Design and Simulation of DC Microgrid with DC-DC Bi-directional Converter

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***Abstract** - This paper presents the modelling and simulation of an autonomous DC microgrid in Matlab Simulink. A DC-DC converter, an inverter, a solar PV array, and DC loads are all included in the proposed microgrid system. A boost converter connects the PV array to the circuit and draws the most power possible from it. This study also covers a bidirectional DC-DC converter, which is in charge of the system's energy flow in both directions. The microgrid system also includes a Battery Storage, which is linked by a bidirectional buck-boost converter. Through its control function, the Battery Storage upholds the general stability of the microgrid. Finally, a simulation study of the microgrid is performed for a range of operational scenarios utilizing the proposed control strategies.*

***Key Words**:* Bidirectional DC-DC converter, photovoltaic, DC Microgrid, Maximum Power Point Tracking, Inverter.

1.INTRODUCTION

Recent years have seen significant concerns about rising emissions, diminishing fossil fuel reserves, and rising energy usage. A boom in interest in distributed renewable energy generation has been driven by these worries. Microgrids look to be a promising strategy for incorporating these greener, more effective renewable energy sources into the grid. In addition, they offer a host of other advantages, including as reduced transmission losses, enhanced power quality and dependability, lower emissions, and even support for a range of power quality. Most importantly, it makes it possible to electrify remote communities that are outside the range of the conventional power system. Depending on their power frequency of operation, microgrids can be classified as AC, DC, or hybrid microgrids. A DC microgrid can save more energy than an AC microgrid by having fewer converters inside the microgrid system. There are converters for connecting distant renewable energy sources, loads, and energy storage systems. Other significant benefits of a DC system include addressing some of the microgrid's control issues. For instance, controllers are no longer reliant on dispersed generation synchronisation and are now purely reliant on DC bus voltage. Furthermore, main control is significantly easier because there is no reactive power flow management.

In this study, it is suggested to develop and analyse a DC microgrid utilising a DC-DC bidirectional converter. The microgrid is intended to function independently from the electrical grid. A number of solar PV modules make up the energy generation component of the microgrid system. The sources are connected to the proper converters in order to provide electricity to the microgrid. Through an inverter, the load is connected to the DC bus. To achieve seamless control of the entire microgrid, a centralised battery unit with a bidirectional converter is also used.

First, the simulation of dc-dc bidirectional is carried out to demonstrate that it is capable of carrying out battery charging and discharging. Then, we demonstrated the algorithm and operation of the maximum power point tracking. Finally, we have examined how the DC microgrid functions when its constituent parts are present.

2. SYSTEM STRUCTURE

2.1. DC Microgrid Architecture

The proposed DC microgrid's overall system configuration is depicted in Fig. 1. It comprises of a common radial DC bus to which the microgrid's numerous parts are connected. In this setup, solar PV is regarded as the main power source. A boost converter is also used to link a 2.5kW solar PV array to the microgrid. The microgrid system provides a variable DC load, which could be a building load or a collection of households. To provide precise control of the microgrid, a centralised BESS is used. In this instance, the battery unit is connected using a bidirectional DC-DC converter.

The DC microgrid's configuration is created such that it can function independently without any connection to the utility.

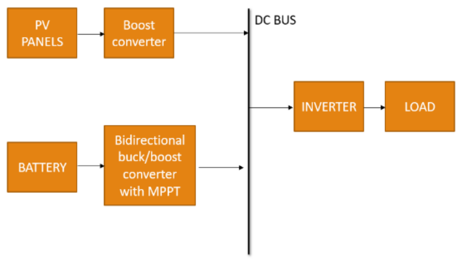

Fig. 1. Architecture of the DC Microgrid

The thorough modelling processes for each of the microgrid system's components are covered in the section that follows.

2.2. DC-DC Bidirectional buck boost converter designing

The Battery Storage is connected to the microgrid network using a bidirectional DC-DC converter (shown in Fig. 2). Its primary purpose is to increase the stability and security of the microgrid's overall performance. The bidirectional converter, as depicted in the figure, is made up of two converters: a boost converter and a buck converter. The Inverted Gate Bipolar Transistors (IGBT) used in each converter are powered by the appropriate Pulse Width Modulated (PWM) signals. The converter's control mechanism is designed to permit a controlled flow of electricity in both directions. A control signal that drives the circuit in buck mode is generated during the period of excess power.

