Power Management Strategy for Solar Photovoltaic Systems with Battery Protection Scheme in DC Microgrid

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Abstract **- Renewable Energy Sources (RES) have seen increasing interest in research and industry due to the numerous advantages compared to AC. Our project reported here proposes a control algorithm for optimal power management system with battery protection for a Standalone Solar Photovoltaic (SPV) system microgrid to minimize its operating cost. The microgrid includes SPV and battery. The control system consists of three stages: power management system, battery protection and supervisory control. The power management system is responsible for scheduling the power flow between the microgrid sources, battery and loads on economic analysis. Battery protection scheme is responsible for the protection of battery from overcharging and over discharging. Supervisory control is responsible for compensating the mismatch power between the schedule power and microgrid power. The effectiveness of the proposed system is demonstrated via case studies, simulation results and experimental setup.**

Keywords - Battery protection, power management system, solar photovoltaic converter, supervisory control.

I. INTRODUCTION

Microgrids are novel form of distribution systems, which belong to the wider concept of smart grids. The microgrid can be considered as a small-scale electricity grid at the distribution voltage level, which can operate either in grid-connected or islanded mode. It consists of Distributed Generation (DG) units, such as renewable energy generators and combined heat and power units, along with storage devices and controllable loads (e.g. air conditioners) [1]. Their unique characteristic is that they can be islanded, especially during fault incidents to increase the supply reliability. Currently, the most common application of DC MGs is the electric power supply of isolated systems like vehicles, space crafts, data centers, telecom systems, while they have been proposed for rural areas and islands [2]- [4].

The current increase in the use of DC loads has prompted the creation of DC MGs due to their advantages in terms of low cost and efficiency [5] - [7]. However, to decrease the quantity of a couple of conversion degrees and to connect the AC and DC sources and loads in a efficient/economic way, AC/DC MGs have grow to be an best desire to connect the MGs [8].

There are many challenges that face microgrids operation. The first challenge is to limit the operational value of the MG. Secondly, the intermittency of RESs such as photovoltaic (PV) and wind turbine (WT) due to the fact of the climate version which may additionally reason energy imbalance and power-quality problems. Therefore, the decision makers are focusing on finding a solution to make the MG operate in a stable and financial way.

The power management system plays a key role in controlling the power generation and/or drift of power in microgrids and thus minimizes the working cost. Power Management system controls the power flow in the MG based totally on choicest fee and affords the scheduled, reference values to the nearby controller of the MG. The power scheduling problem to provide reference values to the nearby controllers has been studied earlier than [9]–[11].

The proposed system consists of three stages: power management system, battery protection and supervisory control. Power management system is responsible for scheduling power flow between the microgrid sources, battery and loads on economic analysis. Battery protection scheme is responsible for protection of battery from overcharging and over discharging. Supervisory control is responsible for compensating the mismatch power between the schedule power and microgrid power.

This paper is organized as follows: Section II explains DC microgrid, section III explains power management system, section IV deals with battery protection control scheme, section V deals with simulated performance. Finally section 6 conclusions are reported.

II. DC MICROGRID

The structure of typical DC microgrid system is shown in figure 1. It should be noted that the DC MG topology may differ from the radial single feeder configuration to two-pole or ring configuration. In these topologies either unipolar or bipolar configurations can be implemented. Bipolar configurations can provide more voltage level options in comparison with unipolar connections. With respect to the voltage levels, they can differ in accordance with the operating requirements of each system.

