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CONTROL OF BI-DIRECTIONAL DC-DC CONVERTER FOR MICROGRID APPLICATION

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Abstract
This paper describes the battery charging and discharging controller for a battery connected with the micro grid. Some instruments or devices connected in a micro grid need uninterruptable power supply so we need a backup power supply system for those devices. Backup supply always increases the power quality of a system by giving a continuous service. In islanding mode of operation battery supply the critical load connected with it and in grid connected condition the main supply operates the devices. The battery feeds some loads in the micro grid in case of any grid failure occurs. This paper describes the operation of a battery from charging to discharging operation smoothly without disturbing the other circuit and critical loads connected to it. Total battery operation divided into three parts charging condition, discharging condition and idle period. There is always a need of interfacing circuit while connecting a battery in the micro grid. This paper describes the interfacing circuit with the charging and discharging controller of battery. The paper describes the power control of a DC-DC bidirectional converter for interfacing battery in micro grid. The proposed controller and the bidirectional converter was designed and the operation verified by using MATLAB/Simulink.

Introduction
Storage device play an important role in the operation of the Microgrid. Batteries are the typical storage element which attracts user to use as a backup system. Batteries can work independently or can work as a connected source to other secondary resources. Fig.1 shows battery connection in microgrid.
Control of the interfacing circuit used to interface battery was studied extensively. Different type of controller circuit may be used to control the battery charge flow smoothly without any disturbance in the circuit. In this study the converter control the battery charge flow as well as the voltage and frequency control of the total circuit.

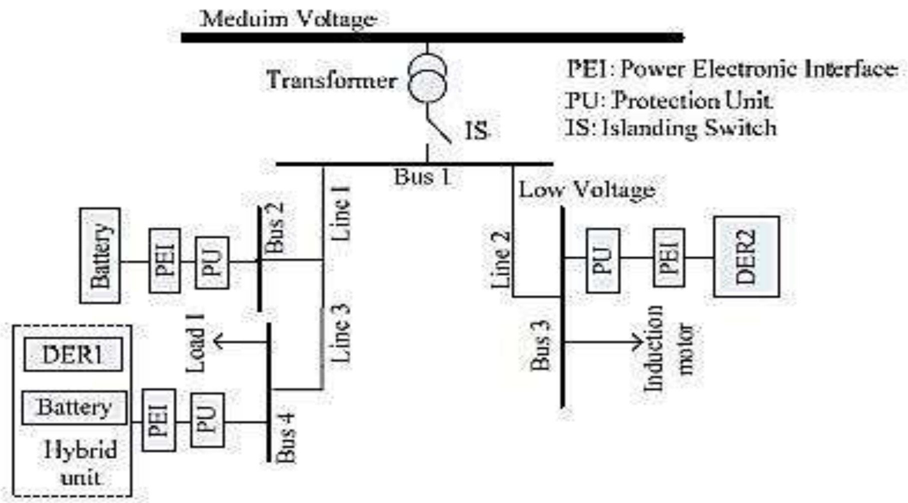

Fig.1 Two types of battery connection in microgrid

The use of battery in microgrid depends upon the dynamic behavior of the distributed energy sources in the system. It is important that the operation of the battery should be fast to increase the dynamic response as well as to increase the power quality of the total system.
In the first step it is discussed about which converter topology is suitable for the application in microgrid. DC-DC bidirectional converter is working as buck-boost converter with the properties of working in both of the mode in different dynamic conditions. That is it works as a buck converter in battery charging condition and as a boost converter in battery discharging condition.
Different dynamic conditions occur due to the variation of the voltage supply in a microgrid. Depending on the current flowing through inductor there are two modes of operation those are continuous current mode and discontinuous current mode. When the

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converter is in boost mode that is the light load condition or no load condition current through inductor become zero this is called as the discontinuous mode of operation.
The supply side voltage is considered to be 24V and the battery side voltage is considered to be 12V while connected with the load.

