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Control Techniques for Bipolar Bidirectional Converter for Interfacing Renewable Energy Storage System to DC Micro-grid

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Abstract

Electric vehicles have become more popular as they help in reducing pollution and require no gasoline in comparison to other automobiles. As a result, it is essential to develop fast-charging terminals for electrical vehicles (EV) where terminals are operated through dc microgrids. This will help us to alleviate concerns about power quality and increase the efficiency. This work proposes the model predictive control (MPC) and Proportional-integral (PI) techniques to control a bidirectional Buck-Boost converter that is utilized to exchange power between a dc-microgrid and energy storehouse devices. This presented system comprises 2 solar panels with attached converters, storehouse systems, dc loads, and ports for Electric Vehicle charging, and a converter for AC utilities. By controlling the gating of proposed converter by PI and MPC control techniques, the flow of power between battery and microgrid is controlled. Using MATLAB, a bipolar DC microgrid under different climatic conditions and for various loads is simulated and examined voltage unbalance issues.

Keywords. Three-level bidirectional converter, PI controller, MPC technique, Energy storehouse, three-level DC microgrid, Voltage regulation, NPC inverter, State of charge, Buck-Boost converters.

1. Introduction

A Microgrid is a simple system for transferring power among storage units and loads; A DC microgrid has good efficiency compared to AC microgrid. Ac grids have higher losses such as power factor losses; power density is low, reactive power losses, and poor efficiency. We picked dc microgrids for enhanced performance due because of these losses and complexities in AC. While in bipolar microgrid, the linkage between distributed generation units (DGU) and dc load is versatile. In terms of sharing loads, bipolar microgrid possesses superior control and versatility [1,2] as well as improved voltage profile and Balance. Unstable grid voltage, power issues are the most common issues encountered during load disturbances and power generation variation. bipolar converters or Voltage balancers are better alternative for these issues. There is more literature on voltage equality [7] and fewer papers on voltage balancing by using three-level Boost mode. [5] describes a

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bidirectional converter controlling strategy for balancing voltage of the bipolar boost converter. [6] explains how to use a neutral point (NPC) converter to manage an EV charging port utilizing voltage balancing approach. [3] shows the MPC controlling technique for a wind farm's bipolar converter combined with addition of an NPC inverter. In order to obtain high gain for bipolar DC grids, this study suggests a non-isolated three level converter with an overlapped switching capacitor appropriate for both less & more power applications [9]. MPC is to be a powerful, quick, and effective control strategy for the best power translation. The power produced from the PV system is transmitted to dc microgrid by using boost converter [10]. The bipolar bidirectional converter connects the energy storage devices to the microgrid, furthermore loads connected to a dc microgrid. Additionally, this system can reduce imbalance losses while maintaining good voltage profile. bipolar bidirectional converter is controlled, based on the battery's state of charge (SoC).

2. CIRCUIT DESCRIPTION

2.1. *Bidirectional converter*

There are two modes to operate the three-level bidirectional converter i.e., Boost mode and Buck modes of operation. In buck mode, switch3 (S3) and switch2 (S2) will operate simultaneously and switch1 (S1) and switch4 (4) will be used to make the operation in Boost mode. The equations for the calculation of the three-level bidirectional converter are given below equation 1 & 2.

Switching equations are derived by monitoring the four modes of operations in buck mode as well as Boost mode. In boost mode, the power will transfer to the microgrid from the Battery to balance the voltage at capacitor1 by diodes 1 and 4 in conducting position and the voltage is controlled at the capacitors. The battery becomes discharged. In a similar way the voltage across the capacitor is get charged by doing the operation of diodes 2 and 3 and it will control the voltage across the capacitor2.

$$V_{dc} = V_{cap2} * (1 - S_3) + V_{cap1} * (1 - S_2) \quad (1)$$

Switches 1 & 4 will be in the ON position and the battery will gain power by taking the voltage from load capacitor1 to give or transfer the power to the microgrid when it needs more power. To process for discharging the load capacitor1, switch1 should be in on position. Similarly, battery will also take the power from capacitor2 by making switch 4 ON.

$$V_{dc} = V_{cap1} * S_1 + V_{cap2} * S_4 \quad (2)$$

2.2. *Energy Storage System*

Renewable energy is always varying the generating power depending on nature and environmental conditions. In a solar plant, the power is high when the sunlight maximum and power generation is low when the sunlight minimum. So, it is necessary to store the power and supply it to the consumers according to their needs. In this study, we are using

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the Li-ion battery to store the generated power from the PV. The battery is designed with the specification of 120V, 25A in Simulink. So, it can store the power when generating power is high and supply it to the consumers when the generated power is low. The battery is designed with the minimum capacity to store half of the power from the grid. The equation for the design of the battery is analysed from [8] and the modelling is done in MATLAB.

