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DEVELOPMENT OF DIRECT CURRENT MICROGRID CONTROL FOR ENSURING POWER SUPPLY FROM RENEWABLE ENERGY SOURCES

Budiyanto[1*], Rudy Setiabudy[1], Eko Adhi Setiawan[1], Uno Bintang Sudibyo[1]

[1]*Department of Electrical Engineering, Faculty of Engineering, Universitas Indonesia, Depok 16424*

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ABSTRACT
Renewable energy sources such as wind, solar, and microhydro have the potential to fulfill the energy needs of society. To optimize their utilization, the generators using this kind of energy are connected to a microgrid. A microgrid combines electrical power supplied from several renewable energy power plants; it can operate as an isolated distribution network or it can be connected to the utility national grid. In this study, a control device for a 254-volt direct current microgrid supplied by a solar cell, a wind turbine, and battery storage is discussed as a potential solution toward ensuring a stable supply to the microgrid's loads, even when the energy sources supply reduced power. The experimental result shows that DC microgrid can be applied widely as alternative solution for renewable energy utilization particularly in low voltage level to supply DC and AC loads.

Keywords: Battery; Control; Microgrid; Solar cell; Wind turbine

1. INTRODUCTION
Currently, energy and environmental issues are topics of interest due to increased attention around the world to green environmental programs. Advances in economics, technology, and environmental programs will change the pattern of power generation systems from centralized systems to distributed systems, which are simpler since they adjust to local economies. The development of an infrastructure for an electricity system requires consideration of the following (Ramakumar et al., 2002) :

- Deregulation of the electric utility industry and the ensuing break-up of the vertically intregrated utility structure,
- Negative public reaction to the construction of new transmission lines for reasons relating to the environment,
- Public awareness about the environmental impact of power plants,
- Very rapid increases in electricity demand in some areas,
- Rapid technological advances that are more environmentally friendly (i.e., wind power, microturbines, fuel cells, and solar cells) than conventional technologies such as power plants that still use coal, oil, and gas.

The concept for the microgrid is clustering of electrical and thermal loads with small-scale sources of electrical power (Lasseter, 2002; Lasseter et al., 2004). The microgrid is one example of the distributed generation pattern that encompasses a variety of energy sources, ranging from fossil fuel sources to renewable energy sources such as solar cells, wind, and biogas.

[*] Corresponding author's email: yan.budiyanto@yahoo.com, Tel. +62-21-727-0078, Fax. +62-21-727-0077

A microgrid is an interconnected system, loaded from a variety of distributed energy resources that can operate independently or connected to the utility national grid (Figure 1).

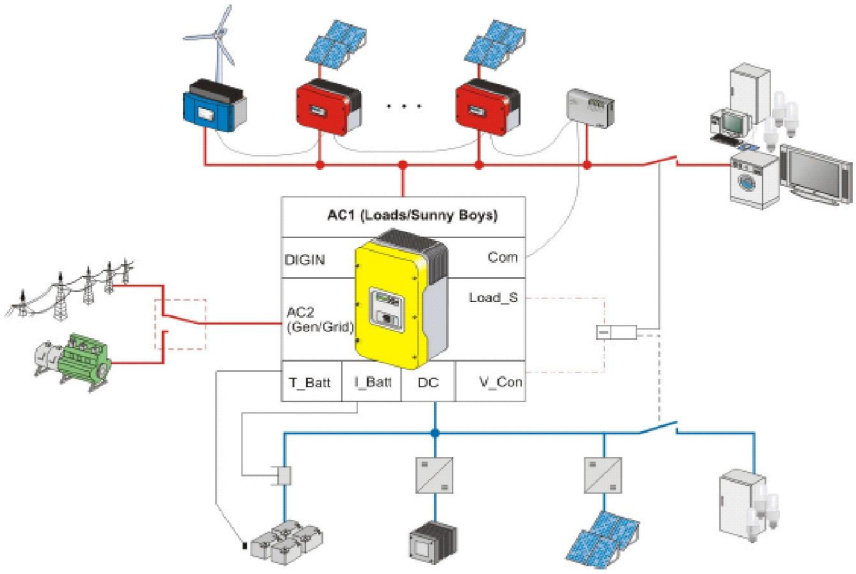

Figure 1 Conceptual microgrid system (SMA Technologie AG-Germany, 2007)

