

Energy Management with Bi-Directional Converters in DC Microgrids

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Abstract. The application of Bi-Directional converter has been well notified in Electric Vehicles and the energy flow between the Grid-2-Vehicle and Vehicle-2-Grid are flexible, reliable, efficient and with reduced number of hardware components as compared with conventional DC-DC converters. Using these benefits, the Bi-Directional Converters are used in the DC Microgrids to charge the storage elements in the grid connection mode and to discharge the storage elements in the islanded mode of operation. In this paper, the balanced energy flow between the Storage Elements (Charging Mode) and DC loads (Discharging Mode) using Bi-Directional Converters with Fuzzy control technique is proposed. With this system, the Demand Response objectives like minimization of energy cost and awareness to the social welfare are achieved. The proposed Bi-Directional Converters system is developed using MATLAB-Simulink software and the energy flow between the battery and utility grid or DC load waveforms are shown.

Nomenclature

BDC	Bi-Directional Converters
EV	Electric Vehicle
G2V	Grid to Vehicle
ILC	Inter Linking Converter
MPPT	Maximum Power Point
PMSG	Permanent Magnet Synchronous Generator
RES	Renewable Energy Sources
SE	Storage Elements
SoC	State of Charge
V2G	Vehicle to Grid
V2H	Vehicle to Home

1. Introduction

The internal combustion engine technique is most popular from many decades in the transportation sector because of its efficient usage of fuels and over a long driving range with refueling. However, the high penetration carbon emissions is significant and most troubling



parameter to the environmental issues. In addition, the fuels are said to be limited availability in the long run and with highly volatile prices. With the developments of renewables, the battery based EVs become more popular in terms of net reduction of carbon emissions, high efficiency, flexible and with fuel is inexpensive or free from nature. In Evs, the BDC plays an important role in charging the battery with good SoC and discharging the energy from battery to V2G or V2H applications. It is proven that the BDCs are flexible in bidirectional flow of energy, more reliable and uses less number of components with isolation transformer [1, 2, 3].

From the past research and literature it is understood that the most common issues in the islanding mode of Microgrid, the utility workers may get exposed to hazard such as shocks, damage to customer appliances due to voltage fluctuations, inverter damage leads to malfunction of the inverters . The detection of islanding situations in microgrids are very much needed to reduce the impacts on various sensitive loads and the BDCs could provide the energy to such loads in the Microgrids. During islanding mode, the bidirectional flow of energy feature using BDC is found to be more useful, in order to balance the available energy with the battery and demand of critical loads for a short duration [4, 5].

The paper is organized as follows: section II defines the Microgrid structure and communication topologies, section III explains the significance of SEs like Li-ion and supercapacitors or ultracapacitors, in section IV, the operation and control strategy of BDC with Microgrids and in section V, the various simulation waveforms like SoC and grid/load voltage waveforms with BDC in conventional grid mode and islanded mode are discussed.

2. Microgrid Structure

The Microgrid structure is classified in 3 categories.

- (i) AC Microgrid
- (ii) DC Microgrid
- (iii) Hybrid AC-DC Microgrid

The Fig. 1 shows the DC Microgrid structure with SEs and BDCs. DC bus provides energy to its own loads and follows the standards of IEEE 1547. The single DC Microgrid is said to be decentralized and more reliable and cost effective. The control techniques such as Droop control (with Power and Voltage variables), Bus signaling and Bus leveling are well suited for this DC Microgrids. In addition, the SEs are associated with renewable sources and it will be better to operate the RES in MPPT mode to extract the energy from PV array and Wind turbine, thus the maximum power can be achieved.

The Fig. 2 shows the Hybrid AC-DC Microgrid structure with SEs and BDCs. Both AC bus and DC bus provides energy to its respective loads. An ILC plays an important role in exchange of energy between the AC DC bus without any interference of utility grid. The ILC operates and control the energy with communication and standards of IEC 61850 and IEEE 1547.

