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Power Transfer Enhancement in Hybrid AC-DC Microgrids

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Abstract: Microgrids can be grouped into 2 types: AC and DC, depending on the main bus for supplying the load. When hybrid microgrids, AC and DC types are physically separated by the location, but near by, a bidirectional converter is required to connect and to transfer the power to each other. This study proposed a bidirectional converter system for connecting AC and DC microgrids. The converter transfers power from the surplus microgrid to the lack one. It also converts dc power from the microgrid to ac power of the other microgrid and vice versa. This control arrangement is used to improve the system performances. Some simulations to a hybrid AC-DC microgrid had been done in four different cases. Every simulation had gained result for bi-directional converter performance to maintain stable system operation under various load and resource condition.

Key words: Hybrid microgrid, renewable power generation, power transfer, converter

INTRODUCTION

Indonesia has thousands of islands and uneven population distribution, but the electric power generation only found in certain regions. However, some remote areas has also provide a power supply for power generation. Fulfillment of electricity in remote areas mostly use conventional power plant like diesel power, as we all know that the use of fossil fuels is expensive. By utilizing the available renewable energy sources in each region, microgrid can be used as a solution to provide self-sufficient energy for remote areas. Different characteristics of each renewable energy source and also the condition of the energy potential sources in each region that can be utilized is a challenge to build a microgrid system.

Microgrid or micro network is a distributed generation pattern that can cover a wide variety of energy sources, from fossil sources, as well as renewable energy sources such as wind, solar, biogas, etc. Among the various types of renewable energy sources, solar energy and wind energy have become the most promising and atrractive sources of renewable energy Fuel cell, battery, solar energy, microhidro can be operated in DC systems. Therefore DC distribution system or DC microgrid is recently being developed. DC microgrid can be operated in islanded mode but it is also required to operate with AC system (Ferreira *et al*., 2012). The combination of AC and DC resources is called hybrid microgrid. The power generated by Renewable Energy Source (RES) makes hybrid microgrid system become complicated because it contains varying sources and load. The application of such system requires many power converters (Huang *et al*., 2011; Ashari *et al*., 2000; Bambang *et al*., 2010; Park *et al*., 2014).

Based on the function and application of converters, there are several type of converters (Bambang *et al*., 2010; Purnomo and Ashari, 2012; Zadeh and Molinas, 2013; Kalavalli *et al*., 2013; Pardhu *et al*., 2013; Deeb *et al*., 2014). The application of power converter usually needs filter to eliminate ripples, there for power converter equipment not only will increase the harmonics in the microgrid system but also need control. This is very complicated and expensive.

In this study, a new hybrid microgrid system is developed based on the power generated as shown in Fig. 1. The configuration is grouping the same type of power generated with the same type of load. That means DC RES will supply DC load and ac RES will supply AC load only. Bi-directional converter is used as interface between DC and AC microgrid. This study is to enhance the power transfer between both microgrids.

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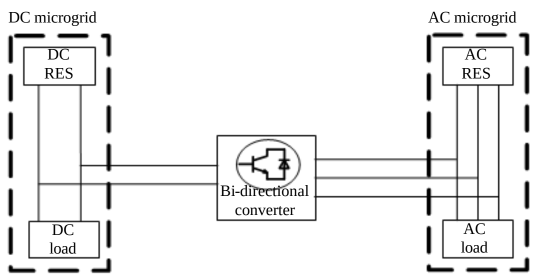

Fig. 1: Schematic diagram of the AC-DC microgrid

MATERIALS AND METHODS

Power transfer in hybrid AC-DC microgrid: The load is connected directly to the RES. When the DC RES and ac RES are available and within the specified tolerances of voltage and frequency, the DC RES and AC RES will deliver the required active power to the load. The load voltage is maintained constant by the converter. The active power for DC load is:

$$P_{dc}^* = V_{dc} * i_i^* \quad (1)$$

where i_i^* is the sum of the currents derived from the dc RES and the current flowing into the converter. The active power transfered to AC microgrid:

$$P_g^* = P_{DC}^* - \sum(P_{DC\text{-}AC}, P_{LC}) \quad (2)$$

Where:

- $P_{DC\text{-}AC}$ = The loss power which due to the conduction and commutation of the converter IGBT (Insulated Gate Bipolar Transistor)
- P_{LC} = The instantaneous power absorbed by the filter

