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Voltage Stability in DC Micro Grid By Controlling Two Battery Units With Hybrid Network Systems

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***Abstract*—In DC network systems micro grid battery storage units are used to assist the main source of renewable energy (PV array) in providing stable voltage on the DC bus. Micro grid storage systems play an important role in providing services on demand. The lithium-ion batteries are used in this design, because these batteries have high energy density. In the micro-grid design is used three units of PV arrays and each unit consists of two PV arrays and two batteries. Battery units are used for storage of PV array sources and single phase gird AC. The PV array unit provides 22.8 V output voltage and the battery unit provides 22.78 V output voltage. Boost converter increases the voltage of the PV array and battery unit to a DC bus of 48 V. The PID controller is effectively used boost converter in raising or lowering the voltage. The advantage of using two battery storage systems is that if one unit is not sufficient to provide a voltage to the DC bus, then the battery unit on the AC grid side will also rapidly provide a voltage to the DC bus.**

Keywords-Hybrid systems; DC-DC converters; power electronic converter

I. INTRODUCTION

In previous research, the storage system on a micro grid DC network is usually used battery. The disadvantage of the battery storage system is that the DC source is not capable of servicing sudden load changes. The occurrence of such changes causes changes in the charging and discharging process, so the temperature in the battery will increase and the usage life will be reduced. To improve the storage system is used ultra-capacitor. [1]. In another study of hybrid AC-DC micro-grid control system with different sources and loads. The purpose of this research is to develop distribution network interconnection system with customers. The design of the micro grid system uses several renewable energy sources, namely wind energy, PV, and fuel cells. The system created can be used to transmit electrical energy on micro grid AC and DC micro grid. The control system used can divide the electrical power between the micro grid AC and the micro DC grid. In addition the AC bus and DC bus voltages remain stable with load changes. Control uses two bidirectional converters, bidirectional main converter and bidirectional back up converter [2] [3].

In DC voltage control strategy micro grid is done using droop control technique. Analysis of DC voltage stability is done through small signal modeling of DC / DC converter which serves to connect DC bus source with load. [4]. In addition stability development on the DC bus is also done with a hybrid system between renewable sources with baeter storage connected to the grid [5] [6]. Along with the development of renewable energy systems, then the need for reliable storage systems is needed. A good storage system can support a reliable DC distribution system. Energy storage systems can effectively support the integration of renewable energy generation systems into distribution systems [7]. Single-phase AC / DC converters are able to adjust the power flow between the grid and the battery and perform other support services on the energy storage unit. Therefore a new voltage regulation technique is performed for a single phase AC / DC converter connected to the grid, whose function is to regulate energy storage. [8].

Energy storage systems are essential for Micro-grids, as they can improve the power of the system. It also reduces power fluctuations caused by energy sources derived from wind turbines whose power depends on wind power. Moreover, less favorable weather conditions, such as heavy rain, will affect PV. Therefore energy storage systems become an important energy source for Micro-grid systems. Energy storage in a Micro-grid system actually serves as an energy reserve for the entire system when the grid is

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connected. To get good performance, hybrid energy storage systems used batteries and ultra-capacitors. Batteries are used for the purpose of providing long and continuous energy for all loads on the micro grid during "islanding" mode. [9]. Development of electricity distribution network using battery storage. Batteries are used to energize when load increases [10] [11]. At present the distribution network is facing challenges in reliability and power loss. Integration with renewable energy sources can help solve this problem. Storage systems in a micro grid using batteries should be efficient and reliable. [12] [13].

In this paper, a technique for setting up bateray storage systems with hybrid network systems is proposed. The first network with the energy source of solar sell, while the second network of the AC grid. In this micro grid DC system used battery storage unit, either from the side of the grid DC or on the side of the grid AC. The PID controller is used to adjust the turn of two batteries in providing voltage to the DC bus, when there is a change of voltage on the renewable energy source and the AC grid, so that the bus DC voltage will remain stable. The advantage of using a two-unit battery storage system is that if one unit is not sufficient to provide a voltage to the DC bus, then the battery unit on the grid side of the AC will also rapidly provide a voltage to the DC bus.

