Energy Management System of Standalone DC Microgrid

Supriya Sharma and Pankaj Gupta

Abstract Solar photovoltaic (PV) energy usage that is stochastic and intermittent necessitates energy storage systems for continuous power delivery to loads. This research offers an energy management system (EMS) for a hybrid PV-battery system supplying local load in an independent DC microgrid (MG). The developed EMS algorithm ensures uninterrupted power supply to both critical and non-critical loads via storage unit during nighttime or cloudy days following load shedding in order to maximize power continuity to critical loads based on battery state of charge (SoC) levels when PV generation is low or unavailable. During peak solar hours, the load is supplied by PV, and the battery enters charging mode. If the battery is fully charged, the dump load is attached to absorb the extra energy. To test various scenarios, the Simulink model designed with MATLAB is tested under changing irradiance levels and battery SOC. The results demonstrate a seamless transition between PV and battery charging/discharging modes while maintaining a consistent DC connection voltage.

Keywords Isolated DC microgrid · PV · Renewable energy · Battery energy storage systems · Bidirectional buck–boost converter

1 Introduction

Microgrids (MGs) are yet another development made possible by the rising usage of renewable energy sources. According to the IEEE standard 2030.7, a MG is defined as follows: A collection of loads and distributed energy sources (DESs) coupled to form a single, manageable unit with respect to the grid, with clearly defined electrical boundaries and the ability to connect and detach from the grid to enable operation in both grid-connected and islanded modes [1, 2]. DC MG is preferred not only due to the increasing popularity of DC loads like as electric vehicles, LEDs, and battery storages, but also because of lower transmission losses, greater coordination among

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DESs, enhanced dependability, simpler connections, and the absence of frequency control difficulties [3]. EMS is utilized by MG to effectively manage the load and the available resources. Using a collection of computer-aided tools known as an EMS [4, 5], a generating and transmission system can be monitored, managed, and optimized. This is achieved while adhering to specific restrictions. Numerous EMS methods for DC MG with PV and battery storage systems (BSSs) for both AC and DC loads have been proposed in the past. Some of the work on EMS of islanded DC MG are discussed here. The author of [6] focused on off-grid DC MG systems comprised mostly of hydrogen, PV, and batteries. In order to achieve decentralized operation of the EMS, a two-level control with droop control is implemented. The goal of developing a PV-based MG with a rule-based prioritizing system is to give a consistent and continuous supply to critical loads [7]. The usage of a fuzzy controller for energy management in a MG with PV in order to extend the battery life is discussed in [8]. In the same context, [9] proposes an optimal control strategy for a freestanding PV-battery-supercapacitor system based on hybrid approaches using fuzzy logic control (FLC) and particle swarm optimization (PSO), with the aim of extending the battery's life. The EMS presented in [10] is capable of maintaining a constant DC bus voltage across the whole system. Another FLC-based EMS was designed and implemented in islanded mode [11] in order to govern the switching of the DC–DC converters and maintain power balance as well as a constant DC bus voltage. On the other hand, the primary focus of this effort will be the design of a rule-based EMS for an isolated mode-operating PV-battery hybrid DC MG. Another rule-based approach for DC standalone MG with PV, wind, battery, and supercapacitor feeding dump and local load is provided in [12].

The primary purpose of energy management in this developed isolated DC MGs is to accomplish the following objectives: (a) Maintaining continuity of power supply to the load for the maximum duration; (b) Maximizing power from PV system with Perturb and Observe (P&O) MPPT algorithm; (c) Keeping the DC bus voltage fixated at desired voltage levels, i.e., 300 V; and (d) Managing the battery operation mode (charging/discharging) based on the battery's SoC.

