Power Management of a Solar PV and Battery-Based Dc Microgrid System

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Abstract — This paper describes the energy management and control of a PV array with a battery-based DC microgrid. The design and functioning of PV and battery DC-DC converters are thoroughly covered. The variance in radiation intake from the solar array was measured on a typical sunny day. The battery is the primary component in charge of maintaining the DC bus voltage constant by charging and discharging while servicing the dynamic load. In MATLAB, the programme used for microgrid modelling, there are standard built-in models for solar PV and batteries. The microgrid energy management and control seem to function as intended.

Index Terms—*DC Microgrid, Energy Management, Distributed Control Method, PV Systems, Boost Converter, Battery Energy Systems, Incremental Conductance, DC Load, Bi-Directional DC/DC Converter.*

I. INTRODUCTION

Nowadays, use of renewable energies as a suitable choice for clean energy is expanding. Recent advances in increasing the efficiency and reliability in MGs have made renewable energies good choices for decentralizing electric power generation. Since most renewable sources, such as PV systems, fuel cells and variable speed wind power plants produce DC voltages with variable voltage and frequencies, use of power electronic converters is necessary to connect these resources to the network [1]. In addition, new loads such as electric vehicles, as well as common loads require DC power. So, the wide applications of DC networks over the AC ones are reasonable. DC MGs have advantages in terms of cost and efficiency; in addition, they can convert DC to AC or AC to DC power in AC MGs to aggregate the mentioned loads and renewable energy sources [2]– [5]. Power systems in commercial centers containing sensitive loads [6], industrial [7] and aerospace industries [8] are examples of typical DC MG applications.

Due to the unpredictable behavior of renewable energy sources, the use of energy storage resources for continuous islanded operation is required. In systems consisting of a storage and renewable energy, the storage provides the power difference between the source and the load in unpredictable conditions. Indeed, in such conditions, a supervisory control strategy for energy management is needed.

Similar to AC MGs, a power management system is required for guaranteeing the reliable operation of renewable energy sources and storages in DC MGs [3]. In the grid-connected mode, the renewable source is in the maximum power state and provides its generated power to the network [5]. The network also has the task of balancing power and adjusting DC voltage. In the case that the MG operates in islanded mode, the renewable energy production capacity should be able to meet all demand for the load. If the renewable source power cannot meet the load demand, the storage provides the difference between demand and production. Also, in the case of higher output power than the load demand, additional power is stored in the storage source to keep the balance in the network [8]. So in this paper, the focus is on proposing a proper DC MG configuration along with an efficient control and energy management approach.

II. PROPOSED CONTROL SYSTEM

A. Photovoltaic system:

The Photovoltaic system consists of 3 main parts that are: MPPT controller, Solar panel, DC-DC Boost Converter. Solar panel's output voltage is supplied to DC-DC Boost Converter to drive the load. From solar panel, voltage and current are sensed and fed to MPPT Controller. The controller needs voltage and current for computing incremental conductance algorithm. Fig.1 shows Photovoltaic system's block diagram.

