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Fuzzy Based Modular Bidirectional Energy Conversion for Hybrid Vehicle and Renewable Energy Applications

A Arikesh, Maumita Saha

Abstract*: This paper deal with the Fuzzy based simulation of bi-directional converter suitable for renewable energy based energy storage applications. A control algorithm for bidirectional power flow management connected with a grid based or renewable energy based power system with a three phase bi-directional converter and battery charging and discharging with DC – DC converter is proposed with considering AC-DC and DC-AC filter design. The proposed system with fuzzy controller and energy storage is simulated in SIMULINK platform and the outputs are plotted. For the proposed system LC filter is designed for the charging and discharging modes of energy storage and the values are tested in the MATLAB simulation.

Index Terms*: Filter Design, Fuzzy Logic Controller and Bidirectional Converter.

I. INTRODUCTION

As the power sector is moving towards next generation of power production, distribution and utilization there is lot of research going in the wide area of power generation, integration [22][25][31], utilization and security. In renewable energy sector there is need of more advanced power conversion methods and techniques [6][15][19] to harvest more energy from renewable energy also the effective utilization of the power generated with less losses and low THD. The achievement of less loss with low THD is greatly influenced by the role of power conversion components in the renewable energy systems (RES) [20][26][28]. Converters are one of the major component in RES and more research is focused on DC to DC energy conversion, Alternating voltage to DC voltage conversion, DC to AC inversion and its power flow management.[1] Nowadays bi-directional converter [2][5][8] gain more focus due to its bi-directional power flow with lesser number of components and its modular structure. Bi-directional converter serves the purpose of stepping up and stepping down the energy transfer in the network. It has the ability of energy transfer in both the directions [17][20][27].

The step down DC to DC converter also named as buck converter is while the step up DC to DC converter also called as Boost Converter. Where the buck topology operates in such a way to decrease the source voltage supplied at the input side in output side and the boost topology operates in as reverse of buck topology. The bi-directional converter provides reversible power flow in the system which uses the combined operation of buck and boost topology.

In Bi-directional topology the power flows from grid to the battery and vice versa [8-14]. The output of the converter is either greater or lesser with respect to the applied voltage. The principle operation of a buck boost chopper is that when the controlled switch S_1 is ON the storage component inductor L energises itself and saves energy from the source and gets discharged when it is switched OFF. The capacitor C is assumed to be high such that the RC time constant value is sufficiently large. The large time constant of the circuit is maintained by required switching period which ensures that the required fixed voltage is always available across the load terminals. Figure 1 shows the general configuration of basic buck boost topology. The buck-boost converter operates in the following two modes

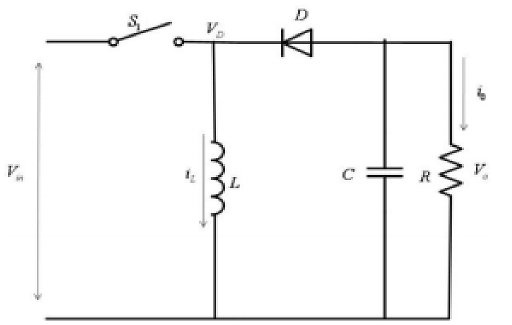

Fig.1 General Configuration of Buck Boost Converter

a) Continuous current mode: In this configuration the current in the inductor always has a non-zero value i.e. in full cycle the inductor doesn't discharges fully.

b) Discontinuous current mode: In this configuration the current in the inductor reaches a zero value i.e. in the region of full cycle the inductor discharges fully and the current touched zero.

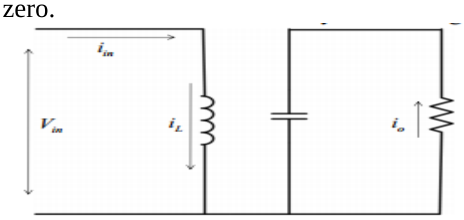

Fig.2 Buck-Boost Converter in Mode-1

During Mode1, the controllable switch S_1 is operated with the inductor L charging and the diode D reverse biased and

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***** Correspondence Author

A Arikesh*, Department of Electrical and Electronics Engineering, Hindustan Institute of Technology & Science, Chennai, India.

Maumita Saha, Department of Electrical and Electronics Engineering, Hindustan Institute of Technology & Science, Chennai, India.

not operated. The current charges L with respect to the operating frequency (figure 2).

