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Energy Management of a Grid-Connected and Islanded Direct Current Microgrid

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Abstract:- Direct Current (DC) microgrids have received a lot of attention due to their advantages over traditional Alternating Current (AC) grids, such as enhanced efficiency, higher power quality, and lower losses. The state of charge (SoC) is an important indicator for energy management in a DC microgrid that connects to the utility grid bidirectionally. We describe an energy management system for a DC microgrid with bidirectional power flow with the utility grid in this paper. The SoC of the battery determines how much energy can be stored and discharged from the battery. The mathematical equations for SoC in the proposed energy management system are presented in this study. Further, The analysis is done for both grid-connected mode and islanded mode. Various system attributes and situations are used to assess the proposed statement. The simulation results show that the proposed system can successfully regulate the energy flow in the microgrid and achieve the desired objectives.

Keywords:- *DC Microgrids, Energy Management System, State of Charge*

I. INTRODUCTION

The energy management system (EMS) is a crucial component of a DC microgrid that is responsible for optimizing the energy flow among different components. The EMS should be designed to ensure the reliability, efficiency, and sustainability of the microgrid. The properties of each component, as well as the operating circumstances, must be considered by the EMS. The PV system generates power throughout the day and has the capacity to fulfill load demand. When solar radiation is low, the fuel cell system can create electricity and serve as a backup power source. The battery system may store surplus energy generated by the PV system and provide electricity during times of peak demand. Supercapacitors can provide fast energy storage and discharge and can be used for power smoothing. The EMS can be designed to optimize the use of these different systems and ensure that the microgrid operates efficiently. The EMS should be able to manage the energy flow in real-time to ensure that the system operates at its maximum efficiency [1-3].

SoC analysis is an important aspect of monitoring and controlling the performance of a DC microgrid with directional flow. The SoC analysis comprises monitoring the amount of energy stored in the microgrid system's energy storage devices. In a directed DC microgrid, energy storage devices such as batteries, supercapacitors, or flywheels are utilised to store energy from the central power supply and provide electricity to the loads. The SoC of these energy storage devices is a vital parameter that must be checked and modified in order for the microgrid to run consistently and effectively. The SoC of the energy storage devices is typically measured using sensors that monitor the voltage and current of the storage device. The SoC can then be estimated using a mathematical model that takes into account the capacity and efficiency of the storage device, as well as the amount of energy that has been charged or discharged.

A photovoltaic/fuel cell/battery/supercapacitor DC microgrid's energy management is a complex and demanding task. A variety of parameters, including system efficiency, reliability, and stability, must be carefully considered. In this article, authors discussed various aspects of energy management in a DC microgrid, along with the role of photovoltaic, fuel cell, battery, and supercapacitor systems. Photovoltaic systems are the most common renewable energy sources used in DC microgrids. They convert solar energy into electricity, which can either be used directly or stored in batteries for later use.The efficiency of PV systems depends on various factors such as sunlight intensity, temperature, and shading. Fuel cell systems are another type of renewable energy source that can be used in DC microgrids. They create electricity by mixing hydrogen and oxygen, which results in the production of water and heat. Fuel cell systems are highly efficient and reliable, making them an attractive option for microgrid applications.

Battery systems are essential components of DC microgrids as they provide energy storage capacity. Batteries can be charged using PV or fuel cell systems, and the stored energy can be used during periods of high demand or when there is no renewable energy available. Battery systems are available in various chemistries, each with its own set of advantages and disadvantages. Supercapacitor systems are another type of energy storage system that can be used in DC microgrids. They store energy in an electric field rather than a chemical reaction, making them highly efficient and durable. Supercapacitor systems are particularly useful for applications that require high power output and fast charging and discharging times. Effective energy management in a DC microgrid requires the integration of these different renewable energy sources and energy storage systems. The energy management system must ensure that energy is produced and consumed in the most efficient manner possible, while also maintaining the stability and reliability of the microgrid.

DC microgrids are gaining popularity in recent years as an efficient and sustainable solution for energy management. These microgrids may be built with a number of renewable energy sources, including as photovoltaic systems, fuel cells, batteries, and supercapacitors. The goal of this research is to investigate the energy management of a DC microgrid composed of these distinct technologies. [7-8].

II. LITERATURE REVIEW

These articles discuss various energy management strategies for DC microgrids with bidirectional power flow with the utility grid, including the use of renewable energy sources, energy storage systems, and advanced control techniques. They provide insights into the latest developments in the field and offer valuable information for researchers and practitioners interested in DC microgrid technology.