3. Storage Elements

The SEs in DC Microgrid shows an efficient way of storing energy in MPPT mode. Since the loads are varying from time to time, which disturb the DC bus in the DC Microgrid. The battery is said to be have high energy and offers low power density. Thus the life of the battery will be reduced. The battery based storage device alone cannot meet the requirements, when variable loads are connected to the DC bus. To increase the storage capacity with high power density, the Ultracapacitors are used along with the battery systems. Because the Ultracapacitors compensate the high frequency switching transients. The combination of battery system and the Ultracapacitors together improve the life of the battery in DC Microgrids. The most popularly used batteries for Microgrids are in table 1.

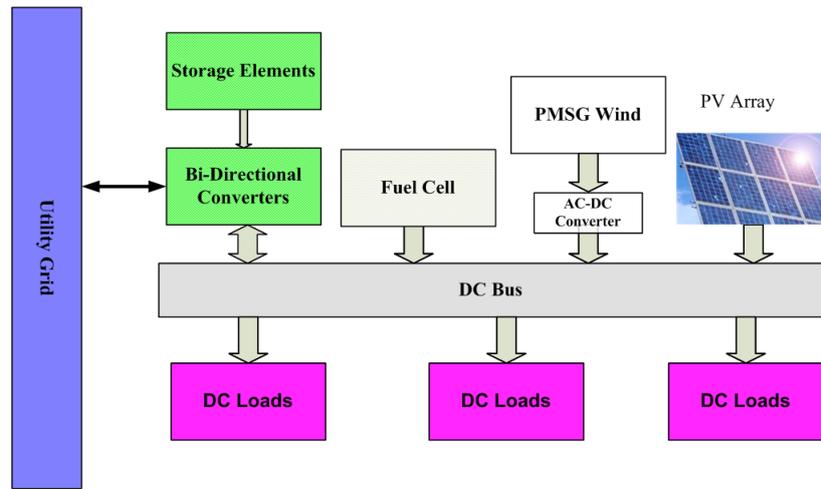


Figure 1. DC Microgrid with BDC

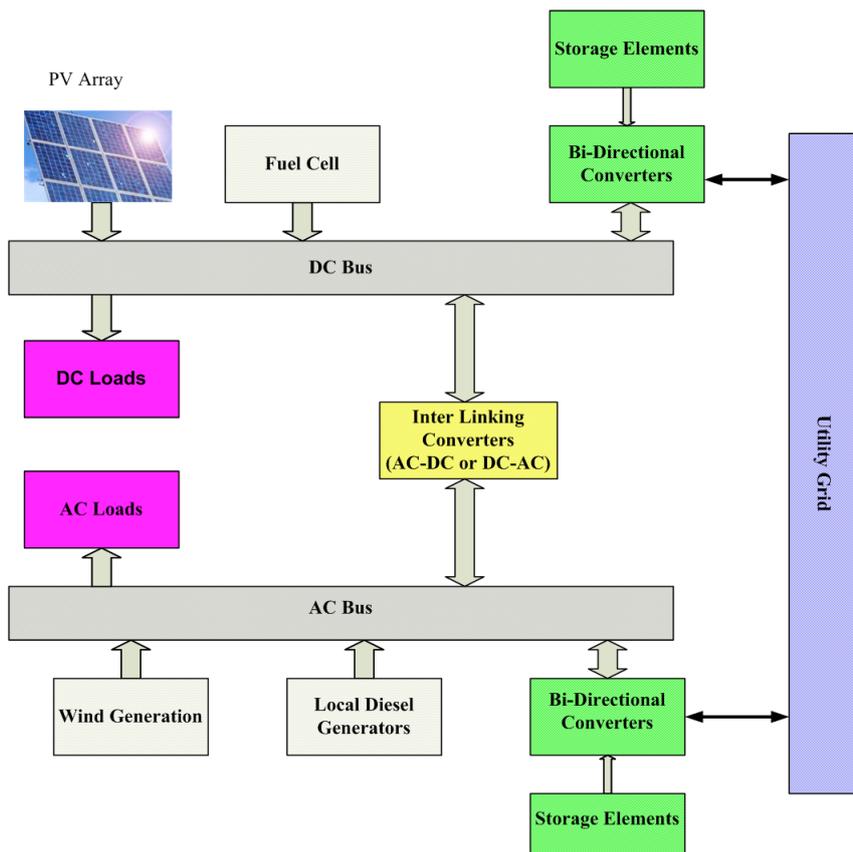


Figure 2. Hybrid AC DC Microgrid with BDC

4. Operation of BDC

The BDCs are broadly classified into two types:

- (i) Non Isolated BDC
- (ii) Isolated BDC

Table 1. Battery Types

Battery	Characteristics
Sodium Sulphar (NaS)	High energy Desity, Long Cycle capability
Nickel Metal Hydride (NiMH)	Low internal Resistance, High Current density
Lithium-Ion (Li-Ion)	Environment friendly, portable

In this paper, the isolated BDC with DC Microgrid for energy flow between SEs and DC loads is discussed. The table 2 shows the details of different operating conditions in 3 cases.

Table 2. Mode of Operation for DC Microgrids

Mode	Case I	Case II	Case III
Utility Grid Mode	Battery Charging, PMSG Wind and PV in MPPT mode	Battery in Charging mode, PMSG Wind and PV in Voltage regulation mode (Off MPPT mode)	Battery Charging, PMSG Wind and PV are OFF
Islanded Mode	Battery Discharging, PMSG wind ,PV and Fuel Cell will supply energy to the loads	Battery Discharging, PMSG wind , PV in off MPPT mode and some of the loads are curtailed	PMSG wind and PV OFF and Battery Discharging, Fuel Cell will supply energy to sensitive (critical) loads

4.1. Control strategy in BDC

The Fuzzy Logic Control technique is simulated for the operation of BDC. When the DC Microgrid is in conventional grid mode, the BDC is operated in the charging mode. The AC supply is converted to DC with the bridge rectifier of BDC and charges the battery through the high frequency transformer in Buck mode.

In the islanded mode operation of DC Microgrid, the battery discharges through the high frequency isolation transformer in Boost mode and then the energy is supplied to the needed DC loads[8, 11, 12].

The Fuzzy logic error function and change in error has seven Gaussian functions i.e.,

$$e(t) = \{PS_e, PB_e, PM_e, ZE_e, NS_e, NB_e, NM_e\} \quad (1)$$

and

$$\frac{de(t)}{dt} = \{PS_e, PB_e, PM_e, ZE_e, NS_e, NB_e, NM_e\} \quad (2)$$

and the values are in the range of $\{-1,1\}$. The error member function and change in error member functions are shown Fig 3 and in Fig 4 respectively.