3. THREE LEVEL CONVERTER MODELLING

3.1 Review of the Boost Mode

After examining the different stages of Boost mode, KVL and KCL are used to buck and boost modes, with direct voltage (Vdc) serving as the input signal, capacitor voltages (V cap1, Vcap2), and inductor currents (I_ind) as state variables. The following matrix representation of the set of equations makes it simple to understand.

$$\begin{bmatrix} \frac{dI_{ind}}{dt} \\ \frac{dV_{cap1}}{dt} \\ \frac{dV_{cap2}}{dt} \end{bmatrix} = \begin{bmatrix} \frac{-R}{L_{ind}} & \frac{-1+S2}{L_{ind}} & \frac{-1+S3}{L_{ind}} \\ \frac{1-S2}{Cap1} & \frac{-1}{R1*Cap1} & 0 \\ \frac{1-S3}{Cap2} & 0 & \frac{-1}{R2*Cap2} \end{bmatrix} * \begin{bmatrix} I_{ind} \\ V_{cap1} \\ V_{cap2} \end{bmatrix} + \begin{bmatrix} \frac{1}{L_{ind}} & 0 & 0 \end{bmatrix} * \begin{bmatrix} V_{dc} \\ 0 \\ 0 \end{bmatrix} \tag{3}$$

3.2 Analysis of Buck Operating Mode

A buck converter's four operational modes are examined for the given case, and the state-space equation is completed in the mathematical form shown below.

$$\begin{bmatrix} \frac{dI_{ind}}{dt} \\ \frac{dV_{cap2}}{dt} \\ \frac{dV_{cap2}}{dt} \end{bmatrix} = \begin{bmatrix} \frac{-R}{L_{ind}} & \frac{S1}{L_{ind}} & \frac{S4}{L_{ind}} \\ \frac{-S1}{Cap1} & \frac{1}{R1*Cap1} & 0 \\ \frac{-S4}{Cap2} & 0 & \frac{1}{R2*Cap2} \end{bmatrix} * \begin{bmatrix} I_{ind} \\ V_{cap1} \\ V_{cap2} \end{bmatrix} + \begin{bmatrix} \frac{-1}{L_{ind}} & 0 & 0 \end{bmatrix} * \begin{bmatrix} V_{dc} \\ 0 \\ 0 \end{bmatrix} \tag{4}$$

where Vcap1 and Vcap2 represent the voltage across the first and second capacitors, respectively. I_ind stands for inductor current, L_ind for load inductor, and Vdc for supply dc voltage. Figure 2 displays the bipolar bidirectional converter's voltage output.

3.3 Discrete Time Modelling

There are numerous ways to change a continuous-time model into a discrete-time model. The first technique is known as discretization by matrix transformation, and the equations needed to turn a continuous-time model into a discrete-time model for state-space analysis are provided by,

$$X = e^{AT} \; ; \; Y = (A-1) * (X-1) * B \tag{5}$$

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$$Y=\int_0^{Ts}(1+At)*Bt \tag{6}$$

$$X(n+1) = [X]*x(n) + Y*u(n) \tag{7}$$

Similar calculations are made using the Backward Euler's technique, which is the second way, for (n+1) intervals of current and voltage and specific types of data are anticipated using existing current and voltage values are displayed as follows for the nth sample moment in discrete-time model.