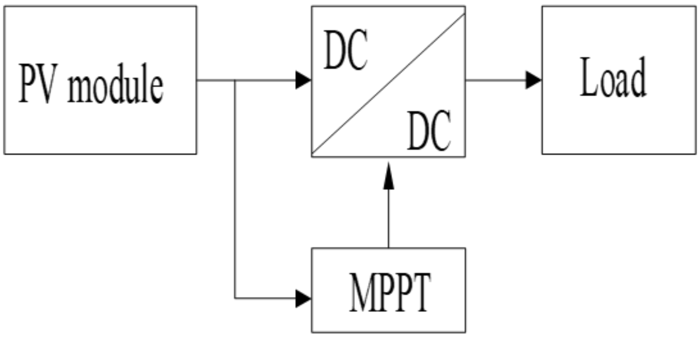

Fig. 1. Photovoltaic system block diagram

B. DC/DC Boost Converter:

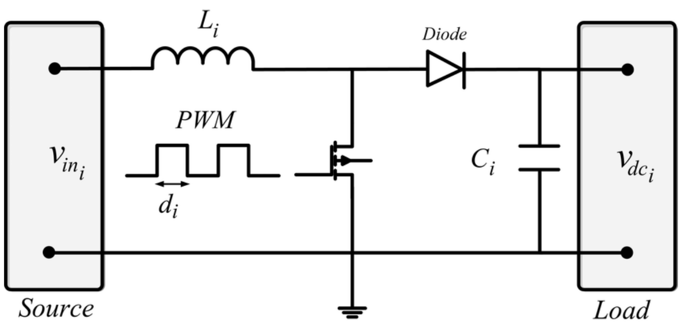

Fig. 2. DC-DC Boost Converter

This section is a prime part of the system. Boost converter is the simplest non-isolation topology. Converter steps up the voltage coming from solar panel. If converter isn't used then the load connected to the panel will have voltage and current independent of MPP. Means the solar panel won't operate on MPP and efficiency is less. Converter is applicable for service when the battery voltage is high and the array voltage is low. Hence the boost converter transfers maximum power from source to load by matching of source and load impedance. MPPT controller adjusts the duty cycle of MOSFET, which keeps on changing according to the climate conditions. Proper

MOSFET switching would try to maintain steady output. Figure of DC-DC Boost Converter is shown in Fig.2.

C. Incremental conductance:

Using solar panel without MPPT controller will result in wasted power and will demand installation of more panels on the site. Such PV system hardly operates on MPP that would give output according to the need. According to this method extraction of maximum power becomes indispensable in PV systems. Incremental conductance is one of the MPPT techniques to track maximum power. Fig.3 shows Incremental conductance algorithm. In this technique incremental ($\frac{dI}{dV}$) and instantaneous conductance ($\frac{I}{V}$) are compared. The formulas for incremental conductance are given by equation (1), (2), (3). By comparing of formulas, the duty ratio is either increased or decreased under varying climate condition to change the output voltage of converter.