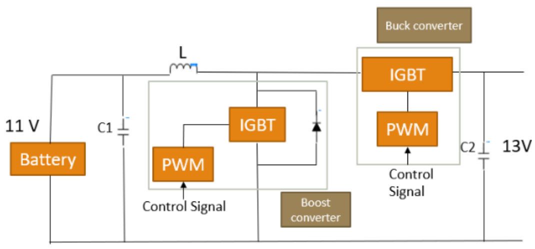

Fig. 2. Bidirectional buck boost converter circuit design.

It is reducing the 13V DC voltage to a level that is appropriate for charging the battery unit—roughly 11V.When there is a power shortage, the control signal activates the boost converter, which raises the battery voltage to the DC voltage in order to draw power from the battery. These values are just for analysis of the DC-DC Bidirectional converter to show that it can perform charging or discharging. The Fig. 3 is the simulation result of the bidirectional dc-dc converter in Matlab.

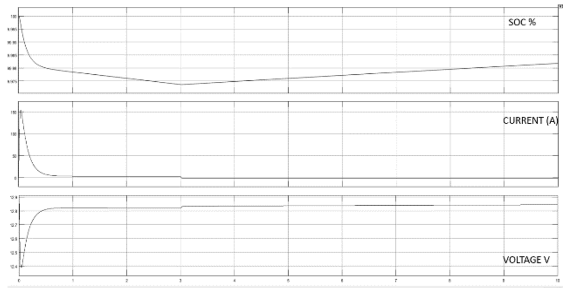

Fig. 3. Output result of modelled dc-dc converter

We have used step signal at 3 second, therefore we are seeing the change in graph of Soc, Voltage and current. The negative current indicates the discharging of Battery. It confirms that charging and discharging can be done in this converter. So we can use this converter and change the values according to our dc microgrid.

2.3. PV Module

We have used a user-defined PV panel with four module strings and one parallel string. T is held constant at 25, and the irradiances vary. The simulation will last 2 seconds. Irradiance is 1000 at 0 sec, 300 at 1 sec, and remains constant for the rest of the simulation.

A 2.5kW PV array is utilised for the DC microgrid simulation. A boost converter connects this array to the DC distribution network. The Maximum Power Point (MPPT) tracking algorithm is used by the boost converter. This MPPT capability is essential because it will enable the PV array to generate the greatest amount of power for a specific irradiation input. The MPPT incremental conductance approach is applied in this situation. One of the key techniques in this system is incremental conductance, a tracked control mechanism that is frequently used due to its improved steady-state accuracy and environmental adaptability. The P-V and I-V curves of our PV module are depicted in the Fig.4.

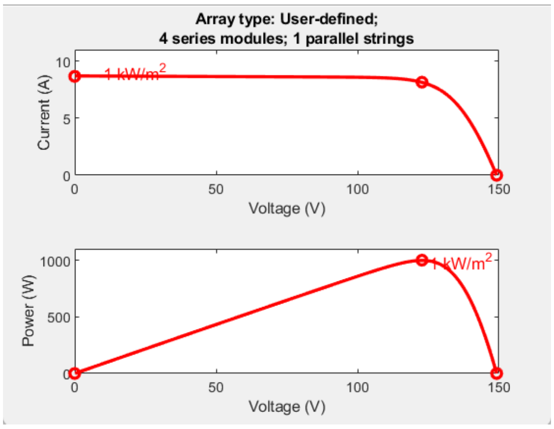

Fig. 4. I-V and P-V Curve

2.4. Battery Storage Modelling

A Battery Storage is an electrochemical device that charges (or gathers) energy from the grid or a power plant and then discharges that energy when electricity or other grid services are required. We used a lead acid battery with a nominal voltage of 56 volts and a rated capacity of 11 ampere hour. The initial state of charge is 45 percent and the battery is connected with the bi-directional converter to the DC Bus.