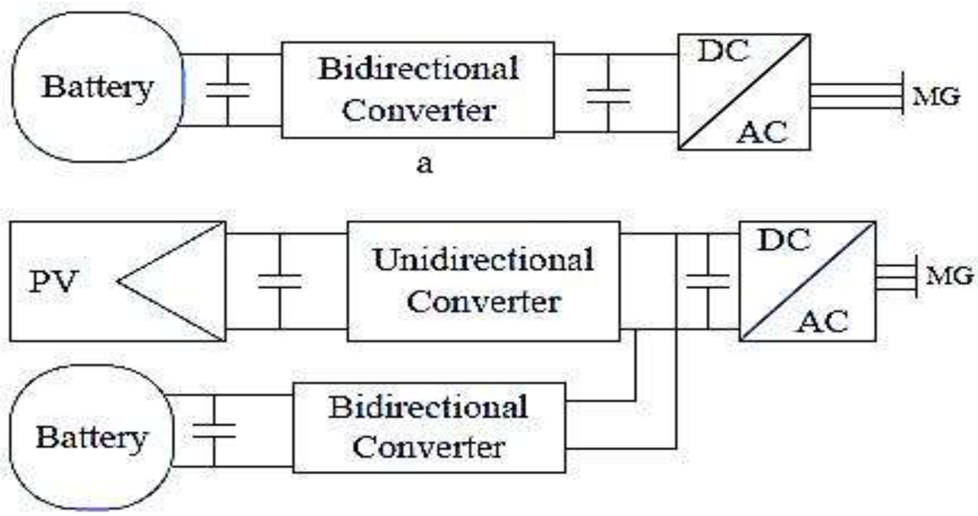

Fig. 2 Power conversion in battery a. island mode of operation. b. connected with a distributed energy source taken as solar PV cell.

The power quality of the system can be improved by using this method. The controller of DC-DC bidirectional converters is responsible for maintaining the dc link between two sides of supply. Using the power flow controller power flow of the battery is controlled. The power flow control of battery is discussed as per the requirement of battery use in the microgrid. Power sharing control technique cannot control the fast change in voltage also this cannot be adopted in direct microgrid application so this method is applied in this paper which uses a fuzzy control for voltage harmonics and a droop control for normal operating condition.
This paper is arranged as follows. Section II describes use of batteries in MGs; section III describes the modelling; Section IV analyses the controller design. In section V, control of power in batteries is discussed. In the last paragraph, conclusions are given.

Application of battery in microgrid

Considering the working principles of microgrids the power electronics interfaces should be designed for microgrids. Working behaviour of the microgrid comes from characteristics of the device connections, loads and secondary energy sources. Disturbance occurring in microgrids should also be taken care of. However, in the microgrids using inverters, there is no use of distributed energy sources. Depending on its characteristics, a microgrid should be sensitive to any disturbance.
For stabilising microgrid during any voltage disturbance batteries are used in microgrid. The power electronic interface is in charge of controlling the battery charge in case of any disturbances. In case of islanding mode of operation batteries are used to work as temporary source for operating the critical loads connected with it. DC-DC bidirectional converter is also connected with the distributed energy resources to improve their response time. Fig. 2 shows the schematic of 2 types of connections. The parametric uncertainties are always exist which affects the system voltages and system frequencies.

