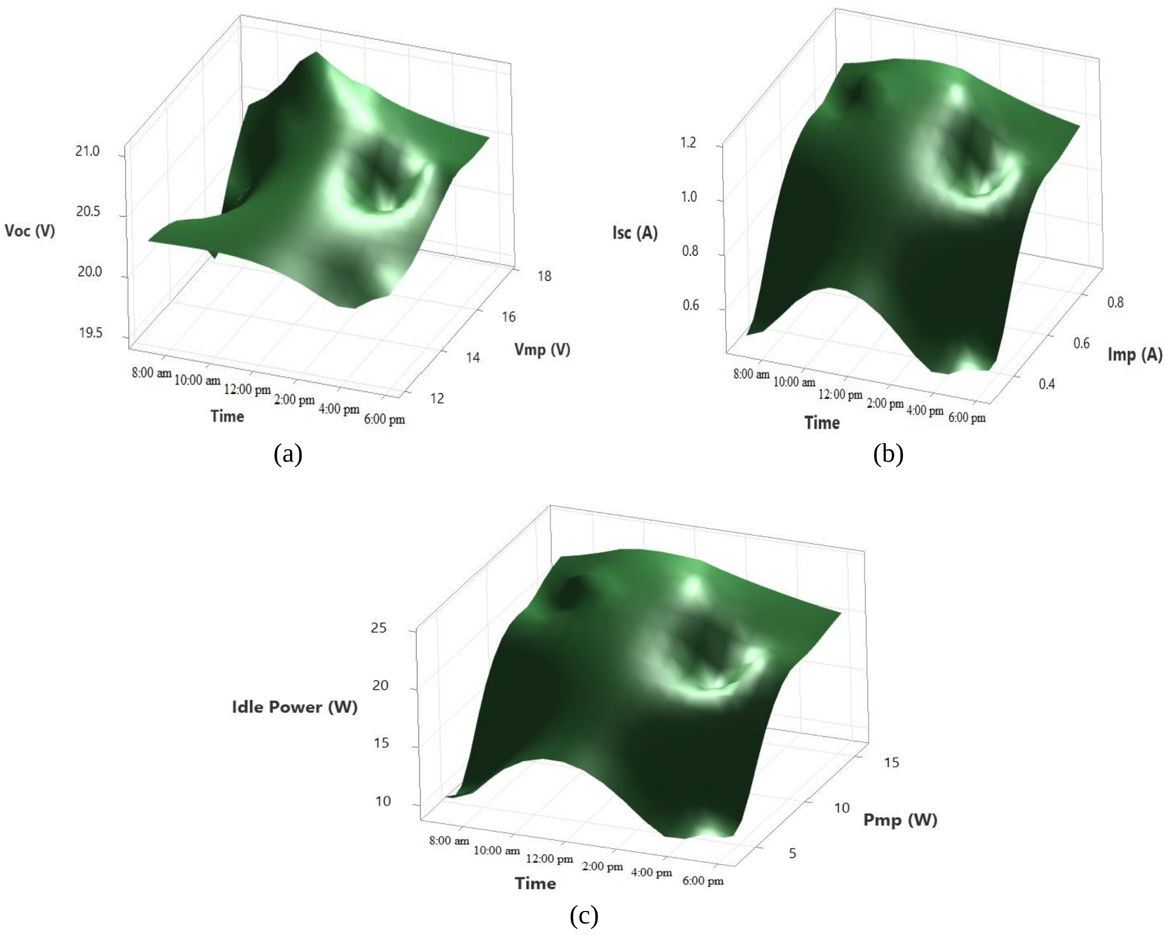
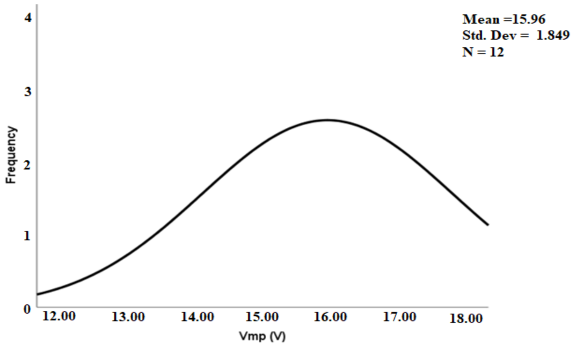


