Hybrid power plant using synchronization controller system to save electricity cost

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ABSTRACT

The application of hybrid energy power plants is one solution to save electricity cost in buildings of government agencies, industries, and universities. The problem with using hybrid power plants that use solar energy sources and paid electricity networks is that sunlight energy cannot produce energy consistently from sunrise to sunset. Maximum energy can only be obtained when the sun is vertically acceptable to the photovoltaic (PV). This results in electrical loads having to be disconnected or switched back to the grid. The application of an electrical power sharing system synchronization controller system (SCS) can automatically regulate the use of electrical energy to low PV energy. The results of research on the application of hybrid PV using the SCS system with a rooftop solar panel system at the Gorontalo State University Building can produce a total electrical power of 600,975 kWh. The need for electrical power from January to September 2022 amounted to 859,151 kWh. The SCS hybrid power plant can reduce the use of paid electrical energy and its costs by 83.60%. The investment, operational, and maintenance cost requirement is IDR 10,747,886,801. The return on investment (ROI) analysis results show that the return on investment can be achieved for up to 34 years.

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1. INTRODUCTION

Hybrid energy power generation is a power plant that combines non-renewable energy with new renewable energy [1]. Photovoltaic (PV) hybrid energy power plants often have lower costs and can offer higher reliability [2]–[4]. A hybrid power plant uses both non-renewable and renewable energy sources in its operation [5]. One of the renewable fuels that has a lot of potential for utilization is solar energy, which is accessible anywhere that receives sunlight [6]. The problem with using hybrid power plants that use solar energy sources and paid electricity networks is that sunlight energy cannot produce energy consistently from sunrise to sunset. Maximum energy can only be obtained when the maximum solar intensity can be received evenly by all solar cell components [7]. The utilization of solar energy as an alternative energy source for the community is currently not the main solution to replacing paid electrical energy [8].

In addition to the problem of a short duration of time to obtain electrical energy, PV power plants need to be installed in a location that can receive sunlight effectively and use a lot of solar cell modules, such as the roof of a building with an appropriate slope [9]–[11]. Building a hybrid energy power plant that uses both renewable and non-renewable energy is required to achieve savings in the usage of electrical energy on a paid electricity network [12], [13]. The problem experienced by large users of electrical energy, such as industries, government offices, and universities is the high cost of paying for electricity [14]. Research conducted in the United States shows that a campus building with an area of approximately 50,000 square feet can cost more than USD 100,000 to pay for electricity each year. The largest electrical energy use is mostly for air conditioning and lighting equipment [15].

Hybrid photovoltaic systems have been shown to cut electricity costs and harmful emissions from fossil fuels [16]. To obtain adequate savings in the use of electrical energy, hybrid power plants must be designed, taking into consideration the factors that could make the power plant run continuously for a long time. The PV component system's quick disintegration is a challenge that is frequently encountered [17]. This is because hybrid electricity generation planning has not been carried out, which considers aspects that affect PV energy generation and the installation of installations divided into several groups to obtain an effective energy supply from the PV system, even though PV performance is low. The majority of the energy drawn from electric storage batteries is also consumed until the battery is depleted [18].

Building a hybrid power plant with a layered control system for the electric supply divider is the aim of this effort. In hybrid energy power plants that use the synchronization controller system (SCS), the value of electrical energy provided to the load will be arranged in stages according to the PV energy capacity. Despite a decline in photovoltaic performance, energy supply can still be provided to other load groups with lower electricity data requirements. A multilevel electrical energy supply is designed so that the PV is at its lowest performance. Large power requirements will automatically be diverted to be supplied via a paid electricity grid. A recent innovation employed in hybrid energy power generation systems to reduce the cost of using electrical energy is the application of SCS. The application of SCS is a new breakthrough used in hybrid energy power generation systems to save the cost of using electrical energy. To undertake a financial analysis of the development of a hybrid power plant, the budget plan is generated using the pertinent national unit pricing standard [19]. For the purpose of determining the return on investment, the feasibility of creating a hybrid power plant to function efficiently, conserve electricity, and be consistent is estimated using the return on investment (ROI) approach [20].

2. METHOD

The research method combines design analysis and simulation techniques to create a hybrid energy power plant that makes use of a synchronization control system to reduce electricity consumption on the Gorontalo State University campus. Investment needs for the construction of hybrid power plants are determined by calculating the cost budget plan with the applicable national unit price standard. To calculate the length of time the return on investment takes using the return on investment (ROI).