$$I_{ind}(n+1) = (1-\frac{RTs}{L})*I_{ind}(n)+\frac{S1*Ts}{L}*V_{cap1}(n)+\frac{S4*Ts}{L}*V_{cap2}(n) - \frac{V_{dc}(n)*Ts}{L}$$

$$V_{cap1}(n+1) = (\frac{-S1.Ts}{Cap1}) * I_{ind}(n) + (1+\frac{Ts}{R1*Cap1}) * V_{cap1}(n)$$

$$V_{cap2}(n+1) = (\frac{-S4.Ts}{Cap2}) * I_{ind}(n) + (1+\frac{Ts}{R2*Cap2}) * V_{cap2}(n) \qquad \text{(8.a, b, c)}$$

Calculations of sampling time for converter's Boost mode of operation could be made using the discrete-time model as follows,

$$I_{ind}(n+1) = (1-\frac{RTs}{L}) *I_{ind}(n)- \frac{(1-S2)*Ts}{L} * V_{cap1}(n) - \frac{(1-S3)*Ts}{L} * V_{cap2}(n) + \frac{Vdc(n)*Ts}{L}$$

$$V_{cap1}(n+1) = (\frac{(1-S2).Ts}{Cap1})*I_{ind}(n) + (1-\frac{Ts}{R1*Cap1}) * V_{cap1}(n)$$

$$V_{cap2}(n+1) = (\frac{(1-S3.)Ts}{Cap2}) * I_{ind}(n)+(1+\frac{Ts}{R2*Cap2}) * V_{cap2}(n) \qquad \text{(9.a, b, c)}$$

4. Control Techniques

4.1 PI Controller for Bipolar Converter

The bidirectional converter can be controlled using the PI controller in two different operating modes. The battery's SOC determines whether the battery is operating in buck mode or boost mode. The converter can operate in Boost mode if the SOC min is smaller than SOC and Buck mode if the SOC max is greater than SOC. The controller's primary goals are to recover produced power and balance capacitor voltage under various load circumstances. The issue will be detected when the reference point and grid voltage are compared by PI controllers. The error will be reduced in the current controller, which will then transmit information to the switches S2 and S4. The voltage throughout both capacitors is checked accordingly at the PI block, which then uses a PI controller to transmit switching sequence to the S1 and S3; the voltage is controlled at 300 volts and adjusted at 150 volts. When the charge status (SOC) meets all requirements, the valves S1, S2, S3, and S4 are turned on accordingly. It will shut off immediately if the SOC condition is not met.

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4.2 MPC Controller for Bipolar Converter

The PI control technique is used to compute the voltage regulation. The charge status (SOC) is used to determine whether the battery situation is within acceptable bounds and to help in selecting the converter's operating modes. The model predictive control technique's objective is to maintain a steady voltage level during variations in load and manage the grid voltage to boost grid efficiency. It will investigate the difference between both the load demand (PL) and produced power (Pg) to decide whether to operate in buck mode or boost mode. If difference of powers is negative or Pg<PL, the battery discharges and delivers energy to the grid while operating in the boost mode. The converter will select the Buck operating mode as well as the storage system will charge or retain from grid power if Pg>PL or difference in the two power is Positive. Figure 5 shows the MATLAB / Simulink environment used to create the model predictive control.

5. SIMULATION RESULTS

5.1 MATLAB Results of PI technique

By varying solar irradiation levels

The DC microgrid is powered by 2 PV panels, and maximum output power is drawn from the PV panels by using incremental conductance algorithm in the MPPT technique. The microgrid is connected with 900w DC-load, irradiation levels for PV1, PV2 are maintained at 500,600 W/m^2 and for this case Pg=1100>PL=900. The needed load power is drawn out of DC microgrid, converter is operated in buck, and battery is charged. At t=2sec, the illuminations are adjusted to 400, 300W/m^2 for PV1&PV2, Therefore, Pg=700<PL=900. The Boost mode is activated, supplying the DC grid. At t=4sec, illuminations are increased to 1800 W/m^2, so the Pg=1800>PL=900, resulting battery is charging by activating buck mode. Figure 6 depicts the corresponding waveforms.

