



DESIGN OF A BIDIRECTIONAL DC MICROGRID CONTROLLED WITH ENERGY MANAGEMENT SYSTEM

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Abstract

Energy management integrating renewables and conventional grids might be viable for meeting current and future energy demands. The amount of energy generated from renewable sources varies from time to time. When a hybrid renewable-based unidirectional dc microgrid is linked to the utility grid, energy might be underutilized during periods of surplus generation. Bidirectional dc microgrid systems can help with energy management and address various environmental challenges. The architecture of a bidirectional dc microgrid, including solar photovoltaics (PV), wind turbines, battery storage and conventional utility grid has been designed in this work. An energy management system (EMS) is designed to supply the required energy to particular loads under various conditions. Maximum available power is extracted from PV using Maximum Power Point Tracking (MPPT), using the P&O algorithm. When the combined power of the PV panels and wind turbine exceeds the demand of the loads, the extra energy is used to charge the batteries. The remaining energy is supplied to the power grid through an inverter when the battery's state of charge (SOC) reaches 90%. When there is a dearth of generated electricity from renewable sources, and the battery's SOC is less than 30%, power is drawn from the utility grid and provided to loads. The system design is implemented in MATLAB/Simulink and the effects of altering the circumstances on the electrical parameters are observed. Variable load and generation circumstances are used to generate the simulation results.

Keywords: Bidirectional power flow, DC microgrid, Energy management system, Hybrid renewable generation, MPPT, Energy storage system

Introduction

Fossil fuel-based energy generation is concomitant with various environmental degrading issues. As fossil fuel reserves continue to deplete and carbon emissions continue to climb, developing countries are moving toward widespread use of renewable, sustainable energy sources. At present, the way energy is generated, distributed, and consumed globally is undergoing rapid change, as evidenced by the expansion and deployment of renewable energy sources in developed and developing countries (Razmjoo et al., 2021). By infusing clean

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energy and offering long-term economic benefits, the integration of renewable energy sources into distribution generation has a long-term effect on this situation. A microgrid powered by renewable energy sources (RES) has the potential to significantly impact the energy-producing sector.

The microgrid concept was first viewed as a viable solution to the progressive depletion and environmental degradation caused by fossil-fuel resources, as well as a more efficient and cost-effective electricity infrastructure (Sabzehgar, 2015). A microgrid is an electrical network made up of diversified loads and distributed generation, such as photovoltaic systems, wind turbines, battery storage, and diesel generators, among others. It can operate independently as an electrical island or in parallel with a larger utility grid. (Bhavsar et al., 2015). Incorporating a large number of individual energy generation units into a microgrid eliminates the need for the transmitting of high voltage distribution networks and results in a more efficient and reliable power system that enables the installation of generating units as well as high penetration of renewables (Sabzehgar, 2015). Microgrids can be used to distribute electricity in either an alternating current or direct current configuration (Sanjeev et al., 2017). DC microgrids are being recognized as a more efficient structure for integrating RES, such as wind and solar for their more adequate and simple system controllability compared to standard ac microgrids. Dc microgrids avoid frequency issues, and while voltage regulation is necessary, reactive power management is not (Li et al., 2020) (Dragicevic et al., 2014).

Energy management is a term that refers to the process of regulating various types of energy sources inside an enterprise. An energy management system (EMS) is a computerized system that monitors and forecasts the generation and use of energy (Borase & Akolkar, 2017). EMSs are simpler in direct current systems than in alternating current systems because they are not subject to reactive power nonlinearities. Additionally, because ac microgrids are three-phase power systems, they generate complicated and computationally expensive energy management system (EMS) challenges based on linear and nonlinear programming models, which are not necessary for dc microgrids, which are simple two-wire systems instead (Li et al., 2020) (Solanki et al., 2019).