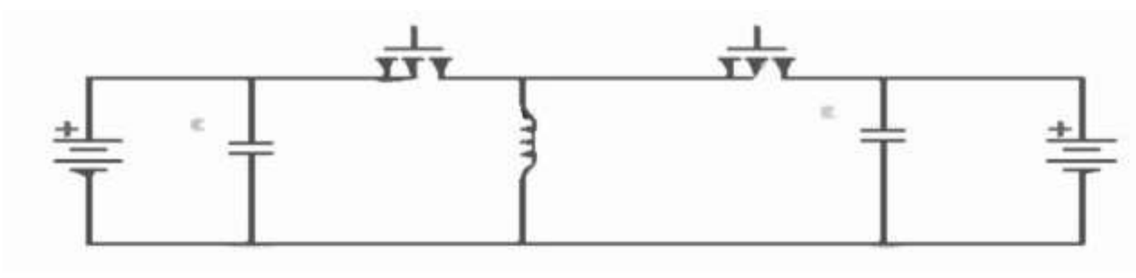

Fig. 3 Circuit model of buck-boost converter

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The converter is used to take care of the constant voltage and frequency output. The operation of the battery and the controller connected for power flow control should be accurate and fast operation should be there for the reliable operation of the critical loads. Robustness of the controller is always taken care for a smooth operation of the devices.

Modeling of converter

The DC-DC bidirectional converter is a dc-dc converter which can convert dc voltage in both sides. The converter can charge and discharge the battery. In both modes the converter maintains the dc link in both the side. The system voltage, frequency and power are always to be maintained constant.

Equations (1-2) can be written for modelling of the converter.

$$x_1(t) = \frac{1}{L}(uV_{in} + (1-u)x_2) \ldots\ldots\ldots\ldots (1)$$

$$x_2(t) = (1-u)\frac{x_1}{C} - \frac{i_0}{C}) \ldots\ldots\ldots\ldots\ldots (2)$$

Where x_1 is the inductor current,i_L . x_2 is the capacitor voltage, V_c. The control equation of both the equation is the function $u(x_1, x_2)$ called as the duty cycle function. $i_0$is the converter output current. C and L are capacitance and inductance respectively. By applying the charge storing capacity of inductor the other side can be charged by one side. The system can be expressed in standard form as follows:

$$\dot{x} = Ax + Bu + Ed \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$y = Cx \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$$X = [x_1, x_2]T \;\; , u\epsilon\{0,1\} \ldots\ldots\ldots\ldots (5)$$

In continuous current conduction mode current is passed through inductor continuously. In the discontinuous current conduction mode current through the inductor is discontinuous for more than one cycle of conduction period. Discontinuous current mode occurs in the boost mode that is when battery is supplying to a small load called as critical load. Note that (equation 1) represents the model of the DC-DC bidirectional converter. This has drawbacks while using in Microgrids. This should be considered that while the loads are operating by battery only there is a chance of voltage disturbances which should be taken care of while modeling.

This method which is designed for the boost converters accounts for all dynamics. This method is called hybrid modelling.

Controller design

Depending upon the different mode of operation of converter the states are taken as Q=$(q_1, q_2, q_3, \ldots\ldots\ldots q_n)$. In this paper only 3 state of conducting mode of converter are considered namely q_1, q_2, q_3 . In the following sections of the paper the three modes are described briefly.

Q1 operation mode

This mode of operation signifies the operation of converter in buck mode of operation. This mode is also called as the battery charging period. In this mode the assumed constraints are

1. Battery is totally discharged.
2. Supply is provided from the microgrid side.
3. The battery system is operating in parallel with the microgrid.

In this mode the first switch S_1 is ON and the second switch is OFF. The charge is stored in the inductor and also the load will operate through direct supply from the microgrid side. When inductor stores charge the diode is connected in a reverse manner to block the current flow. After the inductor is fully charged the diode is connected in forward biased manner allowing the current to flow and hence operates as a closed switch. The circuit operation is as shown in Fig.4. The output is stabilised at 12V. This voltage will charge the battery. As this is a buck mode operation input voltage 24V is stepped down to 12V. As the battery system operates in parallel with microgrid so the load side will tend to operate in 24V. The output simulation circuit as well as the voltage output is shown in the Fig. 5 and Fig. 6 respectively.