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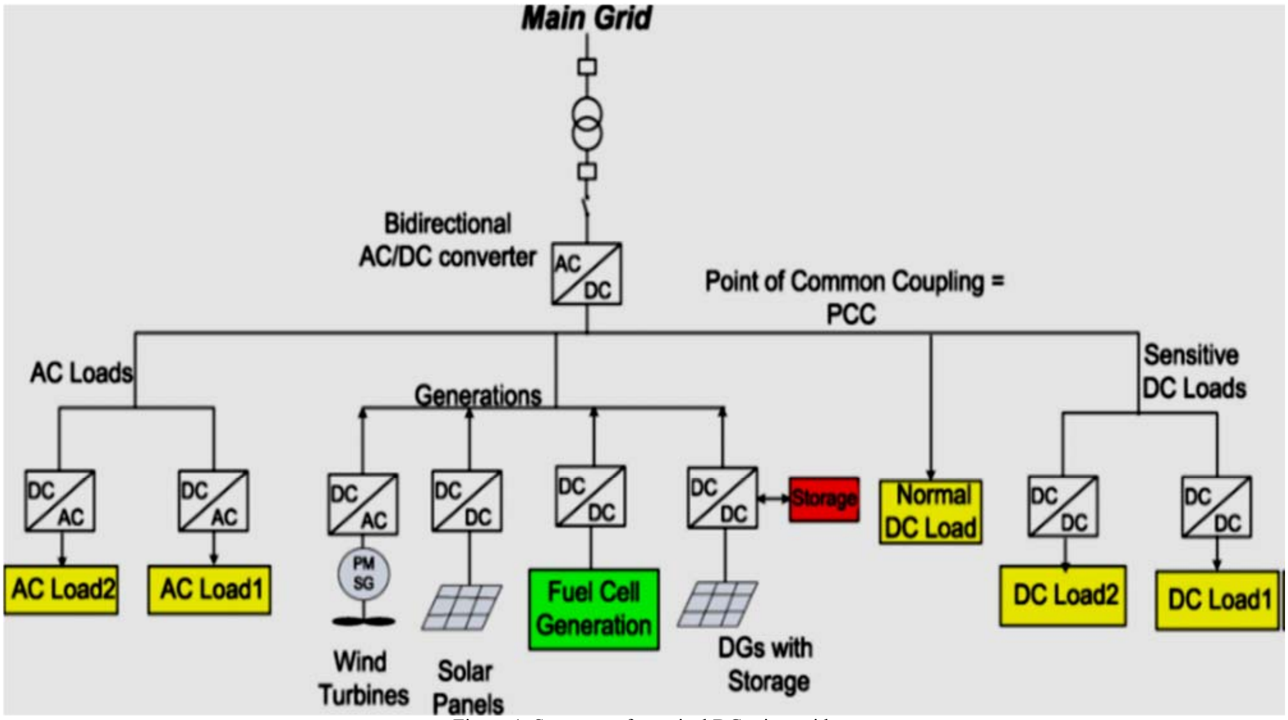

Figure 1. Structure of a typical DC microgrid.

Microgrid control need to insure that: (i) new distributed generation and storage systems can be brought or removed from the microgrid seamlessly, (ii) equal and stable contemporary sharing between parallel strength converters (i.e. sources) is enabled, (iii) output voltage fluctuations can be corrected, and (iv) favored strength glide from/to the microgrid together with technically and economically workable operation is enabled.

For safe and reliable operation of DC MG, a well-functioning protection system is instrumental in any topology. Its principal objective is to minimize the propagation of disturbances by detecting and isolating faults within the minimum time frame [12], [13]. Protection of DC systems is in general a challenging task due to difficulties in extinguishing arc, which on the contrary happens naturally in ac systems. Accurate short-circuit current calculation and fault detection are the most important prerequisites for the good design of protection system [14] - [19].

III. POWER MANAGEMENT SYSTEM

The proposed diagram is shown in figure 2. From this diagram it can be noted that no dedicated converter is employed for ensuring the MPP operation of the PV array, which leads to the improved utilization of the converters involved. Furthermore, only one converter stage is present in the path between the PV array and the battery, thereby improving the charging efficiency of the battery. The inductor current iL is designed to be continuous. The switches S1 and S2 are operated in complementary fashion. All semiconductor devices and passive elements are assumed to be ideal in the following analysis.

The controller of a stand-alone system is required to perform the following tasks: 1) extraction of maximum power from the PV array; 2) manipulate the battery usage without violating the limits of overcharge and over discharge; and 3) dc–ac conversion while maintaining the load voltage at the prescribed level.

In order to achieve the desired functionalities, proposed system is required to operate in one of the following modes.