Microgrids can function alone (autonomous) or in cooperation with utility grids (Sanjeev et al., 2017), depending on the availability of conventional grids. At any time, an isolated microgrid energy deficit may occur owing to high demand or environmental consequences (as PV and wind generation varies), and if a utility grid link to the dc microgrid is not possible, power cuts are implemented. A DC microgrid connected to the utility grid in a unidirectional power flow configuration can be a dependable method for meeting demand.

Several studies utilizing ac or dc microgrid energy management control techniques have been conducted. In Sanjeev et al. (2017), it effectively showed the energy management and control of a secluded dc microgrid. Photovoltaic (PV) systems, wind turbines, hybrid energy storage systems, and diesel generators comprise the microgrid. When storage and sources of energy are unable to meet demand, a power interruption occurs. For a specified period of time, when the system is unable to meet demand due to a lack of grid connectivity during periods of peak demand from critical loads; as a result, the critical loads must be discharged. A paperwork presented in Subramanian et al. (2021) to extract the maximum power possible from the PV by the MPPT technique along with a supercapacitor. This article demonstrates the DC micro grid's increased efficiency and reliability. However, because it is a stand-alone system. It may experience an energy deficiency. A research work was on Bhavsar et al. (2015) about the Energy Management System in DC Microgrid. This research utilized a unidirectional power flow from the utility grid to the dc microgrid. Due to the design's connection to the utility grid, any energy shortfall caused by reduced renewable generation and battery storage capacity can be compensated for by the utility grid's power flow.

In this instance, a concern emerges regarding the reason for the underutilization of generated energy during periods of surplus generation from renewable energy sources, as their generation changes according to environmental and meteorological characteristics. An energy management system for the bidirectional DC Microgrid may prove useful in this scenario. When the dc microgrid has excess generation, it can deliver clean energy to the conventional ac grid's loads, so increasing the process's sustainability.

Based on the aforementioned difficulties raised in the literature, the paper focuses on the design architecture and simulation of a bidirectional DC microgrid and its Energy Management System, as well as the observation of the impacts of varying the electrical characteristics under various conditions. The rest of the paper is organized following Materials and Methods, Results, Discussion, and Conclusion.

Materials and Methods

Simulation Model

Figure 1 depicts the complete simulation model of a dc microgrid, which consists of PV arrays, a wind turbine generator (WTG)(PM DC generator), a battery storage system, grid, and load. The 2 kW PV array and wind turbine generator are coupled to a 48 V dc bus using a constant voltage closed loop boost converter that raises the 24V PV array voltage to 48V.

