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Performance of single axis tracker technology and automatic battery monitoring in solar hybrid systems

Habib Satria[1,2], Sapto Nisworo[3], Jaka Windarta[1], Rahmad B. Y. Syah[2]
[1]Professional Program Education of Engineer, Faculty of Engineering, University of Diponegoro, Semarang, Indonesia
[2]Department of Electrical Engineering, Faculty of Engineering, Universitas Medan Area, Medan, Indonesia
[3]Department of Electrical Engineering, Faculty of Engineering, Universitas Tidar, Magelang, Indonesia

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ABSTRACT

Utilization of elevation angles and azimuth angles is a very important part in maximizing solar energy into electrical energy in photovoltaic (PV). One way to maximize PV power output is to design a single axis tracker system and take into account the azimuth and elevation angles of the sun using the sun position calculator application. The single axis tracker system is set based on the position of the angle of inclination of the surface of the PV 45°, then the angle of 90° and the angle of inclination of 135°. The test results show that the single axis tracker PV system design can work based on the angle settings that have been programmed. Then the use of a battery control system to support the PV reliability system automatically cuts off electricity when the battery voltage drops below 12 V during cloudy weather conditions and excessive battery usage. The integration of the PZEM-017 module with the battery will support monitoring of battery power usage in real time. PV energy data conversion performance uses single axis tracker technology for maximum power reaching 631.72 Watt DC at 12.00 pm and the lowest power reaching 56.02 Watt DC at 6.00 pm.

Corresponding Author:

Habib Satria
Department of Electrical Engineering, Faculty of Engineering, Universitas Medan Area
Kolam St. No. 1, 20223 Medan, Indonesia
Email: habib.satria@staff.uma.ac.id

1. INTRODUCTION

The importance of optimizing renewable energy has a significant impact on the energy conversion that will be produced. Therefore, the use of renewable energy must be managed appropriately so that it can reduce dependence on conventional energy to reduce costs or become a backup in the operation of current electricity usage [1], [2]. One of the most supportive renewable energy technologies in the territory of Indonesia is photovoltaic (PV) technology [3]–[5]. This is supported by the territory of Indonesia which is a tropical area with a high level of solar intensity and has an excess of solar energy [6], [7]. The working principle of PV is simple, namely that it has the main role as a converter of solar energy into electrical energy [8], [9]. Medan city is a city that has sunlight intensity and is quite potential if solar panels are installed. However, there are still many erratic weather changes in the Medan city area. This greatly affects the output of PV to convert solar energy to the maximum [10]. The output voltage and current from the resulting PV will always be directly proportional to the weather fluctuations received by the solar panels [11]–[13]. In addition, energy conversion from PV reliability is based on temperature differences on solar panels, the influence of cloud conditions, wind direction speed, and the influence of the shadow effect on solar panels [14], [15]. Erratic weather fluctuations will have a direct impact on the conversion of electrical energy produced by PV, moreover using a battery as a backup will of course greatly affect charging time [16], [17].

The design of a single axis PV tracker system (single axis PV) and an automatic controller system for battery charging will be more useful so that the application of renewable energy such as PV can be an alternative in converting solar energy [18]–[20]. In order to be more optimal and support the reliability of the battery system to be more durable, it is done by controlling the voltage drop [21]–[23]. Then several methods for optimizing solar cell testing using a single axis tracking system are still not optimal due to the large amount of motor energy used [24]–[26]. PV optimization in flat panel positions is still not optimal because the angle of arrival of the sun is not directly proportional to the position of the solar panels. Therefore, the system is designed to be a more effective single axis solar tracker so that it can absorb sunlight optimally and reduce propulsion energy consumption. Previous research still has some shortcomings, especially in the use of single axis PV solar tracker technology that is used is still not optimal because it still uses an active motor control system. The design of the PV tracker system used has a more efficient difference, namely the single axis tracker technology system on PV is designed with 3 different panel surface positions which will reduce the torque consumption of the actuator motor used. Another supporting technology is the design of automatic battery controller monitoring so that it can monitor battery usage so that it lasts longer. Determination of the sun's elevation angle is reviewed using the sun calculator application and based on the azimuth angle to influence the position of the panel to be installed. PV output monitoring is carried out directly from 7.00 am to 6.00 pm. The data will be processed in graphical form using a personal computer. To facilitate further analysis, real data collection was carried out. PV conversion results are very useful for building small-scale or large-scale PV by considering the placement of PV based on the elevation angle and azimuth angle of the sun with the aim of maximizing output voltage, current and power. Therefore, the energy conversion output performance is carried out using single axis tracker technology and automatic battery controller monitoring on a hybrid PV system connected to the grid network. The lack of discussion of the problem of single axis tracker technology and monitoring of automatic battery controllers on PV and the potential location of the North Sumatra region makes this research very appropriate, especially in the city of Medan.