Research on the alternating current microgrid has been conducted, but there are still many obstacles associated with the integration of generating systems, especially in the parallel inverter system. This method has been widely applied to parallel systems, such as the phase locked loop (PLL) and the voltage and frequency droop control method (De Brabandere et al., 2007). Problems of frequency and reactive power generation are separate issues within the microgrid system (Xiao, et al., 2003). To develop solutions to these problems, several studies have been undertaken using a direct current system for the supply of electric power (Nilson et al., 2004). A direct current system can also be used for residential and office systems (Kakigano et al., 2008), household appliances, and switching power supply technology that can utilize a direct current source (Lu, et al., 2009).

This study proposes the design of an electric power supply control to regulate renewable energy in a direct current (DC) microgrid. The electric power supply controls can be used for various types of renewable energy in a given area or locale; use of controls will ensure that the generation of renewable energy does not depend on climate so that the microgrid can be supplied with sufficient power at all times.

2. DC MICROGRID CONFIGURATION

Figure 2 illustrates the DC microgrid system configuration that operates on an independent network of renewable energy generation. This system uses 3 units of combined power generated from solar cells, wind, and battery storage.

To generate energy, solar cells and wind power are equipped with storage batteries covered by the battery control unit (BCU), which regulates the supply that charges the battery and the current flow in the load (Sinyoku, 2010). In a study of the DC microgrid, the capacity of the battery energy-storage system used is two times larger than the first generation so that if one power source fails or is lacking, the system continues to operate. By installing a control system on renewable energy sources and the battery energy- storage system, the microgrid continues to operate.

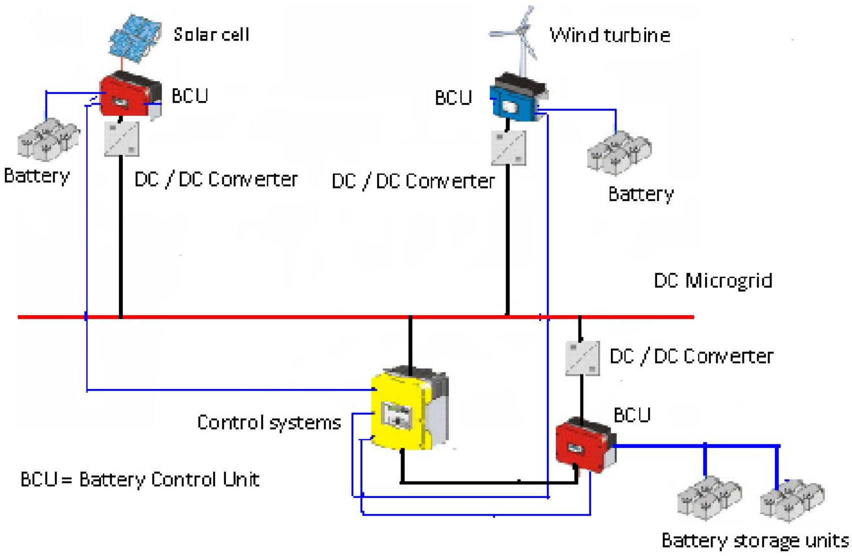

Figure 2 DC microgrid configuration

2.1. Solar cell

Equivalent circuits of solar cell modules are illustrated in Figure 3. A solar cell module is defined as a collection of several modules connected in a series (Ns) and parallel (Np) combination circuit to generate the required voltage and current.

