ARCHIVES OF ELECTRICAL ENGINEERING VOL. 72(4), pp. 931 –950 (2023)

DOI 10.24425/aee.2023.147419

Solar power and multi-battery for new configuration DC microgrid using centralized control

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(Received: 12.03.2023, revised: 27.07.2023)

Abstract: The abundant use of solar energy in Indonesia has the potential to become electrical energy in a microgrid system. Currently the use of renewable energy sources (RESs) in Indonesia is increasing in line with the reduction of fossil fuels. This paper proposes a new microgrid DC configuration and designs a centralized control strategy to manage the power flow from renewable energy sources and the load side. The proposed design uses three PV arrays (300 Wp PV module) with a multi-battery storage system (MBSS), storage (200 Ah battery). Centralized control in the study used an outseal programmable logic controller (PLC). In this study, the load on the microgrid is twenty housing, so that the use of electrical energy for one day is 146.360 Wh. It is estimated that in one month it takes 4.390.800 Wh of electrical energy. The new DC microgrid configuration uses a hybrid configuration, namely the DC coupling and AC coupling configurations.The results of the study show that the DC microgrid hybrid configuration with centralized control is able to alternately regulate the energy flow from the PV array and MBSS. The proposed system has an efficiency of 98% higher than the previous DC microgrid control strategy and configuration models.

Key words: centralized control, DC microgrid, multi-battery, PV array

1. Introduction

Currently, the use of renewable energy sources (RESs) in Indonesia has increased in line with the reduction in fossil fuels. Combining several renewable energy sources in a microgrid creates problems such as power and voltage stability, high load currents, and alternating arrangements of several sources. With the increasing need for electrical energy, the International Renewable Energy Agency (IREA) estimates that 66% of energy needs will be obtained from renewable energy sources. Energy sources that are widely used in Indonesia are solar and wind energy. To increase the output of solar energy, MPPT (Maximum Power Point Tracking) is used [1]. Power plants with large capacities, especially in Indonesia, still use fossil fuels. A grid configuration with distributed generation sources (DGs) from PV and turbine energy was developed to supply power to the load, as a substitute for conventional power plants [2]. At present, microgrids have received a lot of attention for use as distributed generators to meet the needs of the electricity load. The changing demand requirements are met with distributed generation sources. The need for electric loads increases according to technological developments. In addition, global energy needs are increasing every year. In 2017 global energy demand is 17%, in 2018 it is 22%, and in 2050 it is predicted to increase by 80–90% [3, 4].

There are two types of microgrids, DC microgrids and AC microgrids. DC microgrids have many advantages when compared to AC microgrids. Because in AC microgrid it raises problems of harmonics and frequency on the grid and load, and reactive power control. In addition, synchronization is also required when operating islanded [5, 6]. DC microgrids are easier to integrate with multiple sources and loads, for example, PV sources and wind turbines with loads such as DC computers, lights, and mobile phones. Although DC microgrids require a lot of configurations and are more expensive, DC microgrids are more efficient and reliable for controlling energy loads. In addition, DC Microgrid does not require synchronization. In the DC microgrid there is a lower power loss when compared to the AC microgrid [7, 8]. Microgrids can operate in islanded mode and grid in connected mode. The energy sources used are DC microgrids and AC microgrids with renewable energy sources, so they can reduce pollution [9]. The problem with the use of renewable energy is that it occurs intermittently, so that the performance of the microgrid in providing a source of electricity is low. To improve microgrid performance, fossil energy sources are still used, namely diesel and gas. Fossil energy sources are integrated with renewable energy sources in a microgrid system [10, 11]. To regulate and improve the flow of power in the microgrid so that its efficiency increases, the development of a power management strategy is urgently needed. In addition, energy storage batteries and supercapacitors are needed to increase load demand. However, the large number of energy sources used creates difficulties in the control design used, because the controls used are increasingly complex [12–14]. The storage system will charge during the day and the discharging process at night and when the microgrid operates in island mode. Batteries and supercapacitors are used for microgrid storage because they have a high energy density and high power. A bidirectional converter design is needed for the process of charging and discharging energy storage systems in microgrids.

Many researchers have designed DC voltage control in converters and source and load settings in microgrids. This design is widely used in DC microgrids and the control design is simpler when compared to AC microgrids. This aims to stabilize the power of the microgrid [15]. Droop control is widely used as a method for dividing load current in distributed generators. The weakness of conventional droop control is the setting of the impedance parameter of the converter and the network which is different, causing an unequal distribution of power [16, 17]. Several researchers have used droop controllers in managing resources in microgrids. However, an error in selecting the droop controller parameters will cause current and voltage imbalances. The weakness of the droop controller is enhanced by the control hierarchy model [18–21]. Due to the need for battery storage in a microgrid, converter control is needed for battery energy flow by looking at the state of charge (SOC) limit. The droop control method is widely used for battery control and droop parameter changes based on SOC changes. The droop control method for the battery can be replaced with other control methods which are more effective and not affected by the droop parameter. Further development of the microgrid requires coordinated control of each converter. This aims to overcome fluctuations in renewable energy sources and changes in load demand. [22–25].

In [26], the authors presented distributed controls on a microgrid, but the proposed scheme does not include virtual impedance. In addition, in a distributed generation system, multi-agent sources of renewable energy are used for microgrids. In the multi-agent model, a communication channel is used for setting each source to load. However, the authors have not applied for DC microgrids and are still focusing on AC microgrids. The authors in [27] presented a summary of multi-level controls on a DC microgrid. Multi-level control consists of primary and secondary controls. The authors discuss a comparison of control strategies at the secondary level, which include control of voltage, current, energy storage systems, and loads. However, the authors did not discuss the control coordination of each section and the stability obtained. In [28], the authors presented a converter control coordination strategy to improve quality on microgrids. The weakness of the proposed strategy is that it does not discuss the controls on each converter. In [29] presents the balance and flow of energy on a microgrid using a Marine Predator Algorithm (MPA) and Multilayer Perceptron Neural Network (MLPNN). The researchers aim to increase the cost efficiency of microgrids in supplying commercial loads in the country of Algeria. The microgrid sources used consist of photovoltaic (PV), wind turbines, batteries, and diesel generators. The results of the study show efficiency on daily costs, but the paper has not discussed distributed control strategies on DC microgrids and only focuses on operational costs. In [30], the authors focus on managing energy storage systems to overcome the intermittent characteristics of PV and wind turbines, with the Virtual Power Plant (VPP) method. This method manages received and transmitted energy sources, loads, and energy storage systems. The goal is to match supply and demand to the load. However, the authors did not describe VPP control strategy. In the end the authors [31], focused on discussing communication methods at multi-level control, namely between the primary control and the level below it. The authors present that communication at multi-levels influences the performance of the controls below, with better control responses. However, the authors did not take into account the stability produced by comparing distributed controls.