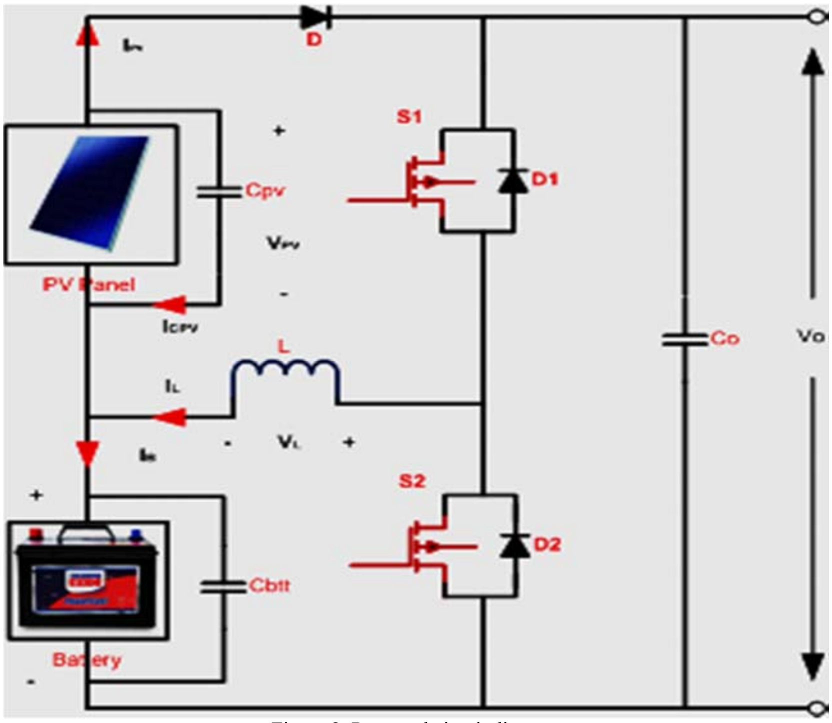

Figure 2. Proposed circuit diagram

Mode 1: MPPT, Maximum Power Point Tracking Mode: Maximum power is extracted from the PV array when the system is operating in this mode. However, in order to operate in this mode, one of the following conditions must be satisfied: 1) Available maximum PV power Pmpp is more than the load demand Pl, and the surplus power can be consumed by the battery without being overcharged; and 2) Pmpp < Pl and the battery have the capability to supply Pl − Pmpp without being over discharged. The PV power in MPPT mode is given by Ppv = Pmpp = (Pb + Pl), where Pb is the battery power which is defined as positive during charging and negative while discharging.

Mode 2: Non MPPT Mode: Based on the State Of Charge (SOC) level of the battery, its charging current is required to be limited to a maximum permissible limit Ibmax to prevent the battery from getting damaged due to overcharge. The maximum charging current limit Ibmax restricts the maximum power that can be absorbed by the battery to Pbmax = Ibmax * Vb. When Pmpp > Pl and the surplus power is more than Pbmax, the system cannot be operated in MPPT mode as it would overcharge the battery. During this condition, power extraction from PV is reduced to a value given by Ppv = (Pbmax + Pl). This mode of operation is known as non-MPPT mode.

Mode 3: Battery Mode: The system operates in BO mode when there is no PV power and the battery has the capability to supply the load demand without being over discharged.

Mode 4: Shutdown Mode: When Pmpp < Pl and the battery does not have the capability to supply Pl − Pmpp, the system needs to be shut down to prevent the battery from being over discharged.

Figure 3 shows the control circuit 1 which sets the maximum power point voltage and figure 4 shows control circuit 2 which sets the reference voltage for PV system (Vpvref). These two control circuits will decide whether the system will be operate in mode 1 or in mode 3 When ipv > 0 it indicates PV power is availability, then it selects mode 1 operation and the output voltage is Vpvref When ipv < 0, system will selects mode 3 operation and Vpvref is taken as Vdc which is a desired value of 250-450 voltage.