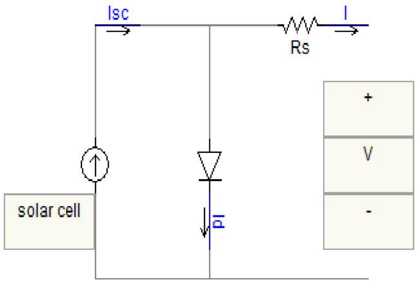

Figure 3 Equivalent circuit of solar cell modules (Seul, et al., 2006)

The simple equivalent circuit model of solar cell modules is used to determine the capacity of solar cells, which consist of a current source parallel with a diode and connected in series with a resistor. Based on the model displayed in Figure 3, the behavior of solar cells array with Ns x NP modules can be written as shown in Equation (1). Parameters for the model of solar cell module (PV) were obtained from the solar cells data sheet (Kim et al., 2006).

$$I_A = N_P I_{SC} - N_P I_0 (\exp\left[\frac{V_A + I_A R_S}{n N_S V_T}\right] - 1) \quad (1)$$

where;

- I_A : current output of PV array (Ampere)
- I_{SC} : short-circuit current of PV module (Ampere)
- I_0 : diode saturation current (Ampere)
- V_A : terminal voltage of PV array (Volt)
- R_S : series resistance (Ohm)
- n : constant ideal diode (1~2)
- V_T : PV module thermal potential (Volt)

2.2. Wind turbine

A suitable model to predict wind turbine performance can be obtained from some simple assumptions and physics calculations. One of the kinetic energy calculations for wind or another fluid passing through an area of fluid flow is expressed by Gilbert et al. (2004):

$$P_w = \frac{1}{2}\rho A V_w^3 \quad (2)$$

where;

- Pw : total wind power in Watts
- ρ : air density (kg/m^3).
- A : area (m^2)
- V_w^3 : wind speed passing through the area (m/s).

Because wind energy is produced only as macroscopic kinetic energy, not all wind power can be utilized to produce electric energy. Most modern European wind turbines have three rotor blades, while American machines tend to have just two. Three-blade turbines show smoother operation since the impact of tower interference and variation of windspeed with height are more evenly transferred from rotor to drive shaft. Wind turbines used in the generation of wind power include the horizontal axis wind turbine rotor / horizontal axis wind turbine (HAWT), and the vertical axis wind turbine (VAWT) (Master, 2004).

3. DESIGN OF DC MICROGRID CONTROL

Voltage control systems on DC microgrids in renewable energy control systems have been examined, but the focus has only been on one energy source (Xiaofeng, et al., 2009). In this study, the voltage control system was a mutual integration between a renewable energy generation system (PV and Wind Turbine) and battery storage system.

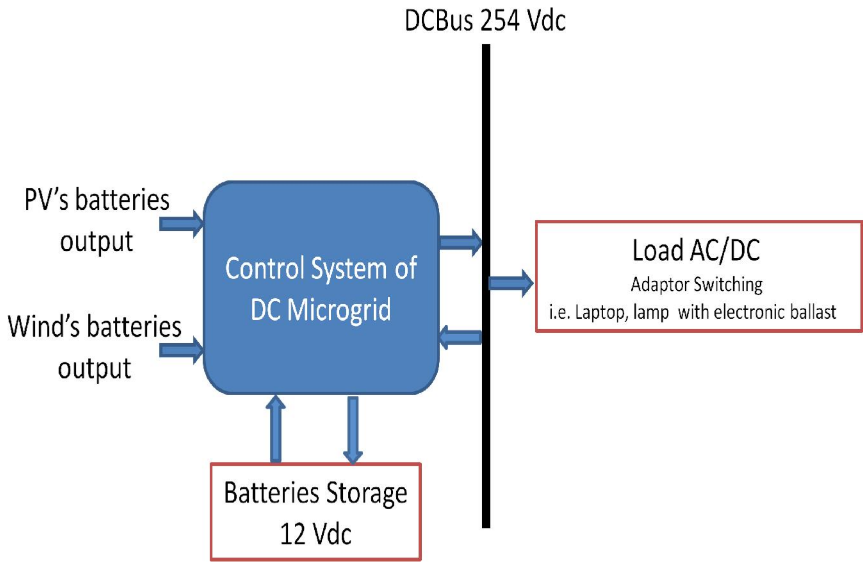

Figure 4 The schematic control systems of DC microgrid

A DC microgrid system proposed in this study consisted of five main components (Figure 4):