Before feeding the battery, the supply 24V should be stepped down to 12V using buck converter. In this paper the simulation diagram is considered to be the conduction of switch S_1 from 0° to 180° and the conduction of S_2 from 180° to 360°. In this way the output as 24V is taken from the output. The output is again fed to a resistive load of 14.4Ω.

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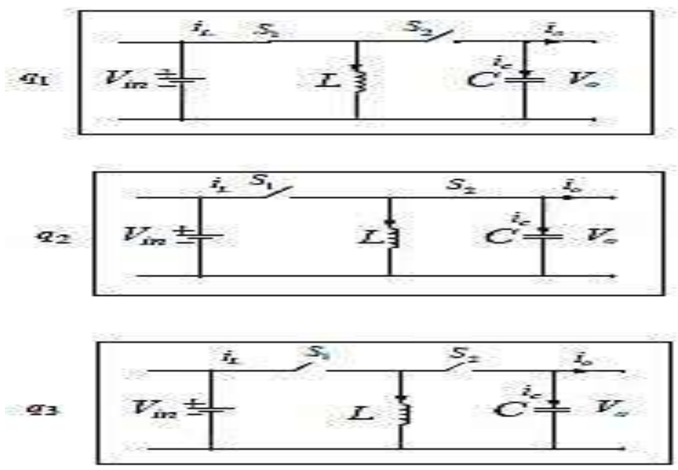

Fig. 4 Circuit operation of three modes.