Microgrids are distributed generators that are in great demand, because they provide a more reliable source of electrical energy for industrial, residential, and other institutional needs. In contrast to the utility grid, which provides an uninterrupted supply of electricity, so that the supply of electrical power to the load is unserved. In addition, utility grids use expensive fuel and do not use energy storage systems. Whereas the microgrid uses an energy storage system, to overcome when there is an interruption of renewable energy sources. Therefore, microgrids can be relied upon to overcome the electricity crisis, at a lower cost. Thus, it is more suitable to use microgrids on a larger scale in Indonesia, in accordance with the depletion of fossil fuels. In addition, Indonesia is a country that has abundant renewable energy potential. Given the importance of providing an uninterrupted supply of electricity sources and not depending on fossil fuel power plants, this paper proposes the utilization of the potential of solar power and wind for microgrid distributed generation. In addition, this paper presents a planning and control approach for DC microgrids. For the regulation of energy sources and loads, a centralized control strategy is used. After the introduction, Section 2: DC microgrid, standards and configurations, Section 3: Modelling on DC microgrid, Section 4: Methodology on DC microgrid design, Section 5: Results and discussion.

2. Configuration on DC microgrid

Indonesia is shifting from the use of fossil energy to renewable energy. The use of this energy can reduce environmental pollution. Therefore, the potential for renewable energy in Indonesia can be used as a distributed generator (DG). This distributed generation method is used as a microgrid concept, and is very suitable for use in areas that have very high renewable energy potential. Microgrids use several renewable energy sources, such as solar energy, wind energy, water energy, and so on. The energy is regulated to supply the load uninterruptedly. The microgrid concept is also suitable for remote areas. The majority of the distribution network and distributed energy resource standards apply to microgrids. High levels of distributed energy resources in low- or medium-voltage distribution networks minimize centralized synchronous generator dependence and controllability, which fundamentally alters the way the power network operates. Microgrids that are connected to utility grids with smaller capacities do not cause many problems in energy management. The conventional power system treats these small-capacity microgrids as negative loads, and the synchronous generator controls the system voltage and frequency. To preserve system stability and dependability, power system operators must integrate a significant number of microgrids into the utility grid. IEEE released IEEE Std. 1547-2018 (a modification of IEEE Std. 1547-2003) for the connectivity and interoperability of distributed energy resources with existing power systems. According to performance standards such voltage and frequency regulation, IEEE Std. 1547-2018 divides distributed energy resources into two main groups and three sub-categories based on disturbance ride. A microgrid can be thought of as a collection of distributed energy resources, hence it must adhere to the specifications outlined in IEEE Std. 1547-2018. Additionally, this standard facilitates the efficient integration of distributed energy resources into the current electric power grid [32–34]. The DC microgrid has PV components, wind turbines, battery storage and supercapacitors, DC loads and AC loads, DC-DC converters, and AC/DC converters [35–37]. The planning and operation of DC microgrids must take into account a number of factors, including dependability, cost, and environmental impact. In addition, effective DC microgrid planning has a significant impact on operations. Therefore, the DC microgrid can maintain its stability and reliability depending on the design used. DC microgrids can run in both islanding and grid-connected modes. In order to maximize system resilience when DC microgrids are cut off from the main grids owing to faults, voltage fluctuations, or other disruptions, it is crucial to plan properly for the available generation units and load [38–40]. Numerous research demonstrate that there are single objective and multi-objective optimization challenges for the best ESS sizing. Cost minimization is the foundation for the majority of single-objective optimization issues [41, 42].

3. Modelling on DC microgrid

The DC microgrid is modeled with renewable energy source nodes and utility grids, as well as load nodes. Figure 1 shows the DC microgrid model with multiple sources and loads. In this model, the AC source is from the utility grid, while the DC source is obtained from photovoltaic (PV), wind turbines and battery storage. DC source and AC source require DC-DC converter, DC-AC converter, and AC–DC converter. The converter will adjust the output voltage according to the DC bus voltage, so that the input voltage is the same as the load voltage level. In the DC microgrid model, control droop is used for power sharing and load matching voltage regulation.