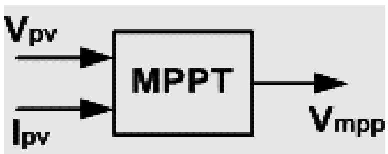

Figure 3. Control circuit 1

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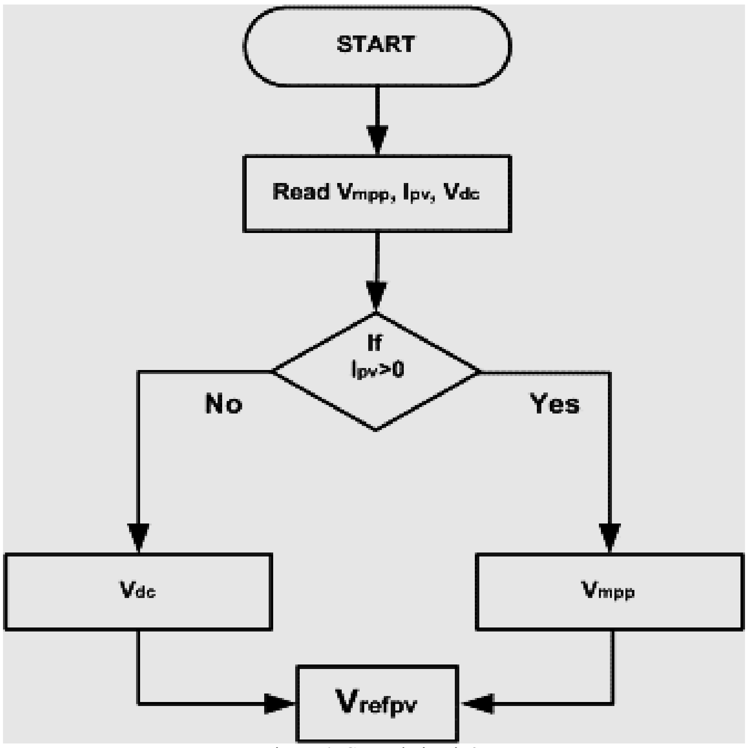

Figure 4. Control circuit 2.

IV. BATTERY PROTECTION SCHEME

Battery protection scheme in the proposed system is explained briefly in this section. Depending upon the SOC of the battery and availability of power from the solar array a control strategy is developed for protection of battery from overcharging and over discharging.

From figure 2, when S1 is ON and S2 is OFF. The voltage across the inductor is Vpv:

$$V_L = V_{PV} \tag{1}$$

When S1 is OFF and S2 is ON the voltage across the inductor is –Vb:

$$V_L = -V_b \tag{2}$$

Average voltage drop across inductor is:

$$V_{Lavg} = DV_{PV} - (1-D)V_b \tag{3}$$

Assuming average voltage drop across the inductor is zero:

$$0 = DV_{PV} - (1-D)V_b \tag{4}$$

$$V_{PV} = \frac{1-D}{D}V_b \tag{5}$$

Applying KCL:

$$I_L + I_{CPV} = I_b + I_{PV} \tag{6}$$

If average value of $I_{CPV} = 0$

$$I_b = I_L - I_{PV} \tag{7}$$

If $I_L > I_{PV}$ Battery Should be charge

If $I_L < I_{PV}$ Battery Should be discharge

There by controlling the I_L and I_{pv} battery charging and discharging can be controlled.