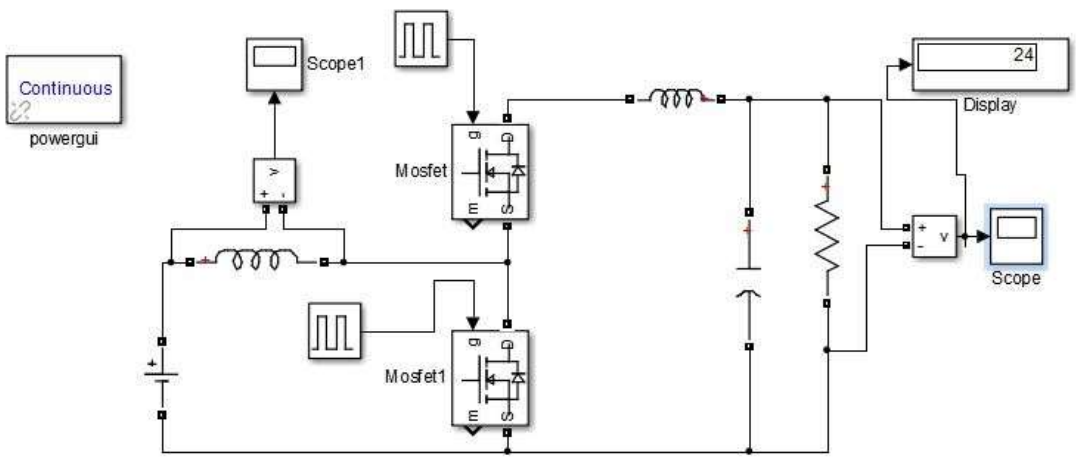

Fig. 5 Simulation of   mode

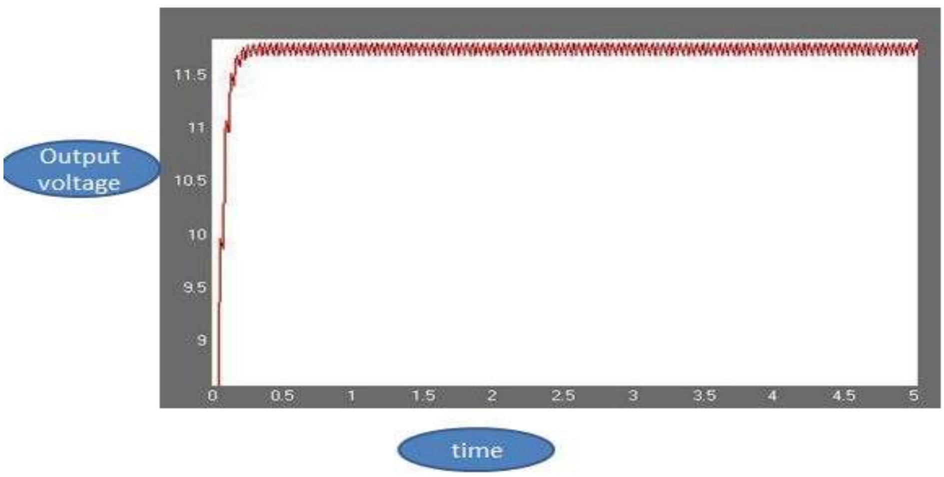

Fig. 6. q_1 Mode output voltage.

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Q_2Operating mode

In this mode of operation the converter works as boost converter. Battery discharges voltage to the load. The voltage fed to load is 24V. The simulation circuit and the output voltage of this mode is shown in Fig. 7 and 8 respectively.

In this mode the switch is in OFF state and the other switch is in ON state. Voltage from the output of battery is 12V dc and this voltage is boosted to 24V dc and fed to the load.

This mode occurs when there is no supply from the microgrid side and battery operate as a temporary source. Battery works as a backup system to increase the reliability of the load.

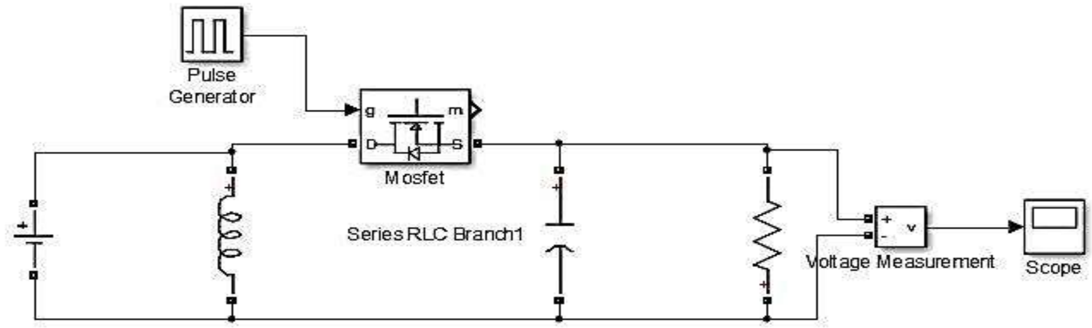

Fig .7 Q_2Mode simulations

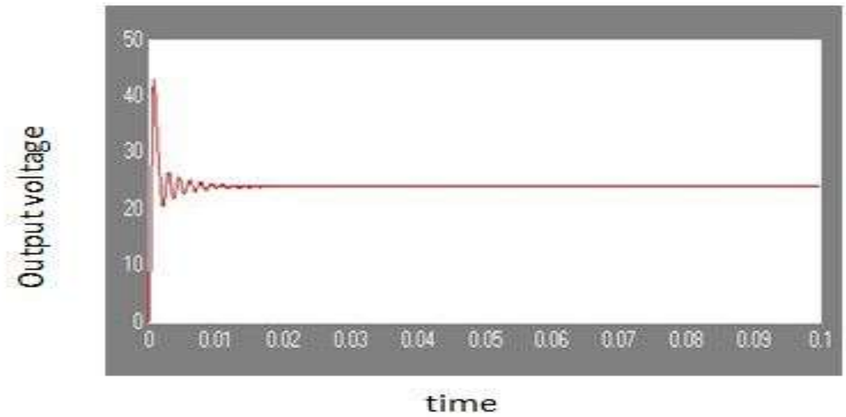

Fig .8 Q_2 Output voltage.

The assumed constraints in this mode are

1. Battery is fully charged or half charge.
2. There is no supply from microgrid side.
3. Critical loads are connected with the battery.

