Design and building of a battery charging system using hybrid solar tracker and electric trip based on FPAO-FLC

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ABSTRACT

The proposed system is a hybrid charging system between a solar tracker and an electric grid using two converter types. The photovoltaic (PV)-based solar tracker has powerful tools, but its weakness is when the absence of sunlight. With a combination of two resources, the weakness can overcome. The control so good is needed so that it can overcome those weaknesses too. This study uses the flower pollination algorithm optimization-fuzzy logic controller (FPAO-FLC). Results of control using FPAO-FLC has a value of a rising time of 0.0123 seconds, settling time of 2.1099 seconds, maximum overshoot of 6.08%, a peak time of 0.9246 seconds, and steady-state error of 3.43%. The efficiency of the ZETA converter using FPAO-FLC control in the tracking condition PV compared to the fixed condition has increased 43, 24%, and the state of charge (SOC) of the battery reaches 39.08%. The advantage of this hybrid system is that it has two modes of operation, which are automatic, including simultaneous and individual operating modes. The data collection results show that the energy obtained by the individual grid mode dan the individually solar tracker mode is 92.62 Wh and 310.38 Wh. The total energy obtained was 479.81 Wh.

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1. INTRODUCTION

The use of fossil-based energy or oil, gas and coal play an important role in human life. The energy demand from year to year has increased along with the increasing population in a country. One source of energy that is currently widely used is electrical energy. Electrical energy is the main source of human life both for daily life and the needs of companies or industries. According to data obtained average solar radiation intensity of about 4.8 kWh/m^2/day [1]. Thus, the supply of electrical energy is expected to meet all aspects of community needs. But on the other hand, the need for electrical energy which continues to increase has resulted in a reduction in non-renewable energy sources. This condition causes the basic electricity tariff to continue to increase sharply. Thus, in order to decrease pollution, it is necessary to either use electricity in a more efficient way for current processes or have alternative sources that are environmentally friendly and also reliable [2].

One of the alternative sources to produce the most potential electrical energy is solar power. The advantage of solar energy from many renewable energy sources is that it is non-polluting and inexhaustible. Indonesia is a tropical country that has the potential for solar energy with an average insolation of 4.5-4.8 kWh/m^2 per day [3]. This useful innovation to take advantage of this energy potential presents a technology that has been developed as a conversion of solar energy into electrical energy, namely photovoltaic (PV).

In operation, the performance of PV depends on temperature and exposure to irradiation, so these two parameters are the main factors affecting the power yield obtained [4]. In the next development, PV which was added by electronic devices presented a more sophisticated technology, namely the solar tracker [5]. The system configuration uses a light dependent resistor (LDR) sensor and an actuator in the form of a DC motor [6], [7]. The resulting efficiency can reach 47% for a single axis solar tracker when compared to fixed-based PV [8]. Thus, this efficiency shows the high electrical energy generated from the solar tracker device.

Then, the electrical energy obtained will be stored in the battery and can be used to meet electricity needs [9]–[11]. In fact, the output power obtained from the solar tracker fluctuates before being stored in the battery [12]. This condition requires a conditioning system to deal with these weaknesses. In 2017, Bachrowi designed a stand-alone PV charging system based on a solar tracker with an efficiency increase of 36.15% and the charging time of 8.5 hours [12].

Research that has been carried out for a battery charging system with a source only from PV based tracking is still not reliable enough due to the long charging time that the system can provide. So that new technology is needed to solve this problem and can support the charging process with a high capacity battery [13]. One of these technologies is the hybrid system technology. There is research on the design of hybrid power control from the integration of AC/DC-DC converter.

The proposed system on the AC-grid uses a SWISS power factor correction (PFC) converter, while the PV source is a Cuk converter. The integration of the hybrid converter can provide high voltage and power [14]. Subsequent research is improvement of SOC estimation in battery [15]. No less important than the system above, the flower pollination algorithm optimization (FPAO) can be used to optimize the controller of the hybrid system.

This algorithm produces a low overshoot response, and the settling time is faster in two studies, namely the permanent magnet synchronous motor [16] and in wind turbines to optimize the proportional integral derivative (PID) parameters for controlling blade pitch angle. The flower pollination algorithm (FPA) shows better response results when compared to particle swarm optimization (PSO) and manual tuning to optimize power conversion [17], [18].