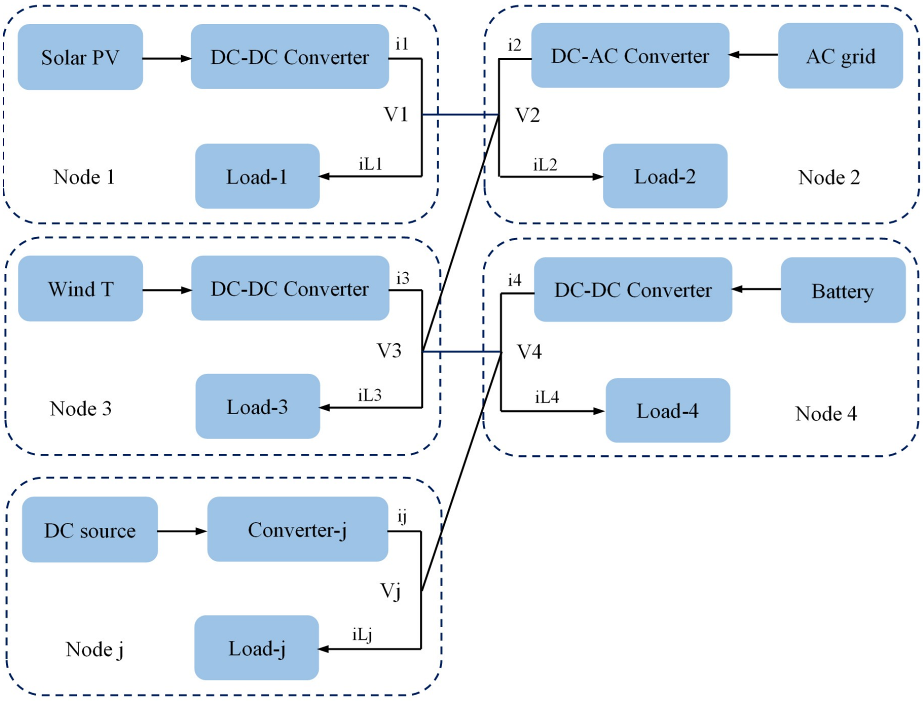

Fig. 1. Modelling on DC microgrid

In the DC microgrid model each source is like a DC source which has a resistance, shown in Fig. 2. Droop control with PI controller parameters provides low voltage and power sharing performance. Therefore, it is very important to design droop control with PID controller. In addition, the DC microgrid model is a non-linear system model, so that linear control cannot be used on DC microgrids [43, 44].

The droop control used in controlling the voltage and current in the DC microgrid system can be stated as follows:

$$v_{sj} = v_s - i_{dcj} R_{dj}\,, \tag{1}$$

where v_{sj}, v_s, i_{dc}, R_{dj} are the j-th node voltage, DC source voltage, DC source current, and virtual resistance of each DC source (with $j = 1, 2, \ldots$). The virtual resistance expressed in

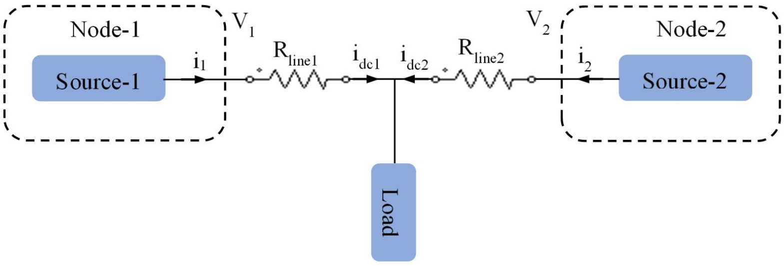

Fig. 2. DC-microgrid model with two DC sources

Eq. (1) is equal to the output resistance and output voltage of each DC source. While the load voltage equation can be stated as follows:

$$v_{\text{load}} = v_s - i_{dc1} R_{d1} - i_{dc1} R_{\text{line1}} \,, \tag{2}$$

$$v_{\text{load}} = v_s - i_{dc2} R_{d2} - i_{dc2} R_{\text{line2}} \,. \tag{3}$$

If Eqs. (2) and (3) can be converted into the DC current ratio equation as follows:

$$\frac{i_{dc1}}{i_{dc2}} = \frac{R_{d2}}{R_{d1}} + \frac{R_{\text{line2}} - \left(\frac{R_{d2}}{R_{d1}}\right) R_{\text{line1}}}{R_{d1} + R_{\text{line1}}} \,. \tag{4}$$

DC microgrid is a distributed generator with a small scale, so the R_{line} resistance is small and the R_{dj} resistance is large. Therefore, Eq. (4) is expressed as follows:

$$\frac{i_{dc1}}{i_{dc2}} = \frac{R_{d2} + R_{\text{line2}}}{R_{d1} + R_{\text{line1}}} \approx \frac{R_{d2}}{R_{d1}} \,. \tag{5}$$

Equation (5) is not suitable for large R_{dj}. For small R_{dj}, there is an incompatibility of current distribution. Whereas with a large virtual resistance, there will be an unequal distribution of voltages. To limit the deviation of the DC microgrid output voltage within certain limits, the droop coefficient is limited by the following equation:

$$R_{dj} \leq \frac{\Delta v_{\max}}{i_{thj}} \,. \tag{6}$$

4. Proposed method

The abundant use of solar energy in Indonesia has the potential to become electrical energy in a microgrid system. The use of a microgrid system with renewable energy sources is very important for previous researchers to develop. Many researchers have used solar panels (PV) connected to battery storage to achieve stability. This paper proposes a DC microgrid and designing a centralized control strategy to manage the power flow from renewable energy sources and load side, Fig. 3. The proposed design uses three PV arrays with multi-battery storage, so as to meet load demands. Therefore, the proposed DC microgrid is more reliable and efficient in controlling the load power for housing. In addition, with the proposed method, housing is no longer dependent on public grid electricity sources and will result in cost savings.