1. Output voltage from PV and Wind Turbine's batteries and battery storage.
2. DC Microgrid Control Center (DCMCC) .The main function of DCMCC is to ensure power to the load supplied from the photovoltaic, wind and battery storage. The DCMCC is designed using Op-Amp comparator to determine the operating voltage relay at 10 volt (lower limit) to 12 volt (upper limit) at PV's and Wind's batteries, shown in Figure 5.

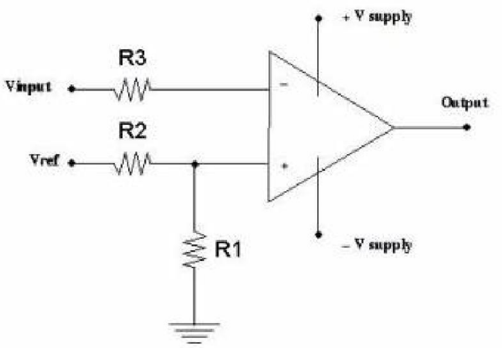

Figure 5 OP-Amp circuit as comparator

The DCMCC consists of:

a. Voltage Control Circuit (VCC) to detect the magnitude of battery voltage from PV and Wind Turbine
b. BCU (Battery Control Unit) to regulate the battery charging
c. DC Boost Converter to raise voltage from 12 to 254 Vdc
d. DC Buck Converter to decrease voltage from 254 to 6.13Vdc

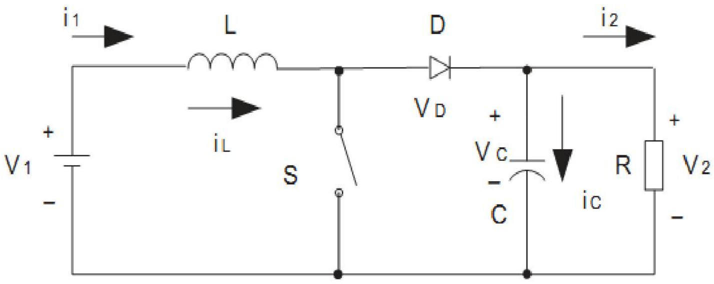

Figure 6 DC Boost Converter (Fang & Hong, 2004)

The output voltage from DC Boost converter be calculated using following equation:

$$V_O = \frac{T}{T-t_{on}} V_{in} = \frac{1}{1-k} V_{in} \tag{3}$$

where;

T : repeating period, $T = \frac{1}{f}$
f : chopping frequency
t_{on} : switch-on time
k : conduction duty cycle, $k = \frac{t_{on}}{T}$
V_o : Output Voltage
V_{in} : Input Voltage

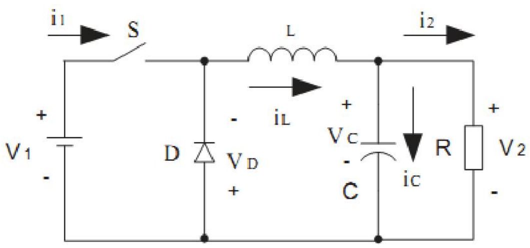

Figure 7 DC Buck Converter (Fang & Hong, 2004)

The output voltage from DC Buck converter calculated using following equation:

$$V_O = \frac{t_{on}}{T} V_{in} = k.V_{in} \quad (4)$$

3. Battery storage. Itwill operate when the voltage from renewable energy sources falls below normal conditions.
4. Bus DC operated at 254 Vdc
5. Loads that are consisting of DC and AC loads

The application of DCMCC at DC microgrid system is showed below in Figure 8.