2.1. Design of hybrid energy power plants

The hybrid energy power plant design process begins with analyzing the building roof area for solar cell placement and determining the type of solar cell to be used (dimensions and solar cell power capacity). Furthermore, figuring out how many solar panels can be mounted on the building's roof. To obtain the ability of solar cells to produce electrical power, trials and measurements of solar cell electrical energy were carried out from 6 a.m. to 6 p.m. (for 12 hours every day in September 2022). At the same time, solar irradiation measurements were also taken (January to September 2022). The results of testing the performance of solar cells by applying SCS in a hybrid generation circuit system can be obtained by determining the value of the power that can be generated for 12 hours (6 a.m. to 6 p.m.). The cost of the electricity generated can be calculated by multiplying the value of the power generated by solar cells by the number of solar cells that can be installed on the building's roof.

The Gorontalo State University (UNG) Campus Building's roof area was examined utilizing the geographic information system (GIS) analytical technique [21]. The determination of the type of solar cell used takes into account the electrical energy produced, the efficiency, and the price of the solar cell. To obtain a high level of efficiency, it is recommended to use a monocrystalline type solar cell because it has a high-efficiency level of up to 24.4%, the price is moderate, and it has a long life span [22]. A rooftop PV system's energy potential can be determined using the CR formula in kilowatt peak (kWp) using (1) [23], where:
- AR is the roof area of the building for solar cell installation in m^2
- RCR is the ratio of building roofs to install solar cell modules in m^2
- CM is the solar cell's capacity in Wp
- AM is its dimensions in m^2
- SO is its area in m^2

$$C_R = \left(\frac{C_M}{1000}\right) x \left(\frac{RCR\ x\ A_R}{A_M}\right) \quad (1)$$

The (2) is used to convert electrical energy (E) to kilowatt hours (kWh) [24], where:
- GSR is calculated as kWh/m^2/month over a five-year period
- Direct current (DC) is changed into alternating current (AC) using a derate factor value
- The derate factor (D) has a value between 0.6 and 0.8. A standard derate factor of 0.75 is used in this study

$$E = CR \times GSR \times D \quad (2)$$

Where is installing a single monocrystalline solar panel allows for testing the production of electrical energy from solar cells, 300 WP, at the Faculty of Engineering Building's rooftop, which is designated as the testing and simulation planning site. Store voltage and current data using a current and voltage logger circuit module with ZMPT101B and SCT-013-100 sensors [25] and an SD card as a data storage medium. To obtain the performance value of solar cells in producing electrical energy, electric light loads are used with regulated power to show the highest solar cell power capacity. Tests and simulations were conducted on September 1^{st}-30^{th}, 2022, at the UNG Faculty of Engineering.

Solar intensity data were obtained from campbell stokes, a solar light intensity measuring station. campbell stokes measures the amount of sunlight that falls on the earth also the time and duration of the sun's exposure in one day. The campbell stokes location is installed close to the campus location with a distance of ±120 meters, belonging to the Bone Bolango Regency's Gorontalo Meteorology, Climatology, and Geophysics Agency. To obtain solar cell electrical energy data for the previous months (January to August 2022) was carried out through curved curve analysis using the linear regression analysis method with the independent variable X as solar intensity data and the dependent variable Y as the solar cell power value. To obtain accurate results, solar intensity, and solar cell energy data are juxtaposed according to the same incident time (hours/minutes). Calculations from (3) can be used to determine the electrical energy generated by a hybrid power plant utilizing SCS from January to September 2022, from 6 a.m. to 6 p.m., during sun radiation in the Faculty of Engineering Building's. As in (3), where:
- EPV stands for photovoltaic output power (Wh) during solar irradiation
- effPV for photovoltaic efficiency
- nPV stands for the most solar panels that may be installed on a building's roof

$$ETot = EPV.effPV.nPV\ Watt - hour\ (Wh) \quad (3)$$

A simulation process using the same methodology as in the Faculty of Engineering Building's is used to determine the value of electrical energy in other buildings on the UNG Campus.

2.2. Analysis of saving energy use, investment value, and investment payback period

By determining the value of electrical energy supplied by the PV system in every building on the UNG Campus every month, an analysis of the reduction of electrical energy use in buildings is carried out. The energy value produced by the PV system per kWh is multiplied by the price according to government regulations. The value of cost savings is obtained from the electricity costs paid each month minus the electricity costs obtained from the PV system.