A negative electrode constructed of spongy or porous lead is used in a lead acid battery. The lead is porous in order to allow lead formation and dissolution. Lead oxide serves as the positive electrode. Both electrodes are submerged in a sulfuric acid and water electrolytic solution.

3. MICROGRID CONTROL

The DC microgrid uses a variety of control techniques to function properly regardless of changes in load and generation. The buck converter, which is the microgrid's converter, is operated in a voltage control mode since it is treated as the main source of energy and runs independently. This indicates that the converter's control action is configured to maintain the necessary 200V DC bus voltage when it is in use. While the PV array's controller runs in a current-controlled mode to draw the most electricity possible. To get the most current and thus the most power out of the PV circuit, the converter uses the MPPT algorithm.

3.1. Maximum Power Point Tracking

When the solar panel is operating at the voltage where the P V characteristic's global maximum is located, the maximum power (MP) is obtained. It demonstrates that the solar panel can produce its maximum power output at a certain operational point. The Maximum Power Point is where the P V characteristic curve occurs (MPP). This point is always at the solar panel's I-V curve's knee. In summation, it can be said that the solar panel's I-V curve has a point called the MPP (Maximum Power Point), which is always found at the knee of the curve and is where the amount of PV power produced is at its maximum. This MPP changes as the temperature and radiation levels fluctuate. The MPP tracking algorithm must operate essentially in real time by changing the duty cycle continuously in order to maintain the tracking's speed and accuracy because the irradiation and temperature are dynamic in nature.

A control device used to keep track of the MPP's continual change is called the Maximum Power Point Tracker (MPPT). This control system or controller is made up of two primary components: a converter that changes the generated voltage to the correct level for the load and a microcontroller that tracks the MPP. On the micro controller, an algorithm is being used to track the MPP. Numerous alternative algorithms are employed to track the MPP, but none of them are effective in rapid fluctuations, such as rapidly changing irradiance levels or when the solar panel is partially shaded. However, it is crucial for the system to have an algorithm that can deliver precise control signals even when irradiance levels are rapidly changing or the solar panel is partially shaded. Therefore, the algorithm's effectiveness is crucial.

The MPPT controller uses the algorithm to determine the MPP. The controller accepts as inputs the measured output voltage and current of the solar panel. The algorithm performs its calculations depending on these inputs. The controller generates an output that is the PWM's modified duty cycle. It powers the switching component of the DC/DC converter. The controller generates a separate duty cycle for each each operating point.

3.2. Incremental Conductance

The slope of the P-V curve is detected by the incremental conductance technique, and the MPP is monitored by seeking the peak of the P-V curve. For MPPT, this technique use the instantaneous conductance I/V and the incremental conductance dI/dV.

The Perturb & Observe Algorithm is enhanced by the Incremental Conductance Algorithm. Particularly in the face of changing atmospheric circumstances, our algorithm guarantees greater accuracy and efficiency. Despite these benefits, there are a few disadvantages to this method, including a longer response time and the fact that small-scale PV plants cannot afford it. When the perturbation and tracking process reaches the MPP, this method can calculate the distance to the MPP and end the process.

3.3. Operating Modes

Mode. 1: When $P_{PV} < P_L$, which indicates that there is insufficient solar power, the PV panels operate in MPPT mode under the control of the boost converter. Meanwhile, the battery provides the complementary power using the bidirectional buck/boost converter, which is operating in boost mode to control the DC bus voltage V_o (the reference direction is shown as in Figure 6.a).

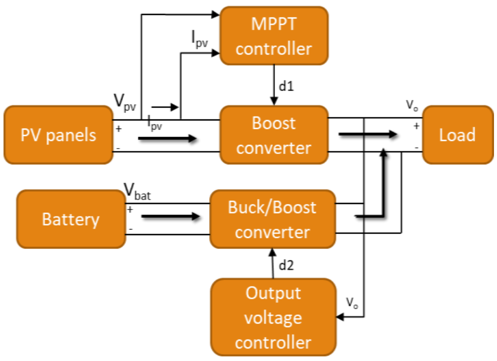

Fig. 5(a)

Mode. 2: The PV panels run in MPPT mode under the supervision of the boost converter when $P_{PV} > P_L$, which denotes an excess of solar power. Bidirectional buck/boost converter is running in boost mode to control the DC bus voltage Vo while the battery is being charged by complementary power utilising the converter (the reference direction is shown as in Figure 6.b).

