Research Article

Increased Load Power With Centralized Control of Multiple Microgrid Resources

Adhi Kusmantoro

Department of Electrical Engineering, Universitas PGRI Semarang, 50232, Indonesia

ORCID

Adhi Kusmantoro: https://orcid.org/0000-0003-4505-6641

Abstract.
There are many rural areas on remote islands that cannot be reached by electricity sources from the utility grid. However, Indonesia is a country that has an abundant supply of renewable energy. One of the renewable energies that is obtained for free is solar energy sources. Renewable energy has great potential as a source of distributed electricity generation or microgrids. This article proposes a new method for providing large electrical power supplies for rural areas, namely multiple microgrids with a centralized control strategy. The purpose of this method is to provide stability of power supply to the load. In this method, each microgrid has solar panels (SP), batteries, and diesel generators (GD). Multiple microgrids provide power supply to DC loads and AC loads. The centralized controller uses an outseal programmable logic controller (PLC) which functions to regulate the power flow of microgrid 1 (MG1), microgrid 2 (MG2), and microgrid 3 (MG3) to the load alternately. Simulation test results show the performance of a centralized control which is able to provide power supply to the load according to demand or changes in load. Power regulation management for rural areas can be developed for large-scale microgrid systems.

Keywords: multiple-microgrid; centralized control; solar panel

Corresponding Author: Adhi Kusmantoro; email: adhikusmantoro@upgris.ac.id

Published 12 March 2024

Publishing services provided by Knowledge E

Selection and Peer-review under the responsibility of the ICESRE Conference Committee.

1. Introduction

Providing electricity resources in remote areas is really needed by the community, because electricity source lines from the utility grid are installed in urban areas. With the increase in the population of rural areas, the need for electricity also increases. Apart from that, with the increasing need for electricity sources, the use of renewable energy sources in Indonesia is also increasing. A renewable energy source that can be obtained easily and for free is solar energy. The use of this source is carried out using solar panels integrated in a microgrid system [1]. To increase housing load services, this is done with a microgrid connected to the utility network on a large scale. The microgrid system used can be developed with multiple microgrids. However, the appropriate requirements and aspects for multiple microgrids must be met before connecting to the grid [2].

Previous research related to multiple microgrids is as follows. Authors [3] used a prototype to conduct microgrid research for small capacity. The proposed research uses cooperative control in the arrangement of battery and capacitor energy storage, while the multiple microgrid used is a DC/AC microgrid. The study results show voltage stability on the DC bus. Authors [4] proposed multiple converters for power sharing from hybrid microgrid sources. The power management strategy is carried out autonomously using a droop model. The strategy carried out by simulation shows the appropriate distribution of power from each converter. Authors [5], [6] proposed DC microgrid and AC microgrid power management using multiple subgrids. In this subgrid, DC-DC converters and AC-DC converters are used which are equipped with energy storage. In this method a decentralized control strategy is used to coordinate each subgrid. What is of concern in this strategy is the capacity and type of load used. The authors of [6] proposed a minimum overhead method to deal with fluctuations in renewable energy. The proposed method takes into account the amount of energy supply and energy demand on the load. The method used is effective for multiple microgrid cluster models. Authors [7], [8], [9] analyzed the dynamic characteristics of microgrid clusters with PV panel sources. In this method, each connected cluster can cause disruption to the stability of the microstructure. In addition, PV output fluctuates with weather changes. The author uses droop control to analyze dynamic characteristics. Droop parameters are selected using a genetic algorithm.

Authors [10] conducted research on the technical aspects and benefits of microgrid distributed generation with a cluster model. Many studies deal with microgrid operating systems in island mode or connected to the grid. However, not many people have carried out research for economic or technical analysis of the impact or influence on society. Authors [11], [12] proposed a new optimal control method based on Proportional Integral (PI) for storing multiple batteries in a DC microgrid. The proposed method is able to increase the stability of DC voltage against intermittency of one of the power sources. Additionally a DC-DC dual active bridge converter is used to regulate power flow in two directions. The strategy used is able to maintain the DC bus voltage in island mode. Meanwhile, the author [13] focuses more on microgrid protection. The author proposes an adaptive coordination strategy for overcurrent relays at many coupling points in a microgrid system. In this microgrid, 7-bus are used and they run effectively when problems occur. The simulation results are implemented using relay devices, digital simulators, and voltage/current amplifiers. The method used is capable of providing protection in various operating modes. The authors of [14] proposed a cooperative control strategy on AC microgrid clusters. The inter-cluster control strategy functions to share power, while the intra-cluster control strategy aims to achieve voltage or frequency balance. The research was carried out using Matlab simulation to verify the method used. The authors of [15], [16]proposed a master-slave control strategy in AC/DC microgrid systems. In this transition strategy, it is verified using PSCAD simulation. Meanwhile, the author [20] uses a decentralized control strategy to regulate the power flow of several PV and battery units. Droop control parameters are used to control multi-loop PV and batteries. This strategy was also validated with Power System Computer Aided Design (PSCAD). Author [17] proposed a multi-microgrid distribution system by considering load management in a three-phase system. Distributing a distributed system of renewable energy sources into multiple microgrids can handle critical loads, but demand management is often neglected. The author verified the research with simulations of Institute of Electrical and Electronic Engineer (IEEE) 123 and 34 bus feeders.