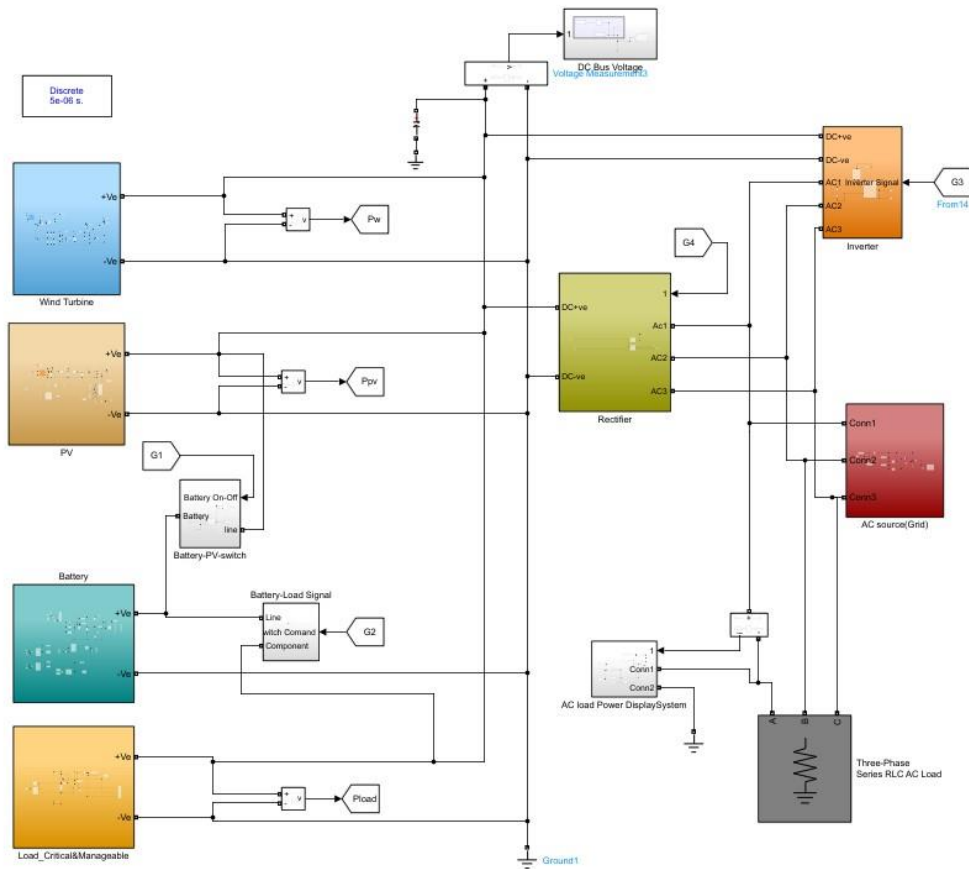


Figure 1. Simulation Model

For the energy storage system, a lithium-ion battery with a capacity of 15 Ah and a voltage of 48V is utilized, along with a charging/discharging controller. The dc microgrid and grid are connected to the dc bus

through an inverter and a rectifier to ensure bidirectional power transmission. The dc bus supplies a resistive load of 2.2kW, whereas a critical load of 1.2kW.

The output signals are G1 for battery charging, G2 for battery discharging, G3 for the on/off status of the grid inverter, G4 for the on/off status of the grid rectifier, and G5 for the on/off condition of the manageable load.

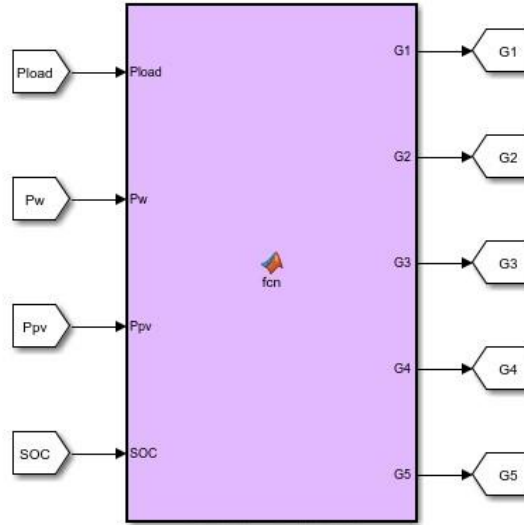


Figure 2. Energy Management System

B. Energy Management System

Energy Management System (EMS) in Figure 2 is the controlling hub of the designed architecture. It gathers the current information on the total energy generation, load consumption, and battery SOC and makes decisions depending on the preset conditions.

Total generated energy from renewable sources:

$$P_{PV} + P_W = P_E$$

where P_{PV} is power generated by PV array and P_W is power generated by wind turbine generation system.

And total load,

$$P_{L1} + P_{L2} = P_L$$

where P_{L1} is the critical load and P_{L2} is the manageable load.

After comparing P_E and P_L ,

$$\text{If } P_E > P_L \text{ and battery SOC} < 0.9$$

then charge the battery with power generated from renewable sources by triggering the charging controller which is giving signal $G_1 = 1$. Otherwise $G_1 = 0$.

If $P_E > P_L$ and battery SOC > 0.9

then supply the excess generated power via dc bus to the grid by switching on the inverter (G3).

Now,

If $P_E < P_L$ and battery SOC > 0.3

battery discharges power to meet the load demand by triggering the discharging controller $G_2 = 1$. Battery discharges until the SOC = 0.3.