2. METHOD

Data retrieval of single axis tracker technology output of the PV-grid hybrid system in the city of Medan with the position of this station at coordinates (3º34'45"N 98º45'23"E) 2.51 km. Materials in data collection there are several main components that are used to support the research results obtained. The equipment includes 3 polycrystalline type solar modules 410, 120, and 120 Wp. PZEM-017 supporting components for battery monitoring, inverter, actuator, lux meter, watt meter, solar charging controller, delay timer relay module, battery charge controller module, digital led voltmeter ammeter active power factor, battery, and personal computer. The technology system that will be used is divided into two parts, the first is in the morning when PV integrated with the battery becomes the main source as well as charging the battery from the PV source. Then the battery is automatically disconnected when the battery capacity drops in voltage and also uses an excess load from the battery capacity. Then at night automatic transfer switch (ATS) automatically switches the energy source from PV to grid, if the battery cannot serve as a backup capacity for household power needs at night (during rainy conditions or when experiencing a power outage). While the data collection technique used is an observation technique, which is a technique of direct observation that occurs in the field. To get the amount of electrical energy that can be generated by PV, it is calculated using (1):

$$\sum \mathrm{Wh} = \sum (Pxt) \tag{1}$$

Data collection was carried out from 7.00 am to 6.00 pm with 3 different panel surface positions using a single axis tracker. Determination of solar elevation is reviewed using the sun calculator application and based on the azimuth angle. The optimization of the Tracker system can be calculated, namely between the angle α from the zenith to the north or south and then the angle β from the zenith to the west or east based on (2) and (3):

$$\alpha_t = \alpha_{sr} + \frac{T_t - T_{sr}}{T_{ss} - T_{sr}} (\alpha_{ss} + \alpha_{sr}) \tag{2}$$

$$\beta_v = \beta_{sr} = \frac{T_t - T_{sr}}{T_0 - T_{sr}} \beta_{sr} \tag{3}$$

The use of battery control aims to maintain a longer battery life, the tool used is the XH-M063 automatic battery control module. This module is set to control the battery automatically. The settings for the module used are based on battery specifications where when the battery reaches below 12 V, the module will automatically disconnect automatically. To get the battery energy capacity (BEC) (kWh) can be calculated based on (4):

$$\frac{d\,(BEC)}{dt} = \left(p_p - p_c\right) * \eta - E_{loss} \tag{4}$$

Before carrying out data collection, a research diagram was designed with the aim of installing tools and also to facilitate the flow of conducting research. Starting from the background of the problem where PV is a power plant that utilizes solar energy as the main energy source. Sunlight is absorbed by solar panels, and the electricity generated by solar panels remains DC. DC then flows to the solar charge controller (SCC). This design uses a hybrid system, namely when the load is unable to receive power from the PV, grid automatically becomes the main source and vice versa. PV installations are installed in parallel based on pulse width modulation (PWM) capacity and also use the ATS system as a two-source work controller. The ATS panel itself can be equipped with a contactor to switch power automatically. The sun tracking position uses 3 positions (2 oblique positions and 1 flat position) in uncertain weather fluctuations. This research is expected to provide information and solutions so that PV using single axis tracker technology can be used en masse in the future. Data processing is done by utilizing a computer using data analysis. The PV singel axis tracker and grid measurement system blocks are shown in Figure 1.