By increasing the AC load, the author [18] designed a three-phase inverter used in AC microgrid with island mode operation. The proposed strategy takes into account the characteristics of the inverter and passive network used. Low frequency stability analysis is measured using the Nyquist criterion. Meanwhile, the author [19] focuses on improving the inductor-capacitor-inductor (LCL) filter connected to the inverter. This is because the LCL filter causes resonance in the AC microgrid, so a functional rotational active damper is used. This method will improve system stability when the renewable energy supply is connected to the inverter. To increase the stability of the DC bus and AC bus, the authors [20] conducted research on modifying the AC coupling microgrid with a coordinated control strategy for battery storage. The study results show that with the new AC coupling configuration, optimal battery energy charging occurs and the power supply to the load can be fulfilled. Coordinated control strategy using a fuzzy logic controller (FLC). Author [21], [22] proposed improving the voltage stability of AC bus and DC bus with multi-PV, multi-battery and maximum power point tracking (MPPT) control using FLC. The proposed microgrid is connected to the utility grid and the proposed method is able to handle critical loads. Meanwhile, the author [23], [24] focuses more on the supply of electrical energy from renewable energy during the day, so the proposed microgrid operates in on-grid mode. The proposed method is able to reduce power supply from the utility grid and is able to overcome peak loads during the day.

Based on previous research that focuses on providing renewable energy sources and control strategies that are not yet optimal, in this article we propose increasing load power using multiple microgrid configurations. In regulating the power flow on the resource, energy storage and load sides using centralized control. Centralized control in this article uses PLC Mega V.3.

2. Method

In microgrid systems with a hybrid AC/DC configuration, it has been widely used to supply DC and AC loads. This configuration is suitable for use in rural areas where electricity sources from the utility grid are not accessible. To increase power supply to loads in large rural areas, multiple microgrids are used. For this multiple configuration, solar energy is used with solar panel (SP) devices and battery storage. For backup energy sources, it uses a power source from a diesel generator. PV is the main source in multiple microgrids.

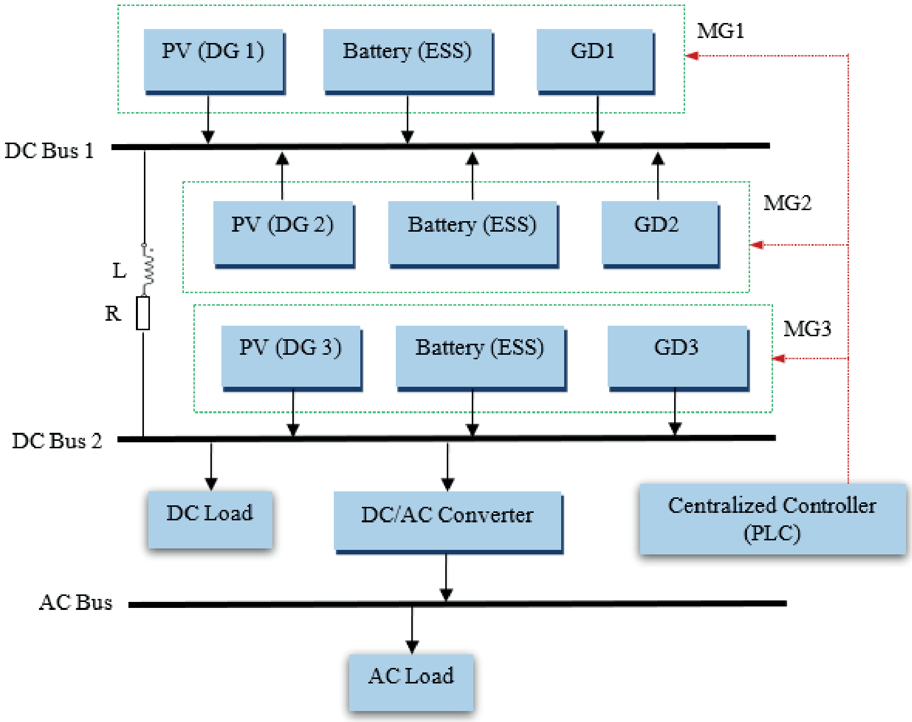

Figure 1: Proposed multiple microgrid configuration.

The multiple microgrid configuration is shown in Figure 1. The figure has three microgrids and each microgrid consists of solar panels, batteries and a diesel generator. The power flow of each microgrid is controlled using centralized control. In the figure you can also see multiple microgrids operating in island mode. In this configuration the AC bus voltage is 220 V, while the DC bus voltage is 24 V. The DC-DC converter is used to adjust the voltage of the first DC bus and the second DC bus. Meanwhile, the solar inverter is used to supply the AC load.

2.1. Multiple microgrid control strategy

The main problem with using solar energy is changes in solar panel output caused by weather changes. Therefore, to overcome changes in solar panel output, a diesel generator (GD) is used. By providing GD, stability of power supply to the load can be achieved.

It is important to note that methods must be written in the same order in the results section. The order of writing methods must also be logical according to the type of research. The method for one type of research will be very different from other studies. For example, writing survey research methods is very different from laboratory test research methods that involve a lot of equipment and materials. The method section can be created with several separate subtitles such as materials, tools, and data collection procedures. Figure ?? shows the centralized control strategy with mode1, mode 3, and mode 3 settings on each microgrid.

