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Energy Management of PV - Battery based Microgrid System

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Abstract

This paper deals with the management of Energy Storage System (ESS) connected in a microgrid with a PV array and regulate the battery charge, hold and discharge operations using DC-DC bidirectional converter based on the requirement of the Load. The PV array along with the battery and load is simulated for various conditions such as PV supplying and charging the battery, PV supplying only the load, battery supplying the load and PV-Battery both supplying the load. The output parameters like voltage, current and power graphs are plotted and analysed for each condition. The entire paper is simulated on Matlab-Simulink environment.

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Keywords: Microgrid; Bidirectional Converter; Battery Management System (BMS); Controller

1. Introduction

Solar Energy is the most abundant form of renewable energy. Its usage has increased considerably in recent times as it has become more feasible and convenient. Power electronics has played a major in this area [1-2]. Power Electronic converters help in converting the DC output power of the PV arrays into AC power. This AC power can then be used for supplying local loads or the grid [3-5]. Batteries are used to store this power in case the load demand is less. Battery banks when used without a bidirectional converter are required to be large in numbers, but using many batteries is not economical and convenient as even one cell failing can disrupt the entire current flow[6]. Transformer based isolated bidirectional converters are expensive and also have greater power loss due to use of many switches [7]. The battery used in this system is a Lead-Acid battery because of its low cost and long life [8-12].

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In this paper the PV array output is boosted to the required value of the load. The battery is connected via a dc-dc bidirectional converter. The dc-dc converter uses IGBT for its fast switching speed and low output impedance. This paper proposes the integration of a non-conventional source of energy such as PV array with a local load and battery system along with various modes of operation. Theses modes depend upon the PV output and battery state of charge (SOC) conditions. The block diagram of the proposed system is shown in Fig 1.

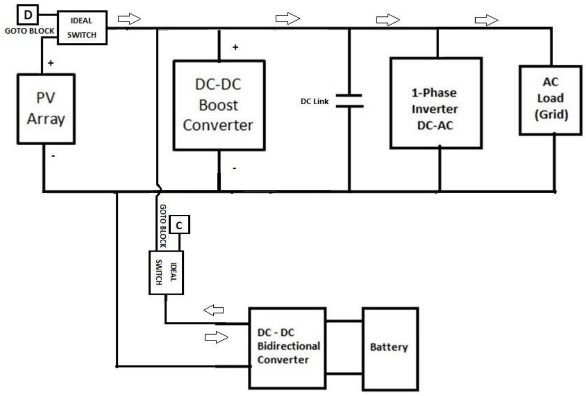

Fig 1. Block Diagram of the proposed system

2. System Configuration

2.1. PV Module

The Solar PV Module used in this paper acts as an input source for charging the battery as well as supplying to the AC Load during normal conditions. Fig. 2 represents the output of simulink model of PV Module whose parameters are shown in Table 1. The PV Module operates at constant irradiation level of 1000 Wm-2 and ambient temperature of 25^{o} C. At optimum conditions produces an output of 23 V. The module is connected to the AC Load through a DC-DC Boost Converter and 1-Phase Inverter. It is connected to the Battery through a DC-DC Bidirectional Buck-Boost Converter.

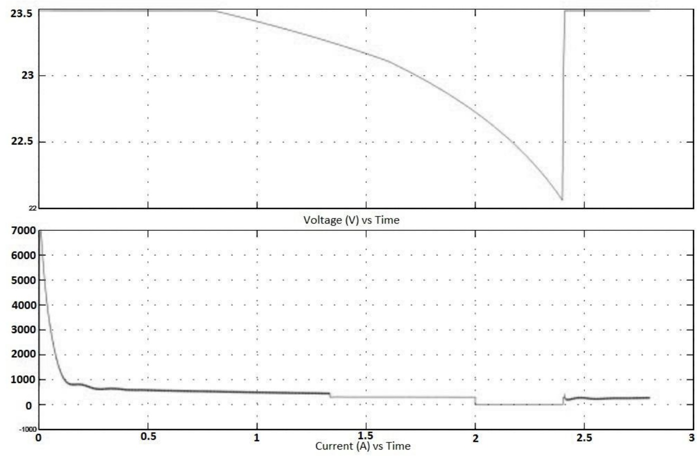

Fig 2 Voltage and current graph of the PV Module.