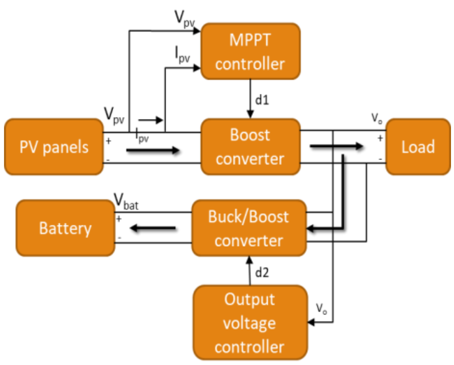

Fig. 5(b)

Mode. 3: I_{bat} must be managed to protect the battery when $P_{pv} > P_L$ and it hits the maximum charging current limit, I_{bmax}. As a result, the bidirectional buck/boost converter controls ibat when operating in buck mode. As seen in Figure c, the PV panels must transition out of MPPT control mode and manage the dc bus voltage.

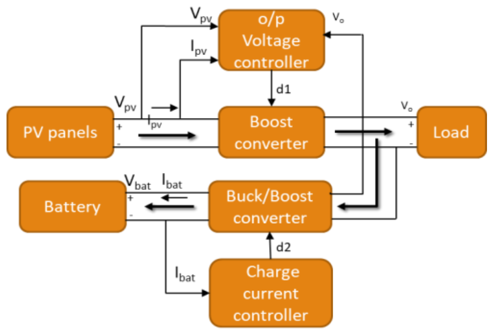

Fig. 5(c)

Mode. 4: The bidirectional converter will work in buck mode to control V_{bat} when $P_{PV} > P_L$ and V_{bat} reaches the maximum battery voltage limit V_{bmax}. The boost converter continues to control Vo at the same time, as seen in Figure 6.d.

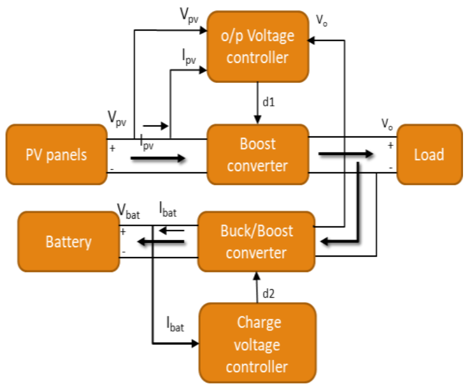

Fig. 5(d)

4. Results and discussions from simulations

A simulink model of a DC microgrid is constructed using the models of its numerous components. A variable load with a maximum demand of 6 kW is considered for the simulation's purposes. Solar radiation inputs are provided to the solar PV array model. The microgrid is then the subject of a simulation study under various operational conditions. The simulations are performed in this example for a total of 2 seconds. We operate our system at 1000 watts per square metre for the first 1.0 seconds before switching to 300 watts per square metre for the remaining 1.0 seconds.

4.1. PV power and Boost Converter power

Initially we took the irradiance as 1000 watts per metre square. That means MPPT should extract the maximum power around 1000 watts per metre square. After 1 second you can see the change in the graph as we have shifted our system from 1000 to 300 watt per metre square.

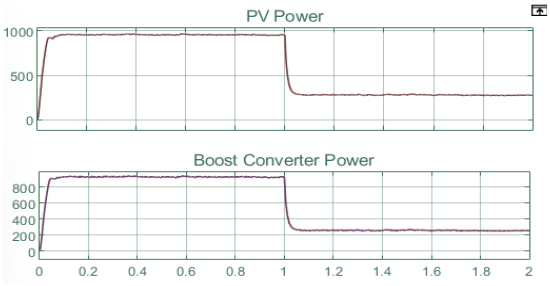

Fig. 6(a)

4.2. PV Current and Boost Converter Current

As you can see, the initial current at the PV is 8 Amperes. For around 1 second, it oscillates between 8 and 6 Ampere before becoming somewhat steady. After 1 seconds, when we reduce the irradiance from 1000 to 300 watts per square metre, it reduces to around 2 Ampere.