The boost converter gives a stabilise voltage of 24V to the output for driving a resistive load of 14.4Ω. This mode may occur when there is a large disturbance in the microgrid side. That is when grid supplies a voltage less than the nominal voltage which is considered to be 24V in this case.

Q_3 Operating mode.

In this mode of operation the two switches are at open state. The battery is totally isolated from the converter. This condition occurs when there is a continuous supply from the microgrid side and this supply is enough to supply the critical load connected.

In this mode microgrid is assumed to supply a constant voltage and frequency. The sw9itching arrangement is shown in the Fig. 9.

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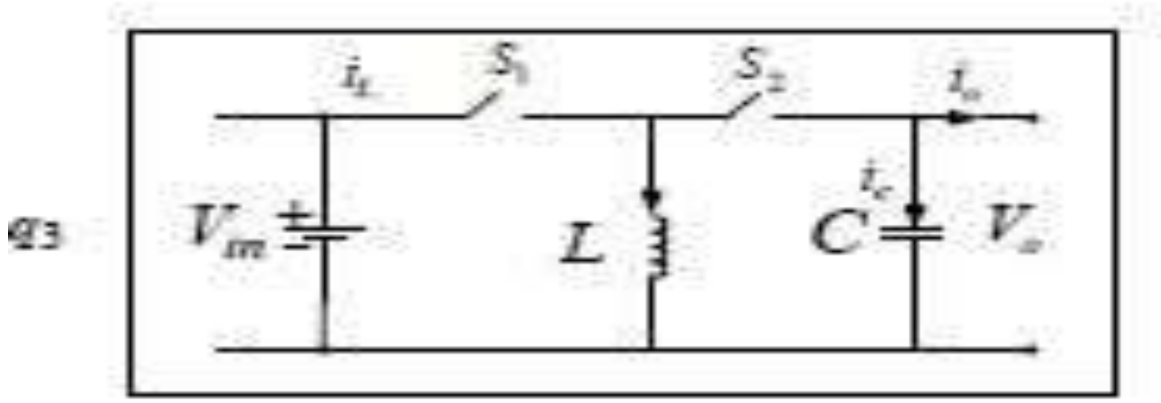

Fig .9 Mode Q_3operations

Battery power flow control

Control of power in batteries connected with microgrids should be taken care of while designing the controller. Designed controller should be fast enough to supply the reference signal to the converter circuit. This Fig. 10 describes the power control on a battery

