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CASE STUDY OF POWER SHARING CONTROLLER WITH THE USAGE OF DROOP CONTROL METHOD TO ANALYZE MANAGEMENT ENERGY SYSTEM IN ISLANDING MODE

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ABSTRACT: Microgrid as Renewable Energy in electricity is usually referred as Distributed Generation (DG). This research analyzes power sharing in a DC Microgrid using the droop control method in islanding mode, which is when the DC Microgrid operates separately from the main grid (PLN), and the load is fully supplied by DG. This Power Sharing Controller ensures that the power generated by each DG is in accordance with the system's requirements. This research uses Matlab Simulink software for its simulations. The DC Microgrid consists of three buck-boost converters connected in parallel. The power capacity and droop value of each buck-boost converter are adjusted according to the case. The test results showed that the determination of the droop value affects the power generated by the buck-boost converter. The smaller the droop value, the greater the power produced, and vice versa. Of the three cases simulated in the first case with an even load distribution on the buck-boost equal to a load increase of 1000w, there is an increase in power to 334 w and a current of 33.4 A, while in the second case with a load increase of 1000w, there is a power variation between 300-360 w and a current in the range of 3.6 to 30 amperes. While in case 3 a load increase of 1000 w buck-boost produces power at a value of 325-345w.

Keywords: Renewable Energy, DC Microgrid, Power Sharing, Droop Control, Distributed Generation

1. Introduction

Microgrids have the potential for the development of Renewable Energy, which produces clean and environmentally friendly electrical energy [1]. Microgrid has 2 modes of operation, namely when connected to the main power grid (Grid-Connected) and when not connected to the main power grid (Islanding) [2]. On Grid-Connected mode, it allows exchange of power between the microgrid and the main grid, both in the form of power supply from the microgrid to the grid and the withdrawal of power from the grid to the microgrid [3]. When resources within the microgrid, such as solar panels, generate energy that exceeds the load requirements, this excess power can be exported to the main grid, and if the resources generate less energy than the load requirements, the microgrid can draw power from the main grid to cover this shortfall. Whereas in Islanding mode, the microgrid operates independently without being connected to the main power grid [4]. This system fully relies on local energy sources such as solar panels to meet load demands.

There are 3 types of Microgrids, namely Direct Current Microgrid (DC Microgrid), Alternating Current Microgrid (AC Microgrid), and Hybrid Microgrid [5]. On DC Microgrid, DC electricity is used for power distribution within the system. And on AC Microgrid, the electricity used for power distribution in the system is AC. Whereas the Hybrid Microgrid combines AC and DC electricity in its distribution system. DC Microgrid has more advantages over other types of microgrids, namely that it does not require DC-AC or AC-DC conversion [6]. Because of that, DC Microgrid has more efficient system. On DC Microgrid, Renewable Energy is usually used as a source of electrical energy. The use of renewable energy sources (RES) in electricity is usually referred to as Distributed Generation (DG) [7]. Unlike centralized power generation systems, which transmit electricity through extensive distribution networks. DG allows electrical resources to be placed at various points close to the load locations [8].

DC microgrid that uses renewable energy sources to generate electricity has a weakness, namely its dependence on weather conditions, which results in uncertainty in generating electricity [9]. Renewable energy sources, such as solar panels, are highly dependent on sunlight intensity and weather conditions [10]. For example, when sunlight intensity decreases (due to clouds, rain, or nighttime), the voltage generated by the solar panels will decrease. On the other hand, when the intensity of sunlight is high, the voltage generated by the solar panels tends to increase. Because the voltage generated depends on weather conditions and sunlight intensity, the voltage of the solar panels fluctuates. This fluctuating voltage can disrupt the stability of the DC Microgrid system [11]. Because the voltage stability is disturbed, the equipment connected to the system can disrupt the performance of the equipment and may suffer damage. This can happen because the voltage received by the device is too high or too low.

One of the methods applied to address voltage fluctuations in a DC Microgrid is power sharing using droop control techniques. With this method, the power distribution among various Distributed Generations is regulated using a power sharing controller. The Power Sharing Controller ensures that the power generated by each DG matches the system's needs, allowing for an even distribution of the load [12]. This method also assists to optimally utilize the capacity of each DG. The principle of power sharing is based on the droop characteristic, where power is regulated based on changes in voltage and current within the system [13]. With this arrangement, the DC Microgrid can respond to load changes. In addition, this method also allows the system to adjust the power distribution evenly in response to fluctuating loads or unstable energy source conditions.

