Performance analysis of a standalone hybrid renewable electric generation system during fault condition

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Abstract. There are several problems or disruptions to the hybrid system, including the availability of limited energy sources, transient conditions when some power plants or loads enter the system or out of the system and short circuit interruptions. The hybrid system used for testing includes photovoltaic system (PV), wind power generation system (WTGS), battery energy storage system (BESS) and load. The system is integrated on the DC bus. Testing for each interference condition is performed after the system is integrated. The parameters seen in this hybrid system performance analysis test are DC bus voltages and currents from each renewable plant. The results of this test will be used as data for hybrid system improvement in future research.

1. Introduction

The limitation of fossil energy reserves causes the urgency of the use of new and renewable energy to be the concern of the government, entrepreneurs and researchers in the electricity sector. Indonesia has diverse energy potential in various regions. Renewable energy potential in Indonesia, such as solar, wind, micro hydro, geothermal energy, biomass, ocean waves and currents, and others. Some regions in Indonesia have more type of renewable energy potential. In order to utilize the existing potentials [1], efforts must be made to integrate several types of new and renewable energy power plants. LIPI as a research institution in Indonesia is developing a smart microgrid consist of intelligent inventors with renewable energy power plants from solar, water, wind and biogas. Excess energy will be stored in the battery and will be used during peak load. This technology has been applied in Raja Ampat, Papua, and Cipary, West Java. A review of hybrid renewable or alternative energy systems for electric power generation has been discussed [2]. Integration of renewable energy generation systems will lead to increased continuity of the system in serving electricity needs.

In addition, the complexity of the system also increases and there may be some problems. There are several problems or disturbances that often occur in hybrid systems with renewable energy sources. Some of these disturbances include limited availability of energy sources that are affected by weather and natural conditions, the occurrence of transient conditions when several new and renewable energy generating units and loads that enter the system and exit the system suddenly, and the possibility of short circuit fault. When a short circuit occurs, the current flowing to the short circuit becomes very large depending on the potential difference in voltage at the point of interference and the short circuit resistance.
Some problems that might occur, it is necessary to perform a hybrid system performance test. This hybrid system will be conditioned as possible problems that will occur on the system. The parameters seen in the performance test of this system are DC bus voltage and the current of each renewable energy generator. There are several related studies that discuss the problem of short circuit on DC systems. Approach based fault to protect microgrid DC diagnosis using machine learning technique has been studied by applying the ANN algorithm to regulate CB termination [3]. The basic concept is used by measure the high magnitude and sharp slope of the fault. Estimation of short circuit current in low voltage DC microgrid and fault characteristic of DC microgrid during bipolar short circuit faults are already explained [4]. The different scenario of the system has also been discussed. The calculation method of short circuit for low voltage DC microgrid has been discussed [5]. DC and AC ground fault analysis in LVDC microgrid with energy storage system also has been discussed [6].

2. Configuration System

Standalone hybrid renewable generation system which analyzed its performance in this study consist of photovoltaic (PV), wind power generation system (WTGS), battery and load. Wiring diagram of the system is shown in figure 1. The discussion about power flow control of the system has been discussed before [7]. Every renewable generator, battery and load are connected to the DC bus. Each renewable energy generation system, both PV and WTGS, is connected to a DC - DC boost converter that is controlled to always produce maximum power as the energy source changes. The battery is connected to a bidirectional converter which is controlled by the droop voltage regulation technique to adjust the DC bus voltage to remain regulated and store excess energy and provide power when there is a lack of energy.

![Configuration of the hybrid system.](image)

2.1. Photovoltaic system (PV)

Photovoltaic generates electrical energy from sunlight received by solar panels. The intensity of sunlight from time to time tends to change. So that the power generated by the solar panel will also change. From the datasheet, the characteristics and maximum points of power on the solar panel change with changes in sunlight intensity. Therefore, MPPT control techniques are needed to optimize the power generated to obtain better efficiency of the system. MPPT control technique is carried out with voltage sensing and output current of solar panels with current and voltage sensors as input controller data. The controller will process the current and voltage data of the solar panel with the MPPT algorithm to produce a control signal to energize the switching component of boost converter. In this research, the
high boost ratio converter is chosen to get the output voltage reaching 311 volts. The explanation of this converter has been discussed before [8]. Incremental Conductance completed by various steps has been chosen for MPPT technique algorithm [9]. The PV panel configuration in the PV system above consists of 2 PV arrays that are connected in parallel, with a single array consist of 2 PV panels connected in series.