If $P_E < P_L$ and battery SOC < 0.3

then power is taken from the grid through the rectifier when $G_4 = 1$. The battery remains idle at this instance. If the grid is unable to supply power, then some manageable load gets turned off by the controller $G_5 = 0$, otherwise $G_5 = 1$. The flow chart of this system is shown in Figure 3.

Results

Simulation of the system shown in Figure 1 is performed with the help of Matlab/Simulink to validate the feasibility of the proposed energy management strategy. The simulation results for variable generation and load are shown, with solar irradiation and wind forecast data expected to be varied during the day. All the power generated by PV and WTGS is plotted on the same axis, with variable solar irradiation and wind speed. The simulation is run for four different possible conditions. Conditions during the experiment are indicated in Table I.

Table 1. Different scheduling conditions for generation and load.

Condition	PV	Wind	Power Generated (PV+ Wind) kW	Load kW	Battery	AC Grid
1	Active	Active	2 + 1.8	2.2	Charging	Disconnected
2	Active	Active	2+1.8	1.4	No action (SOC>=90)	Receiving Power from DC Grid
3	Inactive	Active	1.5	2.15	Discharging	Disconnected
4	Inactive	Active	1.5	2.15	No action (SOC<30%)	Sending Power to DC Grid

According to condition 1, when both the wind and PV panels operate and the DC grid's load demand is less than the generation of renewables, the battery continues to charge.

The variable load linked to the system is 2.2 KW, whereas the total power produced by PV and WTGS is 3.8 KW (2KW+1.8KW). When the load is less than the generation, the battery will charge by triggering the static switch of the charge controller G_1 , allowing the battery to be charged with the extra power provided by renewable sources. Figure 4 shows that from points A to B, while both the wind and PV panels are active, the load stays constant at around 2.2KW as the battery charges in which the SOC of the battery is