In the process of creating EMS, one of the main regulating factors that is frequently employed as a decision criterion is the battery's SoC. This research takes into account lithium-ion batteries since they are the most technologically sophisticated and display superior qualities in terms of reliability, power management, energy density, charging/discharging cycles, and other similar aspects. This paper aims to design a rule-based EMS for an isolated PV-battery DC MG with the objective to provide continuous supply to critical loads for the longest duration and maintain the DC bus voltage stable under various conditions. This has been accomplished by optimizing the PV generation using the P&O method as well as balancing the power by operating the battery in charging/discharging mode. Ultimately, the goal of this strategy is to provide continuous supply to critical loads for the longest duration possible. The following is the structure of the paper: The design of the MG is discussed in Sect. 2. In the following Sect. 3, we will talk about the proposed EMS strategy. In the following section, the results of the simulation will be critically examined for a variety of various operating situations. The concluding section of the paper is Sect. 5.

2 DC MG Structure

The PV system is connected into the DC MG via a DC–DC boost converter in order to supply the DC load. There are three loads, each consuming 500 W, and they are all connected, with the first load being the most important and the third load being the least important. This analysis takes into consideration an additional resistive load, which is thus treated as a dump load. In order to keep the power balance stable, a battery that is coupled by a bidirectional DC–DC buck/boost converter is used. The controlled switches that are linked to the load are used to achieve load shedding in the event that the power deficiency mode is active. This is done in order to preserve power continuity to the vital load and to keep the DC bus voltage stable. The planned structure of the MG is seen in Fig. 1, along with the control signals.

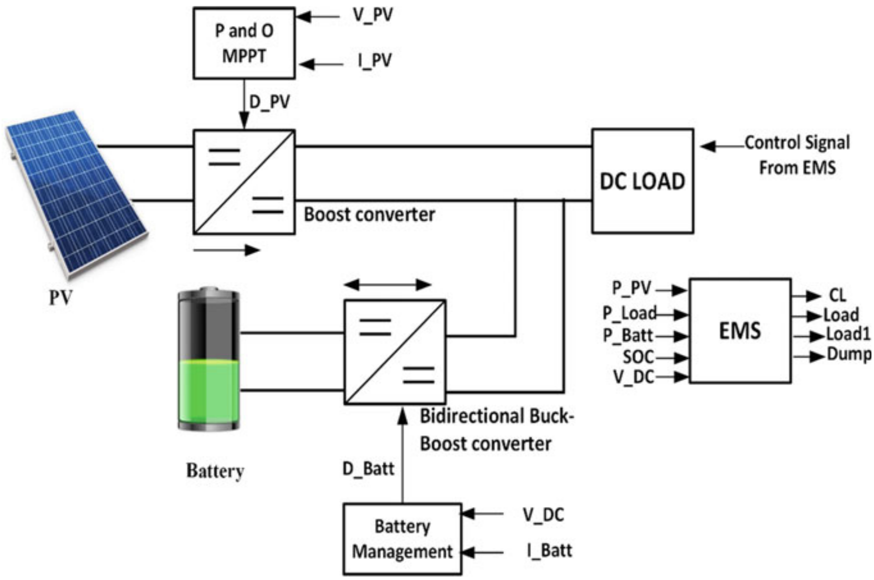


Fig. 1 Proposed DC MG layout

2.1 PV System

In the conduct of this study, a photovoltaic (PV) system is constructed utilizing sixteen modules, two of which are connected in series while the remaining eight are connected in parallel. The total power output is roughly five kilowatts. This PV system is integrated with the help of a DC–DC boost converter to the DC bus, and the Perturb and Observe Maximum Power Point Tracking (MPPT) technique is utilized in order to operate this module at its maximum capacity. This approach is often utilized due to its simplicity of implementation [13].

2.2 Battery System

Due to intermittent nature of solar, it is not possible to rely on this generation completely. The fluctuations in the solar generation are compensated with the help of battery. During day, when the irradiance levels are high and the PV generation is supplying the load, the battery is charged depending on its SoC. Otherwise, during night or cloudy days, the battery is discharged to maintain the power supply continuity to load. The battery is connected with the bidirectional buck–boost DC–DC converter to DC bus to maintain the flow of energy in either direction during charging/discharging mode. An inbuilt battery module available in MATLAB of 150 nominal voltage, and 78 AH capacity is considered in this study. The bidirectional buck–boost converter is used to connect this battery with 300 V DC bus. The main goal of this converter is to maintain a constant DC bus voltage by charging or discharging battery according to the PV generation. Dual-loop PI controller is preferred for the converter as it provides stability to the system. The outer loop tracks the DC bus reference voltage and supplies the inner loop with reference current. The parameters of the controller have been calculated as discussed in [14]. Figure 2 depicts the cascaded PI controller.