II. System Configuration

In general there are three types of micro grid structures, namely micro DC grid, micro grid AC, and micro grid with DC and AC bus. There are many energy storage systems that can be used in micro grid systems [9]. The most frequently used storage systems are battery, ultra-capasitor, flywheel. The stored energy can be used to energize the load [1] [14]. To solve the problem of power generation, the PV energy source can be integrated with other sources in order to meet the availability of long-term energy sources [15]. In this paper for storage systems used two units of batteries. The first battery unit is connected to the solar sell, while the other batteries are connected through a low voltage power grid. The first battery unit uses a bidirectional DC-DC converter, while the other batteries use a DC-DC converter not bidirectional.

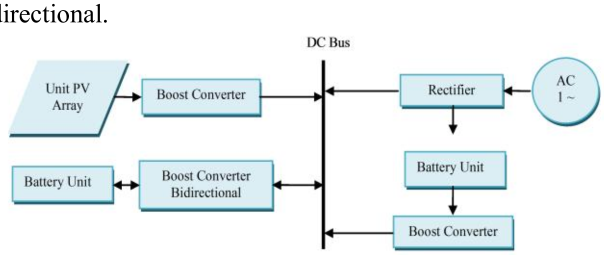


Figure 1. System configuration of DC micro grid.

III. Modelling PV and Battery

A. PV Model

The current in the solar cell is directly proportional to the light radiation and the equation is the shockley diode equation [16]. The current source represents the solar light that can produce current [17].

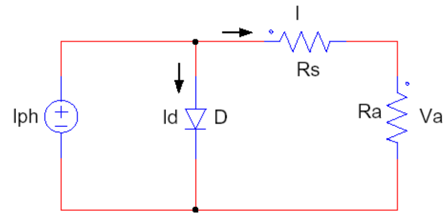


Figure 2. Equivalent circuit of a solar cell.

$$I = I_{ph} - I_D = I_{ph} - I_0(e^{\frac{q(Vo+IR)}{nKT_a}} - 1) \qquad (1)$$

$$I_0 = I_{ds}(\frac{T_a}{T_{ref}})^3 .\exp(\frac{q.E_g}{A.K}(\frac{1}{T_{ref}} - \frac{1}{T_a})) \qquad (2)$$

$$I_D = I_0(e^{VD/VT} - 1)$$

I_{ds} is the reverse saturation current at T_{ref} and solar irradiation (S) as well as the E_g semiconductor energy gap [16]. Photocurrent (I_{gc}) size depends on the intensity of sunlight and the temperature of the solar cell, which can be expressed by equation 3.

$$I_{gc} = G(\mu_{sc}(T_c - T_{ref}) + I_{sc}) \qquad (3)$$

μsc is the temperature coefficient when the circuit is short circuit and I_{sc} is the short circuit current at 25 ^{o}C and 1kW / m^2. G is the intensity of sunlight in kW / m^2 [18].

B. Battery Model

This enclosure comprising internal resistance (R_a) and open circuit voltage (V_{oc}) which is a function of state of charge battery (Q_{SOC}). The state equation of variables is expressed by three equations, which consist of voltage passing through two capacitors and Q_{SOC}.

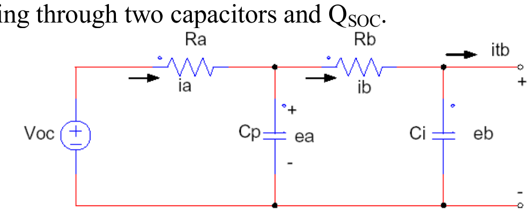


Figure 3. Battery equivalent circuit.

$$V_{oc} = 338.8(0.942 + 46 + 0.057\ 54\ Q_{SOC}) \qquad (4)$$

$$R_a C_p \frac{de_a}{dt} + \frac{R_a + R_b}{R_b} e_a = V_{oc} + \frac{R_a}{R_b} e_b$$

$$R_a C_i \frac{de_b}{dt} + e_b = e_a - R_b I_{tb}$$

R_a is the internal resistance of the battery (Ω) and R_b is the terminal resistance (Ω). The capacitors C_i and C_p are each the incipient capacitance and the polarization capacitance (F). Q_{SOC} is the state variable of the battery system.