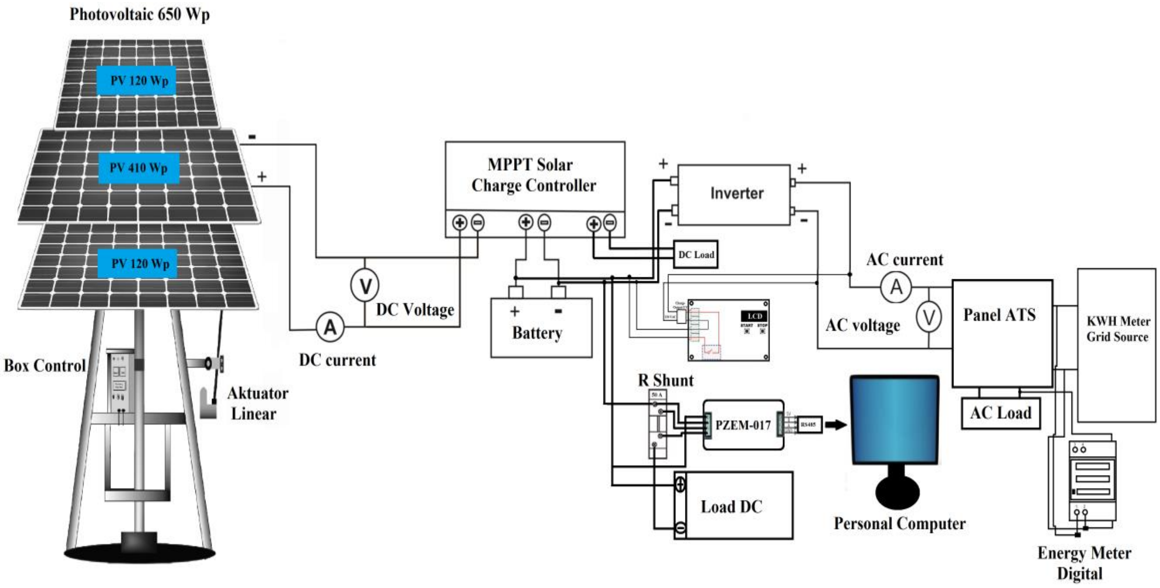


Figure 1. Single axis tracker and grid PV system block

The results of measurement of single axis tracker technology data on PV which will be obtained and further analyzed are DC voltage, DC current, and DC power with household loads at 7.00 am-6.00 pm. Then at night a digital energy meter is used to obtain AC voltage, AC current, and AC power data. Incoming data variables are processed using a PC and can be evaluated further.

3. RESULTS AND DISCUSSION

Data retrieval of hybrid system integration PV single axis tracker, battery and sources from the grid aims to monitor conversion and system reliability resulting in more optimal output of the hybrid system. The panel used has a capacity of 650 Wp with a polycrystalline type that is arranged in parallel. In the tracker system the use of PV is carried out using 3 different panel surface positions, then to make it more optimal it is supported by calculating the azimuth angle and elevation angle. The first thing to do is to look at the position of the north sun using the compass application, then use the sun position calculator application to get the azimuth angle. After the sun position calculator application is opened, then input the coordinates of the city of Medan, namely longitude and latitude. The sun position calculator application will be able to determine the azimuth angle and the position of the sun. The condition of the sun's position at 7.00 am can be shown in Figure 2.

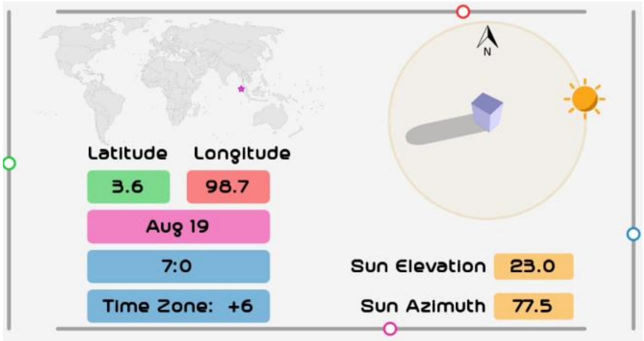


Figure 2. The application determines the azimuth angle and position of the sun

The position of the sun can be seen after the data is inputted, which is like Figure 2, an azimuth angle of 77.5 is obtained, then you can then draw an arc of 0° from north to east so that the position of the sun rising from the east can be seen for data retrieval and the initial position of the PV tracker system. The tracker system is taken using the 3 angle position method by controlling a linear actuator with a delay timer relay module. The angle formed to optimize the PV layout is at an angle of 45° (angle interval obtained using the application 25° to 49° from the east), angle 90° (angle interval obtained using the application 50° to 77°), angle 135° (angle interval obtained using an angle of 25° to 50° from the west). Based on data collection, data collection is carried out using samples that fluctuate in the weather. Prior to data collection, a wattmeter with a multimeter was calibrated. The following test results show that the DC voltage wattmeter has an average error of 1.04%, while the DC current has an average error of 1.50%. The measurement results of the DC voltage wattmeter calibration results and the DC current wattmeter calibration results can be shown in Table 1.