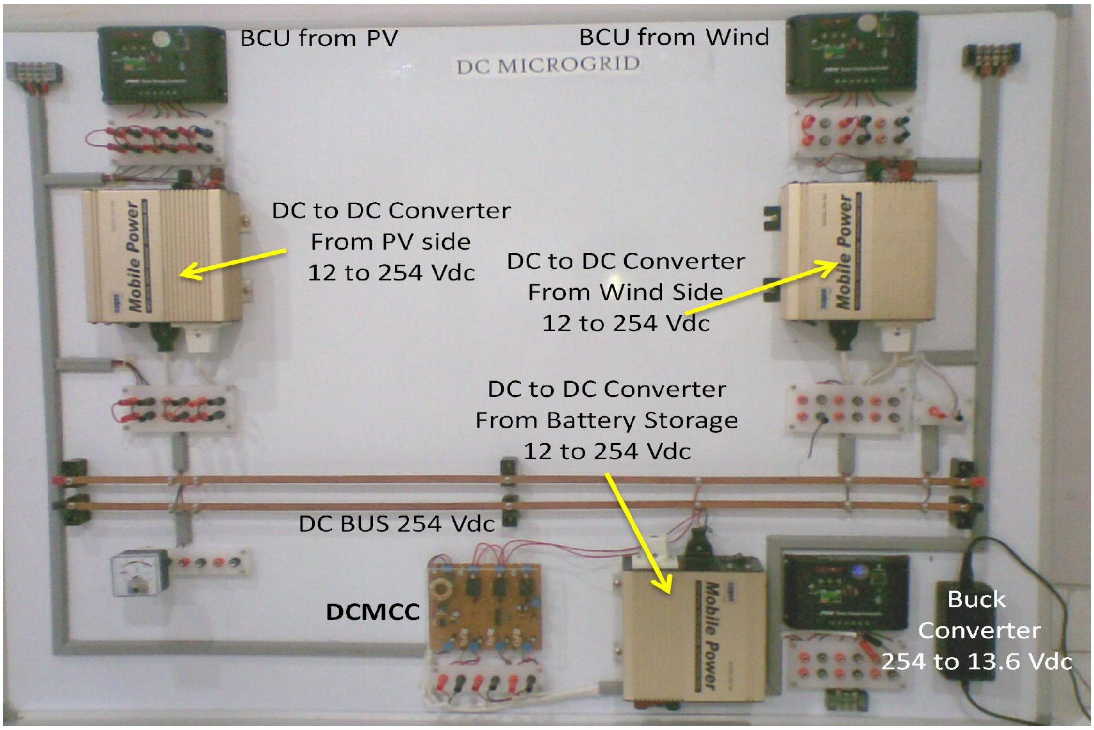

Figure 8 Prototype of DC Microgrid

4. SIMULATION RESULTS AND ANALYSIS

This simulation program was performed by using Multisim 10 with the following parameters; the simulation of battery voltage (Vb) on solar cells and wind power decreases at different times:

- If Vb $\geq$ 12 Vdc, the DCMCC will order PV and Wind to operate.
- If Vb $\leq$ 10 Vdc, the DCMCC will order battery storage to cover the load.

Figure 9 shows the simulation results describing that if the battery voltage of solar cell (PV) decreases to 10 Vdc, and battery voltage of the wind turbine is constant, then the DCMCC orders the battery storage will operate then the voltage on the DC microgrid will be stable at 254 Vdc. Figure 10 shows simulation results describing that if the battery voltage of wind turbine decreases to 10 Vdc and battery voltage at the solar cell remains constant, then the DCMCC orders the battery storage to operate. Finally, the voltage on the microgrid bus will be stable at the level 254 Vdc. The figure 11 shows that household electronics devices such as laptop, handphone charger and fluorescent lamp can be plugged and operated in 254 Vdc.