Relating to rooftop solar power plants connected to the electric power network regulation number 26 of 2021 of the Minister of Energy and Mineral Resources, it is converting the energy generated by the PV system to expenses in Indonesian Rupiah. Export and import kWh must be used by the government. Customers of the roof PV system utilize electrical energy each month based on the difference between the value of imported kWh and the value of exported kWh. Given that the UNG Campus control panel uses more than 500 kW of electricity, it is required to have a Certificate of Operation Worthiness (SLO). The price of PV roof system electricity is determined to be IDR 1,440.7 per kWh. Based on the budget plan and the current national unit pricing, an analysis of the investment value needed to build a hybrid power plant is performed to calculate the ROI for developing a hybrid power plant using return on investment (ROI) methodology.

3. RESULTS AND DISCUSSION

3.1. Locational conditions for the research

The Gorontalo State University campus is located at coordinates 0°33'21.51" North Latitude and 123°7'59.65" East Longitude, according to the GIS mapping findings. On the UNG campus, there are one library building and four faculty building's. Analysis the calculation of the building roof area for the installation of a rooftop solar cell module serves as an example of its application in the Faculty of Engineering Building's. The roof area of each portion of the Faculty of Engineering building is displayed in Table 1 based on the results of the mapping using the GIS technique. The Engineering Faculty Building's has a 4858.93 m^2 roof area. The rooftop space utilized is 3044.91 m^2, or 62.66%, based on the findings of the solar cell installation pattern according to the ratio of the building's roof area and the solar cell's dimensions.

Table 1. Shows how much roof space there is on each level of the Faculty of Engineering Building's

No.	Name of building section	Available rooftop area (m^2)	Rooftop area used for solar cells (m^2)
1.	C2	1276.78	1085.26
2.	C3	636.48	541.03
3.	C4	460.82	391.72
4.	C5	541.22	460.06
5.	C6	396.72	337.23
6.	Civil laboratory section	926.81	787.79
7.	Industrial laboratory section	620.10	527.08
	Total	4858.93	3044.91

The roof area of Faculty of Engineering Building is 4858.93 m^2. The rooftop space utilized is 3044.91 m^2, or 62.66%, based on the findings of the solar cell installation pattern according to the ratio of the Building's roof area and the solar cell's dimensions. According to the layout results, 384 modules of solar cells, each measuring 1640×992×35 mm, can be mounted on the roof of the Faculty of Engineering Building's. Using the same planning process, the Faculty of Mathematics and Natural Sciences roof can support 200 solar cell modules, 136 modules on the roof of the Faculty of Agriculture Building's, and a total of 1,036 modules on the rooftop of the Faculty of Engineering Building's. The roof of the Faculty of Letters and Culture building is 122 modules, and the rooftop of the library building is 34 modules. As a result, 876 modules worth of solar cells can be put in all UNG Campus Building's.

3.2. Photovoltage powered electricity

Based on the findings of testing one solar cell's ability to produce electrical energy when exposed to solar radiation from September 1st-30th of 2022, at 6 a.m. to 6 p.m. UTC +8 Indonesian time, using the solar specification cell power 300 WP, monocrystalline, the total electrical energy produced the system's PV is 78.874 Wh. The electrical energy generated by the Faculty of Engineering by the PV system, specifically the PV system has a 16.24% PV efficiency and a 78.875 Wh output power per module. Overall, the PV system produces 30.287 kWh. Figure 1 displays the power graph of the PV system at the Faculty of Engineering in September 2022.

To predict the electrical energy generated by solar cells in the previous month, namely January to August 2022, a linear regression equation was used. The results of the linear regression analysis, as shown in Figure 2, obtained the equation Y=0.0035 X+1389.30 with R2=0.8837. By entering data X (solar intensity) for January to August 2022, the electrical energy value for January to August 2022 is obtained, as shown in Figure 3.

The PV system's electricity production in January was 20,722 kWh; February 19,223 kWh; March 20,770 kWh; April 20,319 kWh; May 20,719 kWh; June 20,375 kWh; July 20,289 kWh; August 20,353 kWh; and in September 25,375 kWh. From January through September 2022, the Faculty of Engineering solar panels will have generated 188,145 kWh of electricity.