2.2. Multiple microgrid operation modes

Changes in operating modes in a microgrid are influenced by the output of solar panels, batteries and diesel generators. The PV output from each microgrid is in accordance with the size of the load used, while the batteries used must be able to supply the load when the PV is disconnected and battery operation is in accordance with the SOC level setting. In this multiple configuration there are three multiple microgrid operating modes. This change in operating mode also depends on the load demand and resources contained in each microgrid. MG1 represents microgrid 1, MG2 to MG3 also represent each microgrid. Centralized control functions to regulate the power flow from each microgrid to the DC bus and AC bus. In this mode of operation is explained as follows.

Mode 1: MG1 supplies power to DC load and AC load. The available resource from MG1 is greater than the load, so no battery charging occurs because the battery SOC level is maximum. Apart from that, the diesel generator is also in optimum condition.

Mode 2: The resources available on MG1 are at capacity below the load, so MG2 operates to supply the load. In this mode, MG2 resources are in optimum condition, so that load requests can be met. The MG2 battery SOC is also in maximum condition. In mode 2, the MG1 battery is charged. This is because all MG1 resources are used to supply the load.

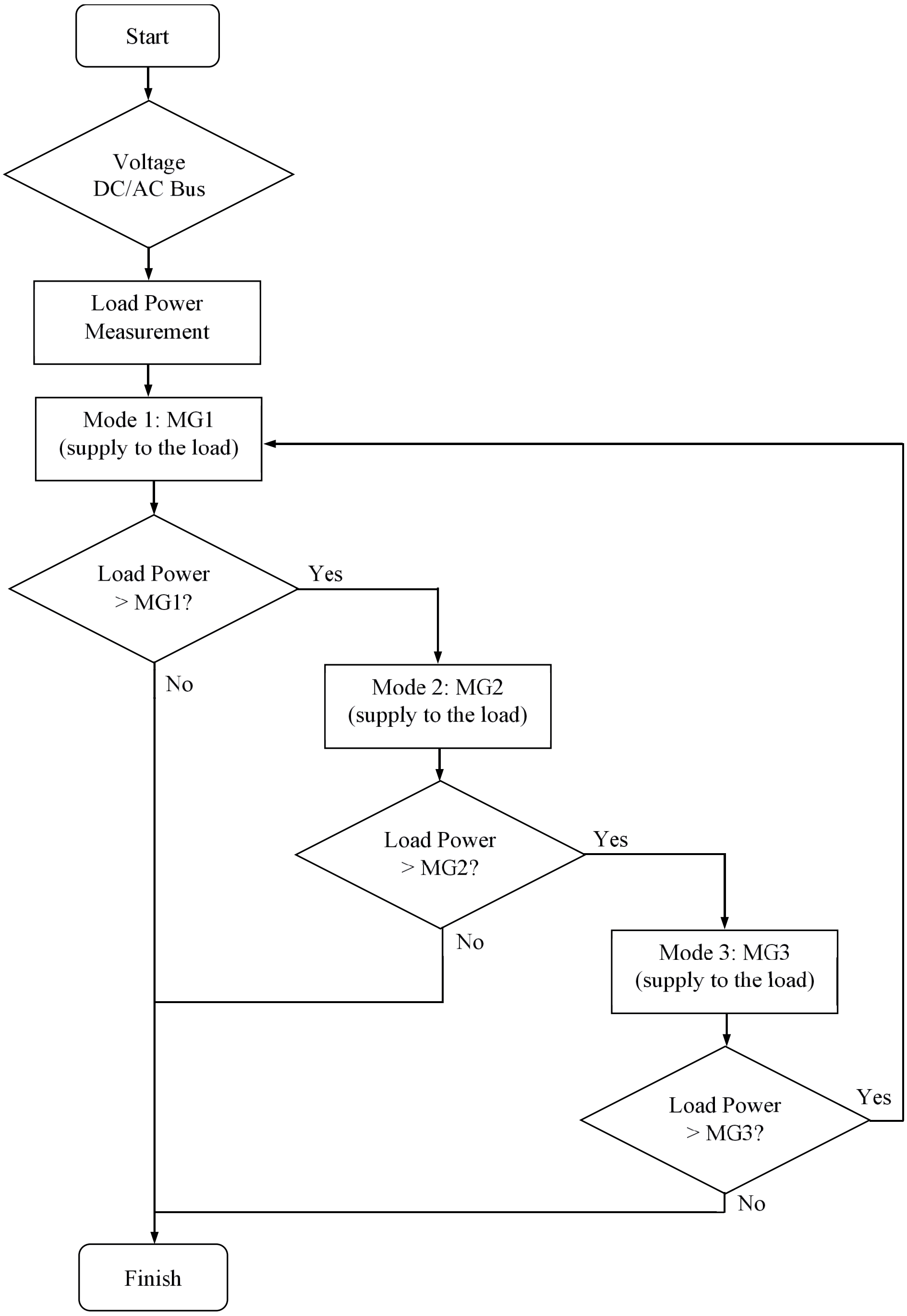

Figure 2: Multiple microgrid control strategy.

Mode 3: In this mode the resource on MG2 has low capacity, so the load request must be supplied from MG3. In this mode the load request is supplied from the resources available on the MG3. In this mode the battery charging also occurs on the MG2.

And so on, when the MG3 resource is at low capacity, MG1 plays a role in supplying the load. The battery in MG3 will charge using the excess power source of MG1. Meanwhile, for diesel generators on MG1, MG2 and MG3, monitoring is carried out on the availability of diesel fuel. When MG1, MG2, and MG3 are not operating, a fuel check is carried out.