Initial boost converter current was 7 amperes, but it swings and drops to around 4.7 amperes in the first second. When the irradiance is changed to 300 watts per square metre from 1000 watts per square metre, it remains constant for more than 0.9 seconds and drops to around 1.7 amps at 1 second.

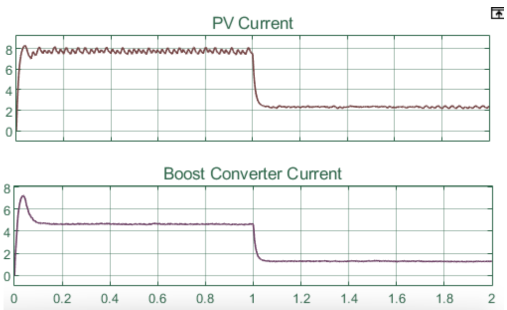

Fig. 6(b)

4.3. PV Voltage and DC Bus Voltage

The MPPT voltage level is maintained as the PV voltage. Additionally, the DC Bus voltage is kept at or near the refrence voltage, or 200 volts.

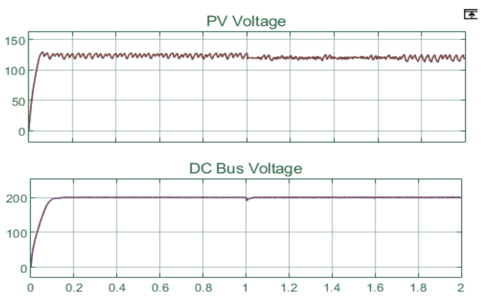

Fig. 6(c)

4.4. Inverter Voltage and Inverter Current

Here, you can see that the graph is static of both voltage and current, indicating that the AC load is receiving power without interruption.

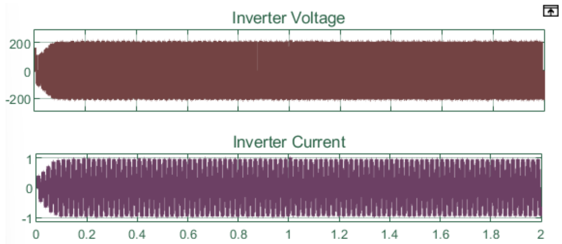

Fig. 6(d)

E. Battery Voltage and Battery Current

56 volts were initially present in the battery, and this voltage was held for about 1.0 second. But when the irradiance is changed from 1000 to 300 watts per square metre, the voltage somewhat reduces to roughly 53 volts.

The fact that the battery's first current was negative indicates that the battery was originally charging. But the current turns positive when the irradiance is reduced from 1000 to 300 watts per square metre at 1.0 seconds. Consequently, the battery began to discharge at 1.0 seconds after the irradiance was changed from 1000 to 300 watts per square metre.

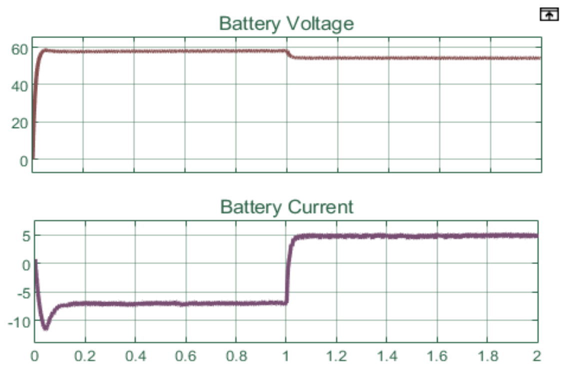

Fig. 6(e)

F. State of Charge

The battery's initial SOC, as shown in the figure, was set at 45%. The battery was charging for the first 1.0 seconds while the irradiance was around 1000 watts per square metre.