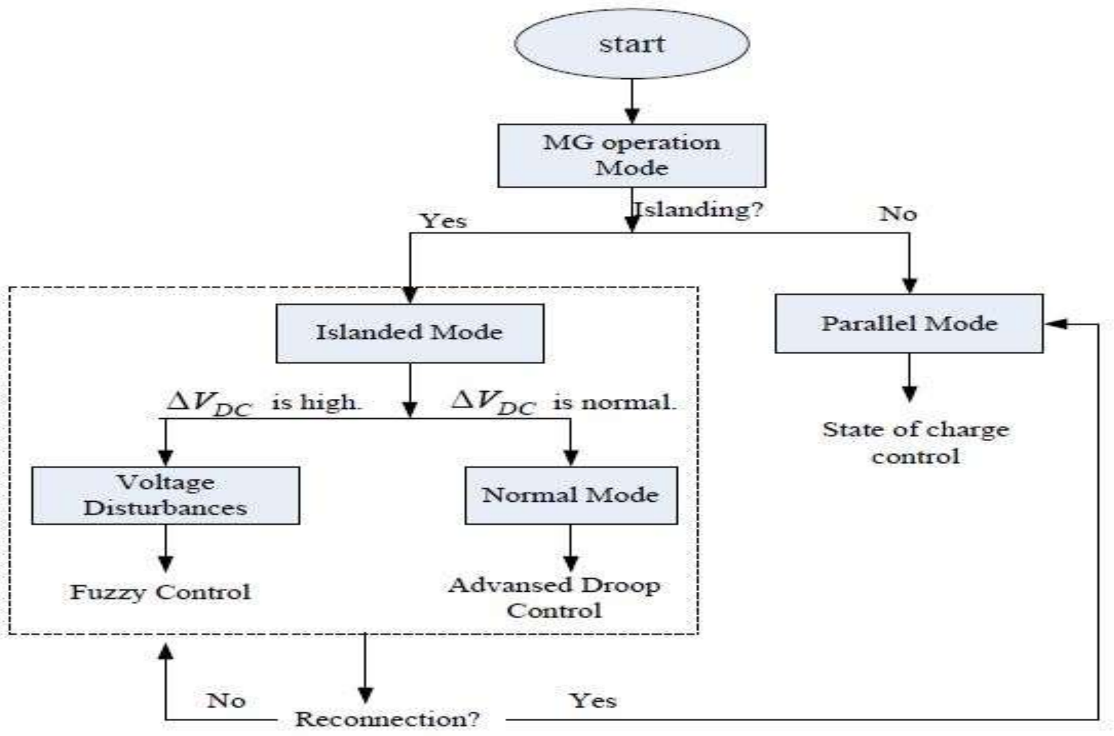

Fig.10 Algorithm for battery power control.

Considering the algorithm for fuzzy logic control, 6 discrete states are considered in this paper. Those steps are taken by comparing the input voltage from microgrid side and the battery output voltage. The difference between them is taken as ΔV_{dc} . The converter works in different modes based on ΔV_{dc}.

The six modes of operation are as:

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If $\Delta V_{DC} = V_{in} - V_{DC} > 0$ and ΔV_{DC} is high and $\frac{d}{dt}\Delta V_{DC}$ is high and i_{BTV} is high then the battery is discharging with maximum power.

If $\Delta V_{DC} = V_{in} - V_{DC} > 0$ and ΔV_{DC} is high and $\frac{d}{dt}\Delta V_{DC}$ is high and i_{BTV} is medium, then the battery is discharging with medium power.

If $\Delta V_{DC} = V_{in} - V_{DC} > 0$ and ΔV_{DC} is high and $\frac{d}{dt}\Delta V_{DC}$ is zero and i_{BTV} is low, then the battery is discharging with the same power of previous step.

If $\Delta V_{DC} = V_{in} - V_{DC} < 0$ and ΔV_{DC} is high and $\frac{d}{dt}\Delta V_{DC}$ is high and i_{BTV} is medium, then the battery is charging with maximum power.

If $\Delta V_{DC} = V_{in} - V_{DC} < 0$ and ΔV_{DC} is high and $\frac{d}{dt}\Delta V_{DC}$ is high and i_{BTV} is medium, then the battery is charging with medium power.

If $\Delta V_{DC} = V_{in} - V_{DC} < 0$ and ΔV_{DC} is high and $\frac{d}{dt}\Delta V_{DC}$ is zero and i_{BTV} is low, then the battery is charging with medium the same power of the previous step.

V_{in} is the input voltage from the battery and V_{dc} is the supply voltage from the microgrid side. In this way the voltages are compared and output voltage is taken across load.

Conclusion

The modeling of DC-DC bidirectional converters for interfacing batteries in microgrid is discussed. The microgrid operations make it necessary to model the DC-DC bidirectional converters for the application in MGs. It shows how hybrid modeling is used for the DC-DC bidirectional converters modeling.

The controllers of the DC-DC bidirectional converter play a major role in battery power control. The effect of transients on the performance of the DC-DC bidirectional converters is discussed. The control technique is discussed.

While designing controller for the DC-DC bidirectional converters for batteries, characteristics of the microgrid should be considered. Power control of batteries connected with microgrid is considered in this paper. This method works with all possible operation modes of microgrids and batteries. This method describes the control strategy of working of battery in different conditions which is connected with microgrid.

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