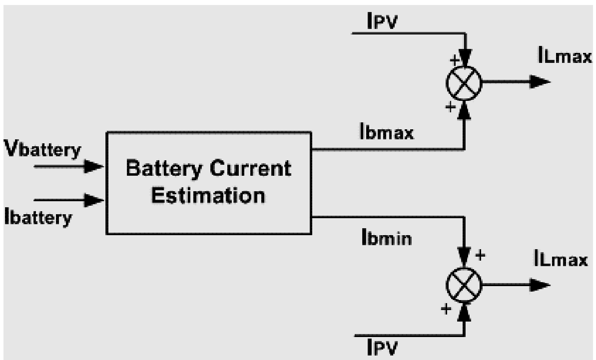

Figure 5. Control circuit 3

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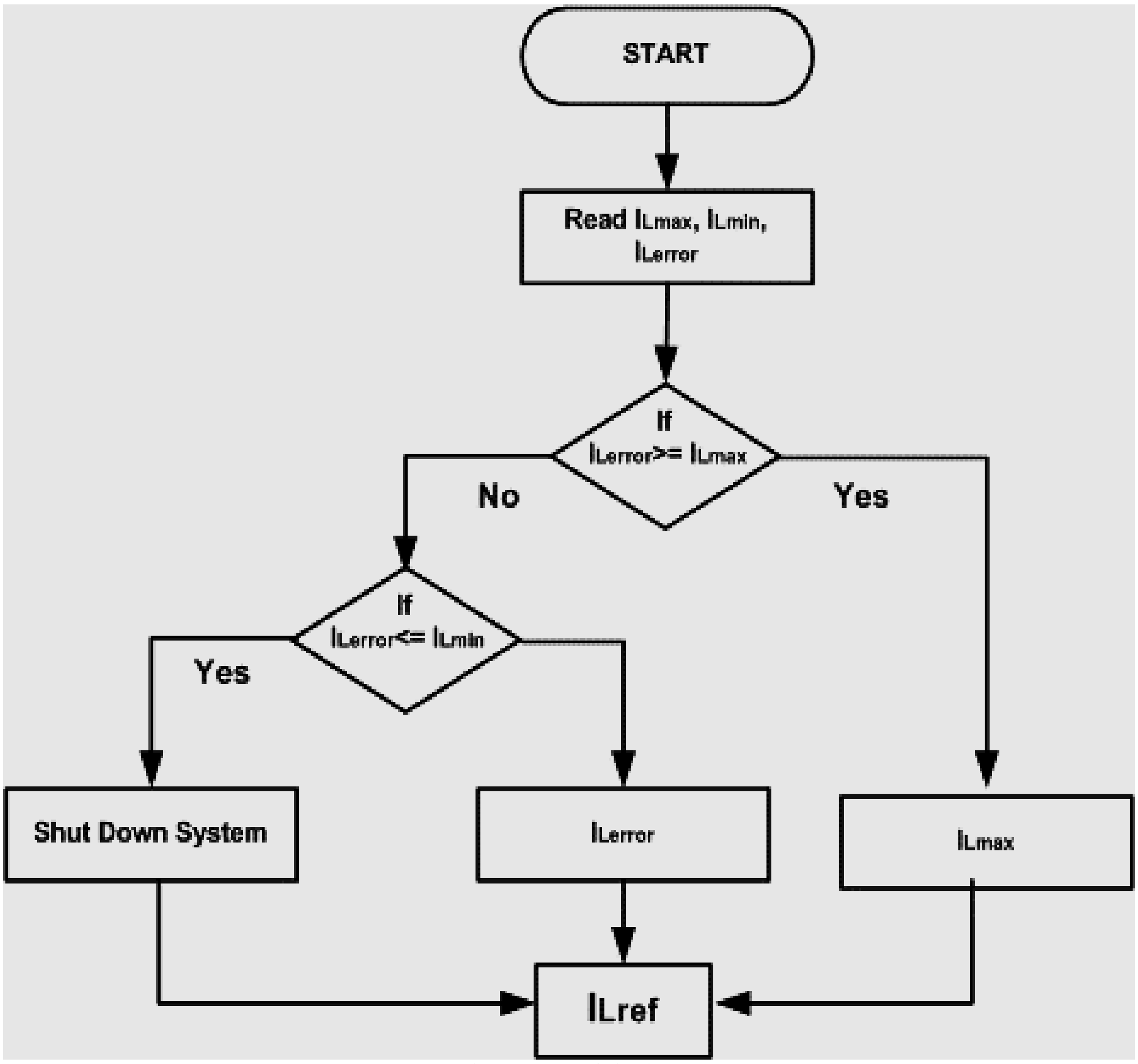


Figure 6. Control circuit 4.

Figure 5 shows the battery estimation control circuit which finds the inductor minimum and maximum current. Figure 6 shows the control circuit 4 which estimates the inductor reference current I_L ref.

To prevent overcharging and over discharging of the battery. These two limits are derived as follows:

$$I_{L\max} = I_{b\max} + I_{pv} \tag{8}$$

$$I_{L\min} = I_{b\min} + I_{pv} \tag{9}$$

Where in Ibmax and Ibmin are the maximum permissible charging and discharging current of the battery, respectively. These two limits are set based on the SOC level and the allowable depth of discharge of the battery.

V. SIMULATED PERFORMANCE

The proposed system is simulated on Matlab/Simulink platform, and the simulated responses obtained under different operating conditions are presented in this section. The different parameters/elements used in the simulation model are provided in Table I.

TABLE I

Parameter	**Value**
MPPT Algorithm	Incremental Conductance
Switching Frequency	15 kHz
Inductor	L=3 mH
Capacitors	Cpv = 2000 µF, Cbtt = 1000 µF

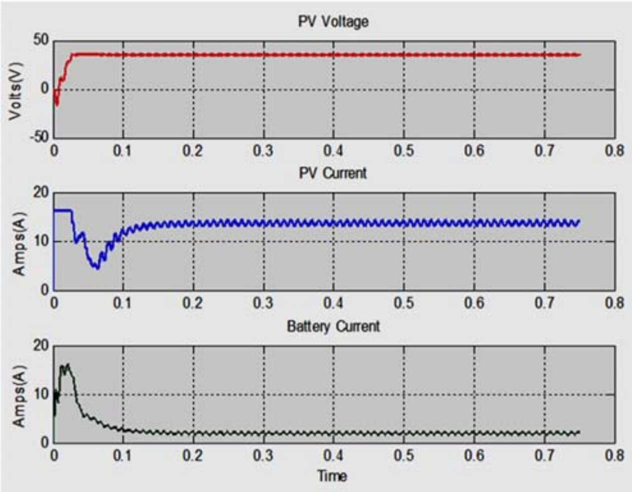


Figure 7. Simulation Response Steady State Operation (a)PV Voltage, (b) PV Current, (c)Battery Current