Authors in [9] proposed a multi-mode EMS for a hybrid AC/DC microgrid. This EMS can effectively manage power flow and guarantee stable system operation. The power flow between various sources and loads is managed by the proposed EMS using a fuzzy logic controller. Authors in [10] proposed a model predictive control (MPC)-based multi-mode EMS for AC/DC hybrid microgrids that can effectively manage power flow and guarantee stable system operation. The suggested EMS forecasts the ideal power flow between various sources and loads using an MPC-based controller. The multi-mode EMS for AC/DC microgrid proposed in this paper can efficiently control power flow and provide stable system operation while taking into account the integration of renewable energy sources. The suggested EMS uses a hybrid controller based on fuzzy logic and linear programming to control the power flow between diverse sources and loads [11].

The best EMS for a DC microgrid was presented by Ferahtia et al. [12]. The salp swarm algorithm (SSA) is the foundation of the proposed EMS. In terms of system efficiency and fuel consumption, the proposed EMS outperforms the state machine control method (SMC), and the results reveal that the proposed EMS is superior (5.2% fuel savings). In terms of power quality, the proposed EMS is compared to an EMS-based PSO to investigate the influence of the optimizer; the results show that the proposed EMS has the potential to provide enhanced power quality. Dong et al. [13] proposed an energy management strategy for a bidirectional DC microgrid employing renewable energy sources such as solar and wind power. The study applies a multi-objective optimisation approach to compute the optimal energy dispatch for the microgrid while accounting for cost, power quality, and environmental impact. The authors of [14] propose an adaptive fuzzy sliding mode control (AFSMC) energy management strategy for a DC microgrid with bidirectional power flow. The proposed method optimises energy dispatch while taking into account variables such as load demand and renewable energy output. The authors provide simulated data to demonstrate the effectiveness of the recommended method.

Furthermore, the authors of [15] present an energy management approach for a DC microgrid with bidirectional power flow that includes EV charging stations. The proposed method combines a mix of optimisation and management techniques to achieve a balance between energy generation and demand while also ensuring efficient charging for EVs. Similarly, the authors of [16] provide an MPC-based energy management strategy for a DC microgrid with bidirectional power flow. The proposed technique accounts for the unpredictability of renewable energy sources and load demand, and optimises energy dispatch to achieve a balance of energy supply and demand. The authors provide simulated data to illustrate the effectiveness of the suggested approach. The authors of [17] propose an energy management approach for a bidirectional DC microgrid that includes renewable energy sources such as solar power. The proposed method makes use of a genetic algorithm to improve energy dispatch and achieve a balance between energy generation and demand.

Moreover, In [18] a dependable EMS for AC/DC microgrids is suggested in this paper. Energy sharing, load frequency control, and effective power flow management are all made possible by the EMS. The proposed EMS uses distributed control, allowing each microgrid node to make decisions on its own while taking the system's objectives into account. The simulation's results are used to demonstrate effectiveness of the EMS. In order to effectively manage power flow and ensure steady system operation, this article presents an EMS for hybrid AC/DC microgrids. The suggested EMS uses fuzzy logic-based control to accommodate for system uncertainties and disturbances. The simulation's results are used to demonstrate effectiveness of the intended EMS [19]. Furthermore, a solid EMS is suggested in this work to control the power flow and ensure stable system operation for AC/DC microgrids employing renewable energy sources. The proposed EMS uses a decentralized control strategy that enables each microgrid node to make decisions on its own while taking the system objectives into account

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[20]. A reliable model predictive control (MPC)-based energy management method for AC/DC microgrids is suggested by Xu et al [21]. The suggested method uses a predictive control strategy that takes the system's uncertainties and disruptions into account in order to ensure stable operation of the microgrid. The effectiveness of the suggested method is demonstrated using the simulation's results.