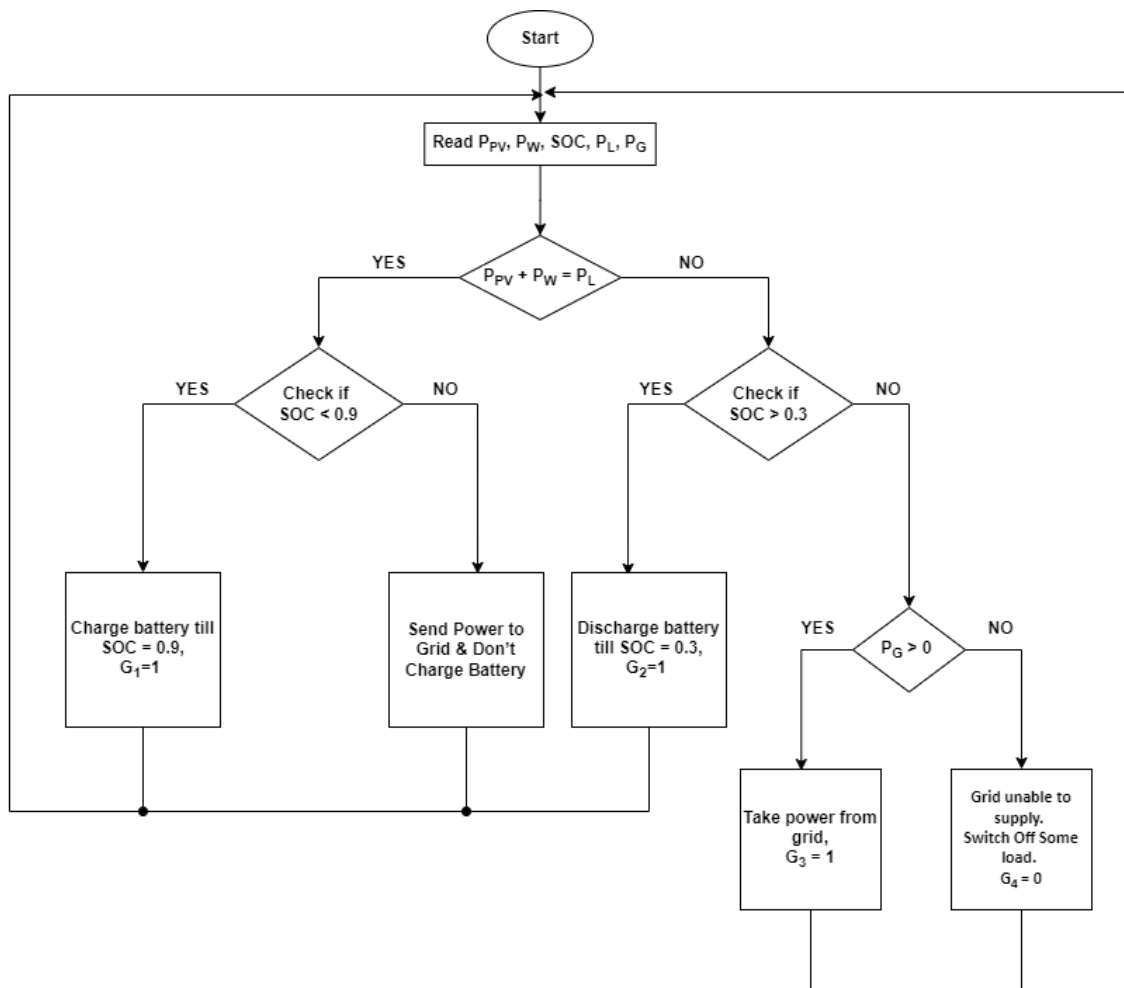


Figure 3. Flowchart of EMS

assumed to be 0.3 (30%). Here, the voltage also remains constant at around 46V. In Figure 5, the SOC of the battery is shown while charging.

Condition 2 implies that when both wind and PV panels are in operation, the AC primary grid receives power from the DC microgrid while the battery remains idle as it is charged. Here, the SOC of the battery stays between 0.9 to 1 (90 % to 100 %).