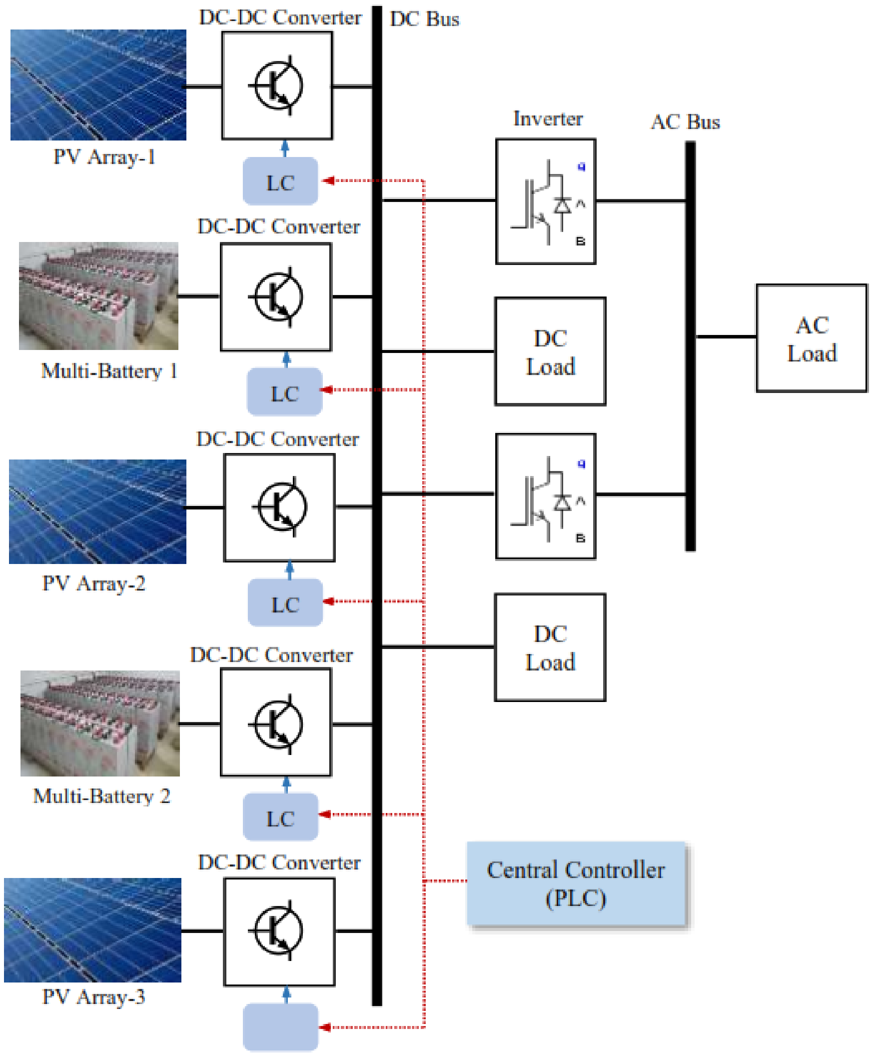

Fig. 3. The proposed DC microgrid

In the first stage it was carried out by reviewing the literature to study and understand the development of the DC microgrid system. The use of the proposed PV array is the use of several PV arrays to produce maximum output. The proposed DC microgrid is planned to have a DC bus voltage of 24 V. This aims to reduce the number of batteries connected in series. This is different from other microgrids which usually operate at a higher DC bus voltage, ranging from 400 V to 800 V DC. The system proposed in this paper uses a hybrid configuration, namely the DC coupling and AC coupling configurations, which include the following two steps

Step I – Development of a DC microgrid system with a hybrid configuration, and multi-battery as energy storage. The model of a DC microgrid system integrated with multi-batteries is shown in Fig. 3. The components used in the DC microgrid were modeled using MATLAB/Simulink software. As shown in the figure, PV array components, multi-batteries, DC-DC converters, inverters, and centralized control using PLC are used. Then analyze and evaluate the simulated system model. This step resulted in a new DC microgrid topology according to Fig 3 and the literature review that has been done. PLC control method in a centralized control system in compared to conventional control systems.

Step II – Development of a control strategy with a centralized control implemented with hardware, and integrated with multi-battery storage. The hardware is designed for residential electrical needs. Centralized control is designed using an outseal PLC. This control will regulate the output power of the PV array, battery, and load. The centralized controller uses the Mega V.3 PLC which functions to give instructions to each local controller in distributing and cutting off the energy flow to the DC bus. The local controller is a DC-DC converter which functions to distribute energy from the PV array and battery to the DC bus. When the weather is sunny, the PLC will give instructions to each local PV array controller to distribute energy to the DC bus. In addition, the PLC also gives instructions to the local battery controller to store excess energy from the DC bus to the battery. When the battery is full, the PLC will give instructions to the local battery controller to stop the energy storage process. At night or when the weather is cloudy, the PLC gives instructions to the local PV array controller to disconnect from the DC bus and gives instructions to the local battery controller to supply battery energy to the DC bus. The multi-battery design serves to serve loads that are always changing, so that energy availability is able to serve the load. Meanwhile, the AC load is autonomously supplied from the inverter without going through the PLC.

With this second step, it is possible to evaluate the capacity of the power produced by the PV array, and evaluate the capacity of the battery when there is a change in the intensity of solar radiation. In addition, it also evaluates the ability of centralized control using a PLC, when there is a change in load.

In this study the microgrid uses twenty residential loads. Each residential has the same load profile. The main load used in microgrids is generally a DC load, and only a small part is an AC load. The load profile for a residential on a microgrid is shown in Table 1. The table shows the type and amount of load, usage, and power rating of the load. Lights, electric stoves, and TV loads in this microgrid system are DC loads that are often used in residential. Based on Table 1, the use of electrical energy for a house to live in one day is 7 318 Wh. In this study, the load on the microgrid is 20 residential houses, so that the use of electrical energy for one day is 146 360 Wh. It is estimated that in one month 4 390 800 Wh of electrical energy is needed. The centralized control strategy for the proposed DC microgrid functions to regulate the power sharing of each multi-battery and PV array in the DC/AC coupling hybrid system. The strategy used has the advantage that all DC sources are connected in distribution to the DC bus. The system continues to operate when a node is not supplying. All source nodes can supply independently without a communication network.

Table 1. Load on residential

Load Type	Quantity	Operation (hour)	Rating (W)	Load (Wh)
LED light (DC)	3	12	6	216
LED light (DC)	5	12	10	600
CFL light (DC)	4	6	20	480
Computer (DC)	1	4	170	680
TV 40″ (DC)	1	3	62	186
DC component	1	2	100	200
Exhaust fan (AC)	3	6	12	216
Water pump (AC)	1	3	180	540
Refrigerator (AC)	1	12	350	4 200

The centralized control strategy for the proposed DC microgrid functions to regulate the power sharing of each multi-battery and PV array in the DC/AC coupling hybrid system. The strategy used has the advantage that all DC sources are connected in distribution to the DC bus. The system continues to operate when a node is not supplying. All source nodes can supply independently without a communication network.