The results of the analysis in the same way as applied in the Faculty of Engineering obtained the electrical energy of PV systems in the faculty of mathematics and natural sciences, the faculty of agriculture, the faculty of literature and culture, and the library building in January to September 2022, as shown in Figure 4. Also, the total electrical energy generated by the PV system at the UNG Building is 426,884 kWh. The graph of the total energy of the UNG campus is shown in Figure 5.

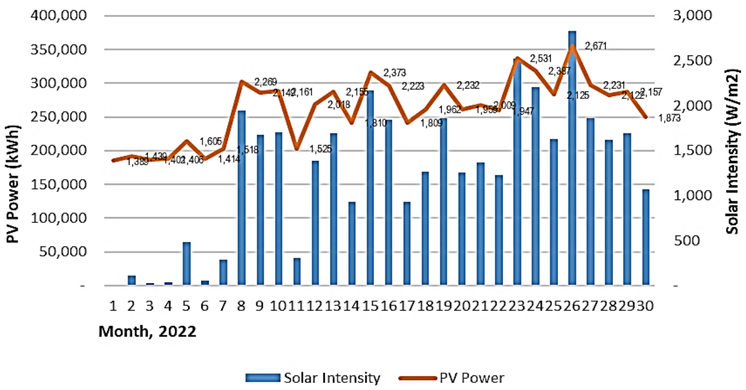

Figure 1. Graph of electrical energy generated by the PV system in September 2022

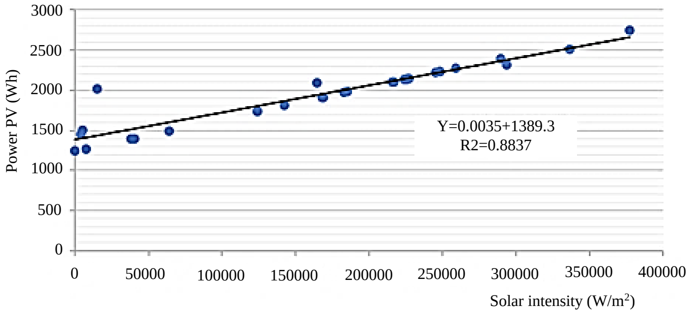

Figure 2. Equation of linear regression line of solar intensity vs. PV power in September 2022