Table 1.Parameters of the PV Module.

Parameter	Value
Short Circuit Current	4.74 A
Open Circuit Voltage	21024 V
Series Resistance	0.004702 Ω
Parallel Resistance	100 Ω
Thermal voltage	0.9248 V
Irradiation	1/100
Diode Saturation Current	3.8300e-010

2.2 DC-DC Boost Converter

In PV systems, generally, dc-dc converters are used either to step up/down the PV voltage. They can also be used to extract maximum power through MPPT (maximum power point tracking). Fig 3 (a) shows the circuit diagram of a dc-dc boost converter. During continuous conduction mode of operation this converter has two intervals of boost operation. We shall do steady state analysis i.e. inductor volt-second balance and capacitor charge balance in both the intervals. Then by applying small ripple approximation we can easily design the boost converter as per requirements.

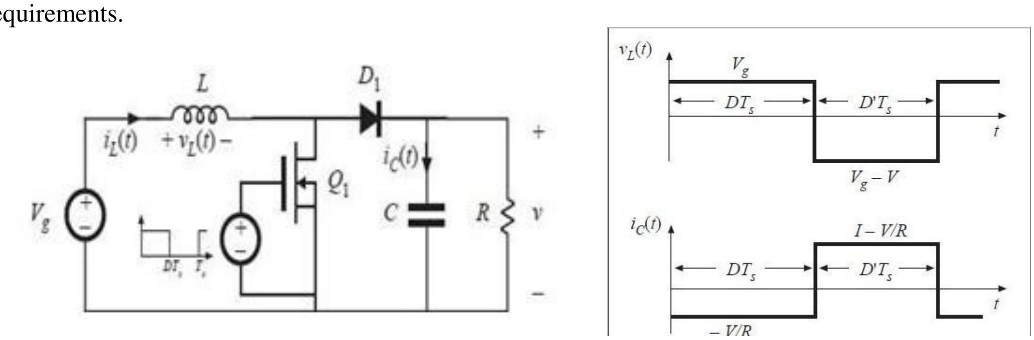

Fig 3. (a) Circuit diagram of a (DC-DC) Boost Converter; (b) V-I graph.

2.2.1 Subinterval 1

In this subinterval, the IGBT/MOSFET switch (Q1) conducts and diode D1 is reverse biased.

$V_L = Vg$ (1)

$I_C = -v/R$ (2)

Applying small ripple approximation gives

$V_L = Vg$ (3)

$I_C = -V/R$ (4)

where V= steady state output voltage.

2.2.2 Subinterval 2

In this subinterval the IGBT/MOSFET switch (Q1) doesn't conduct whereas the diode D1 conducts.

$V_L = Vg - v$ (5)

$I_C = i_L - v/R$ (6)

Applying small ripple approximation gives

$V_L = Vg - V$ (7)

$I_C = I - V/R$ (8)
Combining equations (3), (4), (7) and (8) to form a graph for vL(t) and iC(t) vs t(time) as shown in Fig 3 (b).
Where, D= Duty Cycle, T_S= switching time period, $D^{'}$ = (1-D).

Now, under steady state the average voltage across the inductor should be zero which is inductor volt-second balance. Hence,

$L(t)dt = VgDT_S + (Vg-V)D'T_S = 0$ (9)
$V=Vg/D'$ (10)

Change in inductor current during subinterval 1 is
$[di_L(t)/dt] = V_L(t)/L = Vg/L$ (11)
$dt = DT_S$ and $di_L(t) = 2\Delta i_L$ (12)
where Δi_L = inductor current ripple. Therefore, combining (11) and (12) $\Delta i_L = VgDT_S/2L$

Similarly, change in capacitor voltage during subin-terval 1 is
$[dV_C(t)/dt] = i_C(t)/C = -V/RC$ (13)
$\Delta v = VDT_S/2RC$ (14)
where Δv= capacitor voltage ripple.