Assuming, there is no power losses in the converter and the filter. Then:

$$P_g^* \approx P_{dc}^* \quad (3)$$

Only active power is transfered to ac microgrid:

$$Q_g^* = 0 \quad (4)$$

The converter is bidirectional type, which can convert the power from the dc microgrid to ac microgrid and reverse at required voltage and frequency. The power transfer in AC microgrid can be illustrated as shown

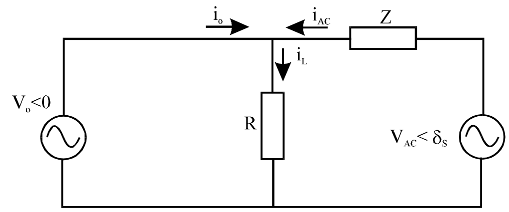

Fig. 2: Simplified circuit for AC microgrid

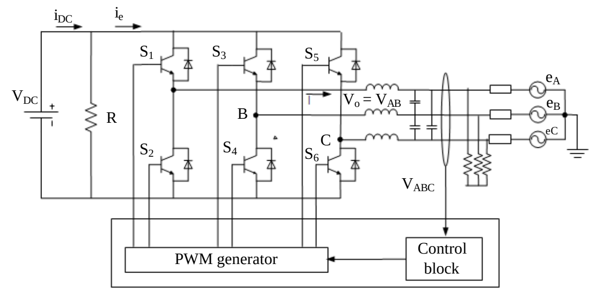

Fig. 3: Bi-directional converter structure

in Fig. 2. Where V_o is converter voltage, V_{ac} is AC RES voltage and assume as pure sinewave. Z is transmitter impedance that contain resistor and inductor (Z = R +jX = |Z|<Y°). The instantaneous power consumed by the AC load is (Bambang *et al*., 2010):

$$S_L(t) = V_o(t) \cdot i_L(t) \quad (5)$$

Transmitted active and reactive power from the AC RES is (Muhammad, 2011):

$$P = (3V_o/Z).(V_{ac}\cos(Y - \delta) - V_o\cos(Y) \quad (6)$$

$$Q = (3V_o/Z).(V_{ac}\sin(Y - d) - V_o\sin(Y) \quad (7)$$

In low voltage distribution feeders, the resistive part dominates, thus Y ≈ 0, Therefore, the transmitted power in Eq. 6 and 7:

$$P = \left(V_o \cdot V_{ac}\cos(\delta) - V_{ac}^2\right)/R \quad (8)$$

$$Q = \left(\left(V_o \cdot V_{ac}\right)/R\right)\sin(\delta) \quad (9)$$

With this all equation, the power transfer through bidirectional converter can be done in AC and DC microgrid.

Converter for bidirectional power flow: The three phase converter that used in this study is identified with three single phase converter like Fig. 3. The converter operates by keeping the AC and DC voltage at the desired value, using a feedback control loop as shown in Fig. 3. The AC voltage is measured and compared with a reference V_{REF}. The error signal generated from this comparison is used to switch the IGBT of the converter into "on" and "off". The converter is capable operating in all four quadrants of voltage and current as shown in Fig. 4. When the current I_o is positive (inverter operation), the error signal ask the control block takes the power from the dc supply. In this way, more current flows from the DC to AC. Reverse, when I_o become negative (rectifier operation), that is mean more current flows from the AC to the DC. The phase relationship between the ac output voltage and ac output current does not have to be fixed and the converter can provide real and reactive power at all leading and lagging power factor.

Voltage control method: The output voltage of hybrid AC-DC microgrid maintained at certain constant value. Stable voltage makes equipment which is not easily damaged. Voltage control is required to keep on voltage stability. The basic block diagram of the voltage control method is shown in Fig. 5. Voltage control method of microgrid converter uses the output voltage as the control signal which produces voltage in the same frequency and phase angle with the grid voltage. The converter output is filtered with LC filter before it is used as feedback signal. V_{ABC} is not only change from abc to dq frame and fed to summing point but also become input of Phase Locked Loop (PLL). PLL is used to synchronize the frequency in the system. It generates phase angle (ω_{PLL}) that locked on the variable frequency system voltage. The