The entire process of power sharing and droop control is the part of energy management, in this case, the term will be used as energy management. Energy management is a series of processes designed to optimally manage energy usage in a DC Microgrid [14]. Thus, one of its main functions is to maintain the balance of power distribution among energy sources. This process includes adjusting the output power of each energy source to meet the needs, reducing the risk of instability due to load fluctuations and energy source fluctuations. With good energy management, the system can continue to operate optimally during fluctuating conditions. Therefore, effective energy management also plays a crucial role in maintaining voltage stability throughout the system. By integrating droop control and power sharing techniques, the microgrid can ensure that power is always available in sufficient quantities.

DC Microgrid consists of several Distributed Generations (DG) integrated into the system to provide energy to various loads [15]. Thus, this system has a high level of complexity due to the interaction between components such as energy sources, loads, and controllers. This complexity requires the DC Microgrid to have a well-planned design approach to maintain operational stability and efficiency. When the system design is inadequate, issues such as power distribution imbalance or inability to respond to load changes can occur.

2. Literature Review

Microgrids have experienced rapid development as part of the transformation of modern energy systems, particularly in supporting the integration of new and renewable energy. As a small-scale electrical network, microgrids can operate independently or connect to the main grid. The development of technology has expanded the applications of microgrids in various sectors, from remote areas to urban areas that require energy stability.

2.1 Microgrid

A microgrid is a system of electrical energy distribution that consists of renewable energy generation and electrical loads integrated in one place [16]. In general, microgrids have a relatively small power supply capacity, often less than 1 megawatt [17].

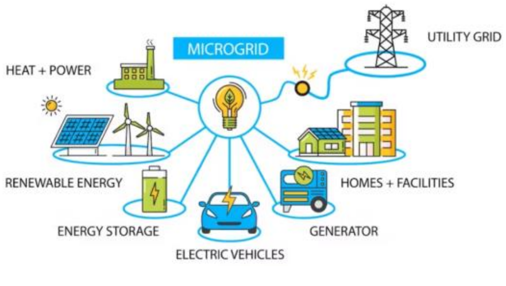

Figure 1 Microgrid

In a microgrid as shown in Figure 1, there are several energy sources such as Solar Power Plants (PLTS), Wind Power Plants (PLTB), and batteries that are interconnected with loads. The microgrid system can also operate independently or be connected to other power grids. When the microgrid is connected to another power grid, the microgrid obtains energy from the other power grid when needed, and supplies the excess energy produced back to the grid. In standalone operation mode, the microgrid functions as an independent energy system that is not connected to the main power grid. This means that the microgrid relies entirely on its local energy sources, such as solar panels. This autonomous microgrid is usually implemented in remote areas far from the main power grid.

The commonly known types of microgrids include AC microgrids, DC microgrids, and hybrid AC/DC microgrids [18]. Among the three, DC microgrids are becoming increasingly favored by many parties compared to AC microgrids and hybrid AC/DC microgrids. This is due to several advantages possessed by DC microgrids. One of them is the use of direct current (DC) voltage in its system, which eliminates the need for conversion between DC-AC, thus not requiring additional devices such as inverters [19]. In a DC microgrid, solar panels are used to generate electrical energy, but the performance of the solar panels depends on weather conditions. When the weather is bad, the production generated by the solar panels decreases. This can disrupt the energy supply to the DC microgrid.

2.2 Grid Connected

Grid-Connected Microgrid is a microgrid that operates connected to the main power grid, as shown in Figure 2 [20]. In this mode, the microgrid can export power to the main grid or import power from the grid as needed. Grid-Connected Microgrid tends to be more stable due to the support from the large and centralized main grid. When local resources are insufficient, the microgrid can rely on the main grid. In this mode, energy management can be more complex because it involves coordination between the microgrid and the main grid to optimize resource usage. Requires an advanced control system to manage the power flow between the microgrid and the main grid. This control must be able to respond to changes in energy production, consumption, and network conditions in real-time.