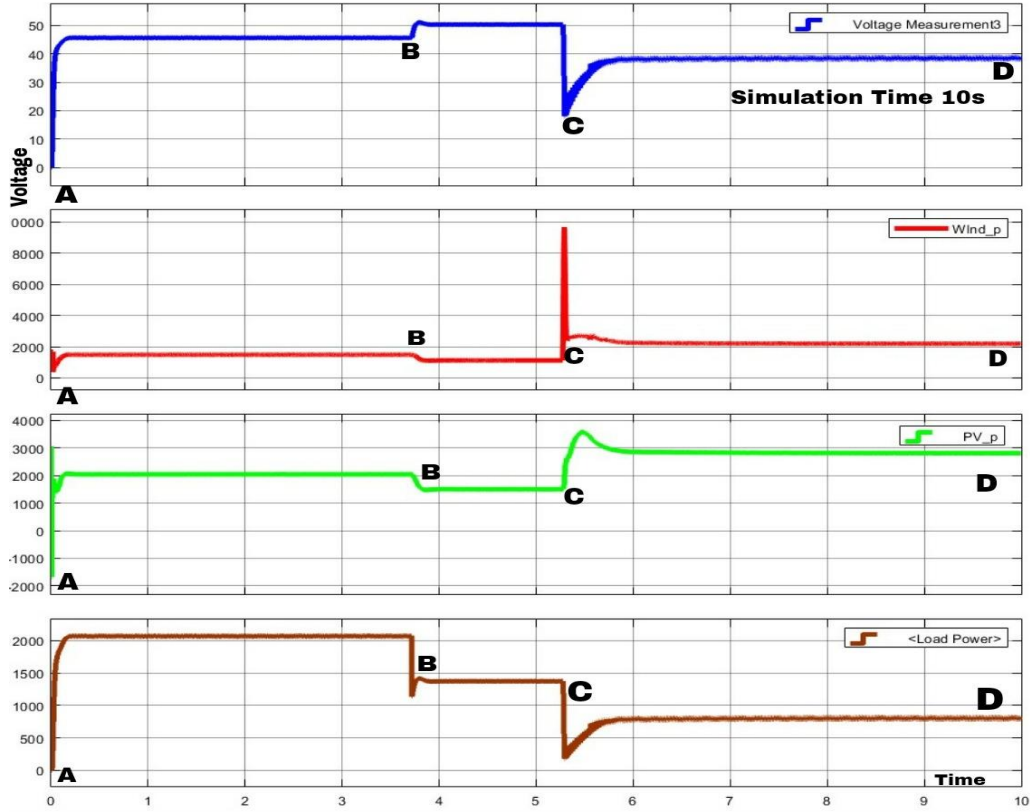


Figure 4. Power Supply from DC Microgrid to Main Grid Load

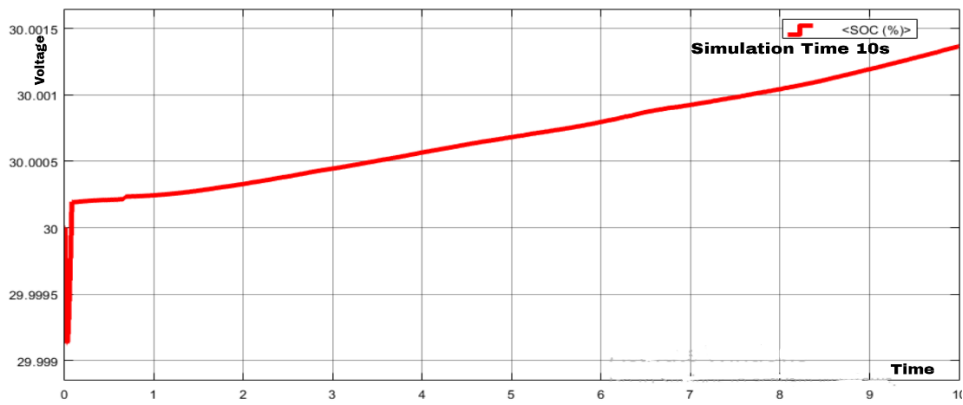


Figure 5. Battery SOC while Charging

Figure 4 shows that from points B to C, load power suddenly decreases to 1.4 kW, and the production of power from wind and PV panels also decreases following the MPPT P and O technique with a sudden increase in voltage. For points, C to D in Figure 4, load demand is less than 1 kW. As the battery is charged up to a defined value so the excess generation of renewables can be sent to the main AC grid's loads causing some voltage fluctuations in the dc grid voltage.