Research on the application of the converter using the FPAO has been widely carried out. In 2017, Purwanto researched the comparison of methods between the modified PSO algorithm, FPA, and gray wolf optimization using the maximum power point tracking (MPPT) single-ended primary-inductor converter (SEPIC) converter. The results obtained indicate that the FPA method has an advantage over other methods, namely the achievement of responses to reach convergent situations more quickly [19]–[21]. In the same year, Shahin, researching about tuning fuzzy logic controllers with FPA on synchronous buck converters for waves systems obtained a small performance index value, so the smaller the value, the more optimal the response will be [22].

Referring to the problems above, a new innovation is needed that can minimize the amount of electricity costs and the use of PV which is limited by time and weather conditions. On cloudy days, in the morning and at night, the charging system sourced from PV is still not reliable enough. Thus, in this study, a battery charging hybrid system design between tracker-based PV and electric grids is carried out to cover each other's shortcomings. This research is expected to produce optimal efficiency by using the flower pollination algorithm optimization-fuzzy logic controller (FPAO-FLC) as a controller of the system.

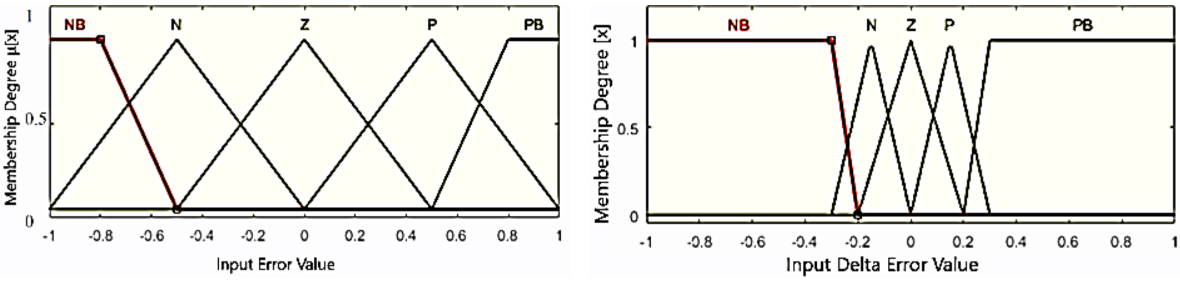
2. RESEARCH METHOD

2.1. FPAO-FLC design

In designing the FPAO-FLC system, first created a fuzzy control system that includes 4 parts, namely fuzzification, inference system, rule base, and defuzzification. Figure 1 is the membership function of the fuzzy logic controller before the optimization. The input for this fuzzy control is voltage error Figure 1(a) and delta error (change in error) Figure 1(b), while the resulting output is a duty cycle. The membership function of the input in the form of error, delta error, and output, namely the duty cycle. The membership function used from the input error and delta error is 3 triangles and 2 trapezoidal. Furthermore, the crisp input number declared by the membership function in Table 1 will be processed by the inference system with the rule base as shown in Table 2, were:

e : error
de : delta error
NB : negative big membership function (trapezoid) = [-1.72; -0.8; -0.5]
N : negative small membership function (triangle) = [-1; -0.5; 0]

Z : zero membership function (triangle) = [-0.5; 0; 0.5]
P : positive small membership function (triangle) = [0; 0.5; 1]
PB : positive big membership function (trapezoid) = [0.5; 0.8; 2.8]



(a) (b)

Figure 1. Membership functions input of (a) error and (b) delta error

Table 1. Input parameters before optimization

Fuzzy number	Error	Delta error
NB	[-1.72; -1.08; -0.8; -0.5]	[-1.72; -1.08; -0.3; -0.5]
N	[-1; -0.5; 0]	[-0.3; -0.15; 0]
Z	[-0.5; 0; 0.5]	[-0.2; 0; 0.2]
P	[0; 0.5; 1]	[0; 0.15; 0.3]
PB	[0.5; 0.8; 1.2; 2.8]	[0.2; 0.3; 1.2; 2.8]

Table 2. Lookup table rule base FLC

e \ de	NB	N	Z	P	PB
NB	NB	NB	NB	NS	Z
N	NB	NB	NS	Z	PS
Z	NB	NS	Z	PS	PB
P	NS	Z	PS	PB	PB
PB	Z	PS	PB	PB	PB

An explanation of the optimization of the fuzzy logic controller membership function, FPAO-FLC do with defining the initial parameters of the fuzzy logic control membership function that been created [23] [24]. Initial parameters: i) Number of insects = 30; ii) Probability of moving to another interest = 0.8; and iii) Maximum number of iterations = 1000.