2.3. Islanded

Islanded is an operational condition where a microgrid operates independently from the main power grid, as shown in Figure 3 [21]. In this mode, the microgrid must manage all aspects of energy supply independently, using local resources and energy storage systems to ensure a stable electricity supply. Technically, islanding mode is a state where the microgrid actively disconnects or is forced to separate from the main grid to operate autonomously. Microgrid must balance energy production and consumption independently. This often involves the use of a combination of energy sources.

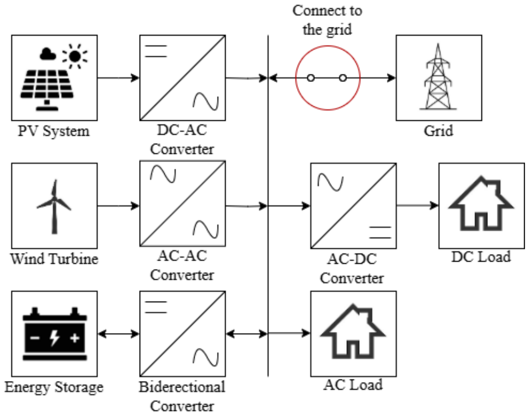

Figure 2 Grid Connected

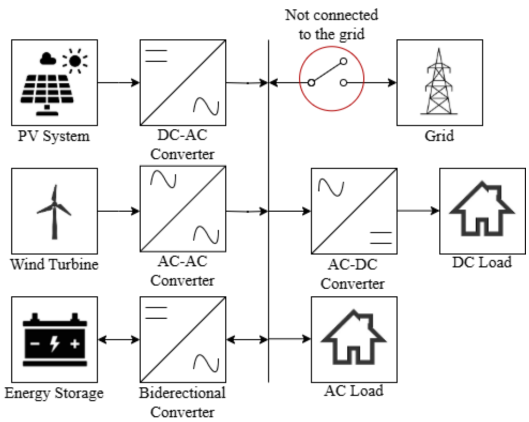

Figure 3 Islanded

2.4 DC Microgrid

DC microgrid is a direct current (DC) based electrical distribution system designed to distribute to various DC electrical loads [22]. Unlike conventional electrical systems that generally use alternating current (AC), DC microgrids utilize direct current to connect energy sources, energy storage, and electrical loads, as shown in Figure 4. DC microgrid operates using direct current, which means the flow of electrons

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in the network moves in one direction from the power source to the load. This system is very suitable for applications involving renewable energy sources, such as solar panels and batteries, because both technologies generate and store energy in DC form.

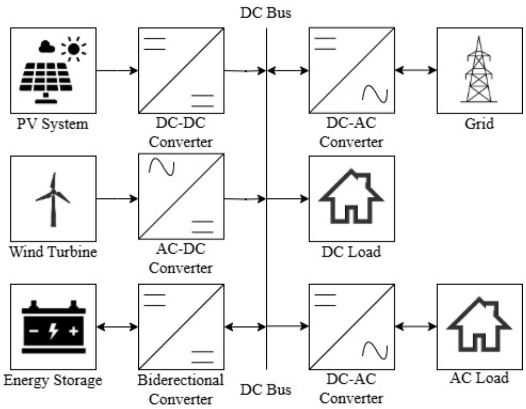

Figure 4 DC Microgrid

2.5 Distributed Generation

Distributed Generation (DG) is the concept of generating electrical energy near the load location, unlike centralized generation which is usually carried out at large power plants far from the end users [23].

Tabel 1 Classification DG

Type DG	Power plant capacity
Micro DG	<5kW
Small DG	5kW-5MW
Medium DG	5MW-50MW
Large DG	>50MW

In Table 1, there are several classifications of DG with different scales. DG with a micro scale has a small generation capacity, which is below 5kW. Because of its small size, this generator is often installed at the end user's location. Small-scale DG has a generating capacity larger than micro DG, with a scale of 5kW to 5MW. Medium-scale DG has a generation capacity between 5MW-50MW, and with a larger capacity, this generation is usually directly connected to the main power grid to distribute power widely. And large-scale DG, with a generation capacity above 50MW, can provide a more stable electricity supply because it can help manage disturbances in the distribution network.