By varying Load conditions

Here by keeping a constant load at the grid, the irradiation levels of the PV1 & PV2 are changed to check the Battery status. Whenever the irradiation levels of PV panels are changed, the Storage system can adjust the power and gives constant required power to the load. By observing the Waveform from figure 1 of irradiation levels, initially, 500W/m^2 at PV1 and 600W/m^2are given to the PV2. After t=2s the irradiation levels of PV1 are changed to 400W/m^2 and PV2 is changed to 300W/m^2. At t=4s again the irradiation levels of PV1 are set to 1000W/m^2 and irradiation levels of PV2 are set at 800W/m^2 and continuously keep on changing the irradiation levels them to check the battery status and to maintain the constant power at load.

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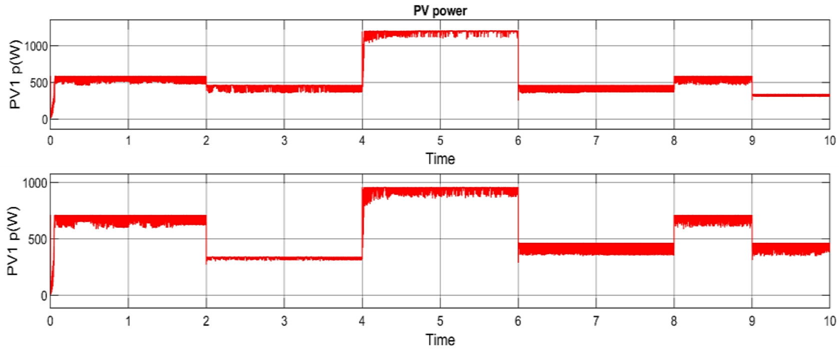

Figure 1. change in irradiation levels of PV1 and PV2

The load is kept constant at 900W and by changing the irradiation levels of the Solar panels, the required power is supplied from the PV panels with a help of a storage system. Initially, 1100W of power is generated from the PV panels and 900W of power is given to load and the remaining power of 200W is stored in a battery. At this moment the Battery SOC is increased. The power exchange from the grid and storage system is done by a Bidirectional Buck-Boost converter. At t=2s the generated power from both panels is 700W, here the generated power is less than the load power so the storage system will provide the remaining 200W of power. At this instant, the State of charge (SoC) is slightly decreased, and this process will continuously happen during the change in generated power by keeping the load constant.

At the time of State of change increased, the Voltage of the battery also increased, and the battery current is negative. Whenever the SoC is starting decreasing, the battery voltage is decreased for 2 seconds and the battery current increases due to the SoC decreasing.

The waveform of Battery Power is the product of the current and voltage of the battery. By observing the waveform of battery SoC and power waveform, at the period of power is low at the Battery, the SoC is high and if the power is high, the SoC starts decreasing during the period of power increment

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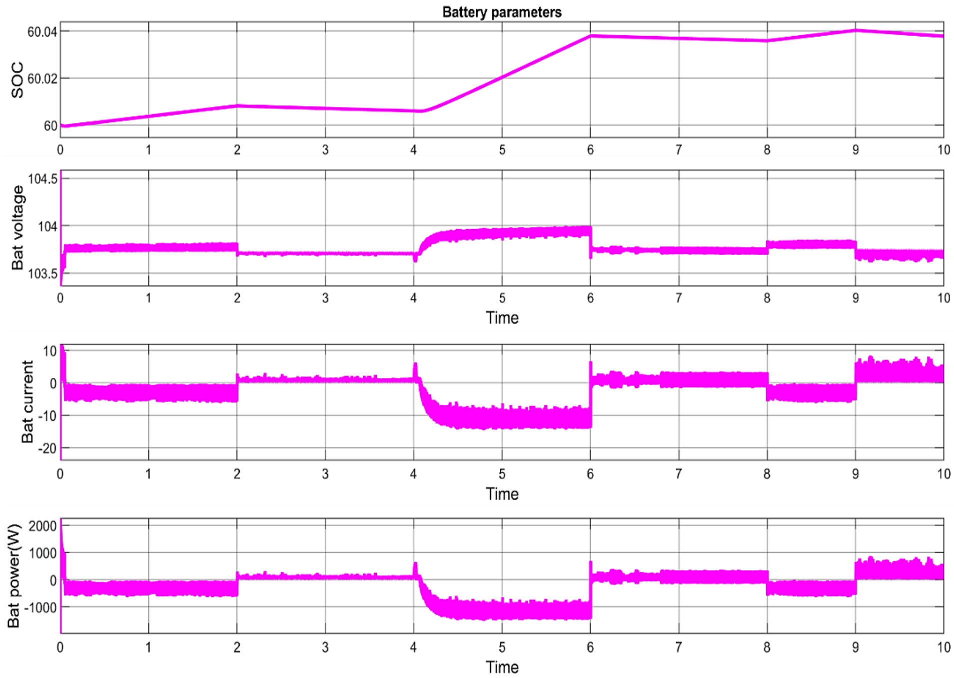