2.2. Wind Turbine Generation System (WTGS)
The electrical energy of WTGS is obtained from a generator with a rotor coupled with a wind turbine to produce rotation. Wind speed has change every time, so that the power generated by the generator also changes. Wind turbine power characteristics change with changes in wind speed. The maximum operating power generated by wind turbines also varies depending on wind speed. So it takes MPPT control techniques to regulate and maximize the power generated by the WTGS to obtain good power efficiency. Sensing voltages and currents are carried out on the output side of the rectifier that has been filtered with an LC passive filter to reduce voltage and current ripple. Voltage and current will be processed by the controller to give a trigger signal to the boost converter. Boost converter with a high ratio is used to get a voltage of 311 volts. The MPPT algorithm used is the Incremental Conductance with various step. This algorithm has good performance with high MPPT control efficiency that is already discussed on reference [9].

2.3. Battery Energy Storage System (BESS)
The battery is used to store excess energy in the system. If there is a lack of energy, the battery will supply power to the system. So the battery is connected to a DC bus using a bidirectional converter. Bidirectional converters are controlled by droop voltage regulation technique to regulate DC bus voltage. This converter also regulates the direction of power flow when charging and discharging energy in the battery. A detailed description of the droop voltage regulation technique is discussed in reference [10].

2.4. Short circuit on DC system
Short circuit is a fault that often occurs in electric power systems. A short circuit in a DC system occurs when a potential electric conductor (positive polarity) touches or is connected to another low potential (negative or zero polarity). Short circuit current levels that occur in DC systems are affected by DC voltage levels at fault points and fault resistance when short circuit occurs. When there is a short circuit, the system equivalent circuit becomes like Figure 2.

![Figure 2](image_url)

**Figure 2.** Equivalent circuit of a standalone hybrid renewable generation system when short circuit happened on DC bus.
The equivalent circuit of this hybrid system when there is a short circuit fault includes converter resistance, cable resistance, short circuit resistance and interference resistance. The resistance of cable is dependent on the length and diameters of the cable. Grounding Resistance is dependent on the grounding type and ground structure. So the equivalent of short circuit resistance can be calculated as the equation below.

\[ R_{eq-n} = R_{conv-n} + 2xR_{line-n} + R_{fault} \]  

(1)

R_{eq1} and R_{eq2} is equivalent resistance for each PV system and WTGS. R_{conv1} and R_{conv2} is equivalent resistance of both boost converter 1 and 2. The value of this converter resistance varies depending on the converter operating mode. Each operating mode has a different equivalent circuit. For this converter, it has 5 different operation modes [8]. R_{line-n} is the cable resistance on channel n and R_{fault} is the resistance of the short circuit fault.

Calculation method of short circuit current level on LVDC microgrid has been discussed [5]. On wind turbine generation system, Effect of wind speed variation on the short circuit contribution also has been discussed [11]. Estimation of short circuit fault on some configuration of LVDC system has been discussed [4]. The research also discusses about the characteristics of DC microgrid interference during bipolar short circuit fault. From the hybrid system in Figure 1, an equivalent circuit of the system can be created when there is a short circuit on the DC bus as shown in Figure 2.

\[ I_{SC...peak} = \frac{V_{SC...point} (t = 0^+)}{R_{fault}} \]  

(2)

I_{SC_peak} is peak value of short circuit current, V_{SC_point} (t = 0+) is voltage value on short circuit point at the first time.

\[ I_{SC} = I_{SC...PV} + I_{SC...WTGS} + I_{SC...Battery} \]  

(3)

I_{SC} is short circuit current value, I_{SC_PV} is short circuit current of PV, I_{SC_WTGS} is short circuit current of WTGS dan I_{SC_battery} is short circuit current of battery. The short circuit current value that flow into the point of fault happened is come from each renewable sources, battery and capacitor which connected to the system. The capacitance of capacitors also defines the transient time of short circuit current.

3. Analysis of performance test hybrid renewable generation system during fault condition

In normal condition, hybrid renewable electric generation can provide electricity for loads connected to DC buses. Simulation parameters including equipment power and system component values are shown in Table 1. When irradiation of the sun and wind speed change, and the load connected to the DC bus also changes, the DC bus voltage is maintained at ±311 Volts by BESS. However, when there is a short circuit at the point on the DC bus area, the DC bus tension has decreased sharply. This voltage drop level depends on the fault resistance value. The smaller the fault resistance value, the greater the DC bus voltage decrease, and vice versa.