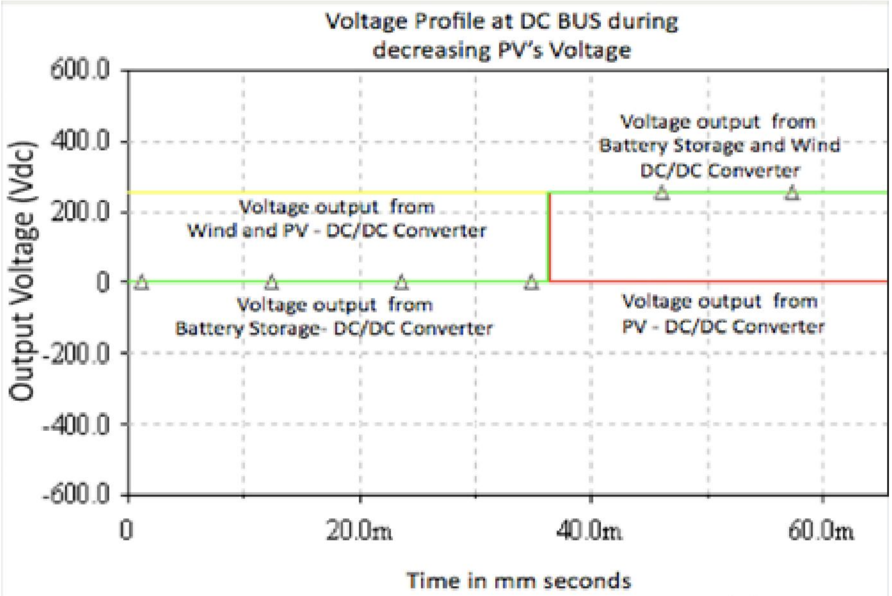

Figure 9 Voltage profile at DC Bus during decreasing PV output

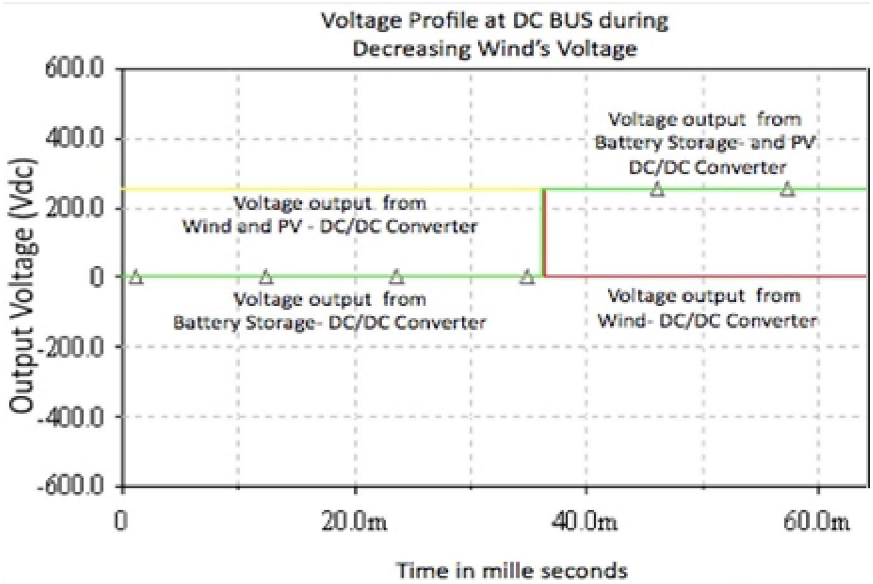

Figure 10 Voltage profile at DC Bus during decreasing Wind output

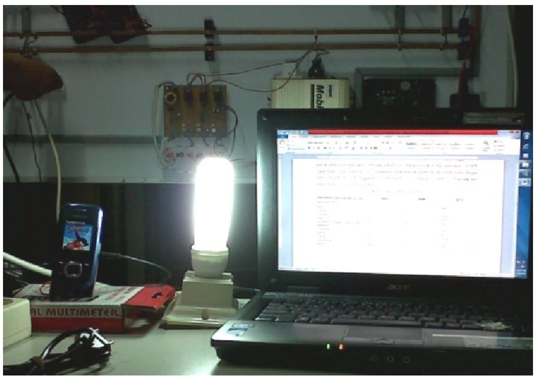

Figure 11 Household devices operated in 254 Vdc

5. CONCLUSION

The design of the DCMCC is based on 12 Vdc from PV's and Wind's batteries output and operated in 254 Vdc Bus systems as result from DC/DC Converter. The advantage of this control is that output voltage can be kept constant at 254 Vdc since installed at the input side of the DC/DC converter.