$$\frac{dQ_{SOC}}{dt} = \frac{I_{tb}}{Q_m}$$

$$I_{tb} = \frac{V_{oc} - \sqrt{V_{oc}^2 - 4(R_a + R_b)P_b}}{2(R_a + R_b)} \quad (5)$$

Q_m is the maximum capacity of the battery (Ah), whereas the I_{tb} current is the battery current (A), and P_b is the output power of the battery (W) [19]. The battery used as a storage system can be used when the power on the DC bus is reduced or the SOC value is above 90%. [17].

$$V_{SOC}(t) = V_{SOC}(0) - \frac{1}{C_{cap}} \int_0^T i(t)dt \quad (6)$$

IV. Boost Converter and Buck Boost Converter

DC-DC converter functions almost the same as a transformer that converts the voltage on the primary side into a certain voltage on the secondary side. In this case there is no change in electric power, so that in ideal conditions the input power is equal to the output power and loss of power.

A. *Boost Converter*

DC-DC boost type converter is used to raise the input voltage, resulting in a higher output voltage. This type of converter is capable of producing a continuous current and does not generate harmonics at the source. The boost type converter is shown in Fig. 4 [20].

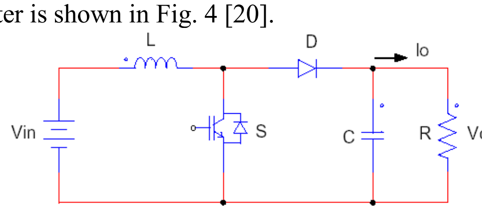


Figure 4. Boost converter circuit.

The comparison of the input voltage with the output voltage will be equal to the ratio when the transistor is working and when the transistor is not working. At the moment the IGBT transistor is working then the current will flow to the inductor, so the energy on the inductor will rise. When the IGBT transistor does not work (off) then the inductor current will go to the load through the diode. This will cause the energy on the inductor to drop. When $0 \leq t \leq T_{ON}$ then output voltage V_D equal to V_o and V_L equal to V_{in}, when $T_{ON} \leq t \leq T_s$ then voltage V_D equal to zero and voltage V_L is the difference between voltage V_{in} and V_o. The equation of the output current ripple of boost converter is expressed by equation 7.

$$i_{ripple} = \frac{-(V_{in} - V_o)}{L} = \frac{V_{in}}{L} T_{on} \quad (7)$$

When the transistor is working, the output voltage can be expressed by the equation 8.

$$V_O = V_S + L\frac{\nabla I}{T_2} = V_S(1 + T_1/T_2) = V_S \frac{1}{1-D} \quad (8)$$

The form of the equation of a boost converter is as follows

$$\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} \frac{1}{V_{in}}\sqrt{\frac{L}{C}} & 0 \\ 0 & \frac{1}{V_{in}} \end{bmatrix} \begin{bmatrix} i \\ u \end{bmatrix} \quad (9)$$

While normalized model boost converter average as follows

$$\frac{dx_1}{d\tau} = -(1 - u_{av}).x_2 + 1$$

$$\frac{dx_2}{d\tau} = (1 - u_{av}).x_1 - \frac{x_2}{Q}$$

B. *Buck Boost Converter*

The buck-boost converter is a combination of two buck and boost converters that can produce a higher or lower output voltage to the input source. This type of converter produces a large current ripple, so an inductor or capacitor filter is required. By ignoring the losses the converter output voltage of this type is expressed in the equation. D is the duty ratio.

$$V_o = -\frac{V_{in}D}{1-D} \text{ and } I_{in} = -\frac{I_o D}{1-D}$$

When the transistor is working the capacitor filter will give current to the load during T_1, then the average discharge current $I_{cap} = I_{out}$. Ripple current peak to peak capacitor expressed by equation, f is the switching frequency [21].

$$\Delta V_{cap} = \frac{1}{C}\int_0^{T_1} I_{cap}dt = \frac{1}{C}\int_0^{T_1} I_o dt = \frac{I_o D}{fC} \quad (10)$$