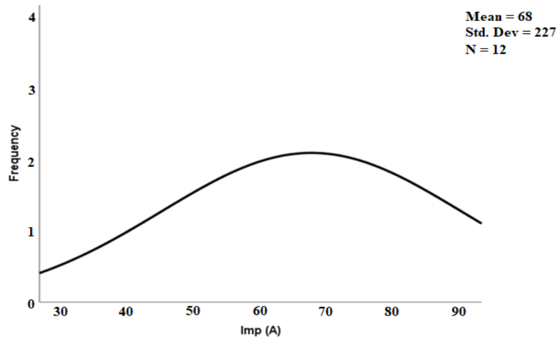
Figure 2. Effect of PV/T output in converting energy; (a) DC voltage without load (Voc) and load (Vmp), (b) current without load (Isc) and load (Imp), and (c) power without load (Wp) and burdened (Wp)

3.1. Photovoltaic/thermal energy conversion frequency

The results of measurements carried out in coastal areas produce optimal accuracy in converting electrical energy. Data obtained by finding the focal point of the sun on the solar panel is assisted by the integration of a pump that flows water through a copper pipe so that the conversion of energy from PV and solar T makes the temperature more stable. The PV/T power output that has been obtained is then formulated into a frequency value to determine the same as the voltage that determines the electrical potential available from the solar panel. Then the solar panel current is able to show how much energy is produced during a blackout in the field, especially in coastal areas. DC power or total power consumed by the system during measurement is the performance of the test carried out on PV/T. After the measurement is carried out, the data collected from the DC power measurement is simulated using software to determine the level of measurement accuracy. The simulated measurements are used to determine the mean, Standard Deviation (std. Dev) and number of samples (N) against the frequency of Figure 3(a) Vmp, Figure 3(b) Imp, Figure 3(c) Voc, Figure 3(d) Isc, Figure 3(e) Pmp, and Figure 3(f) Idle power. The overall simulation of output values in this process includes data storage, analysis and visualization to evaluate the frequency performance of the PV/T parabolic tracker system. The simulation results are shown in Figure 3.



(a)



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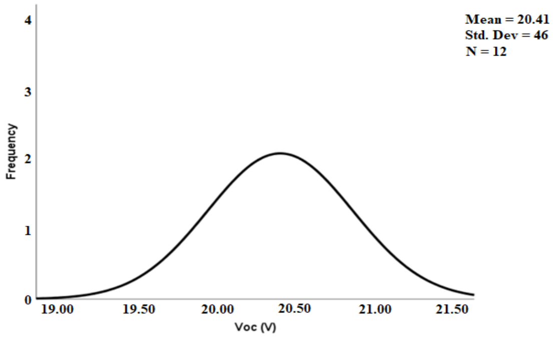
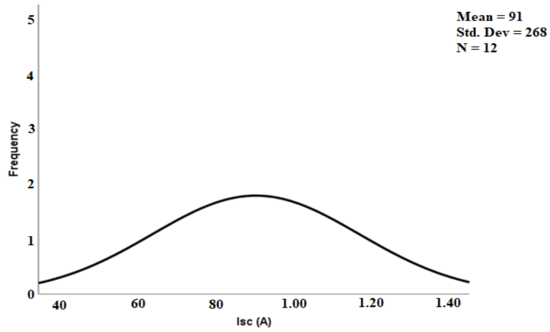


(c)



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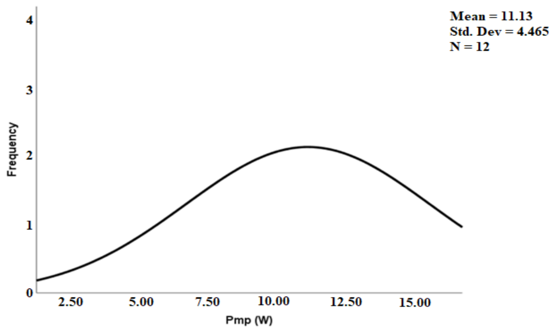
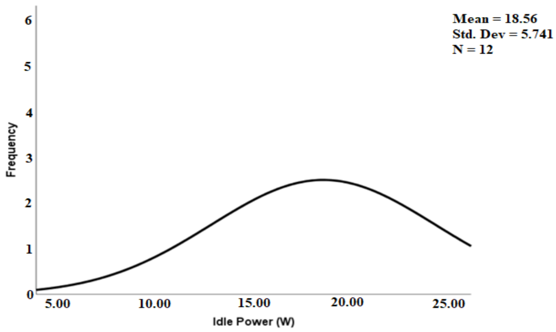


(e)