Figure 4 shows the control strategy for each PV array. When the intensity of solar radiation is bright and the PV array provides a stable voltage to the DC bus, the PLC will provide a signal to controller C1. When the DC bus voltage is unstable, due to reduced PV array output, the PLC will give a signal to controller C2 to stabilize the DC bus voltage. Meanwhile, Fig. 5 shows the control strategy for each multi-battery. In the multi-battery control strategy, controller C4 functions to

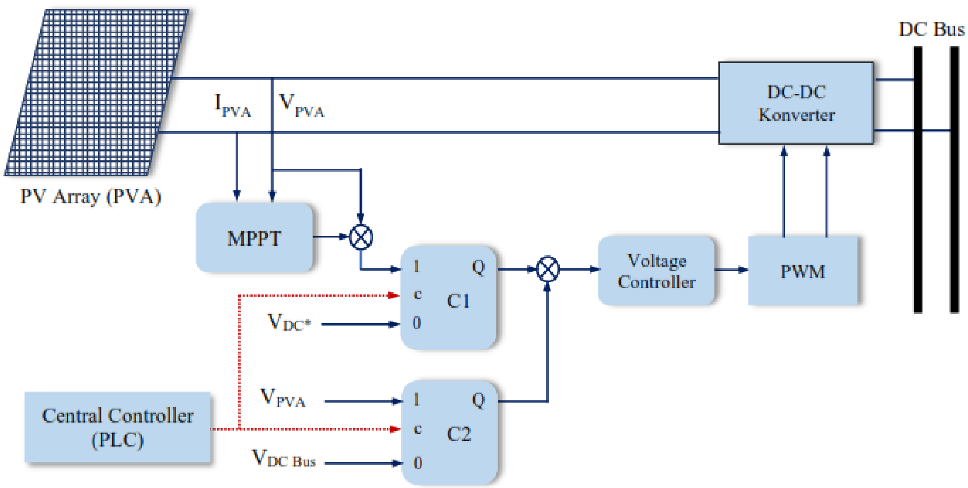

Fig. 4. Control strategy on PV arrays

see the battery's SOC level. When SOC is low, C4 will give a signal to controller C3, resulting in a multi-battery charging process. When the SOC is high and the battery current exceeds the minimum battery current, the battery will supply power and voltage to the DC bus. Centralized control will regulate the replacement of each multi-battery by giving an i_b^* signal.

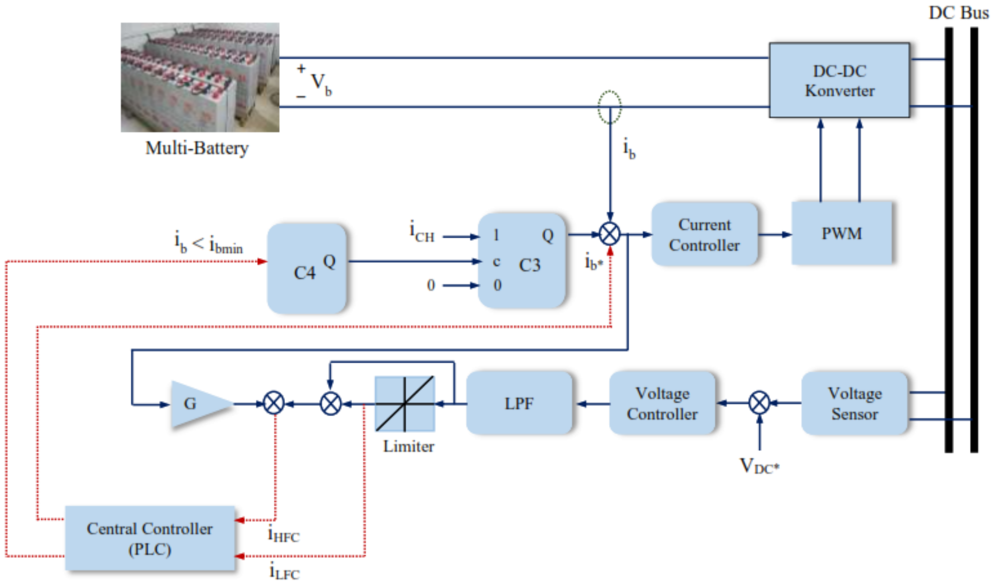

Fig. 5. Control strategy on multi-battery

The amount of solar radiation intensity at the study location in Tambakharjo, based on information from the Global Solar Atlas (GSA) is 5.2 kWh/m^2/day. Therefore, to calculate the number of PV arrays, the following equation is used:

$$P_{\mathrm{PV}} = \frac{E}{P_{\mathrm{SM}} \times \mathrm{eff}_{\mathrm{PV}}} . \tag{7}$$

Assuming the size of the PV array is ideal, the efficiency is one. However, all PV modules have a power reduction factor for the PV modules used. Based on the National Renewable Energy Laboratory's, the calculation of the PV output power is divided by a factor of 84%. Therefore, the resulting PV power is 35 183 W. In the DC microgrid design, three PV arrays are used, so the output power of each PV array is 11 728 W.

Multi-battery size is determined based on source generation and load demand. Considering that the PV output fluctuates with the intensity of solar radiation. Apart from that, when using the battery, the depth of discharge (DOD) is also considered, which does not exceed 50%. In planning the battery also pay attention to the state of charge (SOC) factor. The SOC setting is done by paying attention to the charging and discharging limits of the battery, so that the battery life lasts longer. In a multi-battery management setup, SOC is maintained within a predefined level by the following equation:

$$\mathrm{SOC} = \mathrm{SOC}_S - \frac{1}{E_b} \int P_O \, \mathrm{d}t, \tag{8}$$

where: SOC is rated level, SOC_S is initial level, E_b is battery energy, P_O is output power. The amount of power stored and released by a multi-battery is determined based on the difference in the power stored successively in two timeframes for one full day. After we know the energy consumption in a house for one day, we can consider the type of battery and the size of the multi-battery to be used. The use of electrical energy for one day for housing is 146 360 Wh. Multi-battery is used to supply power with a voltage according to the DC bus voltage, which is 48 V. So, with the required capacity with the following equation:

$$Ah_b = \frac{E \times N}{V \times D}. \tag{9}$$

where Ah_b, E, N, V, D are the minimum multi-battery capacity (Ah), energy consumption in one day, storage time, multi-battery working voltage, and battery DOD of 50% [45, 46]. Based on residential energy consumption for one day of 146 360 Wh, a multi-battery capacity of 6 098 Ah is required. With a DC microgrid design using two multi-batteries, the capacity of each multi-battery is 3 049 Ah.

Figure 6 shows the flowchart of the central controller giving instructions to the local controller in setting the flow of energy to the DC bus.