Table 1. Results of wattmeter calibration for DC voltage and DC current with a multimeter

No	Multimeter measuring instruments (V)	Wattmeter (DC voltage) (V)	Error (%)	Multimeter measuring instruments (DC current) (A)	Wattmeter (DC current) (A)	Error (%)
1.	42.1	42.5	0.94	4.47	4.51	0.89
2.	40.9	41.5	1.44	8.31	8.40	1.07
3.	42.1	42.4	0.71	6.07	6.18	1.77
4.	41.2	41.7	1.19	3.08	3.14	1.91
5.	42.9	43.3	0.92	4.17	4.25	1.88

All components used to be connected to each other and work as expected. The data collection process will produce data obtained in the form of voltage (V), current (I), power (W). Data collection in 1 day was carried out from 7.00 am when the condition of the angle of inclination of PV was 45°, then the angle of 90° at 11.00 am and the angle of inclination of 135° the panel position was at 3.00 am. After the integration of the single axis tracker PV system and battery, data collection was carried out from 7.00 am to 6.00 pm. Then the ATS system that has been set will move to the grid network for use at night. The use of linear actuators in driving the PV is determined based on the length of the actuator produced. The actuator will produce a length of 6 cm and make an angle of 45°, then the length of the actuator 26 cm will produce an angle of 90° and the length of the actuator 49 cm will produce 135°. Actuator length can be shown in Table 2.

Table 2. Linear actuator length

No	Actuator length (cm)	Generated angle (°)
1.	6	45
2.	26	90
3.	49	135

3.1. DC source single axis tracker technology data retrieval

Data taken using single axis tracker technology includes time, DC voltage, DC current, and DC power. For more details, see the single axis tracker voltage data graph shown in Figure 3. Based on the DC voltage chart according to Figure 3, where the weather conditions fluctuate in DC voltage. In historical data obtained during sunny conditions, it was observed that the peak DC voltage reached 45.4 V with an angle of 90° or a flat panel position. During the monitoring time the output voltage on the PV shows irregularities. Then data collection is also carried out, namely the PV current output using the same measuring instrument using a digital wattmeter. The results of monitoring the graphic output on PV using single axis tracker technology are shown in Figure 4.

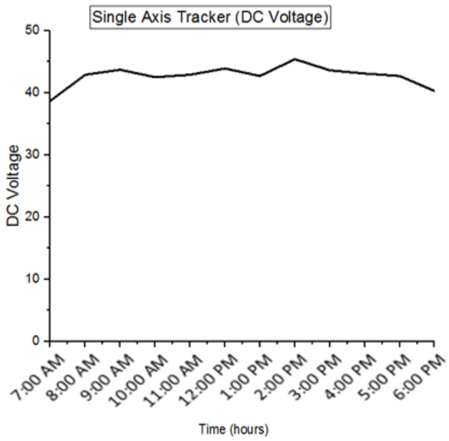


Figure 3. Monitoring output currents in fluctuating weather with single axis tracker technology

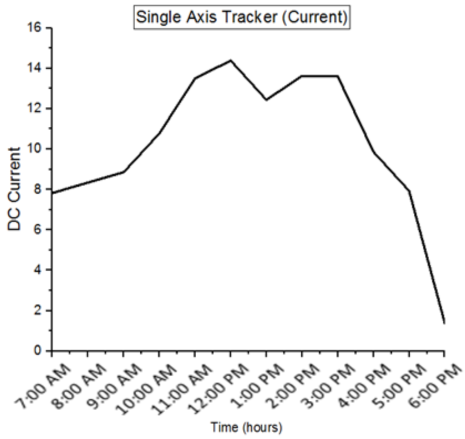


Figure 4. Monitoring flow data in fluctuating weather with single axis tracker technology

Based on Figure 4, the graph shows that around 12.00 pm is the peak DC current, which reaches 14.39 A and the current rating activity continues to decrease because the sun shifts westward until 6.00 pm until data collection is complete. Then the PV power output data is collected using a digital wattmeter measuring instrument. The measurement results of the power data graphic output on the single axis tracker system are shown in Figure 5.

DC power data generated reached 631.72 Watt at 12.00 pm with data collection time intervals from 7.00 am to 6.00 pm. The power consumption obtained when the weather is sunny or at 12.00 pm is very good because the cloud conditions do not prevent the sun from shining on the panel position in the city of Medan. The results of optimizing energy conversion using single axis tracker technology have almost reached the maximum based on PV specifications and previous relevant research [14].