Furthermore, in [22] an effective artificial intelligence (AI)-based EMS for AC/DC microgrids is proposed. This EMS can effectively control power flow and provide steady system performance. For each microgrid node, the suggested EMS uses a deep reinforcement learning algorithm to find the appropriate control approach. Similarly, in [23] an effective AI-based EMS for AC/DC hybrid microgrids is suggested in this study. Even in the face of uncertainty, this EMS can effectively manage power flow and provide steady system functioning. For each microgrid node, the suggested EMS uses a support vector machine and a reinforcement learning algorithm to find the appropriate control approach. In order to effectively regulate power flow and ensure system stability, this study recommends an AI-based robust EMS for AC/DC microgrids that takes energy storage and renewable energy sources into account [24]. To choose the most effective control method for each microgrid node, the suggested EMS employs a neural network and a fuzzy control algorithm. The simulation's results are used to demonstrate the effectiveness of EMS. Moreover, In [25] a hybrid AI-based resilient EMS for AC/DC microgrids is suggested in this study. Power flow may be effectively regulated by this EMS, which also ensures steady system performance. The suggested EMS combines fuzzy logic and deep reinforcement learning methods to determine the appropriate control strategy for each node in the microgrid.

Hence there is an urgent need to bring new innovations in the development of energy management of DC microgrids. Furthermore, in this work the expression of SoC is proposed, and analyzed under the effect of various system parameters. Moreover, the system performance is analysed for both grid-connected and islanded mode of DC microgrids.

III. PROPOSED MODEL

A. Block Diagram

This block diagram depicts a dc microgrid with an energy management system made up of a range of renewable energy sources such as solar panels, wind turbines, batteries, utility grids, and loads. The load and all energy sources are configured such that they can all be carried by the 48V dc bus. PV is connected to the bus through a closed-loop boost converter with 48V continuous outputs. DC power distribution networks were formerly used in communications systems. In communications networks, the most common voltage level is 48 V, which also acts as the system voltage. The DC microgrid system depicted in Fig. 1 is made up of a solar PV array, a BES, a grid connected voltage source converter (G-VSC), and other DC loads.

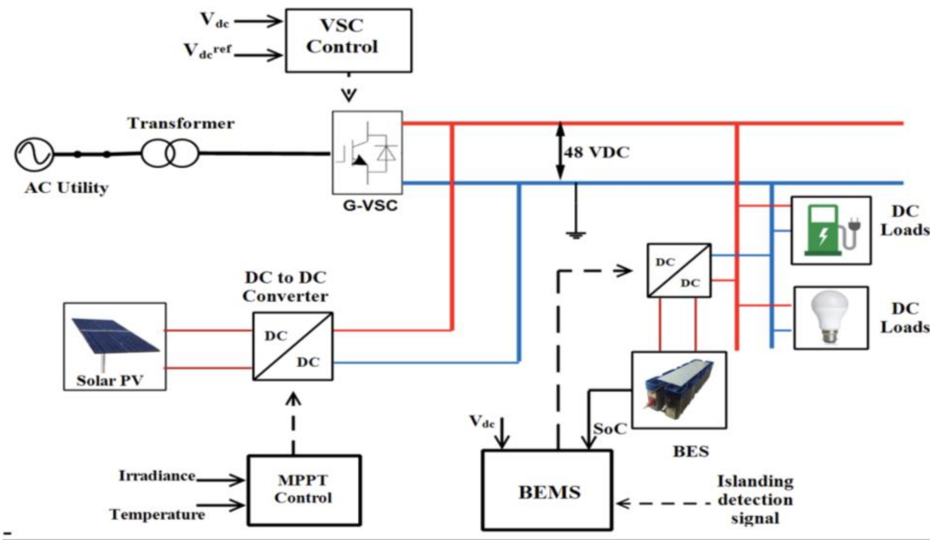

Fig 1 DC Microgrid Model

Further, the DC microgrid can be operated in two modes. When in grid-connected mode, the DC microgrid is linked to the main grid and operates in parallel with it. The microgrid can import or export electricity to the main grid based on its power balance. In this mode, the microgrid can operate in two ways: as a voltage source or as a current source. The DC microgrid is separated from the main grid when in islanded mode. It generates its own energy and distributes it to loads nearby. In this mode, the microgrid must maintain a steady frequency and voltage to ensure that the loads operate properly. To do this, the microgrid must be outfitted with control algorithms as well as energy storage devices capable of controlling power balance and keeping a consistent frequency and voltage. Both grid-connected and island solutions have advantages and disadvantages. Grid-connected mode benefits the microgrid from the main grid's stability and dependability, but it also exposes the microgrid to potential grid interruptions and blackouts. The islanded mode allows the microgrid more flexibility and independence, but it also demands more intricate control and safety methods.