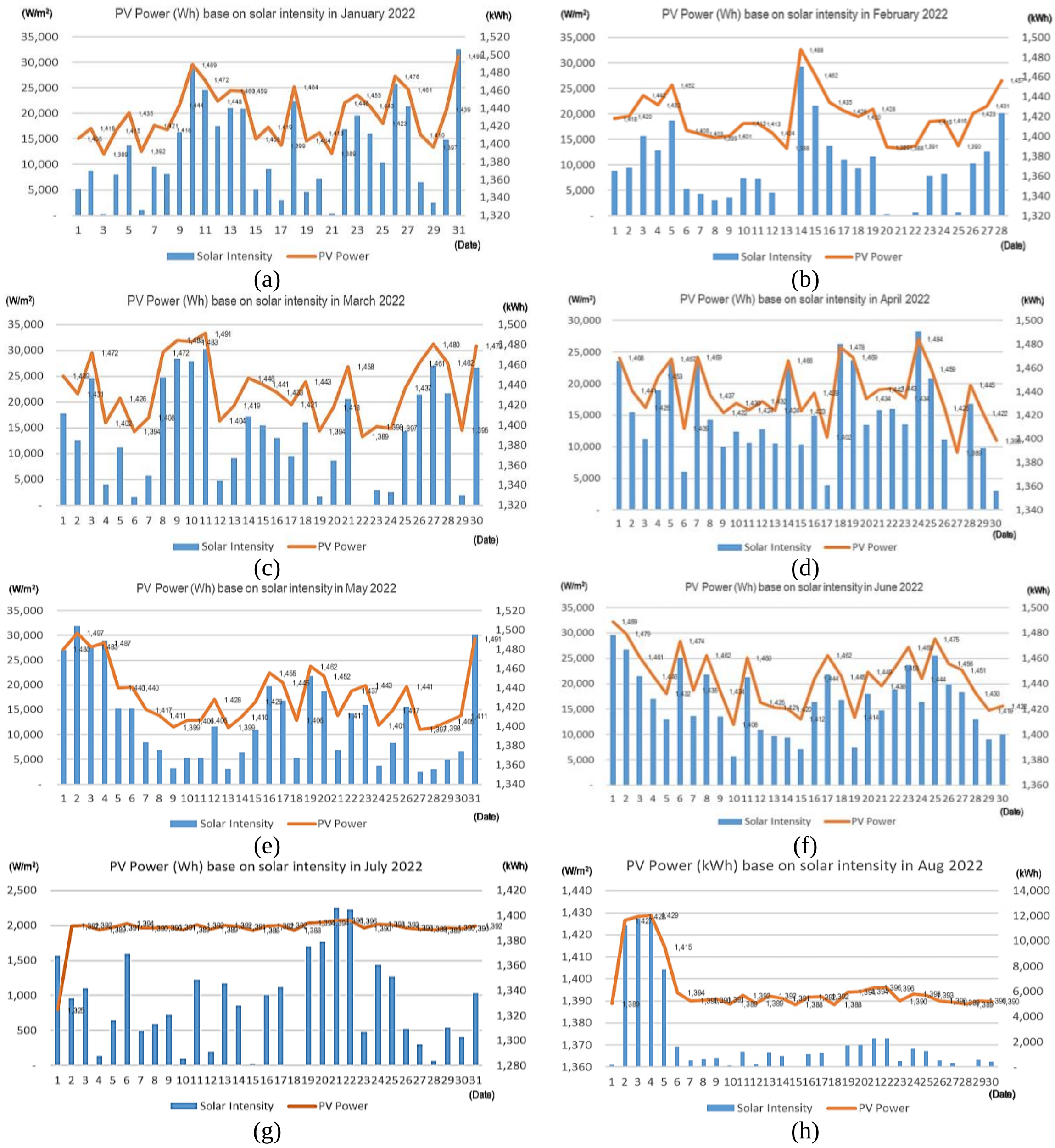

Figure 3. Graph of electrical energy generated by the PV system in the Faculty of Engineering Building's from January-August 2022: (a) January 20,722 kWh, (b) February 19,223 kWh, (c) March 20,770 kWh, (d) April 20,319 kWh, (e) May 20,719 kWh, (f) June 20,375 kWh, (g) July 20,289 kWh, and (h) August 20,353 kWh

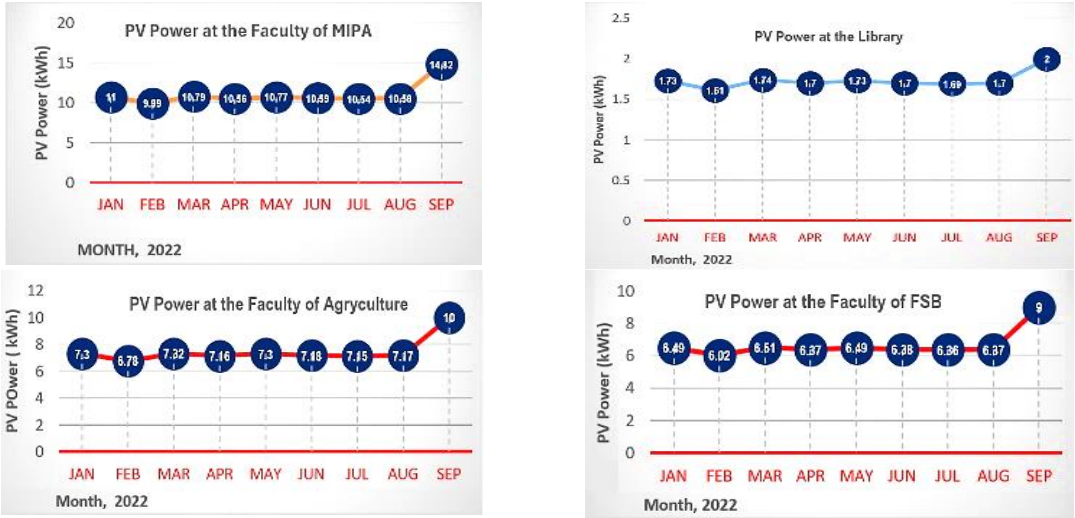

Figure 4. Results of electrical energy analysis of PV systems in other faculties and library building's at UNG, January-September 2022