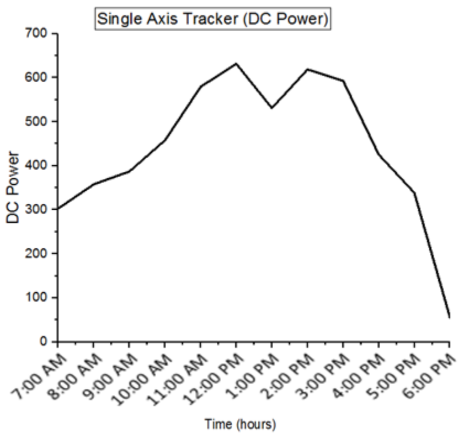
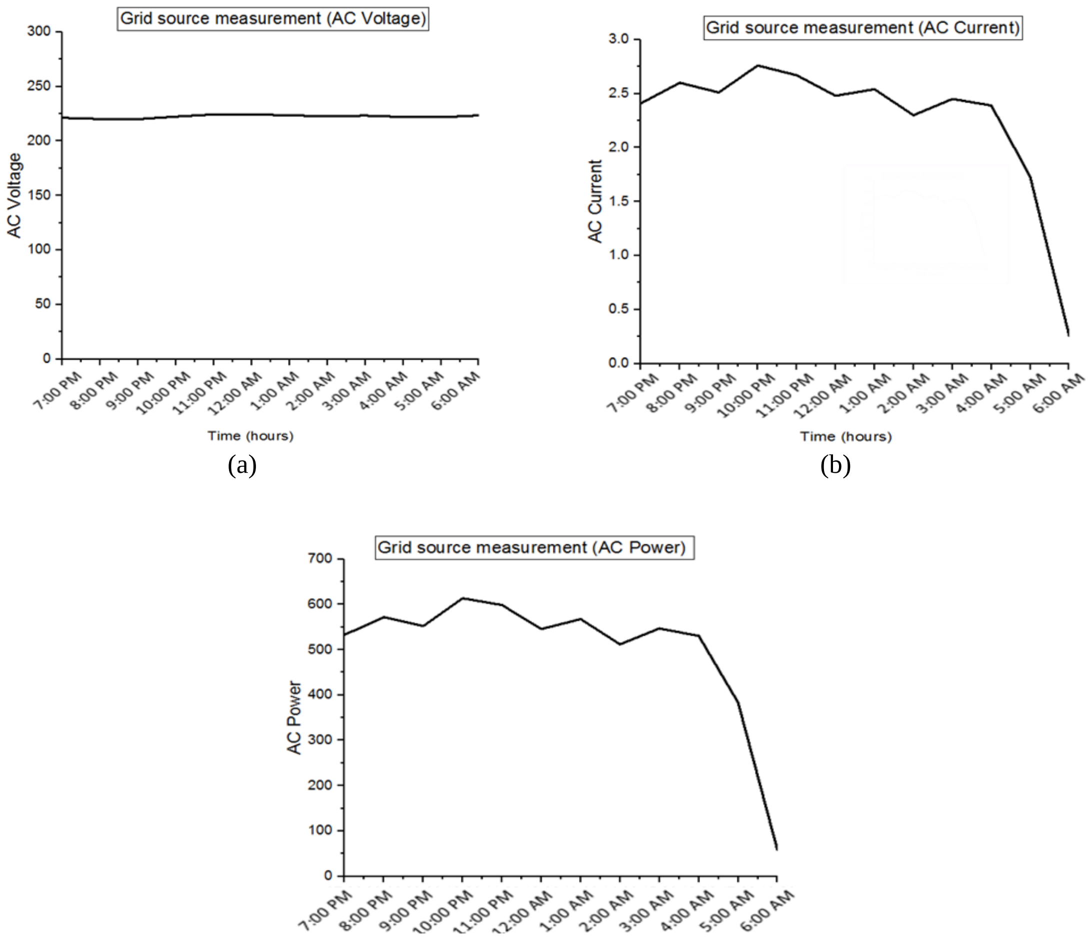


Figure 5. Monitoring DC power output in fluctuating weather with single axis tracker technology

3.2. Measurement data from grid source

Electrical power measurement uses an energy meter which aims to see the consumption of electrical energy consumption on a household scale. Data collection was carried out at night because at 7.00 am in the morning to 6.00 pm using a PV source as the main supplier. The ATS system will replace the electricity supply source from the grid, namely 6.59 pm to 7.00 am in the morning. The monitoring results of the AC source voltage graph can be shown in Figure 6.

The output data for household electrical load data shows that the average AC voltage is in the stable rating range between 221 to 237 V. The data collection activity begins at 7.00 pm and ends at 7.00 am and is automatically replaced by a PV source using the system ATS. The results of the measurement of the AC current graph can be shown in Figure 6. The graphic display of the AC current in Figure 6(a) experiences irregular fluctuations due to different load usage due to the activity of using electrical energy consumption. The peak output AC current based on Figure 6(b) reaches 2.76 A at 10.00 pm. The measurement results based on the AC power chart can be shown in Figure 6(c). In Figure 6(c) graph, AC power is analyzed starting at 8.00 pm the power fluctuates irregularly, for the highest power using an energy meter the highest AC power reaches 615.62 Watt at 10.00 pm. Data collection activities were carried out at 6.00 pm and ended at around 7.00 am.