From the operating mode in the initial section, it is explained that the power supply to the load is carried out alternately from each microgrid. Changes in operating modes are caused by changes in microgrid resource capacity. A centralized control strategy in multiple microgrids will result in efficient energy management, which can be seen in Table 1.

Table 1: Energy source data on multiple microgrid.

Microgrid	Mode	Mode		
		1	**2**	**3**
MG1	PV (DG1)	Surplus	492	525
	Generator Diesel (GD1)	Surplus	25	25
	Battery (BESS1)	Lack	26	26
MG2	PV (DG2)	398	490	528
	Generator Diesel (GD2)	25	25	25
	Battery (BESS2)	28	30	30
MG3	PV (DG3)	398	490	528
	Generator Diesel (GD3)	25	25	25
	Battery (BESS3)	28	30	30

When the PV output is cut off as a result of weather changes and the battery output is also cut off, the diesel generator as energy backup can be used to supply the load. The diesel generator on each microgrid operates when the PV and battery are disconnected. Figure 3 shows the flowchart of multiple microgrid performance. Each microgrid is equipped with a DC-DC converter, to adjust the DC load voltage level and the voltage level as inverter input.

In this research, the outseal PLC functions as a centralized controller. The PLC will regulate the flow of electrical power from MG1, MG2, and MG3 alternately to the load. Apart from that, the PLC also controls and monitors the microgrid battery energy. In each microgrid, power distribution starts from the PV, then the battery supplies the load when the PV is disconnected. When the PV and battery are disconnected then the diesel generator supplies the load. Based on Figure 3, starting with measuring the DC bus and AC bus voltage, then measuring the load power. In this initial step MG1 supplies the load, then the sensor will measure the power capacity and voltage. When MG1's power and voltage are at low capacity or disconnected, MG2 will supply the load. And so on, the sensor will measure the power capacity and voltage of MG2 whether the capacity is low or not. When MG2's power and voltage are cut off, MG3 will supply the load.

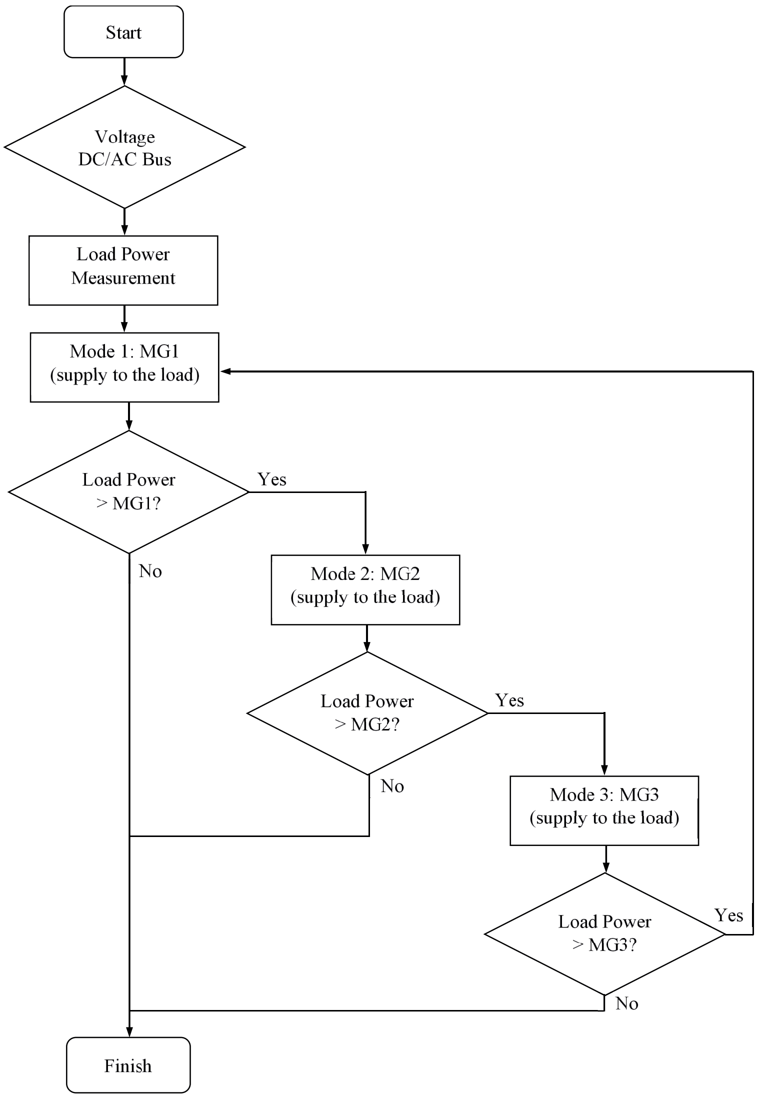

Figure 3: Flowchart of multiple microgrid control strategies.

3. Result and Discussion

3.1. Results of Multiple Microgrid

In the previous section, the configuration and operating modes of multiple microgrids consisting of MG1, MG2, and MG3 were explained.