With given values of Vg and V, D can be found out and with assumed ripples, the values of L and C for the boost converter are found out. The parameters used in this paper are shown in Table 2. The voltage is boosted to 310V. The output voltage graph of boost converter is shown in Fig 4.

Table 2.Parameters of the DC-DC Boost converter.

Parameter	Value
Pulse width	92.5 %
Period	$4*10^{-5}$ s
Inductance	7.63e-4 H
Capacitance	35e-4 F

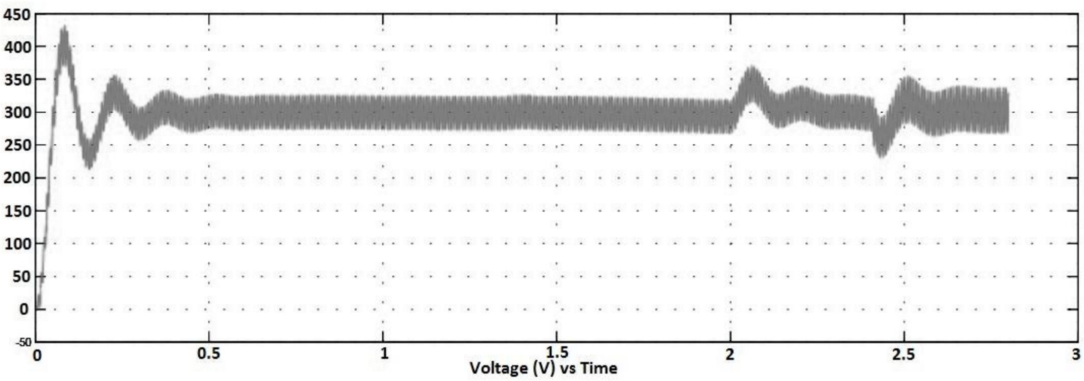

Fig 4. Output voltage of Boost converter

2.3 DC-DC Bidirectional Buck-Boost Converter

A non-isolated DC-DC Bidirectional Buck-Boost converter is used in this paper to boost PV output to battery voltage requirement during charging conditions and in discharging conditions reduce battery output voltage to desired value to supply the load. The parameters required are calculated as follows

For the Buck Converter operating in Continuous mode, the duty cycle is given by

$$\frac{Vout}{Vinp} = 1/(1 - Dboost) \tag{15}$$

The current at the continuous-discontinuous boundary is given by

$$I = \frac{DTs(Vout - Vinp)}{2L} \tag{16}$$

$$L = \frac{(2X10^{-5})(0.209)(110 - 23)}{2X30} \tag{17}$$

The parameters used in the Simulink model of the bidirectional converter are shown in Table 3.

Table 3.Parameters of the DC-DC Bidirectional Buck-Boost converter.

Parameter	Value
Pulse width (IGBT 1)	21 %
Pulse width (IGBT 2)	79 %
Inductance	6.46e-6 H
Capacitance	7.8e-1 F

2.4 Battery

The Battery Model used in this paper is a Lead-Acid Battery with a nominal voltage of 100 V. The simulation parameters used in Simulink are shown in Table 4. The initial state of charge (SOC) of the model can be set according to the need of the simulation.

Table 4.Parameters of the Battery model.

Parameter	Value
Nominal Voltage	100 V
Rated Capacity	6.5 Ah
Fully Charged Voltage	108.8816 V
Nominal current	1.3 A

2.5 Load

The load used in this paper is a 220V, 4.65kW AC Resistive Load of 10 Ω connected with a 1-phase Inverter. The inverter converts the DC input from the PV module or the Battery depending on the mode of operation and converts it into AC voltage with RMS value 310 V.