$$\frac{dI}{dV} = -\frac{I}{V} \qquad At\ MPP \quad (1)$$

$$\frac{dI}{dV} > -\frac{I}{V} \qquad Left\ of\ MPP \quad (2)$$

$$\frac{dI}{dV} < -\frac{I}{V} \qquad Right\ of\ MPP \quad (3)$$

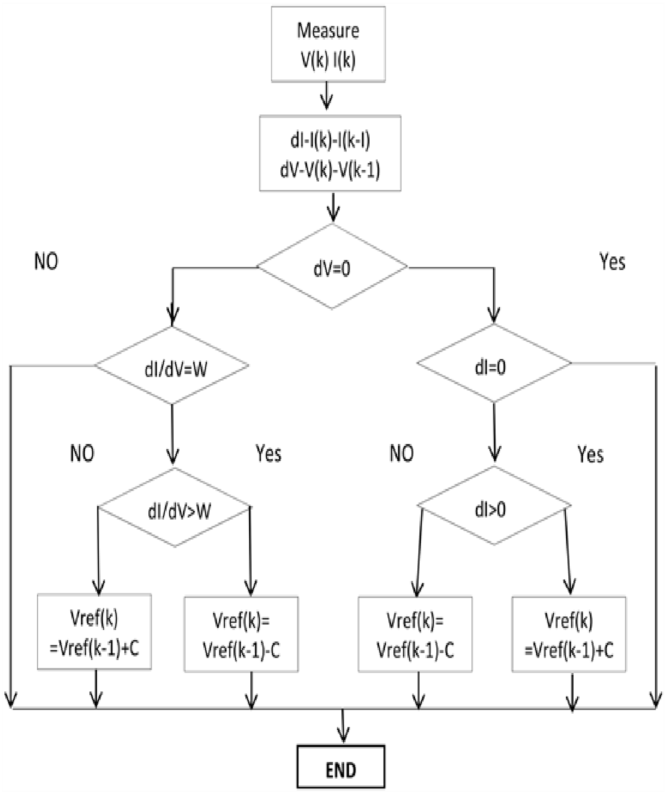

Fig. 3. Incremental conductance algorithm

D. Battery controller

In different conditions that occur for a MG, battery can be charged, discharged or operate off-circuit. Battery performance is controlled by the DC bus voltage level. Figure 4 shows the block diagram of the control structure of the battery. If the DC bus voltage is in the predetermined range (here, 0.95 to 1.1 times of the reference value for the DC bus), the battery retains its previous mode. This is done with the dead zone block. If the DC bus voltage is lower than the bottom limit (0.95 times of the reference value), the battery controller only commands the lower switch in the bidirectional converter structure and, using the high-power switching diode, increases its voltage to reach the desired level. In this mode the battery is discharged by constant current (CC) to maintain the DC bus voltage in the allowed range. Now, as the DC bus voltage passes from the higher limit (1.1 times of the reference value), the battery controller only commands the upper switch in the bidirectional converter structure and reduces the voltage by using the low-switch diodes until the battery charges with CC circuit method and return the DC bus voltage to the specified range. It should be noted that battery charging/discharging by the CC method can increase battery life, but the amount of current that the charging/discharging happens into, will vary depending on the voltage variation of the DC bus. The initial value of the proportional-integral controller changes each time when the battery state changes.

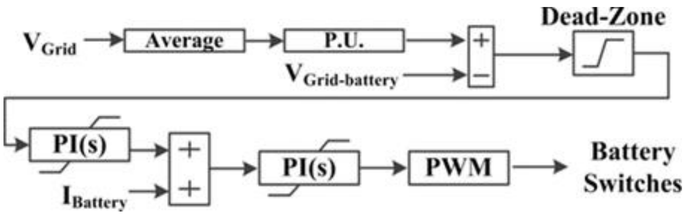

Fig. 4. Battery control diagram block

II. SIMULATION ANALYSIS AND RESULTS

To evaluate the performance of the proposed structure and the control system, MATLAB/Simulink software has been utilized. Table 1 shows the characteristics of the simulated system.

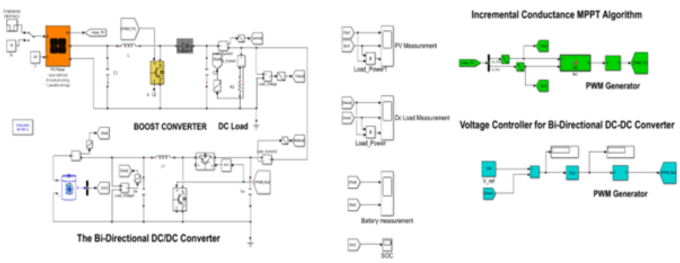

Fig. 5. DC Microgrid

Table 1: PV Parameters

Parameters	Specifications
Maximum power (W)	250.205 W
Parallel strings	1
Series-connected modules per string	8
Cells per module (Ncell)	60
Open circuit voltage Voc (V)	37.3
Short-circuit current Isc (A)	8.66
Voltage at maximum power point Vmp (V)	30.7
Current at maximum power point Imp (A)	8.15

Table 2: Battery Parameters

Parameters	Specifications
Nominal voltage (V)	12*20
Rated capacity (Ah)	48
Initial state-of-charge (%)	50
Battery response time (s)	0.0001

At different irradiances (1000, 500, 10, 500, 1000 IR) and temperatures of 25 degrees Celsius, the performance of solar PV with an applied incremental conductance algorithm to extract maximum power was evaluated.

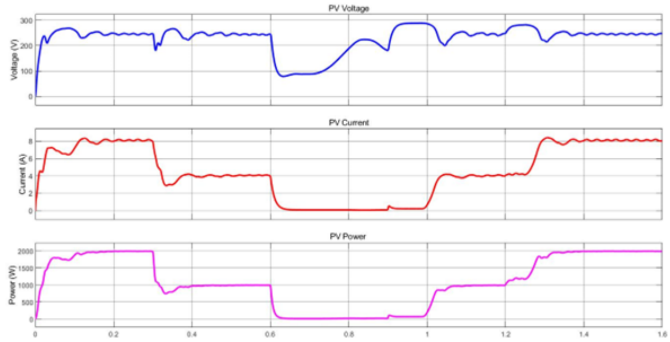

Fig. 6. PV Voltage, PV Current & PV Power Vs Time in (S)

20 * 12V batteries with 48 Ah each are connected to a bidirectional DC/DC converter that is controlled by a DC bus voltage control system.