After defining the initial parameters, then initiating a random number value, when the random number value is smaller than the probability of moving to another flower, global pollination is carried out. Firstly the levy flight is calculated as the power to pollinate with the following calculations [23]:

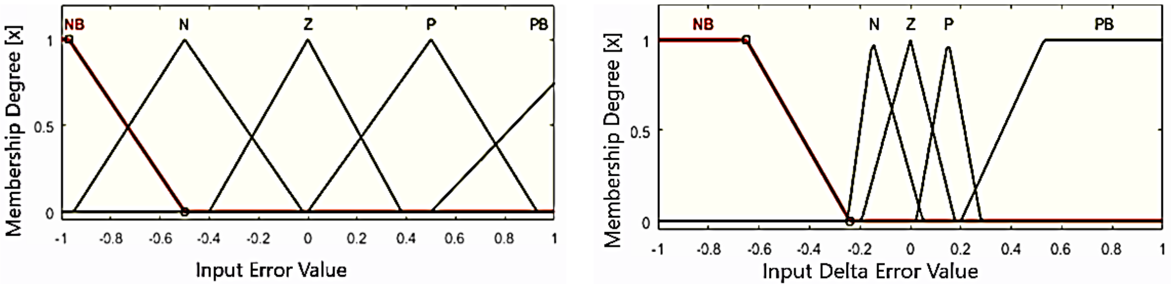
$$Rand = 0.7416$$
$$L(\lambda) = \frac{\lambda\Gamma(\lambda)\sin(\lambda\pi/2)}{\pi}\frac{1}{S^{1+\lambda}}$$
$$= \frac{1.5\ .0.8862.0.0411}{3.14}\frac{1}{1.074^{2.5}}$$
$$L(\lambda) = 0.01455$$
$$X_i^{t+1} = X_i^{t} + L(\lambda)(G_* - X_i^{t})$$
$$= 0.1208 + 0.0145\ (2.4424 - 0.1208)$$
$$X_i^{t+1} = 0.15457$$

The best position produces the lower boundary membership function of NB is -1.1642 and -0.54205, while the lower limit of N is -1 and -0.13635, then the lower limit of Z is -0.42903 and 0.45314, then the limit under P is 0 and 1, the lower bound PB yields a yield of 0.53153 and 1.6893. Figures 2(a) and 2(b) are the results of the optimization membership function error and delta error (change in error) carried out by the FPA optimization to obtain the new membership function. The Figure 2 is the membership function used for the ZETA converter control process.

2.2. Hardware realization

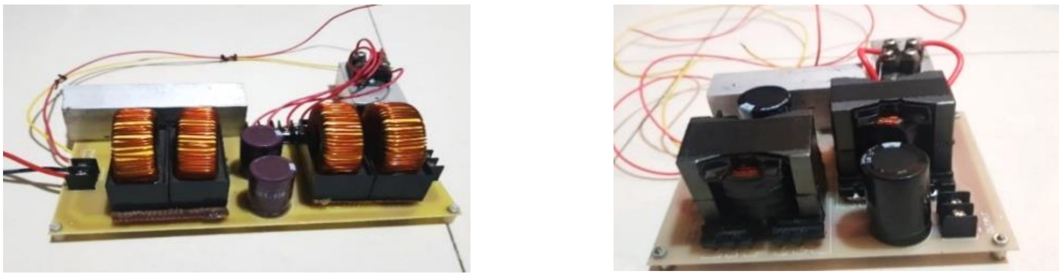
There are two converters used in this hybrid converter shown as Figure 3, Figure 3(a) namely the ZETA converter and Figure 3(b) namely the SEPIC converter. Both of these converters require 2 capacitors, 2 inductors, 1 MOSFET, and 1 diode. The Figure 3 shows the hardware of the two converters.

Hardware of hybrid converter ZETA and SEPIC overall shown as Figure 4(a). The integration of the dual input hybrid converter will be done by adding a 3 MOSFET component to be able to increase the power in the output summing, that shows Figure 4(b). This summing output will charge the battery for energy storage. Figure 5 shows a hybrid schematic that has several modes of operation. In simultaneous operation, two input sources will produce a combined output with the integration part of the two converters. In individual operation, the operating converter is a ZETA converter when the solar tracker input is available, and only the MOSFET 1st switch operates by adjusting the duty cycle automatically. When the solar tracker cannot maintain the voltage output, the power grid will support the SEPIC converter and the duty cycle will be adjusted from the MOSFET 2nd switch automatically.