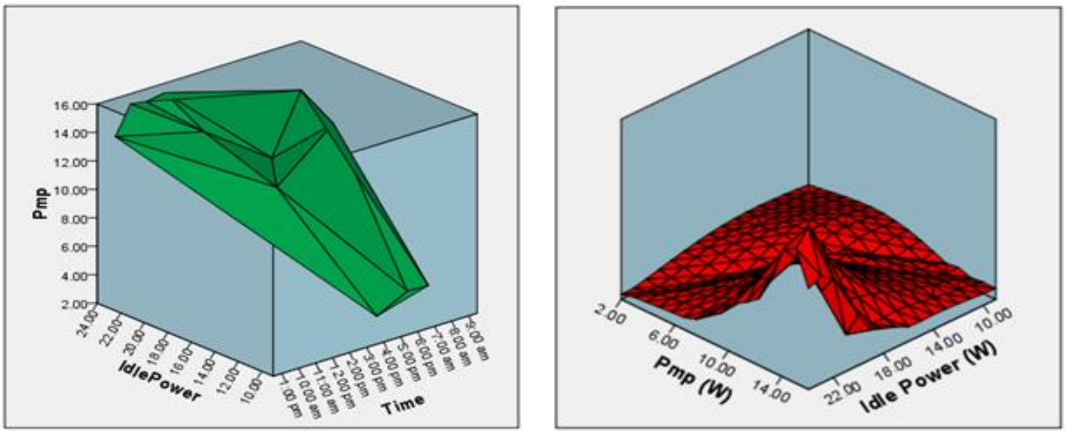
(f)

Figure 3. Integrated PV/T output frequency for load and no-load power; (a) PV/T voltage frequency under load (Vmp), (b) PV/T current frequency under load (Imp), (c) voltage frequency PV voltage without load (Voc), (d) PV/T current frequency when without load (Isc), (e) PV/T power frequency when under load (Pmp), and (f) PV/T power frequency when without load

The results of measurements and tests carried out in the field obtained frequency data based on the results of energy conversion in the field based on Figure 3(a). The data obtained during cloudy, sunny temperature conditions stated that the standard deviation of the PV/T voltage frequency under load (Vmp) was 227 and a mean of 15.96, Figure 3(b) for the standard deviation of PV/T current frequency under load (Imp) of 227 and a mean of 68.3 Figure 3(c) for a standard deviation of PV voltage frequency without load (Voc) of 20.41 and a mean of 46, Figure 3(d) for the standard deviation of the PV/T current frequency when without load (Isc) is 268 and the mean is 91, Figure 3(e) for the standard deviation of the PV/T power frequency when under load (Pmp) is 4.46 and the mean is 11.31, Figure 3(f) for the standard deviation of PV/T power frequency when no load is 5.74 and the mean is 18.56. The data obtained is the result of energy conversion using a reflector with a parabolic model by determining the sun's focal point using the tracker system on the PV/T. Evaluation and analysis results are further evaluated to ensure that the parabolic PV/T tracker system using HTF operates optimally in accordance with the expectations and specifications set.

3.2. Energy conversion performance of liquid-based photovoltaic-thermal collectors

The technology in Upuya adopts a liquid-based PV/T system with the help of water circulation using a pump controlled by an Arduino Uno which is able to produce an effective temperature for PV/T energy conversion performance. The power is accumulated and tested on the coast by determining the no-load power based on the principle of the amount of power received by the solar panels when conditions are not ideal. This condition is of course normal operation or when there is no load connected. Then determine the peak maximum power (PMP) which is obtained from measuring the power that can be produced during optimal conditions, namely when the solar panels receive the highest intensity of sunlight and the resulting voltage and current produce maximum power. In this condition, the parameter that influences PV/T is the unstable panel surface temperature. Therefore, by designing a parabolic PV/T tracker system using HTF, it is able to reduce excessive temperatures to make it more optimal. The additional use of fluid that has been circulated in place of air can enable excess heat to be extracted in the PV/T collector more efficiently as well as act as a cooler when the panel surface is too hot. Then the higher T conductivity and better heat transfer coefficient of the fluid, also allow the desired PV cell operating temperature to be maintained with less temperature fluctuations. Then the basic design of this technology is based on liquid being channeled into a pipe as a single channel to allow the fluid to flow under the PV cells. The output results of Pmp and idle power in forming a surface plot between no-load power and loaded power based on time are shown in Figure 4 and in Figure 4(a) is the Pmp and Idle power performance over time then Figure 4(b) is the grid structure on Pmp and Idle power.