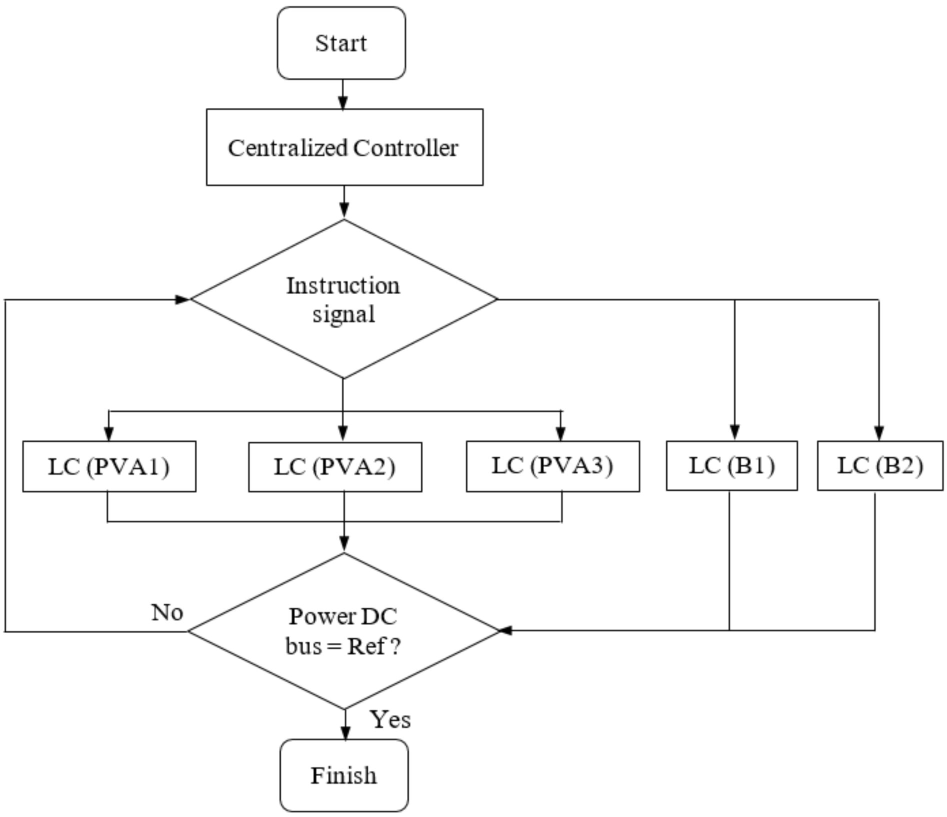

Fig. 6. Flowchart on centralized controller

5. Result and discussion

The study location has a potential average solar radiation intensity of 5.2 kWh/m^2/day, with different changes in solar intensity each month. The average output potential of PV every month, from August to December shows changes. The greatest potential for solar radiation each month occurs in August. Meanwhile, the profile of the average daily output of solar radiation is shown in Fig. 7. The daily profile shows that the intensity of solar radiation is at its peak from 09.00 to

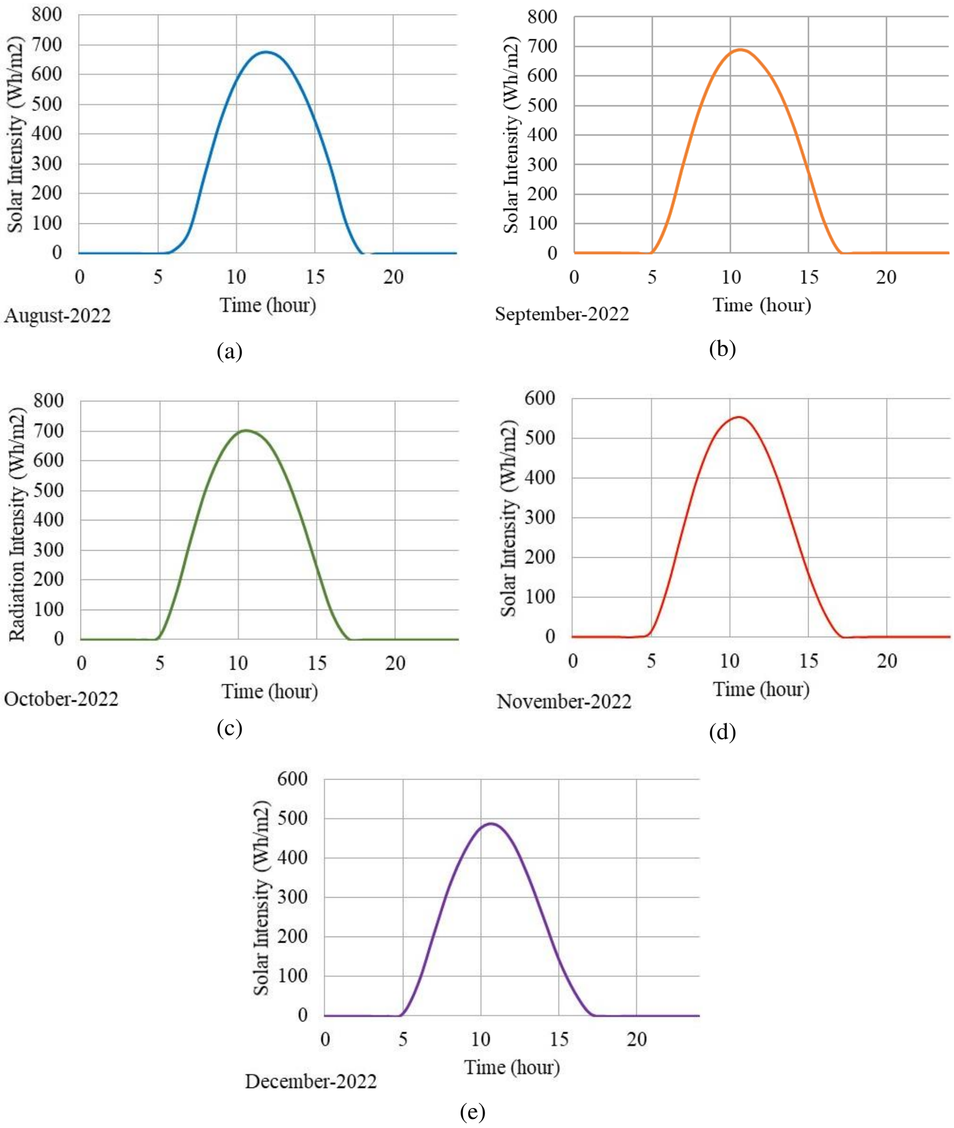

Fig. 7. Daily average solar radiation output profile: (a) August 2022; (b) September 2022; (c) October 2022; (d) November 2022; (e) December 2022

14.00, or for 5 hours. The average monthly output profile of solar radiation is shown in Fig. 8. Based on Fig. 7 and Fig. 8, the study location has the potential to develop a DC microgrid with a solar energy source, so that it can reduce the supply of public network electricity sources.