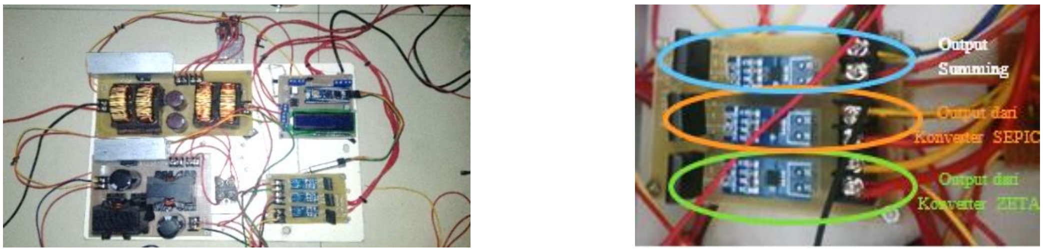
(a) (b)

Figure 2. Functions of membership (a) error and (b) delta error being optimized



(a) (b)

Figure 3. The hardware of (a) ZETA converter and (b) SEPIC converter



(a) (b)

Figure 4. The hardware of (a) hybrid converter ZETA & SEPIC and (b) input converter integration

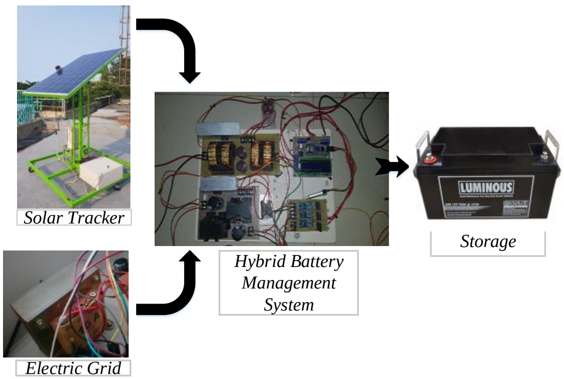


Figure 5. Battery charging system schematic

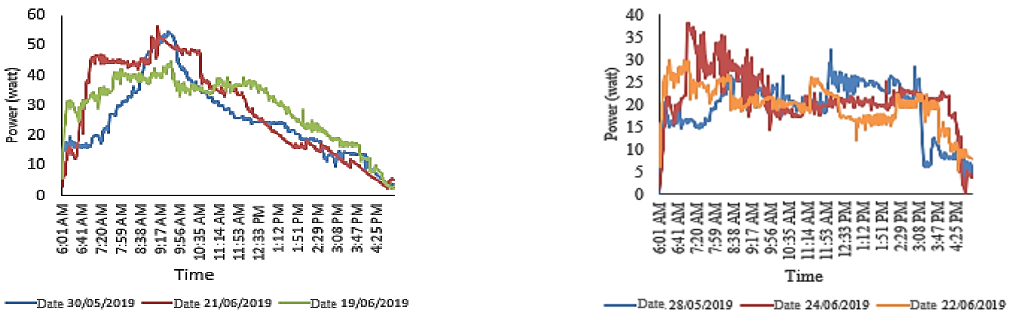
3. RESULTS AND DISCUSSION

3.1. Testing the charging process hardware from the solar tracker

Data were collected continuously with a PV based tracker with a capacity of 250 Wp for fixed PV conditions and tracking on 28, 30 May and 19, 21, 22, 24 June 2019. The controller used is the FPAO-FLC controller on the ZETA converter to achieve the set voltage point 13.2 V. With this voltage the charging process takes place.

Figure 6(a) shows the power generated during the charging process using ZETA FPAO-FLC and an increase in power around 09.00 o'clock, while the decrease occurs when the battery approaches full condition. The energy obtained under the PV tracking conditions on May 30, June 19, and June 21 2019 with a total energy value of 314.79 Wh, 324.91 Wh, and 316.85 Wh, thus it can be said that these values are almost approaching on a different day. The estimated battery state of charge (SOC) obtained was 68.01%, 70.28%, and 68.53% respectively from the final voltage of the sensor taking the data. The less charging current causes the charging voltage to no longer maintain the setpoint (13.2 V). This can be said when the charging current gets lower until it approaches zero, then the voltage measured by the voltage sensor will represent the battery voltage itself. The final voltages are measured at 12.74 V, 12.79 V, and 12.75 V.