Determination of microgrid parameters has been discussed in section 3 and the power management strategy has been clearly outlined. The initial scenario in this study begins with distributing power to the load using MG1, which is shown in Figure 4. The

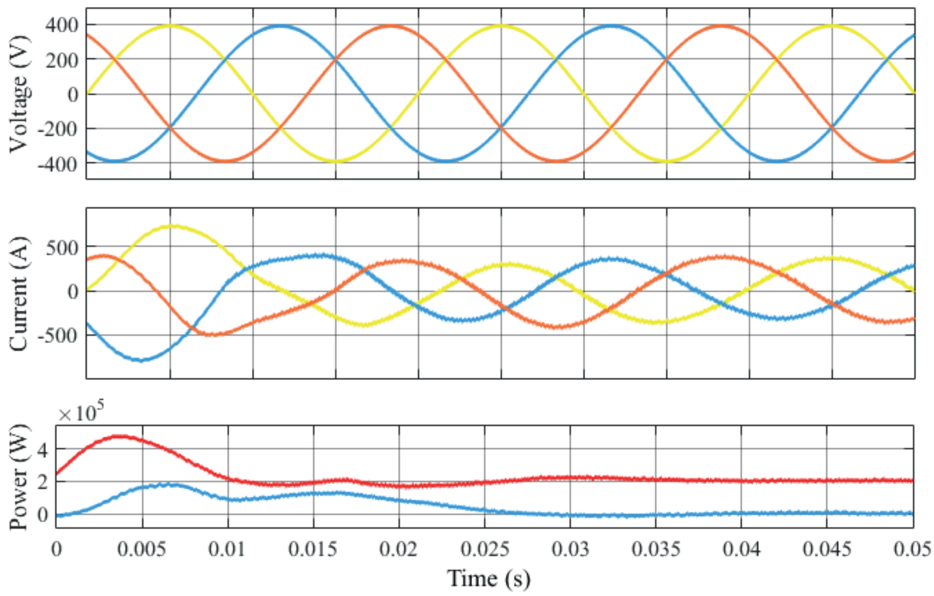

Figure 4: AC load power supply scenario in mode 1.

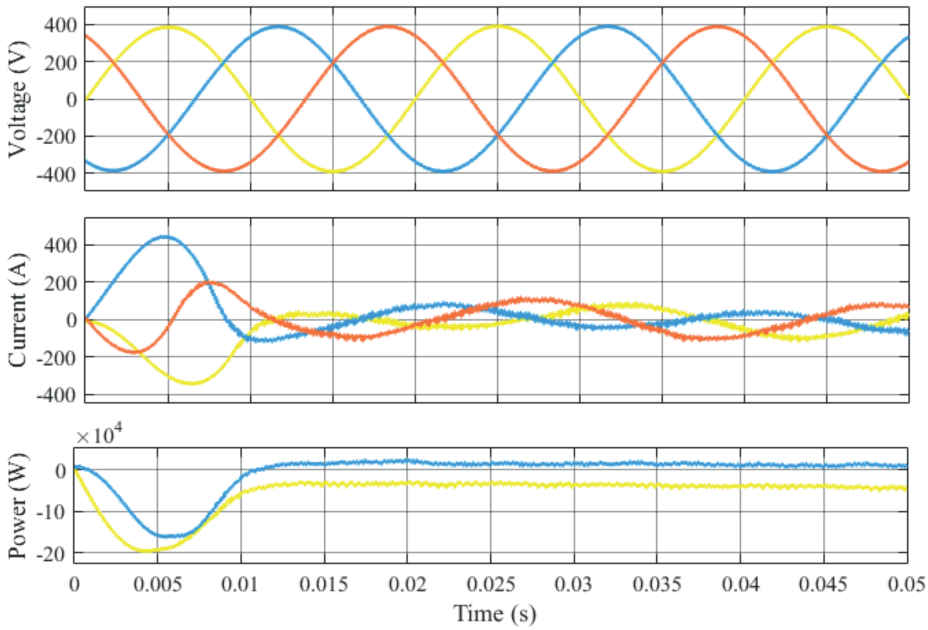

Figure 5: AC load power supply scenario in mode 2.

power generation system used is a three-phase power plant. In the picture you can see a three-phase voltage with an amplitude of 400 V and a three-phase current which is the current in the load. Apart from that, the picture also shows a comparison of MG1 power (blue graph) with load power (red graph). Likewise, Figure 5 is a power distribution scenario from MG2, while Figure 6 is a power distribution scenario from MG3. In this study, apart from the use of AC loads which have been discussed and

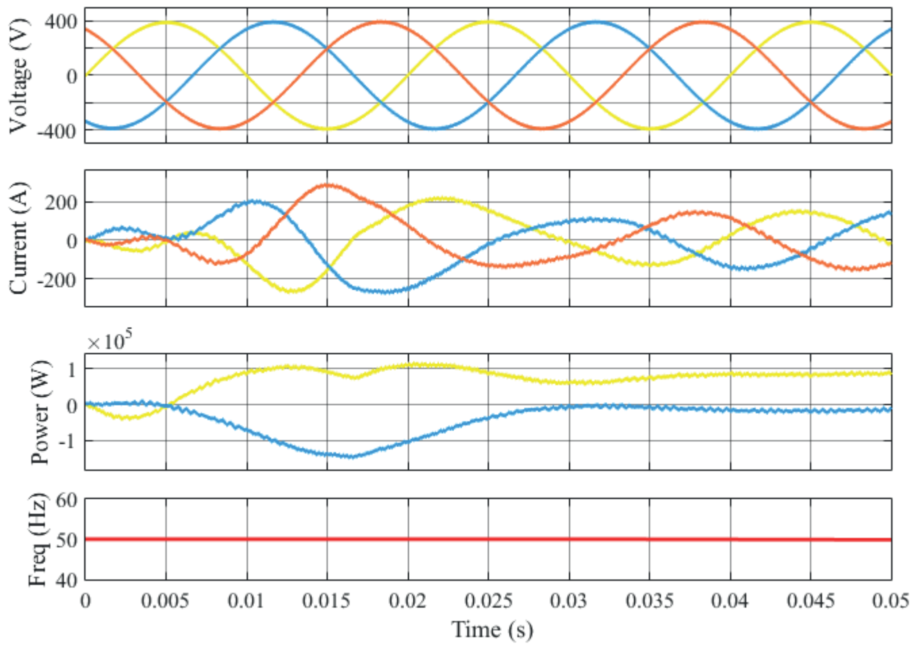

Figure 6: AC load power supply scenario in mode 3.