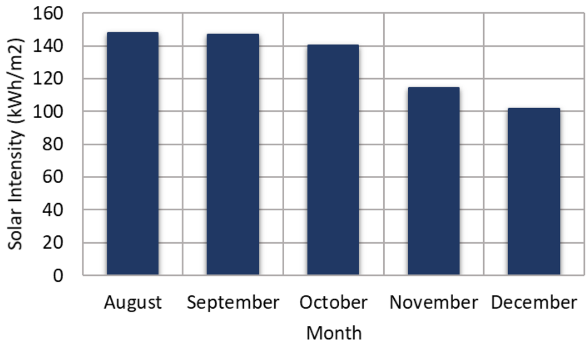

Fig. 8. Profile of monthly average solar radiation output

Figure 9 shows the energy consumption of one housing for one day, the dotted line shows the increase in the average load. Meanwhile, Fig. 10 shows the average energy consumption per month, from August to December 2022. The largest residential energy consumption occurs in August and September, while the lowest energy consumption occurs in December. This is due to the low intensity of solar radiation in December, with an intensity of 101.5 kWh/m^2. This has an impact on the output of the PV array to supply the load and is stored in the battery, shown in Fig. 11. By using centralized control, the availability of electrical energy is regulated efficiently to supply the load, even though the intensity of solar radiation is low. With PLC for centralized control, DC microgrid continues to supply the load with changes in solar radiation intensity. In this study three PV arrays were used and each PV array used twenty 300 Wp PV modules. The three PV arrays are installed in separate locations. Figure 12 shows the difference in the output of each PV array, which is caused by changes in the intensity of solar radiation and the surrounding environmental conditions. PV array 2 provides a higher output when compared to other PV arrays, amounting to 2 010 Wh. PV array 1 output gives the lowest output of 1 140 Wh.

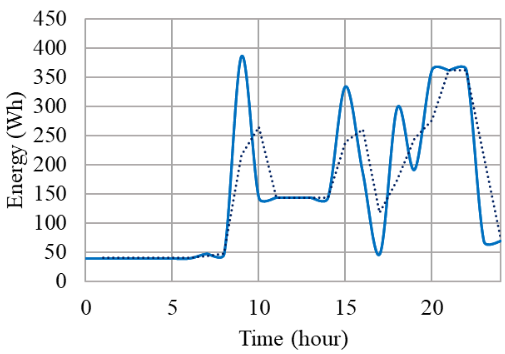

Fig. 9. One housing energy consumption in one day

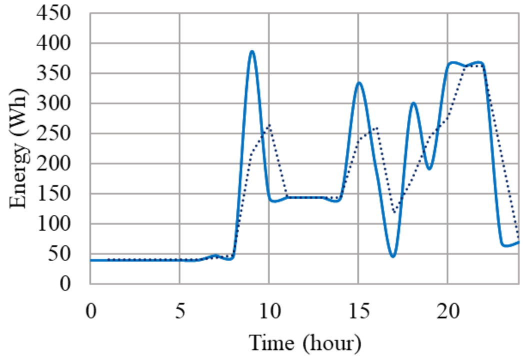

Fig. 10. Average housing energy consumption in one month

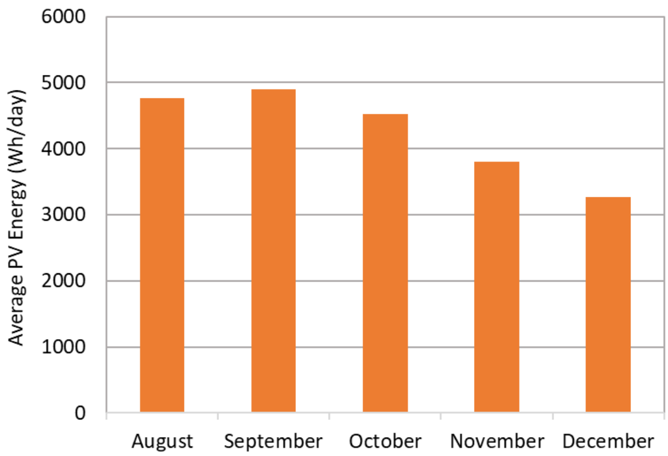

Fig. 11. The average daily energy of the PV array

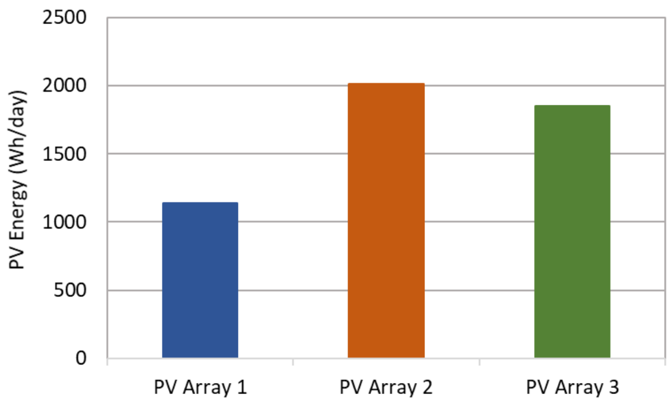

Fig. 12. The energy output of each PV array

In the first case, when the weather is sunny, centralized control using a PLC will regulate the output of electrical energy from the PV array to be supplied to the load. In addition, the output of the PV array is used for charging the multi-battery storage system (MBSS). As seen in Fig. 13, the output of the PV array is greater than the load demand each month. The highest load consumption occurred in September of 4 863 kWh with a PV array output of 7 565 kWh. Centralized control will regulate the distribution of load energy and MBSS, so that when the weather is cloudy and weather changes occur, MBSS will be able to supply load energy.