According to Figure 6(b) shows the power generated by ZETA FPAO-FLC charging in fixed PV conditions fluctuated the most on June 24, 2019, due to irregular weather conditions (sometimes clouds cover the sun). On May 28, 2019, the total energy and battery SOC reached 214.19 Wh and 29.4%. Then, on June 22, 2019, the total energy and battery SOC was 217.97 Wh and 30%. According to data on June 24, 2019, it produced total energy of 235.62 Wh and the SOC of the battery reached 30.2%. The final voltage measured by the voltage sensor produces 12.38 V, 12.39 V, and 12.42 V respectively. The difference between the total energy and battery SOC values between tracking and fixed conditions using ZETA FPAO-FLC is 96.26 Wh and 39.08%.



(a) (b)

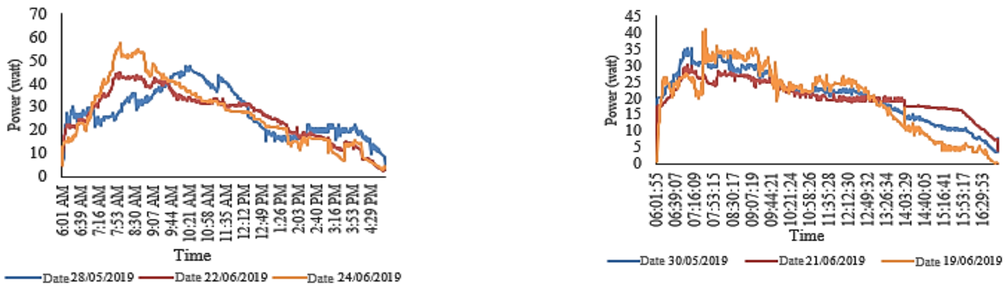
Figure 6. ZETA FPAO-FLC of (a) charging track power and (b) fixed charging power

Based on Figure 7(a) shows the power generated during the charging process using the solar charge controller, the PV tracking condition. Data collection on total energy and battery SOC on May 28, 2019, June 22, 2019, and June 24, 2019, were obtained respectively, namely 301.47 Wh and 65.25%, 293.22 Wh and 63.42%, and 301.39 Wh and 65.2%. The final voltage measured by the voltage sensor is 12.75 V, 12.73 V, and 12.74 V. It can be said that the energy produced is not greater than the use of ZETA FPAO-FLC. In the graph, it can be seen that the highest power is shown on June 24, 2019, but the energy obtained is lower than other data due to a drastic decline starting at 09.13 o'clock.

Figure 7(b) shows the graphic generated by the solar charge controller in a fixed PV condition, the peak power achieved is not too significant, besides that the changes are more regular than the PV tracking condition. After the data is processed, on May 30, 2019, it produces total energy of 227.44 Wh and a battery SOC of 32%. On June 21, 2019, the total energy value was 224.85 Wh and the SOC of the battery reached 32.28%. Then, on 19 June 2019, the total energy was 218.01 Wh and the SOC of the battery was 30.02%. The final voltages that represent the SOC of the battery are 12.42 V, 12.41 V, and 12.4 V. The efficiency increases of ZETA FPAO-FLC in PV tracking conditions with an average energy of 318.85 Wh and fixed PV conditions with the energy of 222.59 Wh reached 43.24% with battery SOC increased by 39.08%, while the solar charge controller on the PV tracking condition was 291.15 Wh and the PV fixed condition was 223.43 Wh, which had an increase of 30.3% and the SOC of the battery increased by 33.13%.

Figure 8 shows that the red line is for the use of the ZETA converter with FPAO-FLC control under PV tracking conditions, the blue line is for the use of the ZETA converter with FPAO-FLC control under the PV tracking condition, the green line is for the use of SCC in the PV fixed condition, the purple line is for use

SCC PV tracking conditions. The graph shows that the charging current using ZETA FPAO-FLC with PV tracking conditions is greater than other conditions or tools.