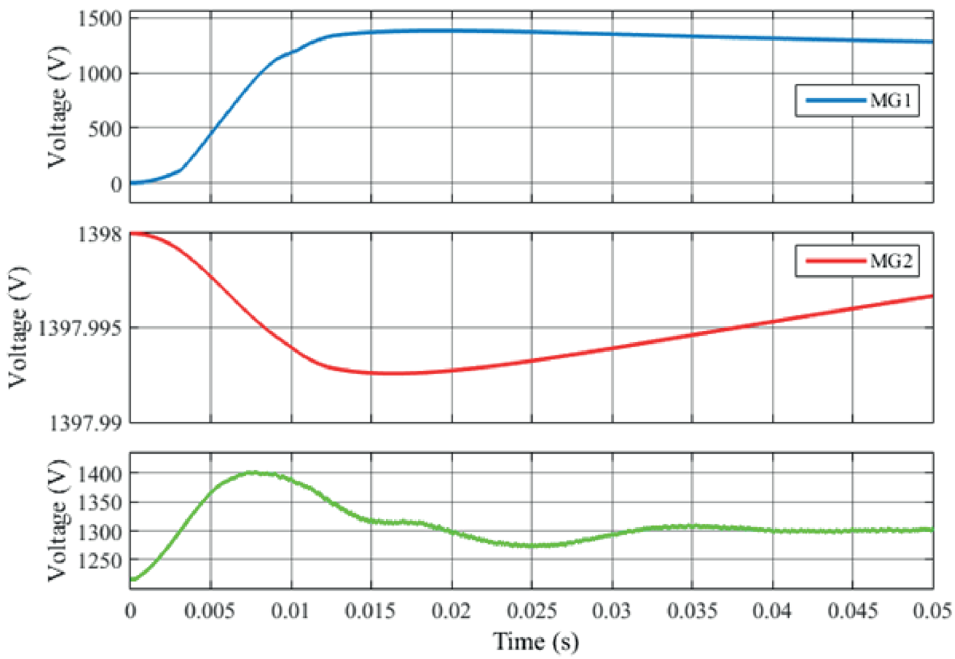

Figure 7: DC load power supply scenario of MG1, MG2, and MG3.

shown in the previous figure, DC loads are shown in Figure 7. In this figure you can see the distribution of DC power from mode 1 to mode 3 from each microgrid. Next, Figure 8 shows the distribution scenario for each resource contained in the microgrid. In each PV power distribution microgrid, the diesel generator (GD) is carried out alternately and the DC load used experiences changes in power. Figure 9 shows the battery power

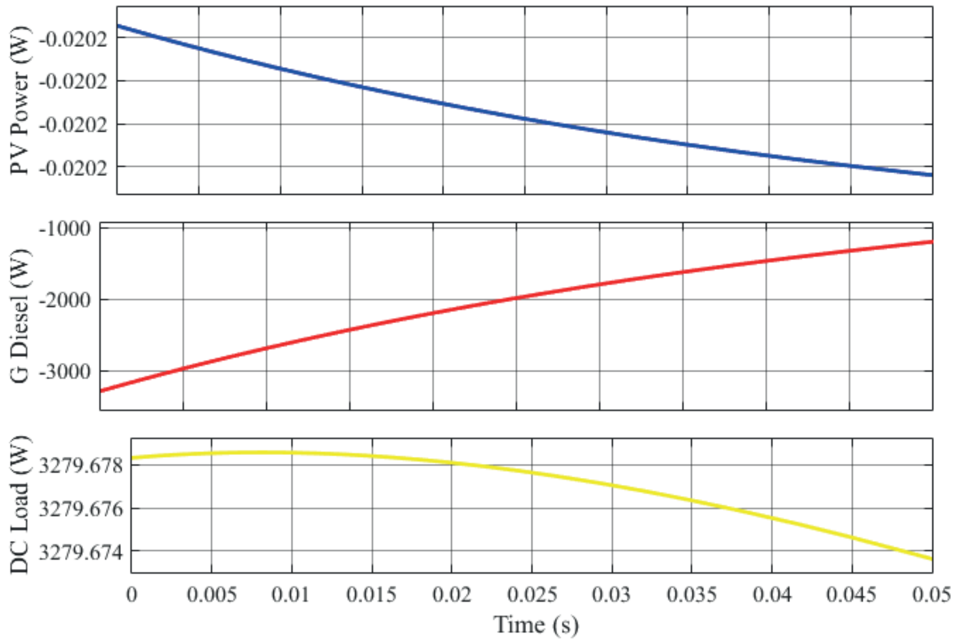

Figure 8: Output power from PV, GD and load.