(a) (b) (c)

Figure 6. The results of the measurement of the AC current graph at household electrical loads (a) graph of AC output voltage, (b) graph of AC current output, and (c) graph of AC power output

3.3. Automatic battery control and battery monitoring

Battery control aims to maintain a longer battery life, the tool used is an automatic battery control module. This module is set to control the battery automatically. The settings for the module are used based on the battery specifications where when the battery is below 12 V the module will automatically disconnect automatically. The battery is monitored using the PZEM-017 module so that the battery can be analyzed in real time. The way to use the module is where the PZEM-017 module port was previously connected to the Rshunt 50 A to prevent a short voltage on the battery load, after connecting the PZEM-017 to the actuator load Rshunt, the lights and battery will also be connected to the Rshunt for testing the control system. On the PZEM-017 port, integration with a PC requires RS485 communication support to obtain current, voltage and power values. Voltage, current, and power monitoring data can be shown in Figure 7. In Figure 7 you can see the output of the battery display from the PZEM-017 module. Test results from the battery control system monitored using the PZEM-017 which has been integrated on the PC obtained battery monitoring results that have the same value based on measurements using a multimeter.

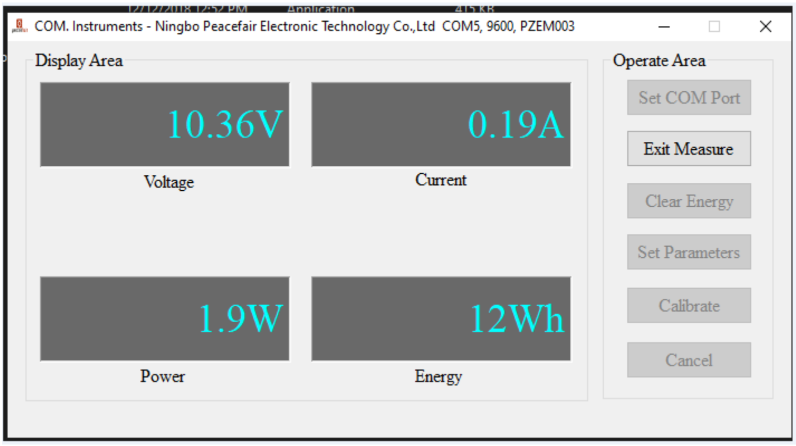


Figure 7. Display of battery power monitoring on personal computer

4. CONCLUSION

The design of the optimization system using single axis tracker technology in optimizing the conversion of energy produced by PV based on the azimuth angle and elevation angle of the sun operates well. The single axis tracker system is set based on the position of the angle of inclination of the surface of the PV 45°, then the angle of 90° and the angle of inclination of 135°. The test results show that the design of the PV single axis tracker system can work based on the angle settings that have been programmed and also based on the sun's elevation angle. Then the use of a battery control system to support the PV reliability system automatically cuts off the current when the battery voltage drops below 12 V during cloudy weather conditions and excess battery usage. When the battery voltage drops below 12 V, the energy supply to the battery will automatically be cut off and monitoring the output of battery usage using the PZEM-017 module can be displayed on the personal computer in real time. The results of measuring data on PV output in converting maximum energy obtained from DC power data produced reached 631.72 Watts at 12.00 pm and the lowest power reached 56.02 Watts at 6.00 pm.

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REFERENCES

[1] R. Fachrizal, U. H. Ramadhani, J. Munkhammar, and J. Widén, "Combined PV–EV hosting capacity assessment for a residential LV distribution grid with smart EV charging and PV curtailment," *Sustainable Energy, Grids and Networks*, vol. 26, Jun. 2021, doi: 10.1016/j.segan.2021.100445.

[2] E. Vartiainen, G. Masson, C. Breyer, D. Moser, and E. R. Medina, "Impact of weighted average cost of capital, capital expenditure, and other parameters on future utility-scale PV levelised cost of electricity," *Progress in Photovoltaics: Research and Applications*, vol. 28, no. 6, pp. 439–453, Aug. 2019, doi: 10.1002/pip.3189.

[3] H. Satria, R. Syah, N. A. Silviana, and S. Syafii, "Sensitivity of solar panel energy conversion at sunrise and sunset on three weather fluctuations in equatorial climate," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 13, no. 3, pp. 2449–2458, Jun. 2023, doi: 10.11591/ijece.v13i3.pp2449-2458.

[4] N. Sumarsono, S. Wahyuni, and L. Sudhartio, "A paradigm shift of energy sources: Critical review on competitive dynamics of solar PV industry in Indonesia," *Renewable Energy Focus*, vol. 41, pp. 236–245, Jun. 2022, doi: 10.1016/j.ref.2021.12.001.