B. Units

The SoC is an important parameter for energy management in a DC microgrid with bidirectional power flow with the utility grid. The SoC of the battery determines the amount of energy that can be stored and discharged from the battery. In this section, we derive the mathematical expressions for SoC in the proposed energy management strategy.

Let V_batt be the voltage of the battery and Q_batt be the total capacity of the battery in ampere-hours (Ah). The SoC of the battery, denoted as SoC_batt, can be defined as the ratio of the current charge in the battery to its total capacity. Thus,

$$SoC\_batt = Q\_charge / Q\_batt \qquad (1)$$

Where Q_charge is the current charge in the battery, in Ah. The current charge in the battery can be expressed as the integral of the charging current, i_batt, over time. Assuming a constant charging current over a time interval, t_1 to t_2, we have

$$Q\_charge(t2) - Q\_charge(t1) = \int t1\hat{}t2\ i\_batt(t)\ dt \qquad (2)$$

Assuming that the charging current is positive when the battery is being charged and negative when the battery is being discharged, we have

$$i\_batt(t) = i\_pv(t) - i\_ld(t) - i\_grid(t) \qquad (3)$$

Where i_pv(t), i_ld(t), and i_grid(t) are the currents from the PV panels, loads, and the grid, respectively. Substituting this expression for i_batt(t) in the above integral, we have

$$Q\_charge(t2) - Q\_charge(t1) = \int t1\hat{}t2\ (i\_pv(t) - i\_ld(t) - i\_grid(t))\ dt \qquad (4)$$

The total capacity of the battery, Q_batt, can be expressed as

$$Q\_batt = V\_batt * C\_batt \qquad (5)$$

Where C_batt is the rated capacity of the battery, in Farads. Substituting the expressions for Q_charge and Q_batt in the definition of SoC_batt, we have

$$SoC\_batt = (1/C\_batt) * \int t1\hat{}t2\ (i\_pv(t) - i\_ld(t) - i\_grid(t))\ dt \qquad (6)$$

This expression shows that the SoC of the battery is a function of the currents from the PV panels, loads, and the grid over a time interval. By monitoring the SoC of the battery, the energy management system can optimize the energy usage of the microgrid by controlling the charging and discharging of the battery to meet the load demand while minimizing the energy cost.

IV. RESULT & DISCUSSION

In this section the simulation results of the above mentioned models are shown. Simulation is performed under different scenarios to understand the energy management of DC microgrids.

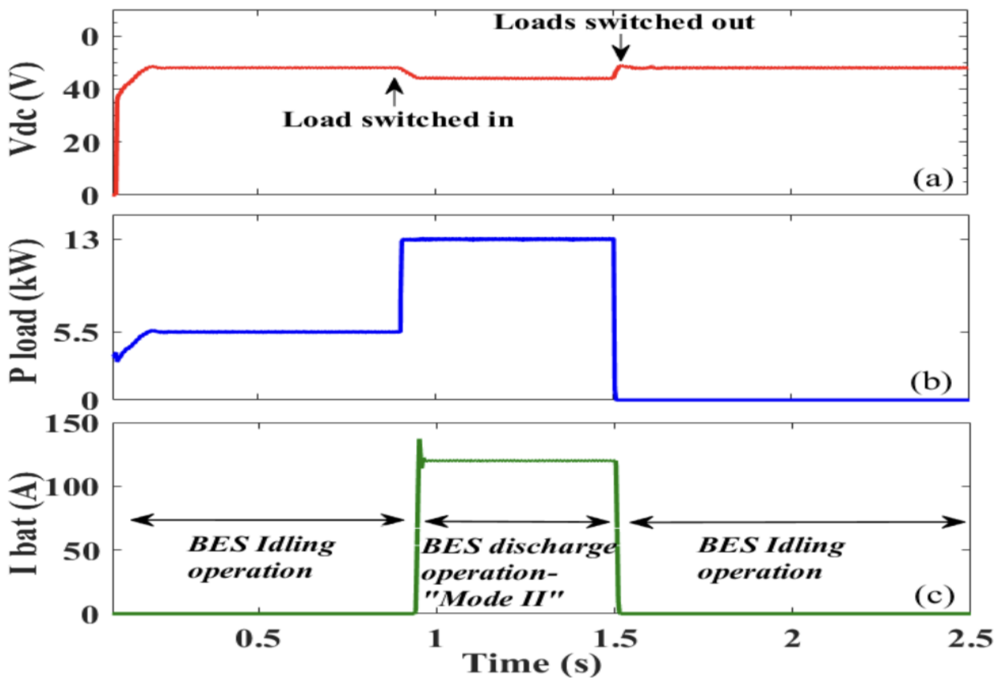

Fig. 2 (a) DC bus voltage, (b) load power and (c) battery current variation grid-connected and islanded mode during DC microgrid operation