Figure 2. Waveforms of Battery parameters

Here the Load at the Grid is maintained constant to check the performance of a Bipolar Bidirectional converter and power exchange between the Grid and Energy storage system. We connected the two constant loads at 400W.

The voltage of each load is constant at 150V, and the Load current of each load is constant at 2.5A. By adding both loads the total required power to the load is maintained at 900W shown in the waveform figure 2.

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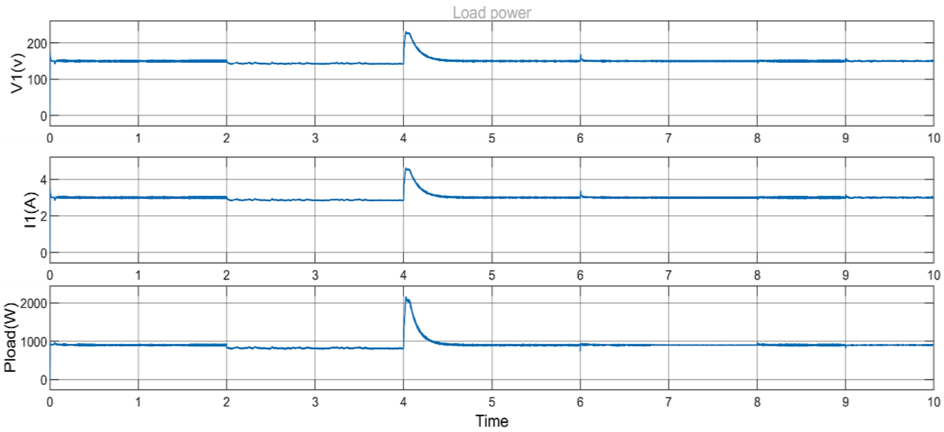

Figure 3. Load waveforms

5.2 *MATLAB results of MPC technique*

By varying irradiation

In this, the illumination rates are altered while maintaining a steady load. Each DC grid pole is interconnected to a continuous load of 650W, and the maximum load linked to the grid is 1300W. The voltage at grid is seen when the PV1 and PV2 irradiation levels are adjusted to 600 W/m^2 and 400 W/m^2, respectively. This results in produced power of 1020W and demand power of 1300W. (Pg<PL).

The boost mode is activated and 280W of electricity from the storage system is sent to the grid network. At t=2s, the PV1 and PV2 have respective irradiation levels of 1200 and 800 W/m^2, as well as the produced energy is 1890W, that is greater than the load demand (Pg>PL). The battery should charge with 620W at this moment since the converter is operating in buck mode. When additional power is needed by the load, the storage system can provide to the grid. This process will continue, and power will be adjusted between the load demand and produced power.

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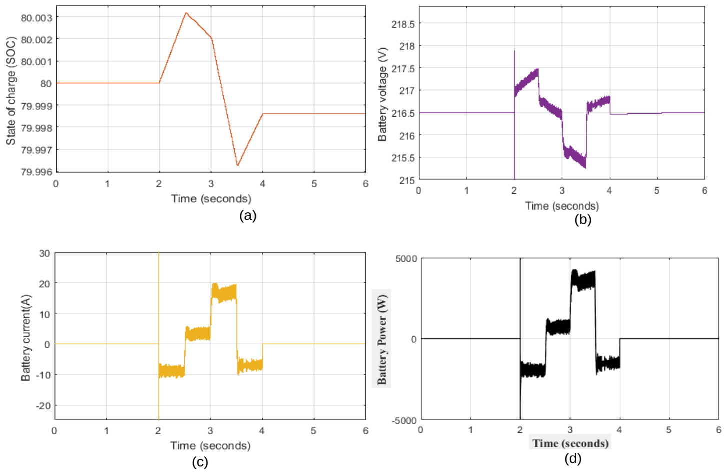