(a) (b)

Figure 7. Charging power of (a) solar tracker and (b) fixed solar charge controller

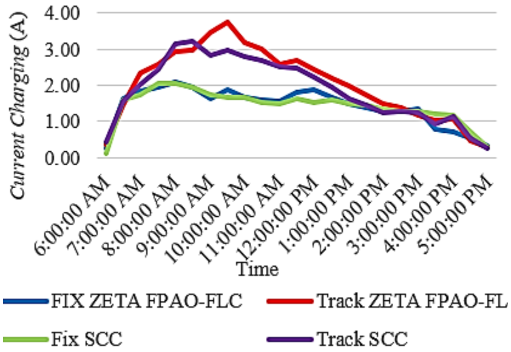


Figure 8. Current charging of battery

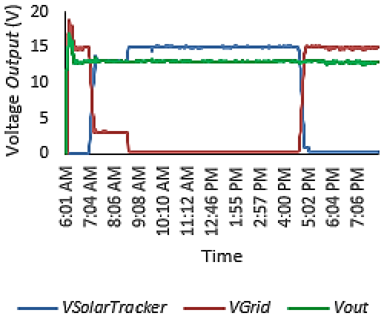
The comparison of the average battery charging current in the six-day data collection above between the use of a ZETA converter with FPAO-FLC control and a solar charge controller resulted in an increase in PV tracking conditions reaching 16.45% with a peak current of 3.75 A, while the increase obtained in fixed PV conditions reached 2.43% with a peak current of 2.11 A. PV using FPSO-FLC control has a SOC greater than using PI control [25].

3.2. Dual input power source backup system

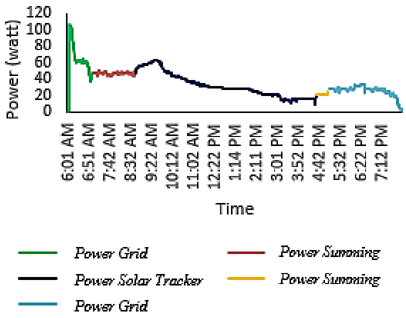
In this hybrid system, there are two modes, namely individual mode and simultaneous mode. Individual mode occurs when the source generated by the solar tracker is available, the operating converter is a ZETA converter, and in another case, the source from the solar tracker is not available, the operating converter is a SEPIC converter with a grid source. Simultaneous mode occurs when the source obtained from the solar tracker is still available but less than 13 V, then the source from the grid will summing the source from the solar tracker to produce this voltage.

Based on Figure 9(a), there is an exchange of charging voltages between the solar tracker and the power grid. This voltage exchange is useful for hybrid systems when one of the supplies starts to decline. The graph shows that the peak charging voltage of the ZETA converter is 15.11 V, the SEPIC converter's peak charging voltage is 15.96 V, the peak voltage obtained after the integration section is 14.04 V. The input is automatically generated graph in Figure 9(b).

Figure 9(b) shows that the greatest power supplied is from the power grid because when the battery is not full or near empty, it makes the power flow bigger. Experimental data dated 05/29/2019 show that the individual mode of the electric grid that has been rectified by the full-bridge rectifier produces energy of 88.38 Wh. Then, the individual mode of the solar tracker gets energy of 304.39 Wh. The simultaneous mode that works from the solar tracker and the grid produces energy of 90.09 Wh. The total energy obtained from this automatic dual supply mode charging process is 482.86 Wh with the SOC battery reaching 83.9%.



(a)



(b)

Figure 9. Results of (a) backup system testing and (b) battery charging power auto mode dual supply

4. CONCLUSION

The efficiency increase of ZETA FPAO-FLC in tracking and fixed conditions is 43.24% with an average energy of 318.85 Wh and 222.59 Wh and battery SOC of around 39.08%, while the solar charge controller experiences an increase of 30.3% with an average energy of 291.15 Wh and 223.43 Wh and the SOC of the battery respectively reaching 33.13%. The average energy from the experimental data that has been carried out shows the individual mode of the grid, the individual mode of the solar tracker, the simultaneous mode of the solar tracker, and the grid produces energy of 92.62 Wh, 310.38 Wh, and 76.8 Wh respectively, so that the total average energy generated from the automatic dual supply mode charging process is 479.81 Wh with the battery SOC reaching 82.27%. The FLC control has a rise time of 0.0108 seconds, a settling time of 3,0007 seconds, a maximum overshoot of 34.28% (17.46 V), a peak time of 1.2661 seconds, and a steady-state error of 32.31%. (17.20 V), while the FPAO-FLC control has a value of rising time, settling time, peak time, maximum overshoot, and steady-state error, respectively 0.0123 seconds; 2.1099 seconds; 0.9246 seconds; 6.08% (13.79 V) and 3.43% (13.45 V). It hopes the future research can use other renewable energy in the hybrid system and add an internet of things (IoT) system in hardware.

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