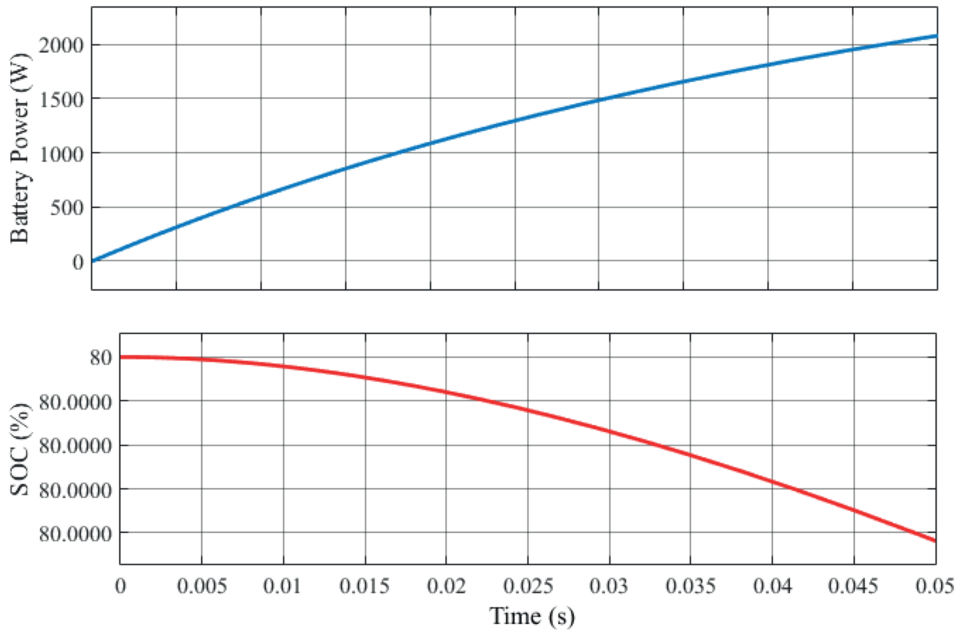

Figure 9: Charging and SOC batteries from MG1, MG2, MG3.

distribution when PV and GD are not operating. Apart from that, the SOC level is set from 50 to 80 percent.

4. Discussion

In a multiple microgrid configuration, MG1, MG2, and MG3 supply power to the load alternately. The resources provided by the microgrid (MG1) are greater than the load power demand. This can be seen in the red power graph being greater than the blue load power graph. Within 0.01 seconds to 0.05 seconds, the power distributed by MG1 looks stable, even though there is a decrease in load power from 0.025 seconds to 0.05 seconds. Meanwhile, in mode 2 MG2 experiences fluctuations due to changes in PV from 0 seconds to 0.01 seconds, but MG2 is still able to supply load power. This is carried out by centralized control which regulates the GD and battery to supply load power when PV fluctuations occur. Therefore MG2 is stable from 0.01 seconds to 0.05 seconds. For scenario mode 3, MG3 experiences fluctuations from 0 seconds to 0.005 seconds, in this condition MG3 is not able to meet the load power demand. This is due to the PV disconnecting quickly and the MG3 taking time to operate the GD and battery. However, from 0.005 seconds to 0.05 seconds MG3 is able to supply more power than the load demand. This is because GD and the battery are operating normally. Figure 7 shows the DC voltage produced by each microgrid to supply the DC bus. A change in DC voltage occurs as a result of a change in PV output from MG1, MG2, and MG3. Meanwhile, Figure 8 shows DC power fluctuations caused by changing power sources from PV and GD. It can be seen that the PV and GD outputs interact with each other in supplying power to the DC bus. When charging occurs on the battery, the SOC will increase. The MG1 battery is charged from the excess power of MG2, while the MG2 battery is charged using the excess power of MG3. Likewise, charging the MG3 battery uses excess MG1 power. When the battery is used, the battery SOC will drop to the level of 50 percent, while the upper limit of the battery SOC is 80 percent. In this study, it was found that multiple microgrid configurations were capable of supplying peak loads, both DC loads and AC loads, when compared with research conducted by authors [5]. In addition, a centralized control strategy was found that effectively regulates the power flow of multiple microgrids, when compared with the controls carried out by the authors [6].

5. Conclusion

The proposed multiple microgrid strategy with centralized control serves to solve the problem of providing electricity resources in rural areas. The configuration of three microgrids that interact with each other to supply the load is very effective in overcoming peak loads. Apart from that, there is also power sharing for charging each battery. Centralized control is able to regulate the power flow of each microgrid according to load demand and regulate the charging of each battery. Multiple microgrid configurations to supply power in rural areas are very beneficial for improving the community's economy.

Acknowledgements

We are very grateful to the Kemendikbudristek Indonesia and LPPM Universitas PGRI Semarang for providing financial support for conducting research and international conferences.

References

[1] Yan H, Lv N, Zhuo F, Yi H, Wang Z. "Energy Management of Household Microgrid with Multiple Energy Resources for Rural Area," ICPE 2019 - ECCE Asia - 10th Int. Conf. Power Electron. - ECCE Asia, vol. 3, 2019, https://doi.org/10.23919/ICPE2019-ECCEAsia42246.2019.8797267.

[2] Guan Y, Wei B, Guerrero JM, Vasquez JC, Gui Y. "An overview of the operation architectures and energy management system for multiple microgrid clusters," iEnergy, vol. 1, no. 3, pp. 306–314, 2022, https://doi.org/10.23919/IEN.2022.0035.