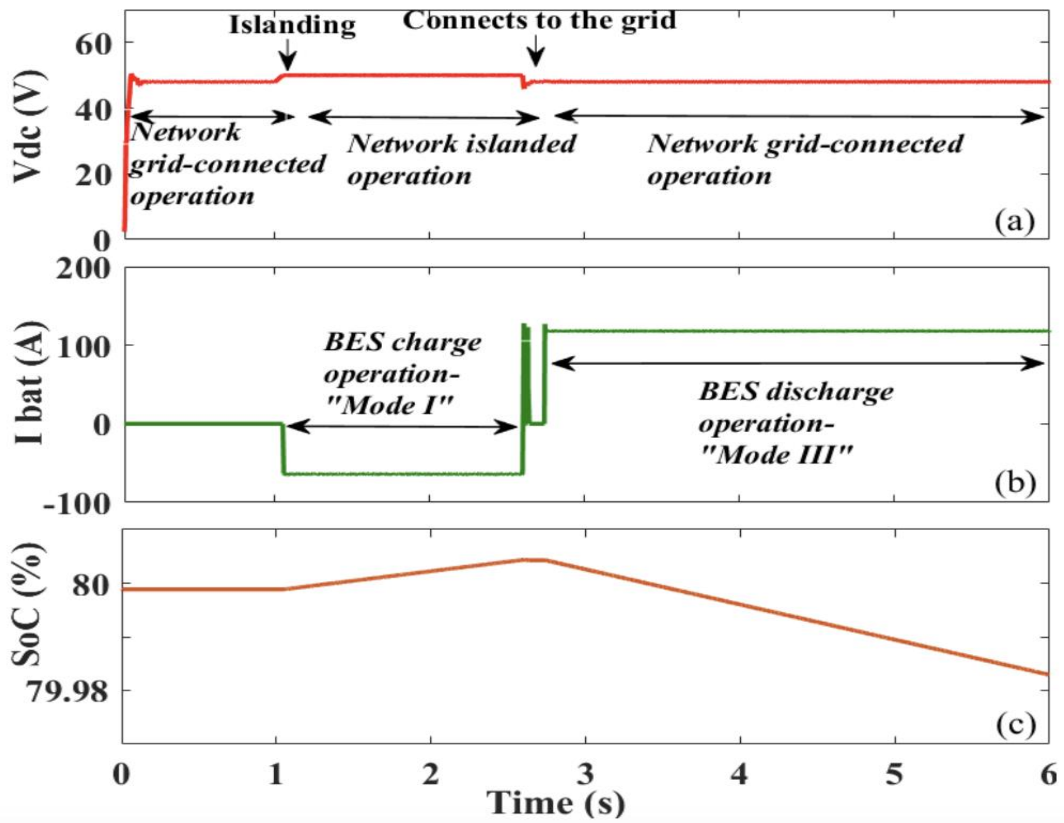

Fig. 3 (a) DC bus voltage, (b) battery current and (c) SoC level during grid connected and islanded mode variation for DC microgrid operation

In Fig. 2 The network is initially activated and functioning in grid-connected mode at t = 1 s. Solar PV power is insufficient to fulfil load demand at the time of islanding (Ppv Pload). As a consequence, BES relieves the excess power demand and controls V, the voltage of the DC connection. The loads are subsequently all turned off at t = 1.5 s, leaving the DC microgrid with additional power. The BES begins to charge in order to keep V at its nominal value.

As shown in Fig. 3, the BES discharges from the time the DC microgrid rejoins the grid at t = 2.5 s and continues until the SoC level hits 70%.

V. CONCLUSION

This work looks at the energy management system of DC microgrids. Simulation studies are carried out to assess the operational performance of the proposed system in a variety of conditions. This paper proposes a new phrase for the state of charge. Furthermore, the simulation results reveal that the proposed control mechanism has the potential to significantly improve network bus voltage stability and robustness to network disruptions. More study is needed to see how the proposed technique may be developed for energy management with numerous dispersed BESs.

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