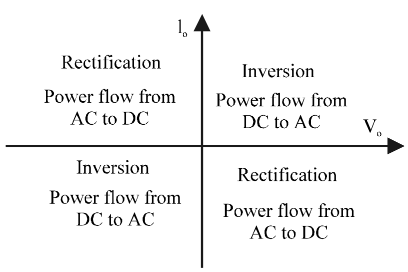

Fig. 4: Quadrants operation of the bi-directional converter

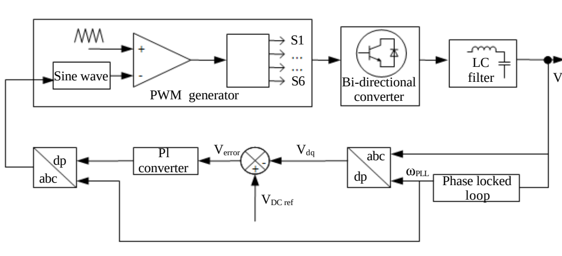

Fig. 5: Basic block diagram of the voltage control method

Proportional Integral (PI) controller requires coordinate transformation to the dq frame of reference in order to obtain the desired controllability

The magnitude of the reference voltage and V_{dq} is fed to a summing point, generate an error signal, V_{error}. Through PI controller the V_{error} controlled and change from dq to abc frame. This signals controlling the sine wave generator.

To generate Pulse Width Modulation (PWM) signals the modulated sinusoidal signal is compared with triangular carrier signal. To make the converter work properly, the sine wave generator must generate a fundamental signal (sinusoidal) with the same frequency as the power source. It caused the output voltage of the converter is maintained constant.

RESULTS AND DISCUSSION

Simulations have been performed using two sources, DC and AC. DC sources represent DC microgrid so did the AC source that represents ac microgrid. There are different cases in these simulation, they are:

- Isolated condition
- Connected between ac and dc system
- Three phase fault in ac system
- Added parallel load in each system

Simulation system parameter that is given to the hybrid AC-DC system is in Table 1.

First case; isolated condition: In Isolated condition the DC and AC voltage maintain constant until given parallel load, the voltage is slightly down. Fig. 6 shows the DC voltage, current and power and Fig. 7 shows the AC voltage and current in isolated mode.

Second case; connected between ac and dc system: When DC system is connected with ac system the voltage in DC source is maintain in 300 V, the impact of three phase fault in 0.2 until 0.4 seccon on ac source coused fluctuation.

Table 1: System parameter

Parameter	Value
DC Voltage	300 V
DC Load	1 = 1KΩ2 = 10 K?
DC Internal resistant	0.25 kΩ
AC Voltage	380 V
AC Internal resistant	0.25 kΩ
AC Load	1 = 2.5 kΩ,2 = 20 kΩ
AC Internal resistant	0.25 Ω
LC Filter	L = 10e-3 H, R = 2 kΩ, C = 10e-6 F
Distribution impedance	Z1 = 2 kΩ + 50e-3 HZ0 = 4 Ω + 100e-3 H
Switching frequency	4000 Hz
Nominal frequency	50 Hz

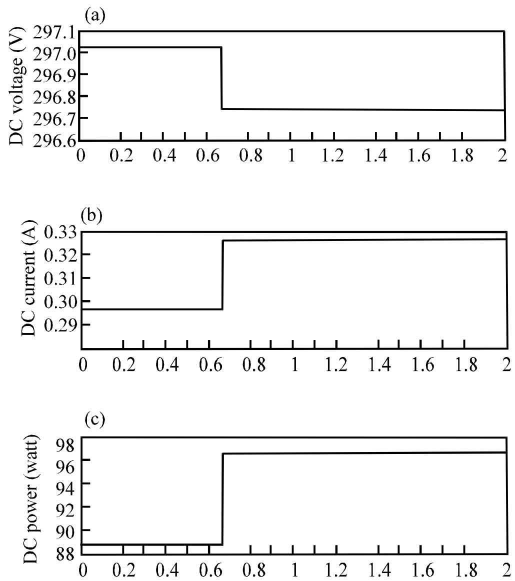

Fig. 6: DC system isolated mode; a) DC voltage; b) DC current and c) DC power

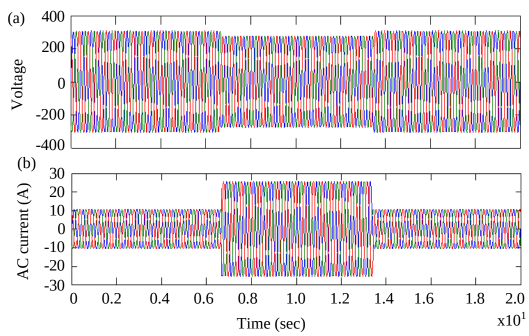

Fig. 7: AC system isolated model; a) AC voltage; b) AC current

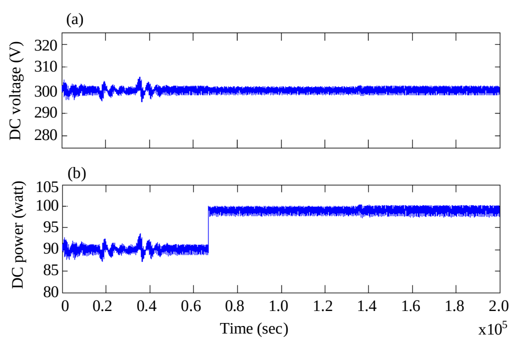

Fig. 8: DC system connected with AC system; a) Voltage; b) Power

And other the DC system is configured in parallel load at 0.65 sec, it has made power increase. It is shown in Fig. 8.