[3] Wu G, Ishida S, Yin H. "DC Voltage Stabilization in DC/AC Hybrid Micro-grid by Cooperative Control of Multiple Energy Storages," pp. 1–5, 2020, https://doi.org/10.1109/ICDCM45535.2019.9232764.

[4] Peyghami S, Mokhtari H, Blaabjerg F. Autonomous operation of a hybrid AC/DC microgrid with multiple interlinking converters. IEEE Trans Smart Grid. 2018;9(6):6480–8.

[5] Xia Y, Wei W, Yu M, Wang X, Peng Y. Power Management for a Hybrid AC/DC Microgrid with Multiple Subgrids. IEEE Trans Power Electron. 2018;33(4):3520–33.

[6] Li F, Qin J, Wan Y, Yang T. Decentralized Cooperative Optimal Power Flow of Multiple Interconnected Microgrids via Negotiation. IEEE Trans Smart Grid. 2020;11(5):3827–36.

[7] Zhao Z, Yang P, Wang Y, Xu Z, Guerrero JM. Dynamic Characteristics Analysis and Stabilization of PV-Based Multiple Microgrid Clusters. IEEE Trans Smart Grid. 2019;10(1):805–18.

[8] Lu X, Lai J, Yu X. A Novel Secondary Power Management Strategy for Multiple AC Microgrids with Cluster-Oriented Two-Layer Cooperative Framework. IEEE Trans

Industr Inform. 2021;17(2):1483–95.

[9] Meng L, Shafiee Q, Ferrari Trecate G, Karimi H, Fulwani D, Lu X, et al. Review on Control of DC Microgrids and Multiple Microgrid Clusters. IEEE J Emerg Sel Top Power Electron. 2017;5(3):928–48.

[10] Yuen C, Oudalov A, Timbus A. The provision of frequency control reserves from multiple microgrids. IEEE Trans Ind Electron. 2011;58(1):173–83.

[11] Zhou J, Shi M, Chen Y, Chen X, Wen J, He H. A Novel Secondary Optimal Control for Multiple Battery Energy Storages in a DC Microgrid. IEEE Trans Smart Grid. 2020;11(5):3716–25.

[12] Hou N, Li Y. Communication-Free Power Management Strategy for the Multiple DAB-Based Energy Storage System in Islanded DC Microgrid. IEEE Trans Power Electron. 2021;36(4):4828–38.

[13] Naveen P, Jena P. Adaptive Protection Scheme for Microgrid with Multiple Point of Common Couplings. IEEE Syst J. 2021;15(4):5618–29.

[14] Lai J, Lu X, Yu X, Monti A. Cluster-Oriented Distributed Cooperative Control for Multiple AC Microgrids. IEEE Trans Industr Inform. 2019;15(11):5906–18.

[15] Jia L, Zhu Y, Du S, Wang Y. Analysis of the transition between multiple operational modes for hybrid AC/DC microgrids. CSEE J. Power Energy Syst. 2018;4(1):49–57.

[16] Mahmood H, Jiang J. Decentralized power management of multiple PV, battery, and droop units in an islanded microgrid. IEEE Trans Smart Grid. 2019;10(2):1898–906.

[17] Fu L, Liu B, Meng K, Dong ZY. Optimal Restoration of an Unbalanced Distribution System into Multiple Microgrids Considering Three-Phase Demand-Side Management. IEEE Trans Power Syst. 2021;36(2):1350–61.

[18] Cao W, Ma Y, Wang F, Tolbert LM, Xue Y. Low-Frequency Stability Analysis of Inverter-Based Islanded Multiple-Bus AC Microgrids Based on Terminal Characteristics. IEEE Trans Smart Grid. 2020;11(5):3662–76.

[19] Guo Y, Lu X, Chen L, Zheng T, Wang J, Mei S. Functional-Rotation-Based Active Dampers in AC Microgrids with Multiple Parallel Interface Inverters. IEEE Trans Ind Appl. 2018;54(5):5206–15.

[20] Kusmantoro A, Priyadi A, Budiharto Putri VL, Hery Purnomo M. Coordinated Control of Battery Energy Storage System Based on Fuzzy Logic for Microgrid with Modified AC Coupling Configuration. Int. J. Intell. Eng. Syst. 2021;14(2):495–510.

[21] Kusmantoro A, Priyadi A, Purnomo MH. “Voltage stability in DC micro grid by controlling two battery units with hybrid network systems,” 2018 5th Int. Conf. Ind. Eng. Appl. ICIEA 2018, pp. 163–168, 2018, https://doi.org/10.1109/IEA.2018.8387089.

[22] Kusmantoro A, Purnomo MH, Priyadi A, Budiharto Putri VL. “Fuzzy-PID Controller on MPPT PV to Stabilize DC Bus Voltage,” 2019 Int. Conf. Technol. Policies Electr. Power Energy, TPEPE 2019, pp. 10–15, 2019

[23] Kusmantoro A, Farikhah I. “Improvement the Capacity of Electrical Energy in Residential Using PV with On-Grid System,” E3S Web Conf., vol. 359, pp. 1–12, 2022, https://doi.org/10.1051/e3sconf/202235901004.

[24] Kusmantoro A. “Enhancement DC Microgrid Power Stability With a Centralized”. 2022 Int. Conf. on Vocational Educ.and Electr. Eng., ICVEE 2022, pp. 10–15, 2022 https://doi.org/10.1109/ICVEE57061.2022.9930460.