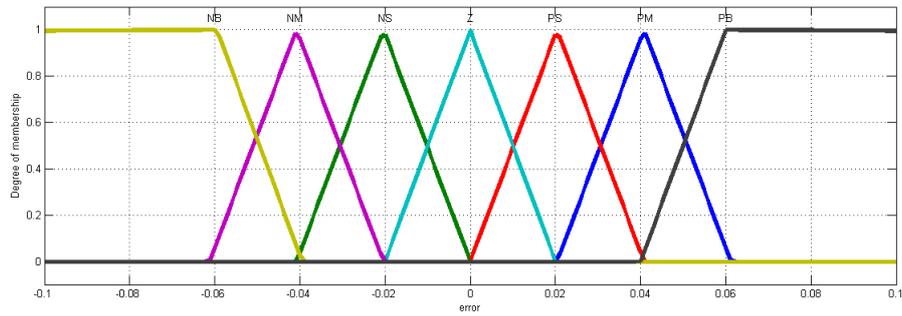


Figure 3. Error Function in Fuzzy

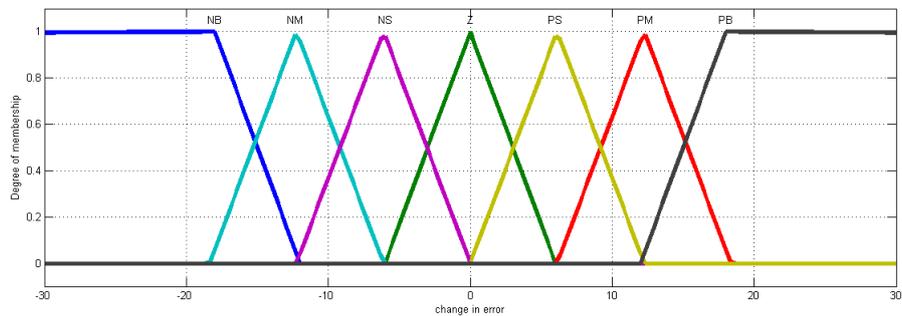


Figure 4. Change in Error Function in Fuzzy

When the DC Microgrid detects the islanding, the BDC identifies the need of energy for any of its DC loads (Discharging mode), otherwise the RES works in the MPPT mode and thus, charges the energy into SEs (Charging mode) and shown in the flowchart Fig. 5.

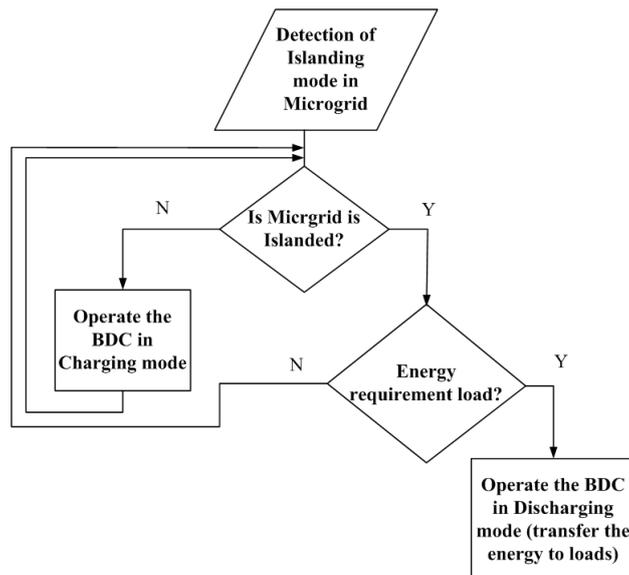


Figure 5. Operation and Control of BDC

4.2. Conventional Grid Mode (Charging Mode)

The Fig. 6 shows the State of Charge of Li-ion battery of the BDC system and is charged to 80% of SoC. The Fig. 7 shows the grid voltage of 218V the BDC system

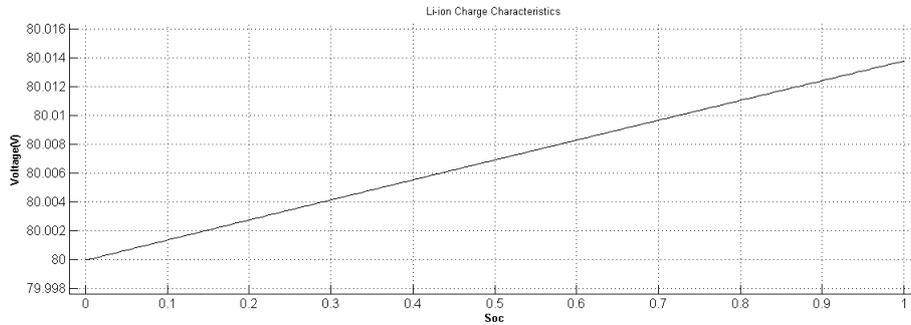


Figure 6. Li-Ion battery Charge Characteristics

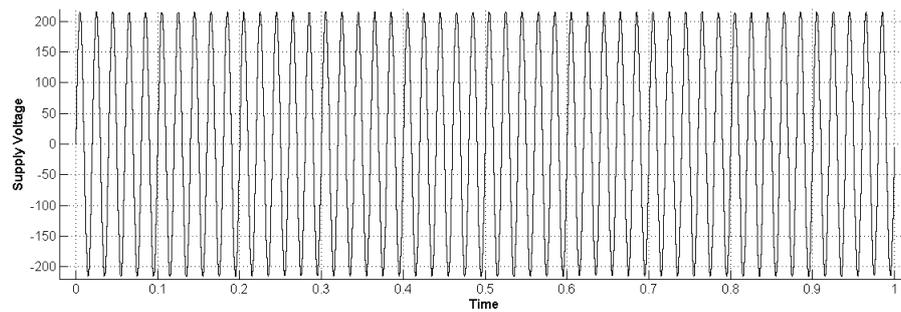


Figure 7. Supply Voltage

4.3. Islanded Mode (Discharging Mode)

The Fig. 8 shows the State of Discharge mode of Li-ion battery in the islanded mode. The