2.6 Controller Logic

The control logic uses relational operator to check when the PV insolation levels or the load current change. It can be seen that the IGBT switches of the Bi-directional converter are controlled using multiport switches. Boost mode IGBT is controlled using [A] Goto block and buck mode IGBT is controlled using [B] Goto block. It can be seen that the Battery module is connected to the main system using ideal switch controlled by [C] Goto block. Also, the

PV array is connected to the system using ideal switch controlled by [D] Goto block. As soon as there is a change in the parameters the control logic generates pulses in terms of 1 or 0 for each Goto block to change the modes of operation of the system. Table 5 shows the various output generated for each Goto block during different modes of operation.

Table 5.Parameters of the Battery model.

Mode of operation	[A]	[B]	[C]	[D]
Mode 1: PV supplying load and charging battery	0	1	1	1
Mode 2: PV supplying load only	-	-	0	1
Mode 3: Battery supplying load	1	0	1	0
Mode 4: PV-battery both supplying the load	1	0	1	1

3. Results

3.1 Mode 1

This mode operates from simulation time 0 – 1.3 seconds.During this mode the PV module operates at the insolation level of 1000 Wm^{-2}. The PV module supply's the load as well as charges the battery. The output voltage and current graph of load in mode 1 are shown in Fig 5. Fig. 6 shows the output Voltage, State of Charge and current graph of battery during mode 1(charging). The initial state of charge of the battery is kept at 50% during Matlab simulation.