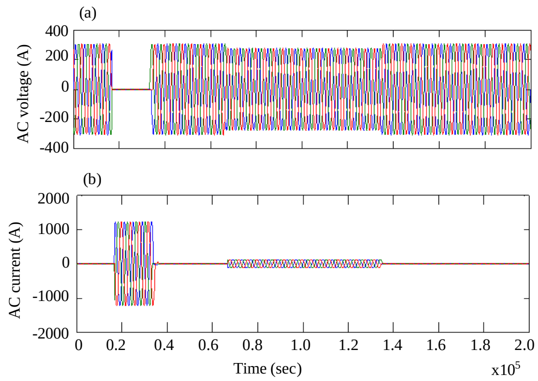

Fig. 9: AC source system; a) AC voltage; b) AC current

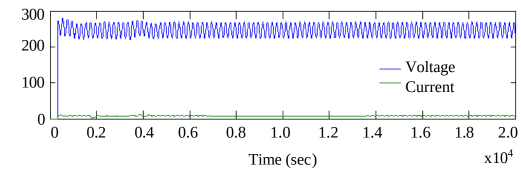

Fig. 10: Inverter voltage and current

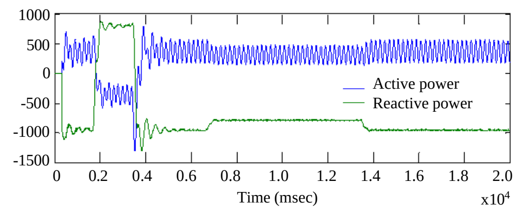

Fig. 11: Inverter active and reactive power

Third case (three phase fault in AC system)

Fourth case (added parallel load in each system): Figure 9. show the condition in ac source, the ac voltage is stable until 3 phase fault occurs in ac source, the voltage is down drastically close to zero and the current flows are very high. When the ac system added paralel load, it has impact to the current and voltage load. When voltage and current conditions of the inverter output remains well controlled, even there are disturbance at the ac source and changing at the load system. All this condition are described in Fig. 10. Figure 11 show the active and reactive power of the converter. When the fault happen the current is very high and the voltage has negative polarity, it changes the converter orientation. Figure 12 described condition on load disturbances in the AC source gives a very big impact to the voltage and load current. These disorders also have an impact on active power and reactive power. Load changes lead to decline in both active and reactive power. This case illustrates the power absorption occurs in the load. Different resource condition and load capacities are tested to validate the

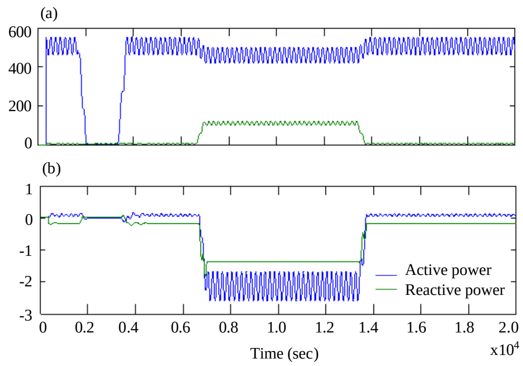

Fig. 12: Load; a) Voltage and current; b) Active and reactive power

control methods. The simulation result show that the system can operate stably in the AC-DC system tied or isolated mode. Stable AC and DC bus voltage can be guaranteed when the operating conditions or load capacities change. And the power is smoothly transferred

CONCLUSION

Some simulations to a hybrid AC-DC micro grid had been done in four different cases. The simulation prove the performance of hybrid AC-DC microgrid condition between isolated mode and connected mode. It shown that hybrid AC-DC micro grid had good performance after it was connected to bidirectional converter. The converter can smoothly transferred the power when load condition changes and even when the fault happened in ac source. All simulation had gained result for bidirectional converter performance to maintain stable system operation under various load and resource condition. Finally, power transfer enhancement in hybrid AC-DC micro grid operation had given guaranty in stable AC and DC bus voltage.

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