2.6 Power Sharing

Power Sharing Controller in a microgrid is a control system used in a microgrid to regulate the distribution of power between energy sources and loads. Power sharing controller involves evenly distributing the load among various connected energy sources, with the aim of maintaining stability and efficiency in energy usage within the microgrid [24]. This distribution serves to optimize energy use within the microgrid. The power sharing controller collects information about the voltage and current from each energy source and load within the microgrid. In a DC microgrid system, there are several techniques that can be used for power sharing, such as Model Predictive Control (MPC), droop control, and Master-Slave Control, but this research uses the droop control technique. This technique is one of the most commonly used methods for power sharing in a DC microgrid. Droop control works by adjusting the output voltage of each power source according to the load.

2.7 Droop Control

When the connected load increases, the output voltage of the source will decrease. On the other hand, when the connected load decreases, the output voltage of the source will increase. The decrease and increase in the output of the source correspond to the predetermined droop value. In other words, the droop value regulates the tolerance or level of voltage deviation allowed from its nominal value during load changes. The relationship between voltage and current can be expressed as follows:

$$V_{DC} = V_{ref} - R_{droop}.I \qquad (1)$$

Where :
V_{DC} is the output voltage (V)
V_{ref} is the voltage on the DC Bus (V)
R_{droop} is the droop constant (Ω)
I is the output current generated (A)

The droop constant in a DC microgrid can be expressed as:

$$R_{droop} = \frac{V_{ref}-V_{min}}{I_{max}} \qquad (2)$$

2.8 Buck-Boost Converter

Buck-Boost converter is a circuit that can produce an output voltage higher or lower than its input voltage, depending on the operating conditions, by adjusting the duty cycle of Pulse Width Modulation (PWM). This is often used when the output voltage needs to be adjusted with high flexibility [25].

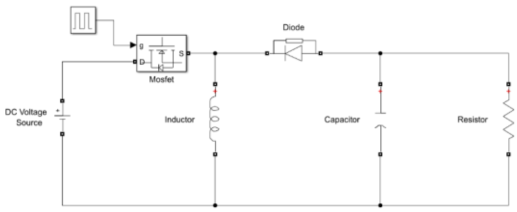

Figure 5 Buck-Boost Converter Circuit

The Buck-Boost circuit can be seen in Figure 5. The buck-boost converter uses several components such as, MOSFET acting as the switching component, inductor used as a filter to reduce ripple in the current, capacitor functioning as a filter component that reduces ripple in the output voltage, and the diode in this circuit functions when the MOSFET is in the open (OFF) condition, allowing current to continue flowing to the inductor.

3. Results and Discussion

In this chapter, the results of the simulation and analysis of the power sharing controller on the DC Microgrid are discussed, based on the design that has been developed in Simulink MATLAB.

DC Microgrid will be simulated with several case modeling. In the first case, the system will have the same buck-boost and droop value. The second case, the system will be simulated with different buck-boost values and the same droop value. And in the third case, the system will be simulated with different buck-boost values and droop values.

3.1 The values of the Buck-Boost Converter and Droop Value are the same.

In case I, the values of the buck-boost are the same, with a resistor value of 0.3 Ohm, an inductor value of 0.0004167 Henry, and a capacitor value of 0.004875 Farad, as shown in table 2. With the same values of R, L, and C, all buck-boosts have the same characteristics and capacity. And also the same droop value of 5%, as shown in Table 2. A droop value of 5% means that each buck-boost has a maximum voltage drop of 5% from its nominal value when the connected load increases to full capacity.

Tabel 2 Data Case I

Buck-Boost Converter 1				
Value Nominal				Value Droop
Vref	R	L	C	
100V	0.3 Ohm	0.4167 mH	4.875 mF	5%
Buck-Boost Converter 2				
Nilai Nominal				Value Droop
Vref	R	L	C	
100V	0.3 Ohm	0.4167 mH	4.875 mF	5%
Buck-Boost Converter 3				
Value Nominal				Value Droop
Vref	R	L	C	
100V	0.3 Ohm	0,4167 mH	4.875 mF	5%

By inserting the data as shown in Table 2, the simulation results obtained are:

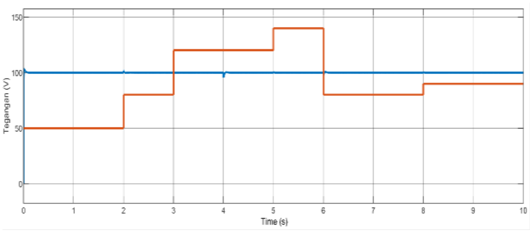

Figure 6 Input Voltage and Output Voltage Graph of Buck-Boost Converter Case I

In Figure 6, it can be seen that there is a blue input voltage graph and an orange buck-boost converter voltage graph. In the graph, the input voltage always fluctuates. At the start of the simulation, the input voltage was at 50V (Volts). And at the voltage of the buck-boost converter, initially, there was an overshoot up to 103V, and after a few milliseconds, the value changed to 100V. When there is a change in input, such as an increase or decrease, like at the 3rd second the input increases to 120V. At the output voltage of the buck-boost converter, oscillations occur, causing the voltage to rise to 101.5V, and after a few milliseconds, the voltage returns to the specified value of 100V. At the 4th second, there was an increase in load, causing the voltage to drop to 95V. However, after a few ms, it returned to the value of 100V. And at the 6th second, there was a drop in input voltage from 140V to 80V, this sharp drop caused the output voltage of the buck-boost converter to decrease to 97.5V, and after a few milliseconds, it returned to 100V.

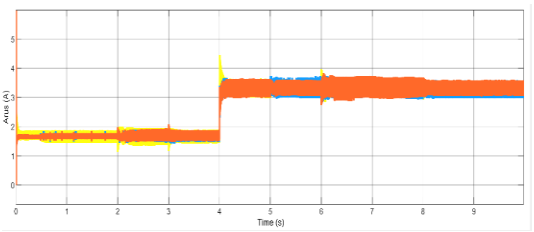

Figure 7 Output Current Graph of Buck-Boost Converter Case I

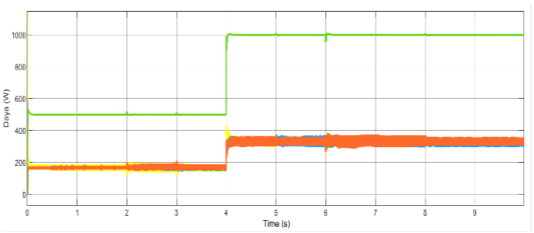

Figure 8 Load Power and Output Power Graph of Buck-Boost Converter Case I

In figures 7 and 8, It can be seen in this simulation that at the start of the simulation, there is a significant increase in current reaching 24.5 A, causing the power generated by the buck-boost converter to also increase significantly. However, after a few milliseconds, it decreases and power sharing occurs. The power sharing occurs automatically among the buck-boost converters. At the beginning of power sharing, the power distribution was still uneven, and it only became even at the 3rd second. At the beginning of the simulation, the load was at a value of 500W (Watt), so the current output from each buck-boost converter was around 1.67A (Ampere) and the power output from each buck-boost converter was around 167W. At the moment of load increase at the 4th second, which initially was 500W, it became 1000W. Power sharing continues and after a few milliseconds becomes stable. Thus, the current output of each buck-boost converter is around 3.34A, and the power generated by the buck-boost converters also increases, with each buck-boost converter producing around 334W.

3.2 The values of the Buck-Boost Converter are different, but the Droop Value is the same

In case II, the value of the buck-boost differs as shown in table 3, with the value: 1. buck-boost I resistor 0.3 Ohm, inductor 0.0004167 Henry, and capacitor 0.004875 Farad, 2. buck-boost II resistor 0.6 Ohm, inductor 0.0003167 Henry, and capacitor 0.003875 Farad, 3. buck-boost III resistor 0.9 Ohm, inductor 0.0002167 Henry, and capacitor 0.002875 Farad. Because the values of R, L, and C differ in each buck-boost, the characteristics and capacities of each buck-boost will also differ. Thus, the power generated by each buck-boost will also be different. And also the droop value is the same as a value of 5%, as shown in Table 3:

Tabel 3 Data Case II

Buck-Boost Converter 1				
Value Nominal				Value Droop
Vref	R	L	C	
100V	0.3 Ohm	0.4167 mH	4.875 mF	5%
Buck-Boost Converter 2				
Value Nominal				Value Droop
Vref	R	L	C	
100V	0.3 Ohm	0.3167 mH	3.875 mF	5%
Buck-Boost Converter 3				
Value Nominal				Value Droop
Vref	R	L	C	
100V	0.3 Ohm	0,2167 mH	2.875 mF	5%