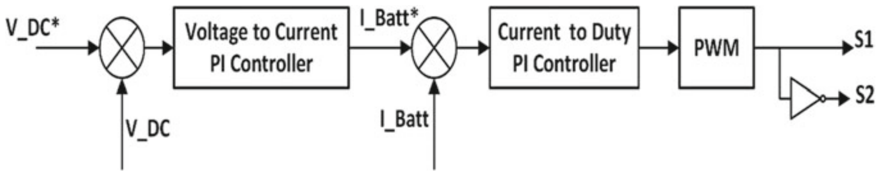


Fig. 2 Dual-loop PI controller for bidirectional buck–boost converter

3 Proposed Energy Management Strategy

The EMS that was designed and is depicted in Fig. 3 operates in two distinct modes: the sufficient PV power mode and the deficient PV power mode.

Sufficient photovoltaic energy: In this mode, for enough PV supply during daytime hours, all of the load, including critical and non-critical, is supplied by this generation when the battery SoC falls between the lowest and highest ranges. While for SoC above the maximum limit, which in this case is 90%, a dump load is linked into the system with a controlled switch so that the surplus PV power may be harvested. If the percentage of charge on the SoC falls below the minimal mark of 10%; however, it will begin charging. The load that is considered to be of the least vital importance is taken off, and the remaining load is fed by the PV.

Deficient PV generation: EMS will operate in this mode whenever the irradiance is either very low or completely absent. By operating in the phase known as discharging, the battery fulfills its role as a source. For a SoC more than 70%, the entire load is kept linked. However, load shedding is chosen by the EMS because the SoC is decreasing, and the generation from PV is either very low or nonexistent. When the SoC drops below 70% again, the load that is considered to be of the least critical importance is turned off so that the vital loads receive a continuous supply for as long as is

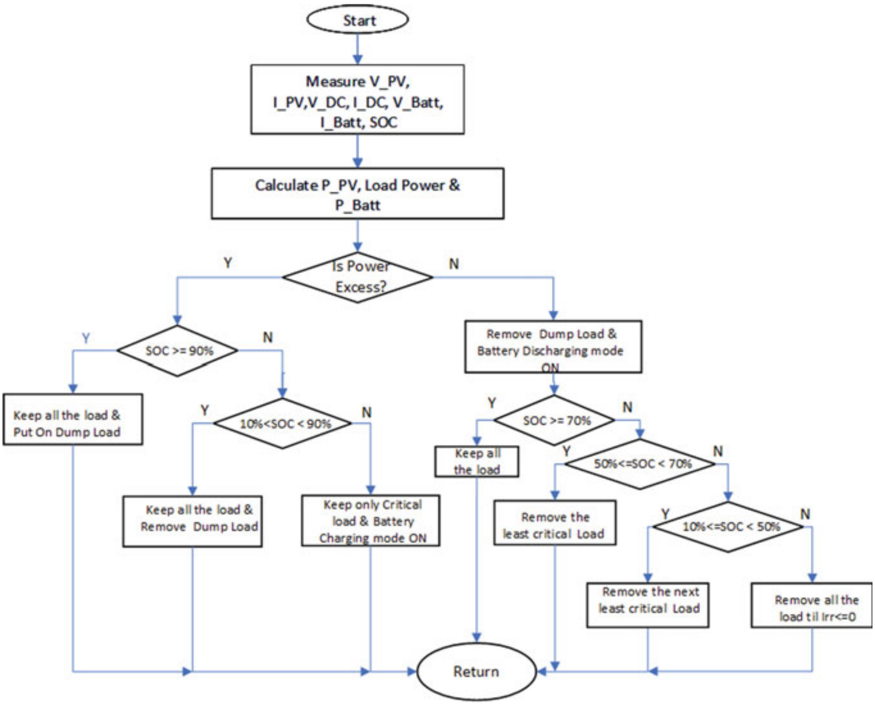


Fig. 3 Proposed EMS flowchart

humanly practicable. When the SoC falls further below 50%, the next least critical load will be taken offline. In the event that the PV system continues to produce an insufficient amount of power and the SOC falls below the threshold level, all of the load is disconnected, and the system remains in this mode until PV generation is restarted.