[5] E. Tarigan, "Rooftop PV system policy and implementation study for a household in indonesia," *International Journal of Energy Economics and Policy*, vol. 10, no. 5, pp. 110–115, Aug. 2020, doi: 10.32479/ijeep.9539.

[6] H. Satria, R. B. Y. Syah, M. L. Nehdi, M. K. Almustafa, and A. O. I. Adam, "Parameters Identification of Solar PV Using Hybrid Chaotic Northern Goshawk and Pattern Search," *Sustainability*, vol. 15, no. 6, pp. 1-24, Mar. 2023, doi: 10.3390/su15065027.

[7] S. Syafii, P. Anugrah, H. D. Laksono, and H. Yamashika, "Economic Feasibility Study on PV/Wind Hybrid Microgrids for Indonesia Remote Island Application," *TEM Journal*, pp. 2001–2006, Nov. 2021, doi: 10.18421/tem104-66.

[8] J.-F. Lelièvre *et al.*, "Desert label development for improved reliability and durability of photovoltaic modules in harsh desert conditions," *Solar Energy Materials and Solar Cells*, vol. 236, Mar. 2022, doi: 10.1016/j.solmat.2021.111508.

[9] U. Rau, B. Blank, T. C. M. Müller, and T. Kirchartz, "Efficiency Potential of Photovoltaic Materials and Devices Unveiled by Detailed-Balance Analysis," *Physical Review Applied*, vol. 7, no. 4, Apr. 2017, doi: 10.1103/physrevapplied.7.044016.

[10] Y. N. Chanchangi, A. Ghosh, S. Sundaram, and T. K. Mallick, "An analytical indoor experimental study on the effect of soiling on PV, focusing on dust properties and PV surface material," *Solar Energy*, vol. 203, pp. 46–68, Jun. 2020, doi: 10.1016/j.solener.2020.03.089.

[11] Y. Zhang and C. Yuan, "Effects of marine environment on electrical output characteristics of PV module," *Journal of Renewable and Sustainable Energy*, vol. 13, no. 5, Sep. 2021, doi: 10.1063/5.0060201.

[12] L. Idoko, O. Anaya-Lara, and A. McDonald, "Enhancing PV modules efficiency and power output using multi-concept cooling technique," *Energy Reports*, vol. 4, pp. 357–369, Nov. 2018, doi: 10.1016/j.egyr.2018.05.004.

[13] T. AlSkaif, S. Dev, L. Visser, M. Hossari, and W. van Sark, "A systematic analysis of meteorological variables for PV output power estimation," *Renewable Energy*, vol. 153, pp. 12–22, Jun. 2020, doi: 10.1016/j.renene.2020.01.150.

[14] H. Satria, S. Syafii, R. Salam, M. Mungkin, and W. Yandi, "Design visual studio based GUI applications on-grid connected rooftop photovoltaic measurement," *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, vol. 20, no. 4, pp. 914-921, Aug. 2022, doi: 10.12928/telkomnika.v20i4.23302.

[15] K. Attari, A. Elyaakoubi, and A. Asselman, "Performance analysis and investigation of a grid-connected photovoltaic installation in Morocco," *Energy Reports*, vol. 2, pp. 261–266, Nov. 2016, doi: 10.1016/j.egyr.2016.10.004.

[16] S. Y. Mousazadeh, M. Savaghebi, A. Beirami, A. Jalilian, J. M. Guerrero, and C. Li, "Control of a multi-functional inverter for grid integration of PV and battery energy storage system," in *2015 IEEE 10th International Symposium on Diagnostics for Electrical Machines, Power Electronics and Drives (SDEMPED)*, IEEE, pp. 474-480, Sep. 2015, doi: 10.1109/demped.2015.7303732.

[17] G. Angenendt, S. Zurmühlen, F. Rücker, H. Axelsen, and D. U. Sauer, "Optimization and operation of integrated homes with photovoltaic battery energy storage systems and power-to-heat coupling," *Energy Conversion and Management: X*, vol. 1, Jan. 2019, doi: 10.1016/j.ecmx.2019.100005.

[18] Y. Gao *et al.*, "Modeling and analyses of energy performances of photovoltaic greenhouses with sun-tracking functionality," *Applied Energy*, vol. 233–234, pp. 424–442, Jan. 2019, doi: 10.1016/j.apenergy.2018.10.019.

[19] M. Mungkin, H. Satria, D. Maizana, M. Isa, Syafii, and M. Y. Puriza, "Analysis of the feasibility of adding a grid-connected hybrid photovoltaic system to reduce electrical load," *Int. J. Power Electron. Drive Syst.*, vol. 14, no. 2, 2023, doi: 10.11591/ijpeds.v14.i2.pp1160-1171.