A DC microgrid can be applied widely in the future as alternative solution for renewable energy utilization particularly in low voltage level to supply DC and AC loads. Moreover the experimental result shows that portable electronic devices such as laptop, electronics ballast of a compact fluorescent lamps, mobile phone etc can be operated in this bus.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

De Brabandere, K., Bolsens, B., 2007. A Voltage and Frequency Droop Control Method for Parallel Inverter. *IEEE Transaction on Power Electronic*, Vol.22, No.4.

Fang, L.L., Hong, Y., 2004. *Advanced DC/DC converters*, CRC Press, ISBN 0-8493-1956-0

Kakigano, H., Miura, Y., Ise, T., Momose, T., Hayakawa, H., 2008. Fundamental Characteristics of DC Microgrid for Residential Houses with Cogeneration System in Each Hause. *IEEE Conference: Power and Energy Society General Meeting-Conversion and Delivery of Electrical Energy in the 21st Century*.

Lasseter, R., 2002. MicroGrids. *IEEE PES Winter Meeting*, Vol.1, pp.305-308.

Lasseter, R.H., Paigi, P., 2004. Microgrid: A Conceptual Solution. *Power Electronics Specialists Conference (PESC) 2004 in IEEE 35th Annual*. German 20-25 June 2004, Vol.6, pp. 4285-4290.

Lu, D.D.-C., Agelidis, V.G., 2009. Photovoltaic-Battery-Powered DC Bus System for Common Portable Electronic Device. *IEEE Transaction on Power Electronic*, Vol.24, No.3.

Master, Gilbert, M., 2004. *Renewable and Efficient Electric Power System*. Hoboken, New Jersey, USA: John Wiley & Sons, Inc.

Nilsson, D., Sanino, A., 2004. Efficiency analysis of low and medium voltage dc distribution system. *In: Proceedings of IEEE Power Engineering Society General Meeting*, Jun. 6-10, 2004, Denver, CO, Vol.2, pp. 2315-1321.

Ramakumar, R., Chiradeja, P., 2002. Distributed Generation and Renewable Energy Systems. *International Energy Conversion Engineering Conference (IECEC) 2002*, pp.716-724.

Seul-Ki, K., Eung-Sang, K., Jong A., 2006. Modeling and Control of Grid-Connected Wind/PV Hybrid Generation System. *IEEE Transmission and Distribution Conference and Exhibition*, 2005/2006 IEEE PES. pp.1202-1207.

Sinyoku, 2010. *Battery Control Unit*, Manual book.

SMA Technologie AG Germany, 2007. AC *Power Supply Product for Rural Electrification*.

Su, Y., Zulati, L., Ken, N., 2009. Efficiency of Micro Grid With Storage Battery in Economy and Environment Assessments. *International Journal of Electrical and Power Engineering*, Vol.3, pp.154-162, ISSN: 1990-7958. Medwell Journals.

Xiao, S., Yim-Shu, L., Dehong X., 2003. Modeling, Analysis, and Implementation of Parallel Multi-Inverter Systems With Instantaneous Average –Current –Sharing Scheme. *IEEE Transaction on Power Electronics*, Vol.18, pp. 844-856.

Xiaofeng, S., Zhizhen, L., Baocheng, W., Xin, L., 2009. A Hybrid Renewable DC Microgrid Voltage Control. *IEEE Power Electronics and Motion Control Conference (IPEMC)*, pp.725-729.