4 Simulation Results

The proposed algorithm is simulated on MATLAB/Simulink, and the effectiveness has been tested for different irradiance levels and battery's SoC in PV surplus as well as deficient mode. The results are illustrated in Fig. 4. The simulation results for PV surplus mode are obtained by varying the irradiance levels as mentioned in Fig. 4a. and keeping the battery's SoC > 90%. The dump load is removed only when the PV system is generating at its 50% of full capacity as otherwise, the system is operating in excess PV generation mode. When irradiance is reduced to nil in deficient mode (Fig. 4b), battery starts discharging to maintain the supply to load. In both the modes, DC link voltage is maintained at 300 V. The load shedding also improved the duration of continuous supply to critical loads. The results in Fig. 4c, d depict the load shedding and restoring conditions at SoC near 50 and 70%. As Soc is below 70%, the dump load and least critical load is already in OFF mode. Now, when SoC further falls below 50%, the next non-critical load turns off but turns back ON when SoC rises above 50% as depicted in Fig. 4c.

5 Conclusion

The proposed EMS achieved constant DC link voltage for variable irradiation levels and various SoC. Using a twin-loop PI controller, charging and discharging have been conducted smoothly, as evidenced by the results. Moreover, the continuity of supply is maintained to critical loads for as long as possible during periods of low irradiance by following load shedding of the least critical load in steps, and when PV generation is high, dump load is used to capture the excess generation if the battery is fully charged to minimize energy loss. This work can be remodeled in the future for grid-tied system, and instead of a rule-based approach, intelligent EMS based on optimization approaches such as FLC can be implemented while exploring more distributed generations.