The normalized average model of the buck-boost converter is expressed by the following equation

$$\frac{dx_1}{d\tau} = (1 - u_{av}).x_2 + u_{av}$$

$$\frac{dx_2}{d\tau} = -(1 - u_{av}).x_1 - \frac{x_2}{Q}$$

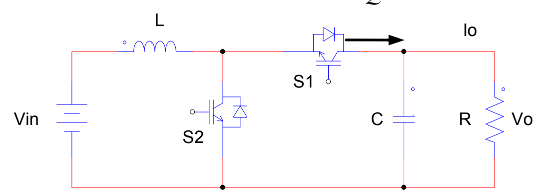


Figure 5. Buck boost converter circuit.

To set the DC-DC converter is used PID controller. The PID controller output will affect the PWM signal, which is the trigger signal of the transistor [22].

$$u(s) = K_p e(s) + K_i \frac{1}{s} e(s) + K_d s.es(s) \qquad (11)$$

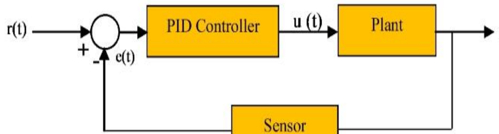
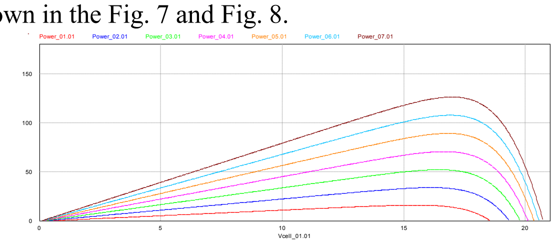


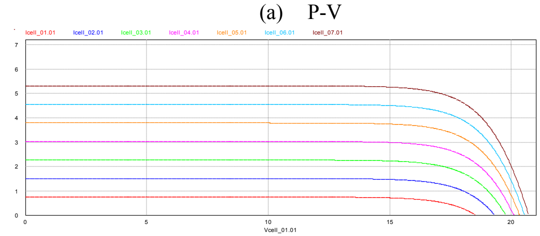
Figure 6. PID controller.

V. Simulation Model

In this simulation model used three units of PV arrays and each unit consists of two PV arrays. In this model used solarex MSX-60, the capacity of each PV array of 60 watts with output voltage of 3.79 V, so for one unit of PV array output voltage of 7.59 V. Characteristics of PV arrays are shown in the Fig. 7 and Fig. 8.

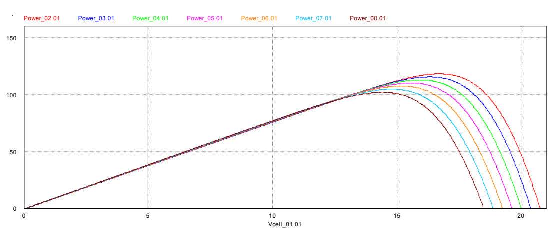


(a) P-V

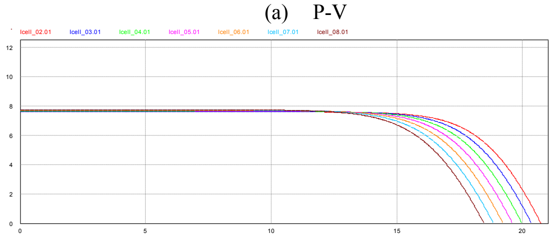


(b) I-V

Figure 7. Simulation PV constant 25°C



(a) P-V



(b) I-V

Figure 8. Simulation PV constant 1000 W/m^2

Fig. 7 Simulation result of different irradiance from 100 W/m^2 until 800 W/m^2 (step 100 W/m^2) and constant temperature at 25°C: (a) P-V Curve. (b) I-V Curve. Fig. 8 Simulation result of different temperature from 20°C until 50 °C (step 5°C) and constant irradiance 1000 W/m^2. a) P-V Curve. b) I-V Curve. The specification data of one unit of PV array used in this simulation is shown in Table I.