(a) (b)

Figure 4. Surface plot of PV/T energy conversion performance; (a) accuracy and reliability of no-load power in Wp and (b) accuracy and reliability of load under Pmp conditions

Based on Figure 4 is a surface plot of PV/T energy conversion performance at load and no load. In Figure 4(a), the Pmp power feature is the point where the solar panel produces maximum power in conditions such as when connected to the load producing peak power reaching 15.73 Wp and at idle power the power consumption is not active reaching DC power of 23.29 Wp. In Figure 4(b) is the grid structure on Pmp and Idle power to visualize the data as a whole with the aim of mapping and identifying the optimal point in energy conversion. At peak power conditions, namely the maximum power produced by the solar panel at optimal conditions where the voltage and current of the solar panel produce maximum power at the MPP. The testing time was carried out from 07.00 am to sunset at 6.00 pm and when the panel conditions were free from the influence of shadows, especially in coastal areas.

3.3. Energy conversion optimization on photovoltaic parabolic tracker with flat position

Testing the results of PV/T measurements in optimization is able to produce greater power in the use of a parabolic tracker system with PV/T placement in a flat position. This is because the angles of 45º, 90º, and 135º to follow the direction of the sun are always centered on the surface of the PV/T. Then, the control and addition of HTF as an assistant to control the surface temperature of the panel and also as a stabilizer of energy efficiency and combined with aluminum foil technology as a heat damper for the surface temperature of the panel makes the system able to operate in optimizing energy conversion well with temperature measurement results ranging from 28-35 °C. Compared to the flat placement of PV/T, the resulting energy conversion is less than optimal due to the angles of 45º and 135º when the position is not directly proportional to the PV surface during the energy conversion process. The results of the PV/T energy conversion test using the same PV specifications by comparing the results of energy conversion power in the data collection system using parabolic tracker technology with a flat PV position installation are shown in Figure 5.

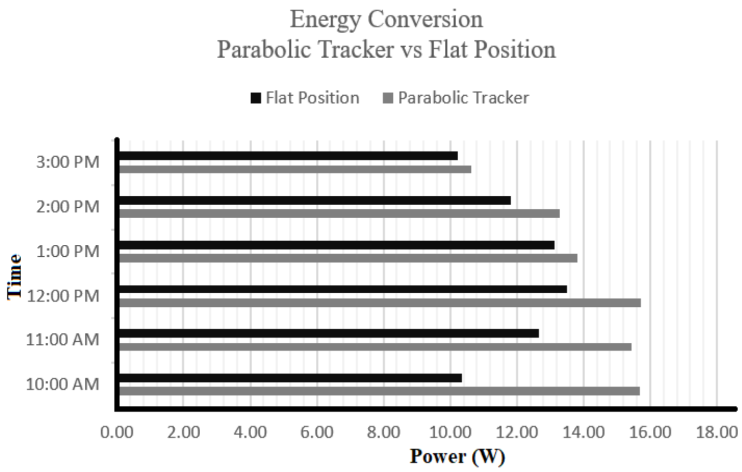
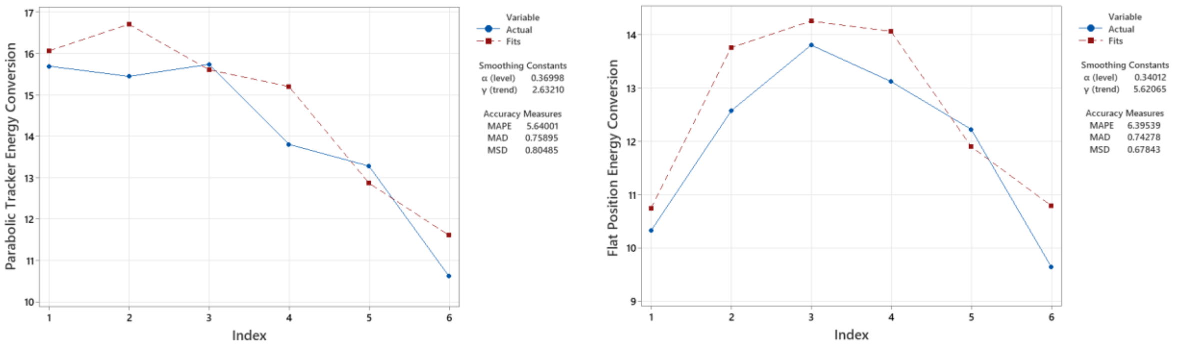


Figure 5. Test results of the parabolic tracker system on PV/T with a flat PV installation position