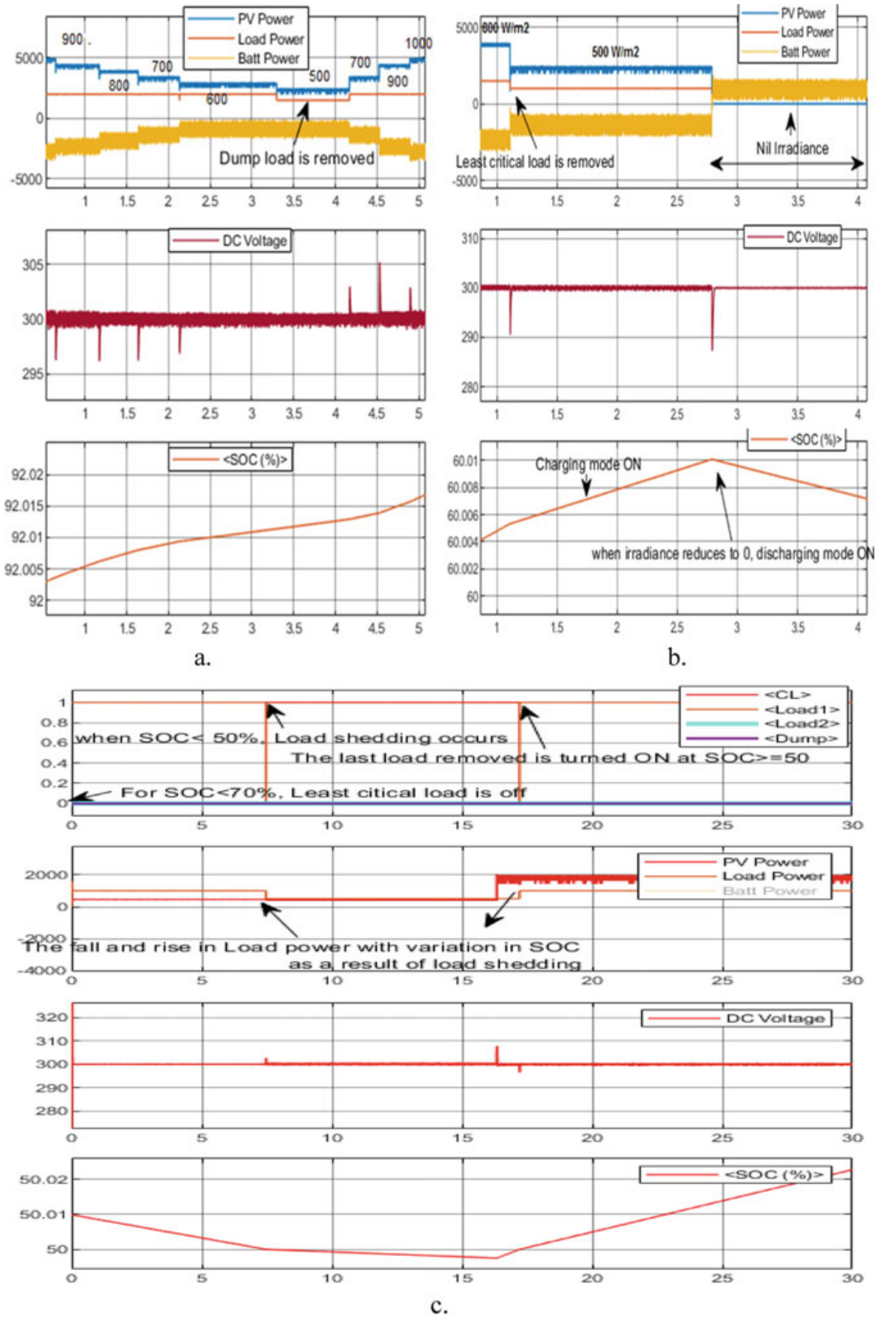
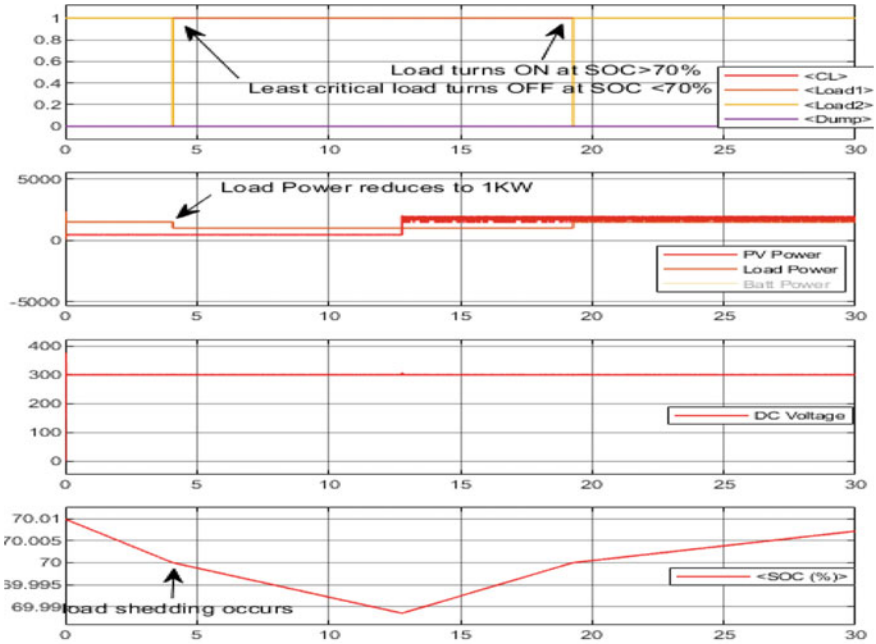


Fig. 4 Simulation results for **a** Surplus mode. **b** Deficient mode. **c** SoC near 50%. **d** SoC near 70%, showing PV power, load power, battery power, DC bus voltage, and SoC



d.

Fig. 4 (continued)

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