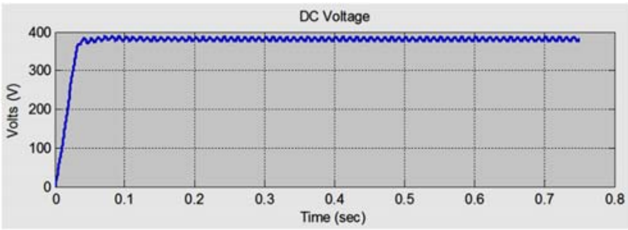


Figure 8. Simulation Response Steady State Operation – DC Link Voltage

The steady-state response of the system while operating in MPPT mode is shown in Fig. 7. The level of insolation is chosen to be 1 kW/m2 with the corresponding Impp, Vmpp, and Pmpp as 14.8 A, 35.4 V, and 525 W, respectively. The load demand is kept at 450 W which is less than Pmpp. It can be inferred from Fig. 7 that vpv and ipv are at their respective MPP values, whereas ib is positive, indicating that the battery is charged to consume the surplus power. The load voltage which is being maintained at 230 V and the dc-link voltage profile are shown in Fig. 8.

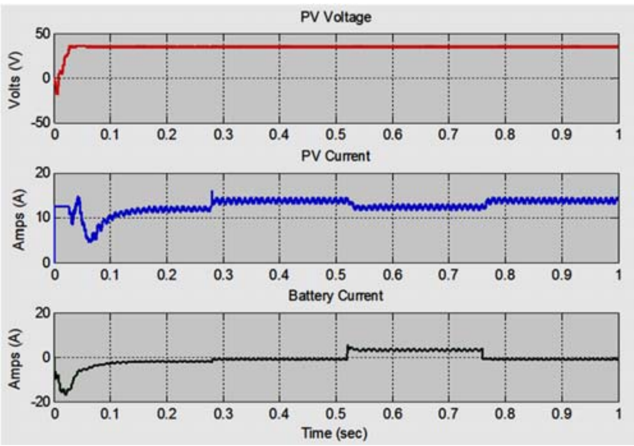
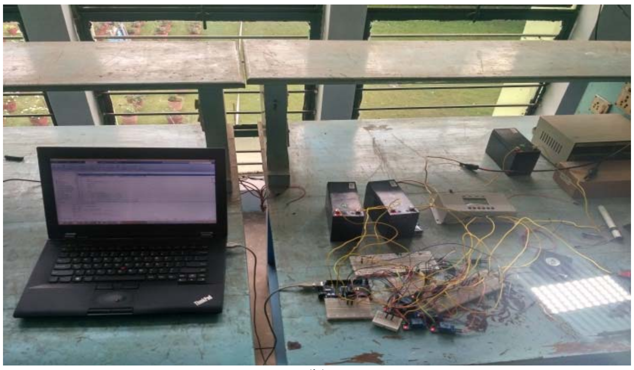


Figure 9. Simulation Response under changes in Load and irradiance (a) PV Voltage, (b) PV Current, (c)Battery Current

The simulated response of the system under changes in load and insolation level while it is operating in MPPT mode is shown in Fig. 9. Initially, the insolation level is set at 0.75 kW/m2 (Impp = 11 A, Vmpp = 35 V). At 0.28 s, the insolation level is changed to 1 kW/m2 (Impp = 14.8 A, Vmpp = 35.4 V).


(a)


(b)
Figure 10. (a) & (b) Laboratory setup of proposed system

VI. CONCLUSION

A solar PV-based stand-alone scheme with battery protection scheme in DC microgrid is proposed in this paper The salient features of the proposed scheme include the following:

1) The MPPT, Maximum Power Point Tracking, of the PV array, charge control of the battery, and boosting of the dc voltage are accomplished in a single converter,

2) Enhancement in battery charging efficiency as a single converter is present in the battery charging path,

3) Simple and efficient control structure ensuring proper operating mode selection and smooth transition between different possible operating modes.

The experimental setup is developed at KLEF laboratory. The viability of the scheme is confirmed through detailed experimental studies.

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