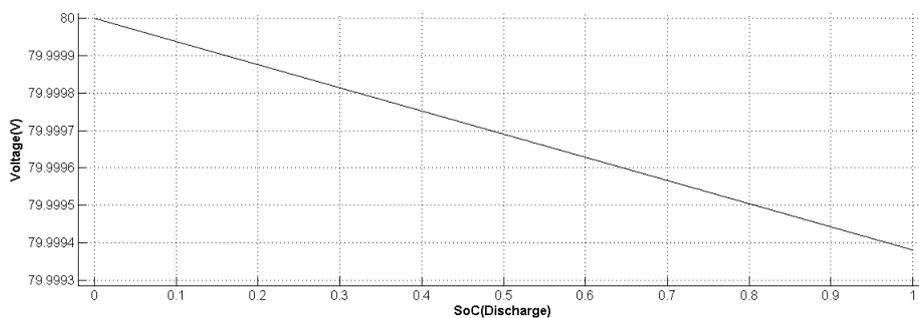


Figure 8. Li-Ion battery Discharge Characteristics

following Figs. 9 & 10 shows the load current and voltage across the load (resistor) respectively. However, the harmonics present in the Battery current will be further reduced using filtering methods.

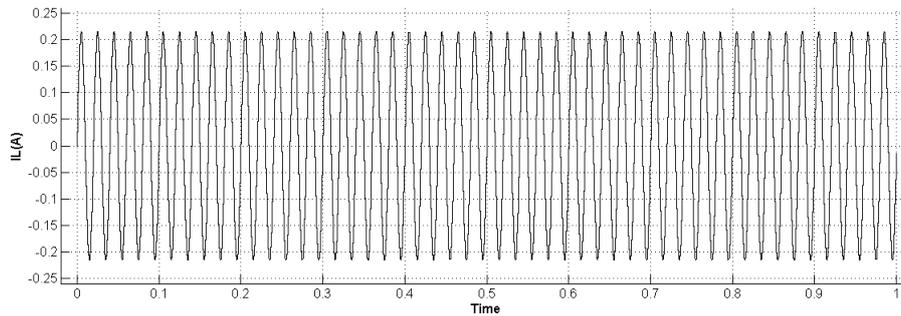


Figure 9. Load Current at Discharge mode

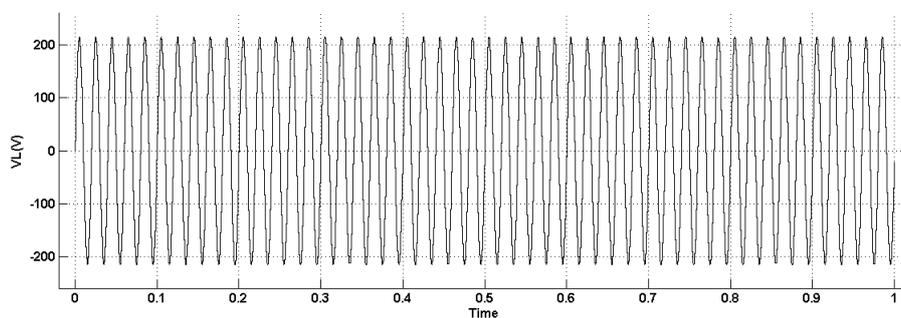


Figure 10. Load voltage at Discharge mode

5. Conclusion

In the conventional grid mode (Charging mode), the BDC is able to charge the SEs effectively in MPPT mode and in the islanded mode of DC Microgrid, the BDC is able to transfer the energy from SEs to the needed DC loads. The Fuzzy logic control strategy used in BDC is flexible, accurate and fast in response for any mode of operation in the Microgrids. The simulated waveforms of the BDC with Li-ion battery, the supply voltage and SoC are shown for the DC Microgrid in grid connected mode. Also, the load voltage, load current and DoD are shown for the DC Microgrid in islanded mode.

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