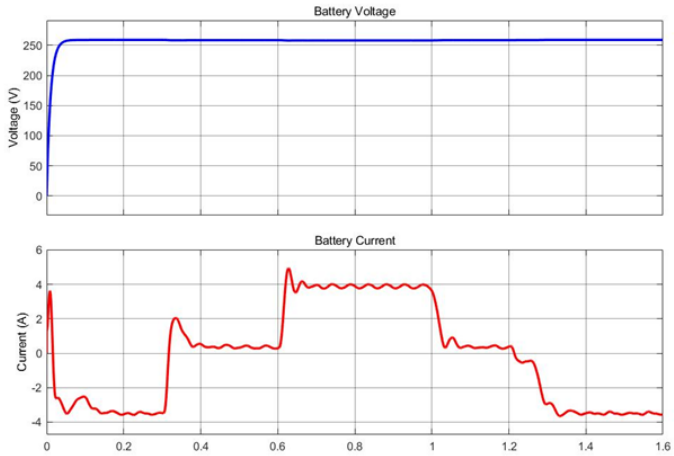

Fig. 7. Battery Measurement (Voltage & Current) Vs Time in (S)

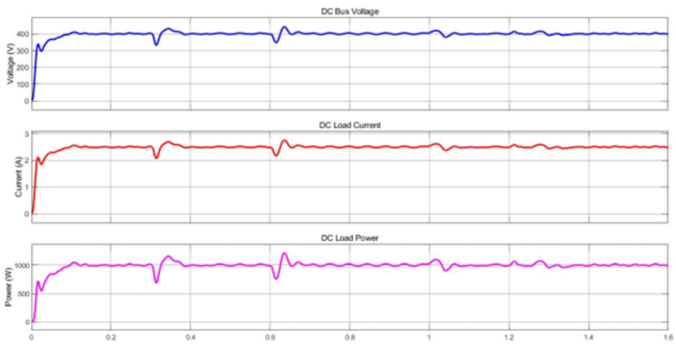

Fig. 8. Dc Bus Voltage, Dc Load Current & Dc Load Power Vs Time in (S)

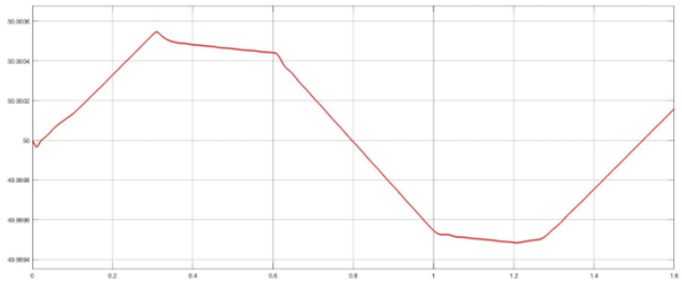

Fig. 9. Battery SOC Vs Time in (S)

CONCLUSION

In this study, a simple energy management technique for DC microgrids built of PV/Battery systems supplying DC loads is given. First, the whole system (e.g., PV, battery, DC-DC boost converter, and DC-DC bidirectional converter) has been presented. The derived models were then utilised to create appropriate controllers for the power converters. The suggested control technique for the boost converter was then verified. In reality, the PV module was able to monitor the maximum power from the PV module while the SoC was within the maximum limit and function in the LPM mode when the SoC was greater than the predetermined maximum SoC. Furthermore, the bidirectional converter is effectively controlled by a dual control loop. By regulating the charging/discharging battery current, the bidirectional converter was able to keep the DC bus voltage at the target value of 400 V in all working modes. The acquired simulation results suggest that the system performs well and is stable. Furthermore, the load was available at all times. This work is now being implemented in order to be integrated and experimentally tested utilising our deployed microgrid system.

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