[20] E. Cuce and P. M. Cuce, "Tilt Angle Optimization and Passive Cooling of Building-Integrated Photovoltaics (BIPVs) for Better Electrical Performance," *Arabian Journal for Science and Engineering*, vol. 39, no. 11, pp. 8199–8207, Oct. 2014, doi: 10.1007/s13369-014-1394-y.

[21] Q. Dai, J. Liu, and Q. Wei, "Optimal Photovoltaic/Battery Energy Storage/Electric Vehicle Charging Station Design Based on Multi-Agent Particle Swarm Optimization Algorithm," *Sustainability*, vol. 11, no. 7, pp. 1-21, Apr. 2019, doi: 10.3390/su11071973.

[22] R. Hanna, J. Kleissl, A. Nottrott, and M. Ferry, "Energy dispatch schedule optimization for demand charge reduction using a photovoltaic-battery storage system with solar forecasting," *Solar Energy*, vol. 103, pp. 269–287, May 2014, doi: 10.1016/j.solener.2014.02.020.

[23] J. Li, H. You, J. Qi, M. Kong, S. Zhang, and H. Zhang, "Stratified Optimization Strategy Used for Restoration With Photovoltaic-Battery Energy Storage Systems as Black-Start Resources," *IEEE Access*, vol. 7, pp. 127339–127352, 2019, doi: 10.1109/access.2019.2937833.

[24] S. Sinha and S. S. Chandel, "Analysis of fixed tilt and sun tracking photovoltaic–micro wind based hybrid power systems," *Energy Conversion and Management*, vol. 115, pp. 265–275, May 2016, doi: 10.1016/j.enconman.2016.02.056.

[25] A. Fudholi, L. C. Haw, K. Sopian, and A. M. O. Abdulmula, "Primary Study of Tracking Photovoltaic System for Mobile Station in Malaysia," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 9, no. 1, pp. 427-432, Mar. 2018, doi: 10.11591/ijpeds.v9.i1.pp427-432.

[26] S. Seme, B. Štumberger, M. Hadžiselimović, and K. Sredenšek, "Solar Photovoltaic Tracking Systems for Electricity Generation: A Review," *Energies*, vol. 13, no. 16, pp. 1-24, Aug. 2020, doi: 10.3390/en13164224.

BIOGRAPHIES OF AUTHORS

Habib Satria received B.Sc. degree in Electrical Engineering Education from Padang State University in 2016, and M.T. degree in Electrical Engineering from University Andalas, Indonesia, in 2018 and Engineer Professional (Ir), degree from Universitas Diponegoro, Indonesia, in 2022. He is currently a lecture in Department of Electrical Engineering, Universitas Medan Area, Indonesia. His research interests are new and renewable energy, concerning about solar power plant, automatic control system, real-time simulation, green computing, and power system. He is a member of the International Association of Engineers (IAENG) and the Institution of Engineers Indonesia. He can be contacted at email: habib.satria@staff.uma.ac.id.

Sapto Nisworo received a Ir. degree in Electrical Engineering from the Universitas Tidar in 1983, and M.T. degree in Electrical Engineering from Gadjah Mada University, Indonesia, in 2001, and Dr. degree from Gadjah Mada University in 2015. He is currently a senior lecturer in the Department of Electrical Engineering, Universitas Tidar, Indonesia. His research interests are new and renewable energy, and power electronic engineering. He is a member of the Institution of Engineers Indonesia. He can be contacted at email: saptonisworo@untidar.ac.id.

Jaka Windarta received a Ir. degree in Electrical Engineering from the Bandung Institute of Technology in 1988, and M.T. degree in Electrical Engineering from Bandung Institute of Technology, Indonesia, in 1995, and Dr. degree from Bogor Agricultural University, Indonesia, in 2009. He is currently a senior lecturer in the Department of Electrical Engineering and Master of Energy of Diponegoro University, Indonesia. His research interests are new and renewable energy, smart grid, and power system computation. He is a member of the IEEE. He can be contacted at email: jakawindarta@lecturer.undip.ac.id.

Rahmad B. Y. Syah is an associate professor in Universitas Medan Area and received head of Excellent Centre Innovations and New Science (PUIN) Universitas Medan Area. His research interests are modeling and computing, artificial intelligence, data science, business intelligent, metaheuristics hybrid algorithm, and computational intelligent. He is a member of the IEEE, Institute for System and Technologies of Information, Control, and Communication, International Association of Engineers (IAENG). He can be contacted at email: rahmadsyah@uma.ac.id.