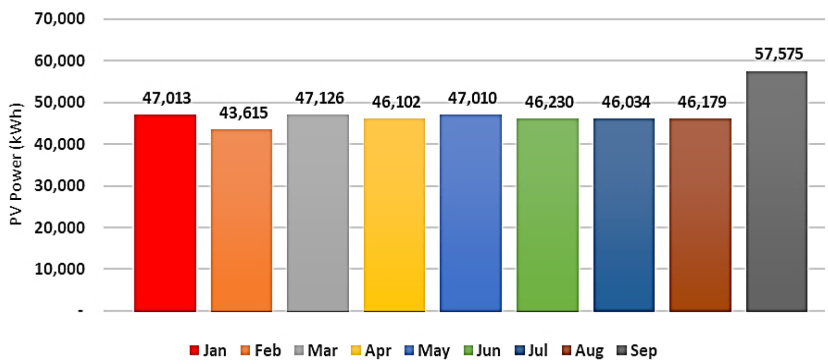

Figure 5. Total electrical energy generated by the PV system at the UNG Building, January-September 2022

3.3. Module for the synchronization controller system (SCS)

Controller drivers function to detect changes in current in the PV system. Suppose there is a decrease in the load current to the lowest limit (according to the program on the Arduino ATmega), the current sensor will signal the Arduino system to cut off the current to the automatic transfer switch (ATS) [26]. ATS automatically switches the PV system network to a grid system and vice versa. If the current sensor detects current according to the highest setting, the ATS system will move the network from the grid system to the PV system. The electrical power source is switched from the grid system to the PV system using a circuit known as a synchronization controller. The test results of the synchronization controller system show that when the PV is at maximum performance, the Arduino Mega driver automatically turns off contactors C1-G, C2-G, and C3-G, then turns on contactors C1-PV, C2-PV, and C3-PV. The synchronization control system will automatically switch the load supply to the PV power plant.

When the PV experiences a decrease in performance, The Arduino Mega system will gradually work to turn off the C1-PV contractor and turn on the C1-G contactor so that the electricity supply in MCB1 automatically switches to the grid system. So on, if the performance of the PV power plant continues to fall, the power supply to MCB2 will automatically switch to the grid system when the C2-PV contactor is turned off by the Arduino Mega driver and on by the C2-G contactor. If PV performance keeps declining, then C3-PV will turn off, and C3-G will turn on and automatically supply the electric load at MCB3 to the grid system. Conversely, suppose the performance of the PV power plant rises again. In that case, the synchronization controller system will again divert the electricity supply to the PV system and turn off the

grid system. Controller drivers system, as shown in Figure 6. The installation of the synchronization controller's load transfer mechanism is shown in Figure 7:
- Current sensors 1 is set at the highest capacity current, which occurs at 11 a.m.-2 p.m;
- Current sensor 2 medium capacity currents occur at 9.00-10.59 a.m. and 2.05-3.30 p.m.; and
- Sensor 3 at low capacity currents, which occur at 6.30-8.55 a.m. and 3.35-5.30 pm.