The short circuit fault point discussed in this system performance testing occurs on DC bus. The amount of fault resistance tested is 1 ohm. In Figure 3 shows the voltage and current output of PV panel array and WTGS before faults and during fault occurred. The voltage and current output of PV has no significant effect during fault. But on WTGS has a significant effect on the output of voltage and current from rectifier. During fault at transient condition (Δt = 0.01s), the rectifier output voltage drops from 88 volts to 30 volts and the rectifier output current rises sharply from 3 amperes to 11.5 amperes. Then the output rectifier voltage and current are constant at 65 Volts and 7 Amperes after 0.01s of short circuit failure. The length of transient conditions is determined by the capacity of all capacitors connected to the system.
Table 1. Simulation parameters.

| Parameters  | Value | Parameters  | Value | Parameters  | Value |
|-------------|-------|-------------|-------|-------------|-------|
| $P_{PV}$    | 250 W | $P_{WTG}$   | 500 W | $P_{Battery}$ | 500 W |
| $V_{in-min}$| 30 V  | $V_{in-min}$| 30 V  | $V_{low}$   | 30 V  |
| $V_{in-max}$| 42 V  | $V_{in-max}$| 60 V  | $V_{high}$  | 60 V  |
| $V_{out}$   | 311 V | $V_{out}$   | 311 V | $V_{out}$   | 311 V |
| $f_{sw}$    | 10 kHz| $f_{sw}$    | 10 kHz| $f_{sw}$    | 10 kHz|
| $n$         | 3     | 2           | 10 %  | $\Delta I_{L-pp}/I_L$ | 10 % |
| $\Delta V_{C-pp}/V_{out}$ | 0.01 % | $\Delta V_{C-pp}/V_{out}$ | 0.01 % |

| Parameters   | Value  | Parameters   | Value  | Parameters   | Value  |
|--------------|--------|--------------|--------|--------------|--------|
| $P_{PV}$     | 4 x 60 Wp | $P_{WTG}$   | 635 Watt | $P_{Battery}$ | 13.5 V |
| $V_{oc}$     | 21.1 V | $P_{elect}$ | 580 Watt | $E_{full}$ and $E_{exp}$ | 12.2 V |
| $V_{mpp}$    | 17.1 V | Wind speed  | 8 m/s  | $Q_{nom} : Q_{exp}$ | 22 Ah; 88 Ah |
| $I_{sc}$     | 3.8 A  | Rotational  | 554 rpm | $Q : A$       | 110 Ah; 1.3 V |
| $I_{mpp}$    | 3.5 A  | speed       | B      | $K$          | 0.06119 V |
| $T$          | 25 o   |             | R      | 3.4 mΩ       |

Figure 3. Voltage and current output of PV and WTGS, a) when t = 0 – 3s; b) at transient condition when short circuit happened with $R_{fault} = 1$ ohm.

Figure 4 shows the response of voltage and current from the battery and DC bus. When short circuit fault occurs, the battery terminal voltage continues to decrease from 97.2 Volt to 95.5 Volt and the battery output current increase sharply up to 500 amperes. If the system is not equipped with a good safety system, this can cause damage to the battery and burning of the conduit, converter and others. While the DC bus voltage was drop from 311 Volts to 75 Volts during transient conditions ($\Delta t = 0.01s$) and constant at 188 Volts. In this condition, the maximum short circuit current reaches 311 Ampere.
Figure 4. Voltage and current response at terminal of battery and DC bus, a) when $t = 0 – 3s$; b) at transient condition ($\Delta t = 0.1s$) when short circuit happened.

Figure 5 shows the short-circuit current contribution of each renewable electric generator (PV and WTGS), batteries and capacitors. When a short circuit occurs, the maximum contribution current of PV reaches 84 Ampere. The maximum short circuit current contribution flow from the WTGS reaches 68 Ampere. The maximum contribution current from BESS reaches 63 Ampere. $I_{\text{load}}$ in Figure 5 shows the load current during normal conditions before a short circuit occurs. When there is a short circuit fault, the value is equivalent to the total short circuit current flowing at the point of fault. The value of $I_{\text{load}}$ when there is a short circuit fault reaches 311 Ampere. This is because the voltage level at the short circuit point (when $t = 0^+$) is 311 Volts, with a short circuit resistance value of 1 ohm.

Figure 5. Short circuit contribution of capacitors which connected in DC bus, PV, WTGS dan battery at transient until steady state condition.
4. Conclusion
From the analysis above, it can be concluded that the effect of short circuit fault on DC systems is very large. The current generated by the short circuit fault exceeds the current carrying capacity of each component. The amount of short circuit current is determined by the magnitude of the voltage at the point of fault shortly before the short circuit fault and the resistance of the short circuit fault are interrupted. The length of transient conditions when a short circuit fault occurs is affected by the amount of capacitor capacitance that is directly connected to the system. The greater the capacitance of the capacitor, the longer transient condition takes place. Besides that, the effect of short circuit fault also causes instantaneous voltage drop on the system. The role of boost converters in PV and WTG systems when short circuit interference is also a current limiting resistance, so it does not have too much effect on PV and WTG systems. In addition, PV and WTG systems also have limited power capacity. While the battery is a voltage source that capable to supply large power requirements. So the largest current contribution is coming from the battery. From the conclusion above the hybrid system requires more reliable safety system.

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