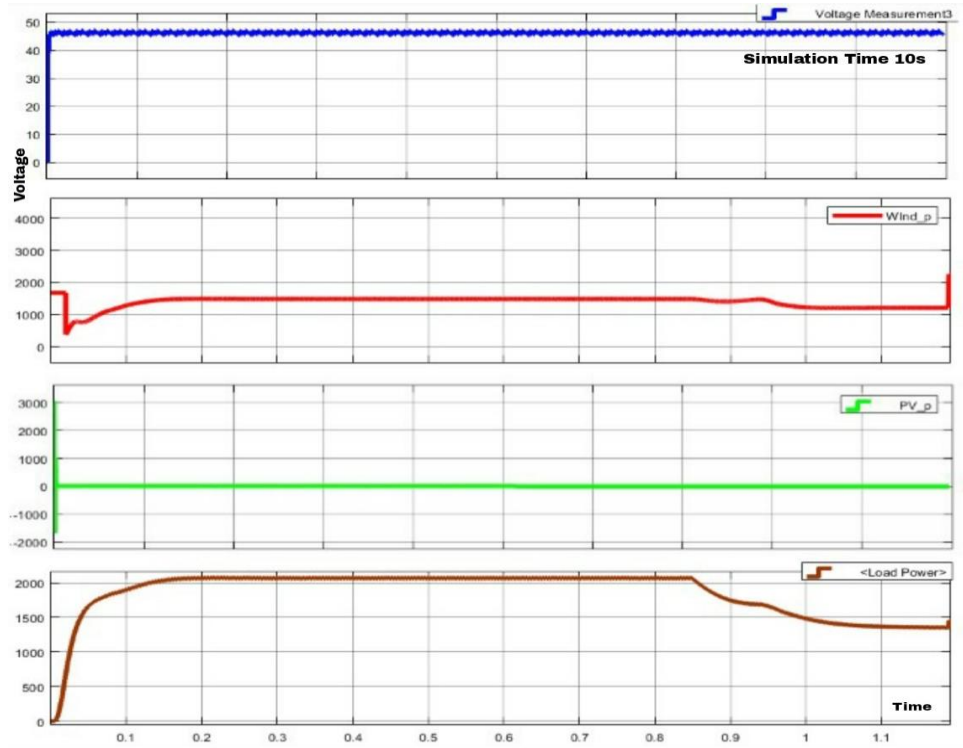


Figure 6. Power Supply when PV Panels Inactive and Wind Active

Condition 3 is for battery discharge, where the battery's SOC is expected to be greater than 0.3. (30 %). Here, only WTGS is active, while PV panels are not active. This scenario happens at night or during cloudy day or rainy weather when solar energy is unavailable for PV panels to produce electricity.

When the load demand exceeds the generation's capacity, more power is drawn from the battery to meet the demand. The battery is depleted up to 30% of the SOC to meet loads of DC micro grid's. Main grid is disconnected from producing electricity. The released energy from the battery and generated power from wind turbines are supplied to fulfill the load needs, as shown in Figure 6. The SOC of the battery when discharging is shown in Figure 7.

As illustrated in Figure 6 condition 4, only has WTGS on while the PV panels are off. After thoroughly draining the battery, the SOC falls below 0.3 (30 %), preventing it from being charged. The AC primary grid then supplies electricity to the DC microgrid to meet the load demand by showing some fluctuations in the DC grid's voltage in Figure 8.