Based on Figure 5, the results of data collection analysis were carried out during peak load, namely at 10:00 am to 3:00 pm. Testing to determine optimization using a parabolic tracker system on PV/T (gray line) with a flat PV installation position (black line). Energy conversion using angles of 45º and 135º on the PV/T parabolic tracker system is able to produce more optimal energy conversion compared to a flat position. Then at an angle of 90º the measurement results also have an impact on the results of the energy conversion test where the PV/T parabolic tracker dominates. Testing was carried out at the same load conditions and also using the same PV. The performance of the parabolic system resulted in an increase in average DC power of 84.57 Wp and the PV installation position with a flat position produced an average DC power of 71.68 Wp. The consistency of PV/T when optimizing energy conversion obtained superior power throughout the day, especially when the sun's intensity was at the zenith position panel or at peak load. The results of increasing DC power during peak load using the PV/T parabolic tracker system obtained a power optimization of 17.98%. Based on the measurement of the test results that have been carried out, the results of this study are in sync with the support of previous research where the results of the parabolic tracker system test were able to improve the performance of energy conversion caused by the focal point of the sun being centered on the panel and also supported by stabilization of the panel surface temperature so that it can improve the performance and efficiency of PV which is useful in optimizing the output power of the panel [32]–[34].

The application of this technology will later have an impact on the installation of PV on the roof of the building and also reduce the electricity bill of the house to be cheaper. Then to support the results of the experimental test, a double exponential method is carried out which is useful for analyzing data as to determine the value of data accuracy in the form of data trend values and data fluctuations in the parabolic tracker system measurement test on the panel installation and also the panel installation when the condition is flat. Furthermore, in the scenario of the data test extraction results to refine the data and produce more accurate estimated values, a method is used to introduce trend patterns in energy conversion data on the parabolic tracker system installation and the flat installation system. The method that will be used is the double exponential method shown in Figure 6, then modeling is carried out in the form of a graph shown in Figure 6(a) smoothing plot for parabolic tracker energy (W), and Figure 6(b) smoothing plot for flat position energy conversion (W).



(a) (b)

Figure 6. Measurement accuracy values using the double exponential method; (a) smoothing plot for parabolic tracker energy conversion (W) and (b) smoothing plot for flat position energy conversion (W)

The results of the output in Figure 6. The measurement accuracy value using the double exponential method presents the value of graphic elements, variables, actual, fits, smoothing constants values and accuracy measures values. Then Figure 6(a) smoothing plot for parabolic tracker energy (W) with the plot results used to predict the output value when the power data fluctuates with a mean absolute percentage error (MAPE) accuracy value below 10%, which means that the feasibility test on the data accuracy performance model tested is very good. Then the test Figure 6(b) smoothing plot for flat position energy conversion (W) which shows the installation test in a flat position for units (W) based on the time index. The results of the accuracy test obtained on the installation in a flat position obtained MAPE of 6.39%, which means that the value of predicting energy conversion is quite accurate in the test.

4. CONCLUSION

PV/T parabolic tracker system model technology uses HTF effectively to ensure optimal operation and efficient performance monitoring when generating electrical energy from solar energy. The research results show that the development of solar panels with a cooling system has a more stable surface temperature compared to solar modules without a cooling system. A cooling system installed on the back of the solar panels absorbs excess heat and transfers it through copper pipes. Water circulation and the addition of an alumunium foil help eliminate excess heat on the surface of the solar panels. The higher the Voc voltage produced by a solar panel, this is evidence of the technical characteristics of the solar panel. In the experiment of installing a reflector using a parabolic without using a circulating cooling system, the surface temperature of the PV module continued to increase, increasing from 28.7 °C in the morning to 48.7 °C in the afternoon. However, with the help of alumunium foil and water circulation for the cooling system, the surface temperature of the PV module is stable at 32.6 °C at a 90° angle. By adding system cooling fluid, the surface temperature of the PV module makes energy conversion more stable with a temperature of 28-35 °C. Testing of the parabolic PV/T system design will also determine the estimated intensity of solar radiation. Power graph display results that have been simulated using no-load and load techniques. DC output data on PV/T performance when under load, the voltage Vmp (V) reaches 17.68 V in the hot sun or at 12.00 pm and without load, the Voc (V) reaches 20.8 V. At the output, the DC current produced when the panel is under load is Imp (A) reaches 0.89 A and the current Isc (A) reaches 1.12 A. Then the accumulated DC power when under load, namely Pmp (W), reaches 15.7 Wp and the accumulated DC power output when not under load or in terms of Idle power (W) reaches a maximum of 23.2 Wp. This research development will be implemented on floating PV in coastal areas of North Sumatra. The recommended technology to be optimized is the development of a dust and dirt cleaning system using IoT and artificial intelligence (AI) on the panel surface so that it is useful for increasing the amount of PV energy produced.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Habib Satria	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓	✓
Dina Maizana		✓		✓					✓					
Indri Dayana	✓			✓			✓			✓			✓	

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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