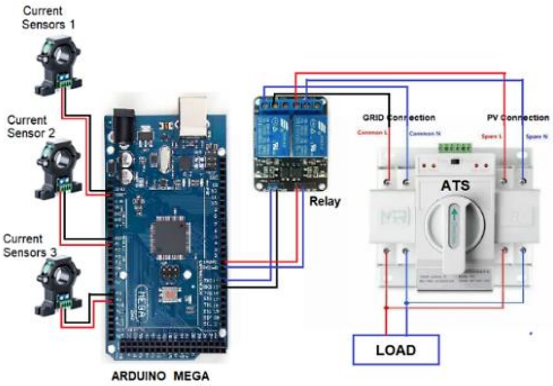

Figure 6. Controller drivers system

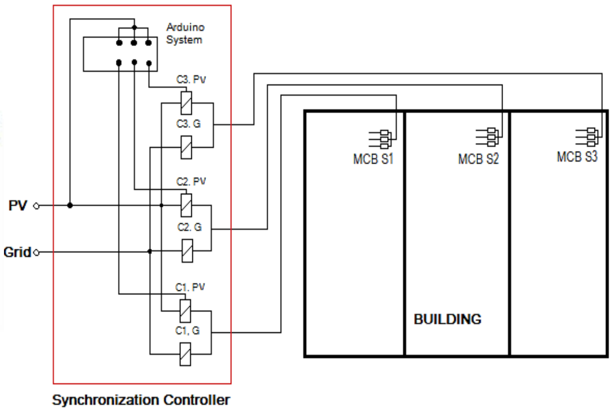

Figure 7. The synchronization controller system installation

3.4. Utilization of electricity on the UNG Campus

Based on information obtained from the finance and equipment department of Gorontalo State University, the use of campus electrical energy from January to September 2022 amounted to 859,240 kWh. Electrical equipment that uses large amounts of energy, based on the electrical energy intensity audit findings for the UNG campus in 2022, is air conditioning [27]. The cost incurred to pay for the use of electrical energy in January to September 2022 is IDR 747,605,340. Information on the use of electricity and the cost of procuring it on the campus of Gorontalo State University is shown in Figure 8.

3.5. Analysis of electricity cost savings

Analysis of saving electricity costs using the equation: savings value = cost of using electrical energy - cost of buying energy produced by a hybrid energy power plant. From January through September 2022, the electrical infrastructure on the UNG Campus used 859,240 kWh at a cost of IDR 747,605,340. Between January and September 2022, the hybrid system produced 426,984 kWh of electricity. The cost per kWh of electricity produced by rooftop solar energy systems in 2021 is fixed at IDR 1,440 in compliance with Minister of Energy and Mineral Resources Regulation No. 730. Therefore, it is possible to compute that the energy investment value of the PV system is 426,984 kWh × 1,440 IDR = 82,908,000 IDR.

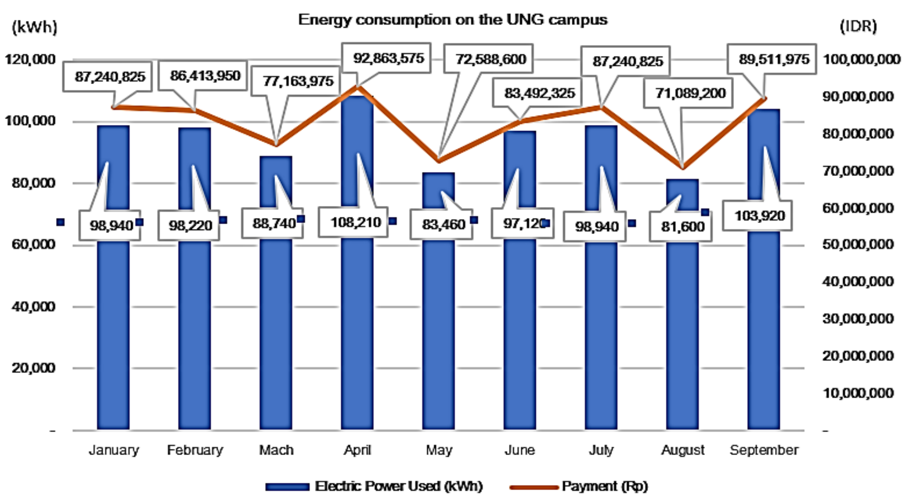

Figure 8. Consumption of electricity on the UNG Campus, January-September 2022

3.6. An examination of the project's return on investment for building hybrid power plants

According to the findings of the bill of quantity (BoQ) method analysis of the construction of hybrid power plants at the Faculty of Engineering, the total budget required is IDR 6,653,590,025. Faculty of Literature and Culture is IDR 4,247,720,000; Faculty of Agriculture is IDR 3,720,675,000; Faculty of Mathematics and Natural Sciences is IDR 5,530,550,000; library building is IDR 810,000,000. Hybrid PV construction at UNG will cost a total of IDR 20,962,535,025.

3.7. Analysis of return on investment (ROI)

From January to September 2022, hybrid PV systems will generate 426,984 kWh of electric energy. The total investment required to construct a hybrid power plant at Gorontalo State University is IDR 20,962,535,025. return on investment can be calculated as:

$$ROI = Total\ Investment/Net\ Cash\ Flow$$
$$= 20{,}962{,}535{,}025/614{,}844{,}090 = 34$$

4. CONCLUSION

Hybrid energy power plants using S in the electricity system on the Gorontalo State University Campus is a good solution for saving electricity use. The results showed that a hybrid energy power plant with SCS could save Rp 68,301,440 or 82% of electricity bills per year at Gorontalo State University. And for the return on investment (ROI) can be achieved for 34 years.

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