By inserting the data as shown in Table 3, the simulation results obtained are as follows:

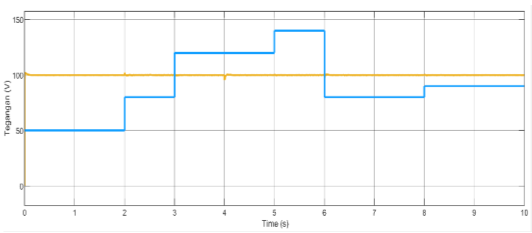

Figure 9 Input Voltage and Output Voltage Graph of Buck-Boost Converter Case II

In Figure 9, it can be seen that there is a blue input voltage graph and an orange buck-boost converter voltage graph. In the graph, the input voltage always fluctuates. At the start of the simulation, the input voltage is at 50V (Volts). And at the voltage of the buck-boost converter, initially, there was an overshoot up to 102V, and after a few ms, the value changed to 100V. When there is a change in input, such as an increase or decrease in input, like at the 3rd second, the input increases to 120V. At the output voltage of the buck-boost converter, oscillations occur, causing the voltage to rise to 101.5V, and after a few milliseconds, the voltage returns to the specified value of 100V. At the 4th second, there was an increase in load, causing the voltage to drop to 95V. However, after a few ms, it returned to the value of 100V. And at the 6th second, there was a drop in input voltage from 140V to 80V, this sharp decrease caused the output voltage of the buck-boost converter to drop to 97V, and after a few ms, it returned to 100V. The difference in capacity in the buck-boost converter affects the output voltage, causing the system to oscillate slightly more than in case I. However, the oscillation that occurs is still within the range of 100V, so the voltage produced by the buck-boost converter is still safe.

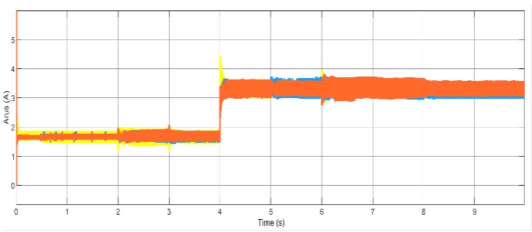

Figure 10 Output Current Graph of Buck-Boost Converter Case II

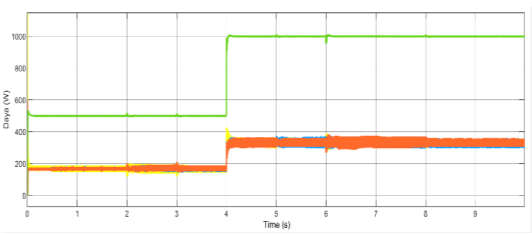

Figure 11 Load Power and Output Power Graph of Buck-Boost Converter Case II

In figures 10 and 11, it can be seen that at the beginning of the simulation, there is a significant increase in current reaching 24.5 A, causing the power generated by the buck-boost converter to also increase significantly. However, after a few milliseconds, it decreases and power sharing occurs. The power sharing occurs automatically among the buck-boost converters. During the simulation, power sharing was evenly distributed from the beginning to the end. At the beginning of the simulation, the load was at 500W (Watt), so the current output from each buck-boost converter was around 1.67A (Ampere) and the power output from each buck-boost converter was around 167W. At the moment of the load increase at the 4th second, which initially was 500W, it became 1000W. Power sharing continues and stabilizes after a few milliseconds. Thus, the current output of each buck-boost converter is around 3.34A and the power generated by the buck-boost converters also increases, with each buck-boost converter producing approximately 334W. The increase in power sharing is in line with the increase in load; when the load increases, the output current of the buck-boost increases, thus the power generated by the buck-boost also increases.

3.3 The values of the Buck-Boost Converter and Droop Value are different.

In case III, the value of the buck-boost differs as shown in table 4.3, show the value:

1. buck-boost I resistor 0.3 Ohm, inductor 0.0004167 Henry, and capacitor 0.004875,
2. buck-boost II resistor 0.6 Ohm, inductor 0.0003167 Henry, and capacitor 0.003875,
3. buck-boost III resistor 0.9 Ohm, inductor 0.0002167 Henry, and capacitor 0.002875.