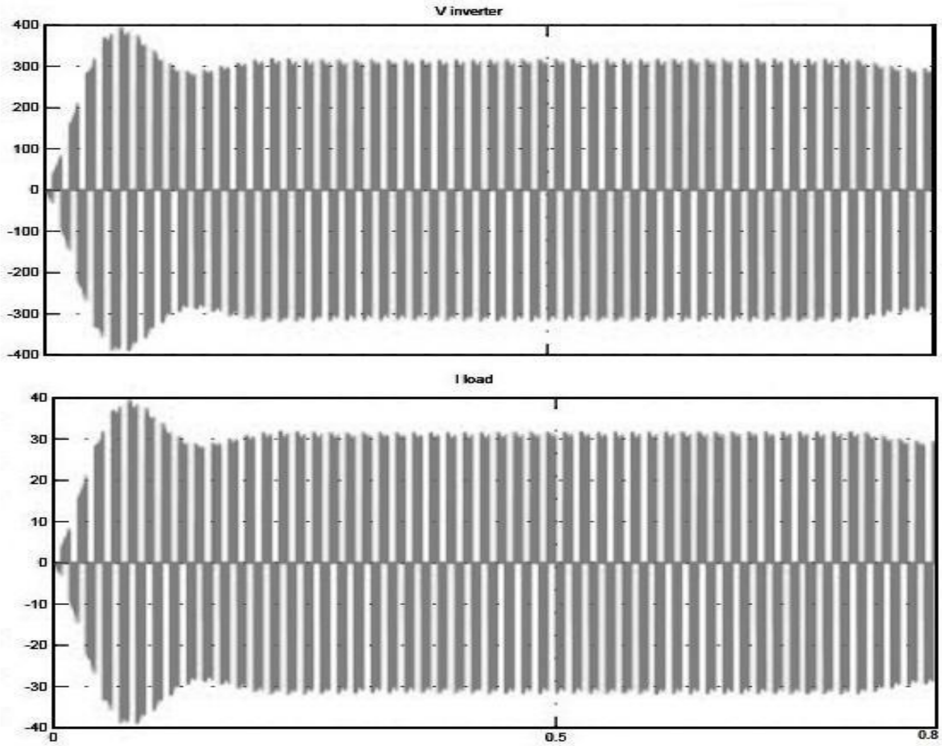

Fig 5. Output voltage and current of load in Mode 1

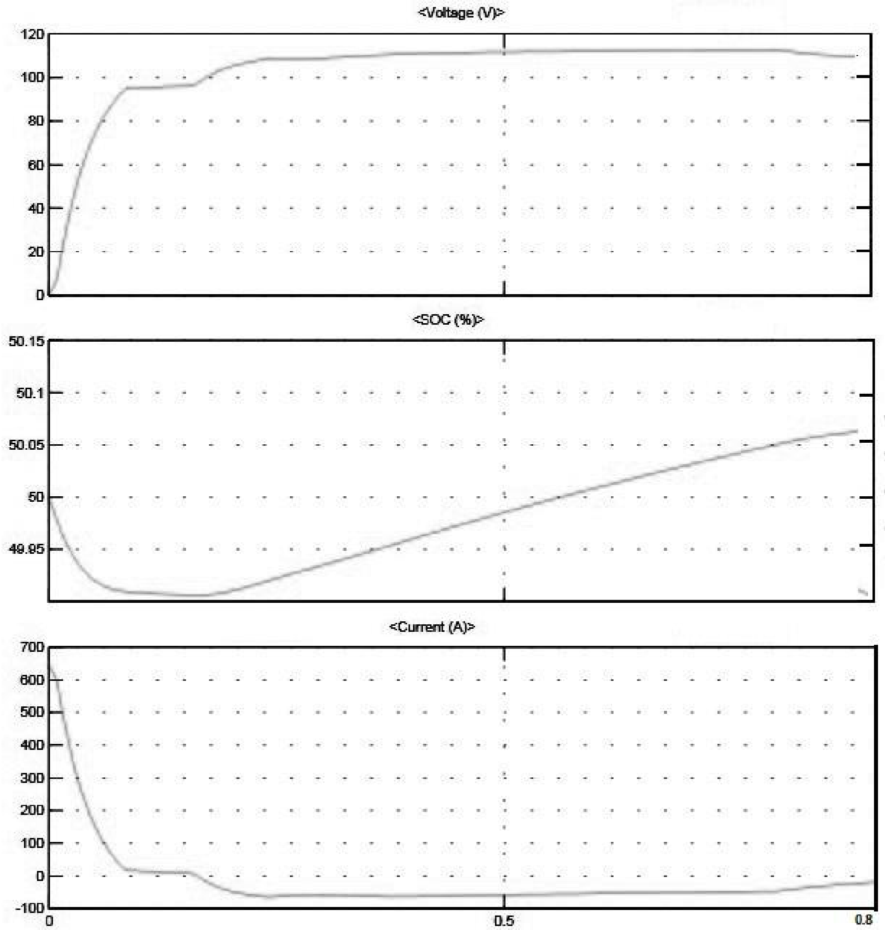

Fig.6. Output Voltage, State of Charge and current graph of battery during mode 1(charging)

3.2 Mode 2

This mode operates from simulation time 1.3 – 2.0 seconds.During this mode the PV module operates at insolation of 700 Wm^{-2}. Due to this the output of the PV array drops and it can no longer support both load and battery charging. Therefore the battery is disconnected and the PV array only supply's to the load during this mode.

3.3 Mode 3

This mode operates from simulation time 2.0 – 2.4 seconds. During this mode the PV module operates at insolation of 300 Wm^{-2}. Due to this the output of the PV array drops below operating conditions and the PV module cannot support the load any longer. Therefore the PV block gets disconnected and the battery supply's to the load during this mode.

3.4 Mode 4

This mode operates from simulation time 2.4 – 2.8 seconds. During this mode the PV module operates at insolation of 1000 Wm^{-2}. The load experiences at an increase in resistance which causes load variation. In order to cater to the increased load, both PV and battery supply to the load during this mode.

4. Conclusion

The paper dealt with the energy management algorithm for a PV based microgrid with battery storage system. The entire simulation was performed in Matlab-Simulink environment. The output V-I graphs of the load and battery obtained during simulation of each modes represent the performance of the system under specified conditions of battery charging and discharging. Mode 1 is from 0 to 1.3 sec simulation time during which the PV output is optimum and it supply's both to load and charges the battery. Mode 2 runs from 1.3 to 2 during which the PV only supply's the load. Mode 3 runs from 2.0 to 2.4 sec during which the battery supply's the load. Mode 4 runs from 2.4 to 2.8 sec during which the PV and battery both supply to the increased load.