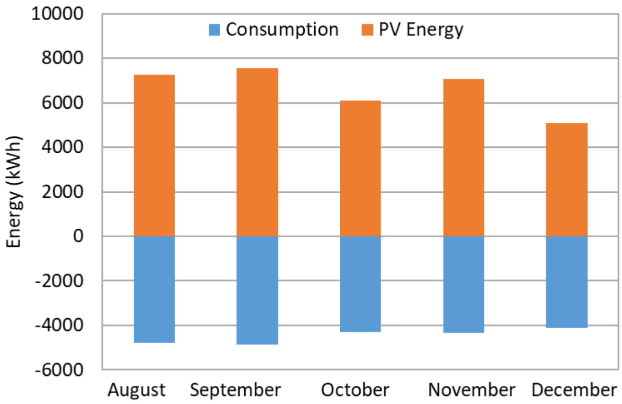

Fig. 13. PV consumption and energy settings per month

In the second case, when there is no solar radiation, at night or in rainy weather, the central control will set the MBSS to supply the load. Figure 14 shows the average amount of electrical energy/day supplied to the load. It can be seen that in September MBSS supplied less electricity than in other months, amounting to 3 750 Wh. This is due to the maximum PV array in supplying the load. Whereas in December the weather conditions often rain, so MBSS supplies more elec-

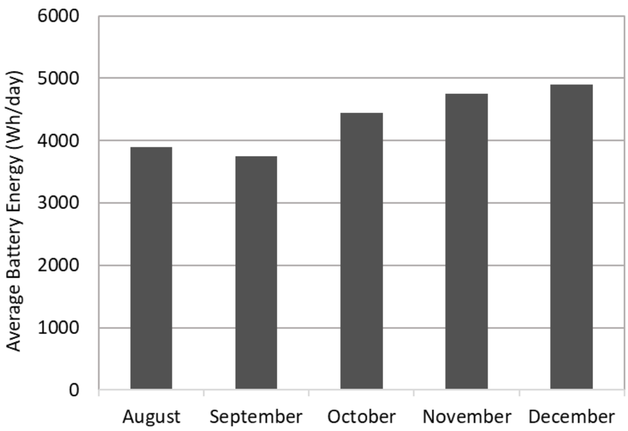

Fig. 14. MBSS average/day energy output to load

tricity than in the previous month. Centralized control effectively manages the interchangeability of the two MBSS operations. In this study each MBSS used sixteen batteries with a capacity of 200 Ah.

Figure 15 shows the centralized control of PV array and battery (MBSS) electricity. From 24.00 to 06.00, MBSS is in discharging operation (red line). When the weather is sunny, from 06.00 to 17.00, the PV array will provide electricity (dark blue line). At the same time, MBSS is filling up (light blue line). At night the energy of the PV array is cut off, so that from 18.00 to 06.00 MBSS returns to discharging operation (orange line). And so on, centralized control will regulate the microgrid DC energy. Meanwhile, Fig. 16 shows the load energy settings. Alternately centralized control manages energy consumption using PV arrays and MBSS. The biggest PV energy output at 12.00 was 4 902 Wh/day. Due to the sunny weather, the load is supplied from the PV array (red line), while from 17.00 to 07.00 the load is supplied from MBSS (green

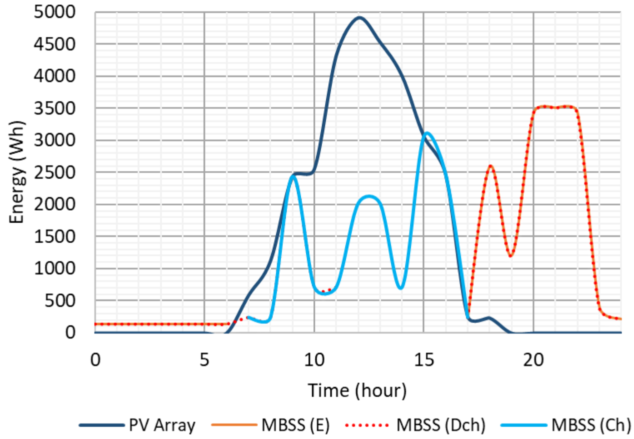

Fig. 15. Daily PV array and battery energy settings

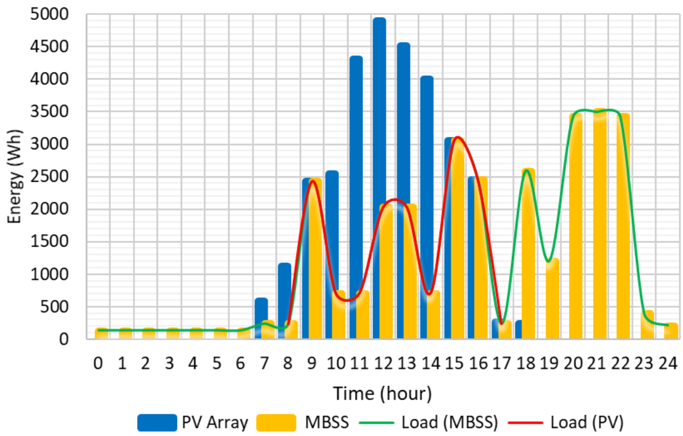

Fig. 16. Load energy settings/day

line). The peak load of 3 500 Wh occurred from 20.00 to 22.00 and MBSS was able to supply the load. The proposed DC microgrid with centralized control results in an energy supply and management efficiency of 98%, higher than the previous DC microgrid control strategy and configuration model.

The Tambakharjo region has a high potential for solar energy, so it has the potential to develop large-scale distributed power plants. In non-sunny weather conditions, the PV array still provides quite a large output of electrical energy. With a DC microgrid hybrid configuration, DC coupling and AC coupling configurations, electrical energy can be obtained that is in accordance with the consumption of housing loads. The use of centralized control in the DC microgrid hybrid configuration effectively manages the changeover of the energy flow of the PV array and MBSS, so that high system efficiency is obtained. The study results can be developed with wind turbine sources and a centralized multi-control strategy.

Acknowledgements

We thank Universitas PGRI Semarang and the research team for the completion of this research.

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