And also different droop values as shown in table 4.3, show the values:

1. buck-boost I of 3%,
2. buck-boost II of 4%.
3. buck-boost III at 5%.

Tabel 4 Data Case III

Buck-Boost Converter 1				
Value Nominal				Value Droop
Vref	R	L	C	
100V	0.3 Ohm	0.4167 mH	4.875 mF	3%
Buck-Boost Converter 2				
Value Nominal				Value Droop
Vref	R	L	C	
100V	0.3 Ohm	0.3167 mH	3.875 mF	4%
Buck-Boost Converter 3				
Value Nominal				Value Droop

Vref	R	L	C	
100V	0.3 Ohm	0,2167 mH	2.875 mF	5%

By inserting the data shown in Table 4.3, the simulation results obtained are as follows:

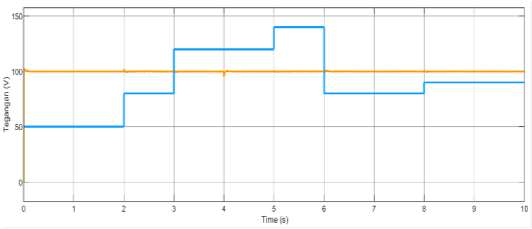

Figure 12 Input Voltage and Output Voltage Graph of Buck-Boost Converter Case III

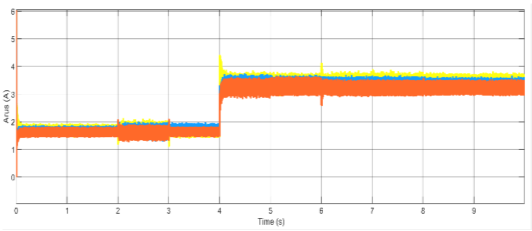

Figure 13 Output Current Graph of Buck-Boost Converter Case III

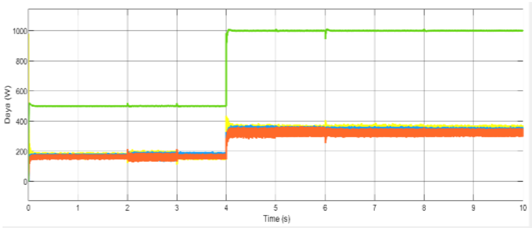

Figure 14 Load Power and Output Power Graph of Buck-Boost Converter Case III

In case III, the difference in buck-boost capacity and droop value can affect system stability. With a small droop value, the buck-boost generates more power, and with a large droop value, the buck-boost generates less power. In this case, buck-boost converter1 has a small droop value of 3%, buck-boost converter2 with a droop value of 4%, and the largest droop value is found in buck-boost converter3 with a droop value of 5%.

In figures 12, 13, and 14 it can be seen that the droop value affects the power output from the buck-boost converter. At the beginning of the simulation with a load of 500W, buck-boost converter1 produced slightly more power with an output of 175W, buck-boost converter2 produced 165W, and buck-boost converter3 produced less power with an output of 160W. Similarly, when the load increases to 1000W, buck-boost converter1, which has a small droop value, can produce more power with an output power of 345W, buck-boost converter2 produces an output power of 330W, and buck-boost converter3 produces 325W.

4. Conclusions

1. Based on the results and analysis of the output from the power sharing controller system on the DC microgrid with the application of the droop control method, the following conclusions can be drawn: The design of the power sharing controller in the DC Microgrid that has been created has two levels. With having two levels of power sharing controller, it will be more optimal, where the first level is the primary controller and the second level is the secondary controller. The first level is the primary controller, which ensures that the voltage remains within the predetermined voltage range, even with changes in input and load. At the second level, there is a secondary controller that functions to correct and restore the voltage to the predetermined value after changes in voltage and load. Thus, the secondary controller ensures that the system operates according to the predetermined system parameters.
2. The selection of the droop value is very important to maintain system stability. The higher the droop value, the smaller the power output by the buck-boost converter, and if the droop value is small, the power produced by the buck-boost converter is also larger. This happens because with a higher droop value, the voltage drop can be greater, resulting in a decrease in the power output due to the significant voltage drop, and vice versa.

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