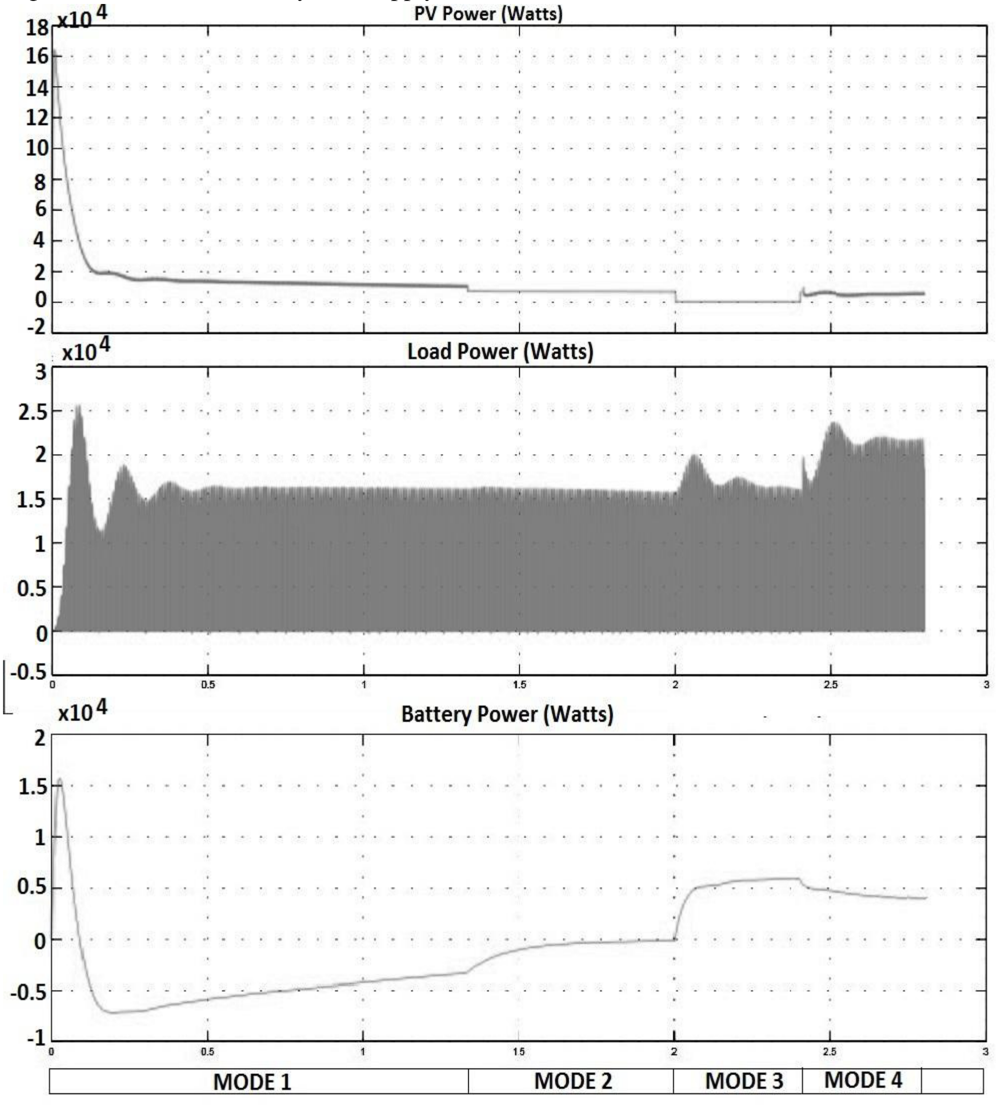

Fig 7. Output power vs simulation time graph of PV, load and battery during the entire simulation.

The Voltage, current and power graphs obtained during the simulation of the system explain in detail the system's versatility in different operating conditions. The output power graph of PV array, load and battery for the entire simulation is shown in Fig. 7. The system exhibits how a renewable source of energy such as PV array can work together with Battery in Microgrid to power local loads. The entire simulation is performed in Matlab-Simulink environment.

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