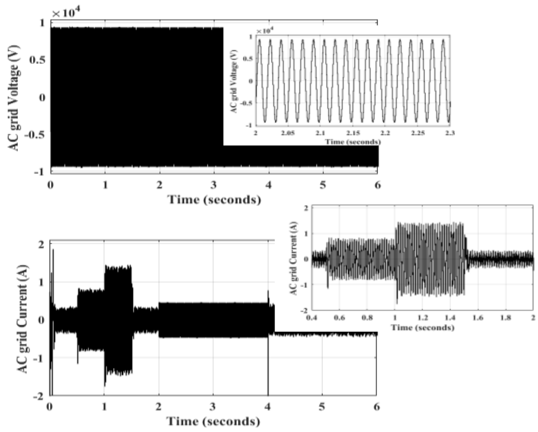

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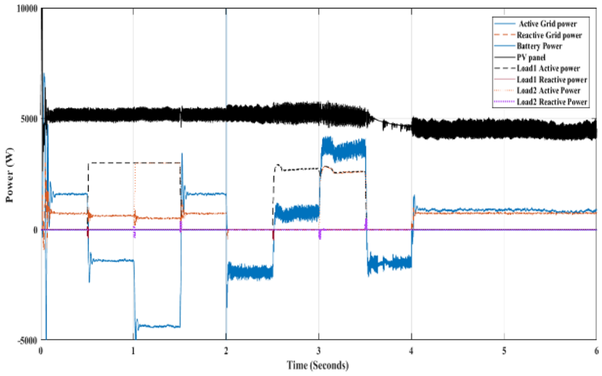

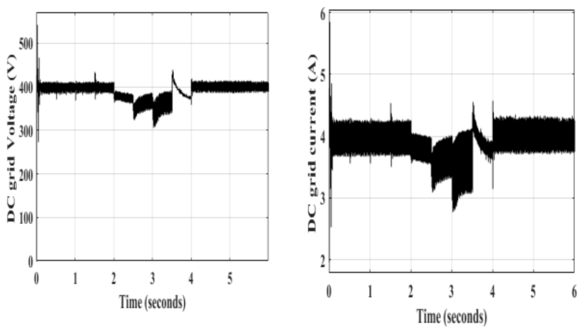

Fig. 4. (A). Battery specifications, (B). Voltage & current of AC grid, (C). Voltage & current of DC grid, (D). power curves

By changing the load

Both PV1&PV2 photovoltaic panels are receive 500 W/m^2 and 600 W/m^2 of irradiation, accordingly, are kept at particular irradiation levels. we adjust the load to get a different

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converter operation. The DC grid is initially loaded with 350W and 450W of power. The Pg is currently 1050 W greater than the 800 W of PL currently put to the grid. At this instant the battery will charge with 250W. The total load is adjusted to 1800W (Pg<PL) at time t=2s, the converter will work in boost mode, and the battery will supply the final 750W of electricity to microgrid to balance the load demand. The MPC technique can regulate the voltage at the Grid network as seen in waveforms, and whole bipolar DC grid voltage is controlled at 300V, much as PI technique. In comparison to PI technique, the MPC technique responds more quickly to changes in load.

6. Conclusion

In MATLAB, the developed scheme of the bipolar bidirectional converter aiding a DC-microgrid is constructed. At various load conditions, various irradiation levels the results of simulation are analysed. load imbalances are introduced in the DC microgrid by varying loads connected to the microgrid while maintaining the balance of load capacitors C1, C2. The DC grid regulates a total voltage of 300V, and balanced voltages at capacitor's are +150v, -150v. The problem of grid's unbalanced voltage is reduced utilising PI and MPC control strategies, and the DC microgrid's efficiency is improved. DC grid voltage is converted to AC voltage for AC loads by using an NPC converter, which balances active power in AC loads.

PI controller does have some disadvantages, such as a slower response time than Model Predictive Control method and has more ripples in output waveform. Model predictive control operation overcomes the issues and demonstrates this is a far more efficient and productive control mechanism in terms of power conversion than that of PI control scheme.

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