However, as the irradiance changes from 1000 to 300 after 1.0 seconds, the battery discharges during the final 1.0 seconds, indicating that the battery is now supplying energy to the system since it is running low.

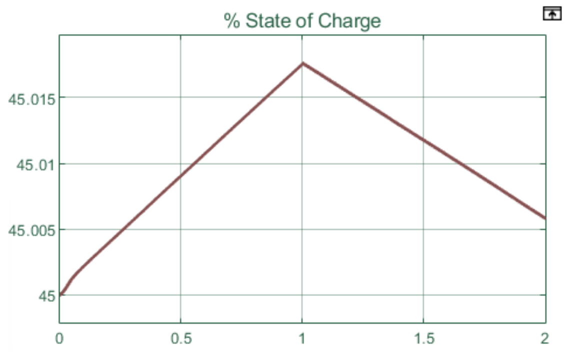

Fig. 6(f)

5. CONCLUSION

With the help of Matlab Simulink, a self-sufficient DC microgrid is developed and put into operation. As a result of their apparent simplicity of control and increased efficiency, DC microgrids are the focus of this paper. The analysis of the DC-DC bidirectional converter and DC microgrid revealed that they successfully produce the outcomes we require. And from this research, it can be inferred that a DC microgrid's design is far more straightforward and reliable than its corresponding AC version. To improve the batteries' charging and discharging modes while utilising a bidirectional DC-DC converter, more thorough investigation is needed.

REFRENCES

[1] P. Sanjeev, N. P. Pandhy and P. Agarwal, "Effective control and energy management of isolated DC microgrid," 2017 IEEE Power & Energy Society General Meeting, Chicago, IL, USA, 2017.

[2] P. Sanjeev, N. P. Pandhy and P. Agarwal, "Autonomous Power Control and Management Between Standalone DC Microgrids," in IEEE Transactions on Industrial Informatics, vol. PP, no. 99.2017.

[3] S. Chowdhury, S. P. Chowdhury, and P. Crossley, Microgrids and active distribution networks: Stevenage: Institution of Engineering and Technology, 2009.

[4] Mirza Mursalin Iqbal, Kafiul Islam, "Design And Simulation Of A PV System With Battery Storage Using Bidirectional DC-DC Converter Using Matlab Simulink, " International Journal of Scientific & Technology Research Volume 6, Issue 07, JULY 2017.

[5] T. Esram and P. Chapman, "Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques," *IEEE Trans. On Energy Conversion*, vol. 22, no. 2, 2007.

[6] V. Agarwal H. Patel. Maximum power point tracking scheme for pv systems operating under partially shaded conditions.IEEE Trans.Ind,55:1689–1698,2008.

[7] Bharath K R, Harsha Choutapalli, Kanakasabapathy P "Control of Bidirectional DC-DC Converter in Renewable based DC Microgrid with Improved Voltage Stability" in International Journal of Renewable Energy Research June, 2018.

[8] Nihad Abdulkhudhur Jasim, Majli Nema Hawas "Modelling and simulation of microgrid power system including a hybrid energy storage system" Middle Technical University, Baghdad, Iraq,2020.

[9] Srikanth Kotra, Mahesh K. Mishra "Design and Stability Analysis of DC Microgrid with Hybrid Energy Storage System" in IEEE, 2019.

[10] C. Phurailatpam, R. Sangral,B.S. Rajpurohit, S.N. Singh, F. G. Longatt, "Design and Analysis of a DC Microgrid with Centralized Battery Energy Storage System" conference paper, dec 2015.

[11] Y. Wang, K. T. Tan, and P. L. So, "Coordinated control of battery energy storage system in a microgrid," in Power and Energy Engineering Conference (APPEEC), 2013 IEEE PES Asia-Pacific, 2013.

[12] M. Kumar, S. N. Singh, and S. C. Srivastava, "Design and control of smart DC microgrid for integration of renewable energy sources," *2012 IEEE Power & Energy Society General Meeting*, p. 1, 2012.