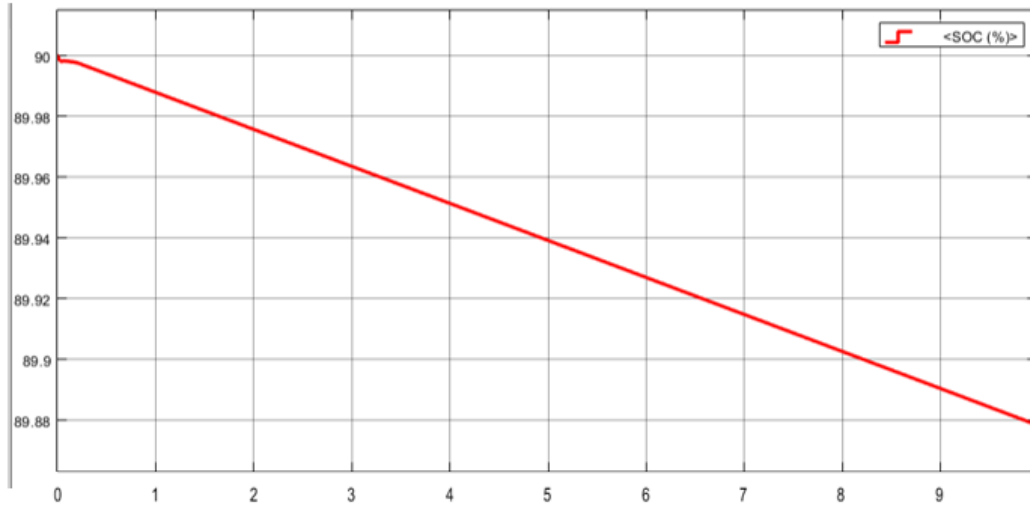


Figure 7. Battery SOC while Discharging

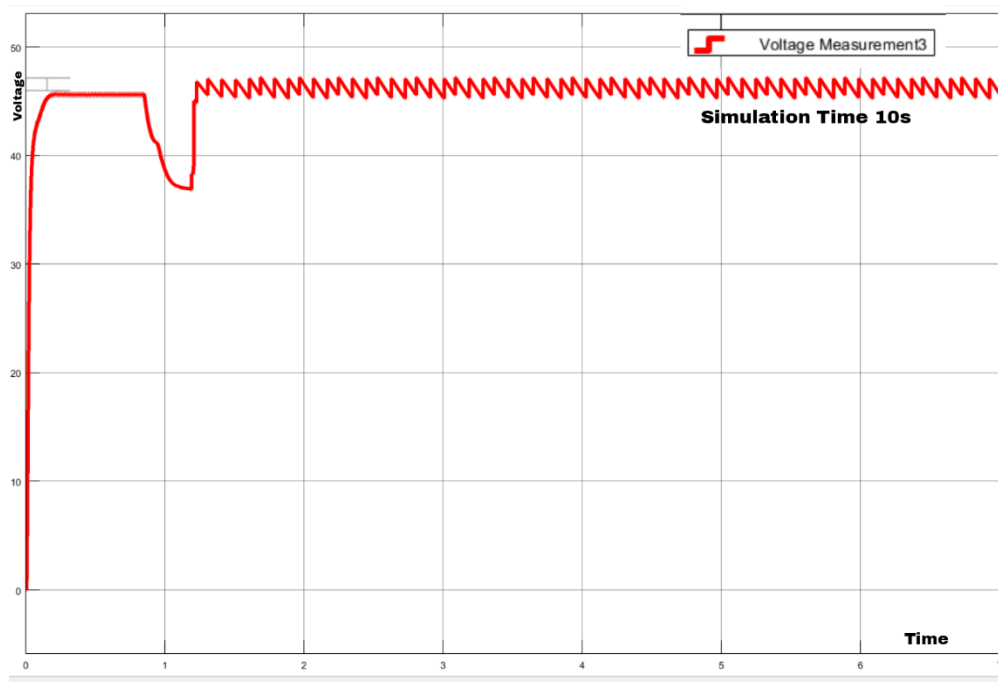


Figure 8. DC Micro Grid Voltage during Receiving Rectified Power from AC Grid

Discussion

The whole system can be highly effective for increasing the use of clean energy and also for distributed power generation applications. This is a two-way power flow-based system. Maximum research works are done is with the one-directional power flow. As the aforementioned conditions discussed, the simulated results show some technical parameter issues during changing the different states of the conditions.

In figure 4, during the transition from AB to BC, as the load reduces, a little over-voltage happens. Some DC microgrid voltage fluctuations also can be seen in the transition period of BC to CD where the excess generation of renewables is sent from DC microgrid to the utility AC grid via the inverter. The wind turbine experiences the most fluctuations but it is for a very short time.

Mainly, when the power supply happens between the DC microgrid and AC grid, the DC micro grid's voltage shows a few amounts of variations. During the receiving power from the AC grid via rectifier in condition 4 in Table 1, for a very short time, the voltage of the DC grid falls and after that it becomes stable. The selection of a quality rectifier can smooth the ripple of the DC microgrid.

Conclusion

Bidirectional DC Microgrid Controlled with Energy Management System can be handy in the concern of distributed generation. Providing sustainable energy to the main grid increases the reliability and sustainability of the grid. But as seen from the simulated results during the transition periods, it experiences some unwanted fluctuations. Uses of the facts devices and quality inverter and rectifier can emphasize the process be much more efficient. Some technical problems may arise during the simultaneous variation in the DC load demand or the varying weather parameters that affect the generation of renewable generation. Proper handling of EMS and short-time load forecasting method can be helpful to balance the generation between DC microgrid and AC main grid and these can reduce the sudden change of parameters effects on AC grid-connected DC grid. The transition of power flow from the DC grid to the AC grid or vice versa could be the focus of future efforts to increase grid stability. In the forthcoming study, fault analysis, transient study, mitigating voltage fluctuations, and economic analysis may also be explored.

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