TABLE I. Specifications of PV Array Unit

Spesifications	Value
Number of Cells Ns	36
Standard Light Intensity S0	1000 W/m^2
Ref. Temperature Tref	25°C
Series Resistance Rs	0.008/2
Shunt Resistance Rsh	1000*2
Short Circuit Current Isc0	3.8*2
Saturation Current Is0	2.16e-8*2
Band Energy Eg	1.12
Ideality Factor A	1.2
Temperature Coefficient Ct	0.0024*2

TABLE II. Specifications of Battery Unit

Specifications	Value
No. of Cells in Series	6
No. of Cells in Parallel	1
Voltage Derating Factor	1
Capacity Derating Factor	1
Rated Voltage	3.7
Discharge Cut-off Voltage	2.5
Rated Capacity	5.4
Internal Resistance	0.05
Full Voltage	4.2
Exponential Point Voltage	3.9
Nominal Voltage	3.6
Maximum Capacity	5.56
Exponential Point Capacity	1.08
Nominal Capacity	5.4
Initial State of Charge	0

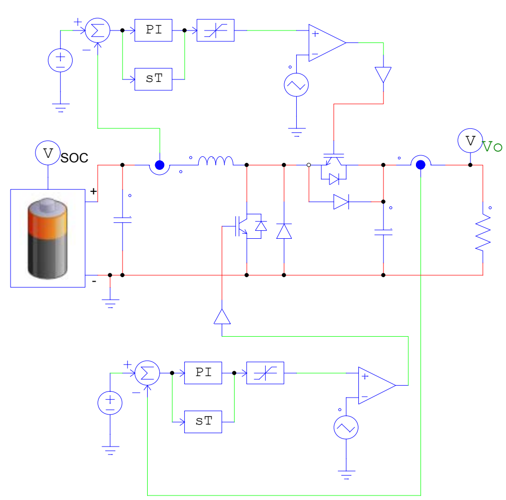


Figure 9. Model charging and discharge batteries

For solar panel simulation model used three units of PV array with temperature 25°C and irradiance 1000 W/ m^2. The output voltage of the PV array unit is increased using a DC-DC converter type boost converter. For control boost converter used PID controller with P = 300), I = 355, D = 45. The battery used in this simulation is Lithium Ion battery 6 units. The battery provides an output voltage of 3.7 V with a capacity of 5.56 Ah, so the maximum capacity of the battery is 33.36 Ah. For charge and discharge settings a bidirectional converter boost is used with a PID controller. The AC grid is used to provide DC power to the battery, so a full bridge rectifier is used. To provide DC power to DC bus used boost converter. To control the system charge and discharge batteries used relay with the voltage sensor on the battery input. The overall simulation model is shown in the fig 10. The purpose of this design is to stabilize the voltage on the DC bus, so use the source of the AC grid to help the stability of DC bus voltage.

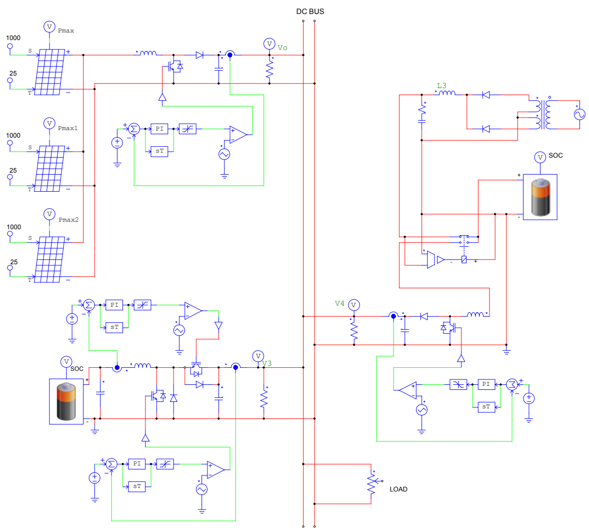


Figure 10. Design of the system setting two batteries for the DC bus

VI. Results and Discussions

By using three units of PV arrays generated a DC output voltage of 22.8 V, each PV array unit produces a voltage of 7.6 V.

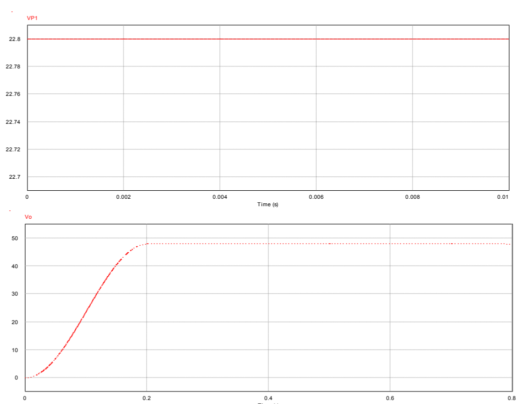


Figure 11. PV array output voltage and output voltage boost of PV array

The output voltage of the array PV is increased using a converter boost, resulting in a 48 V output voltage. In this design the voltage at the DC bus is 48 V. Boost converter use capacitor (C) 94.000 µF, inductor 8.44 mH (L) and resistor load (R) 9.200 Ω. In the storage system generated battery voltage of 22.78 V units of six batteries. The output voltage of the battery is increased using a bidirectional converter boost. The output voltage of the batteries as input of the bidirectional converter boost and the output of the converter are shown in Fig.12 and 13.

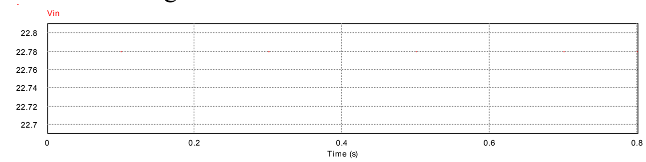


Figure 12. Input voltage of the bidirectional converter.

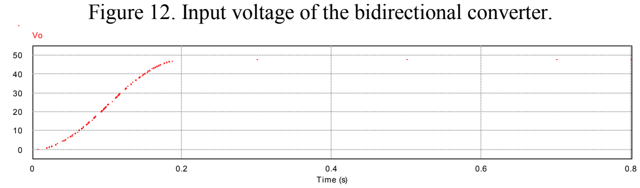


Figure 13. Output voltage of the bidirectional converter.

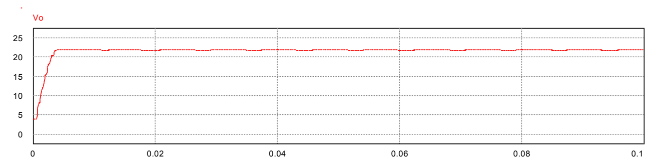


Figure 14. Output voltage of a single phase rectifier

From the AC grid with a 220 V AC voltage source a phase is derived using a diode to a DC voltage of 22.28 V. This same voltage is equal to the input voltage of the battery unit and is used to charge the battery. To help stabilize DC voltage bus is used boost converter, so the output voltage from boost converter is 48 V DC.

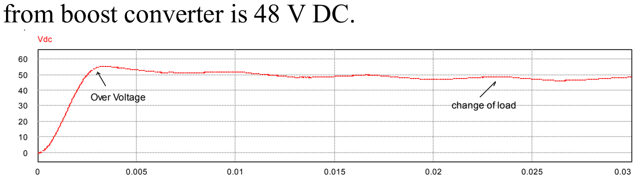


Figure 15. Voltage on the DC bus

Fig. 15 shows a slight change of voltage on the DC bus, but remains at a voltage of 48 V. This is due to the load changes in the DC bus. In this simulation we use R 2KΩ load, L 8 H load, and load C 10 F.

VII. Conclusion

To solve the problem of energy availability in DC bus can be done by using model of battery unit storage system. The energy source of the PV array and AC grid, separately charging each battery unit. By using PID controllers, it can effectively raise the voltage on the unbidirectional converter boost and bidirectional converter boost. The output voltage of the PV array is 22.8 V and the voltage of the 22.78 V battery unit is increased with a boost converter to 48 V. With the load changes on the DC bus, the micro-grid system design is capable of providing a voltage of 48 V. The use of relays in the charge and discharge system is capable of adjusting when the battery should charge and when the battery should provide voltage on the DC bus. The advantage gained with the two battery unit model is that the voltage on the DC bus will always remain.

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