During Mode2, when the switch S_1 is turned off, the direction of flow of current will be through inductance L, capacitance, free-wheeling diode and connected load. In this mode the stored energy in the inductive component is circulated through the free-wheeling and the load connected, hence the current in the inductor goes on reducing till the switch S_1 is turned on again in the next cycle (figure 3).

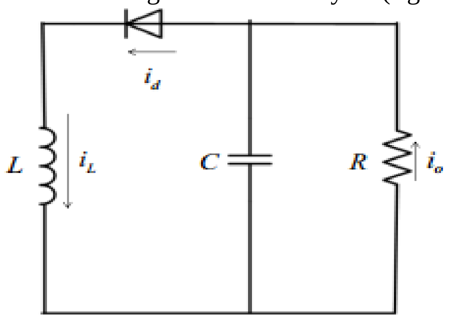

Fig.3 Buck-boost converter in mode 2

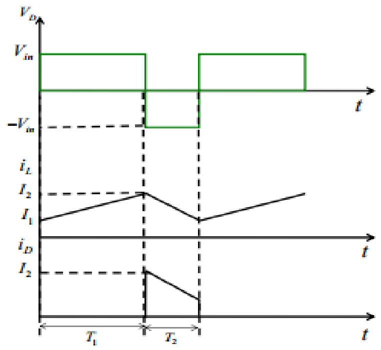

Fig.4 Waveform of a buck-boost topology

Figure 4 shows the current and voltage waveform of a buck-boost topology.

Here,

V= Voltage across the diode

D_i= Current through the diode

L_i= Current through the inductor

II. PROPOSED WORK

The major role of this proposed topology is to produce a Bidirectional power flow in the system by using three phase bi-directional converter with its filter components and DC-Link. The proposed system of power flow control management can be implemented for grid based / RES connected with a bi-directional converter and battery. An attempt of modelling the overall size of the LC filters which is used for the charging and discharging modes of energy storage system is done. Fuzzy Logic has been used for controlling DC voltage level in DC – DC Converter.

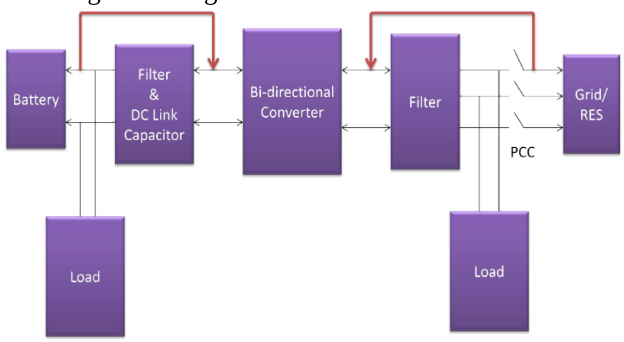

Fig.5 Energy Management System

In hybrid electric vehicles the power distribution operates at different voltage levels providing the availability of the energy storage system. A bi-directional converter allows the power flow in either of the directions with the ability of the circuit to change the direction of current flow and thus, the power flow and the polarity of the voltage in the system remains unchanged. To enable energy transfer in the system, the charging and discharging current directions change from time to time. Therefore, a controller design for a DC-DC converter is very essential in improving the overall performance of a bi-directional converter system. The proposed system consists of a AC-DC and DC-AC bidirectional converter, DC battery Bank and Utility grid. The bidirectional converter is connected to the AC grid and a DC battery bank. It works on the following two operation modes: 1) Battery charging mode and 2) Battery discharging mode.Thecharging mode operates in energizing the storage bank with the help of grid/RES and supply the load. Whereas in discharge mode the energy to the load is through the storage bank. For achieving the above mentioned requirement a buck- boost topology is implemented with fuzzy based control logic.

III. WORKING PRINCIPLE

Buck boost topology with fuzzy base control logic manages the bidirectional power flow in the DC battery storage. Mode of working of a buck-boost topology is divided into two types:

- Charging mode
- Discharging mode

In charging mode, the gird side or RES play the role as the source and energy storage device takes the role as a sink. In this mode the bi directional converter act as a three phase uncontrolled rectifier which rectifies the alternating AC supply to unidirectional DC supply, this output DC supply is further filtered and step downed by a filter circuit and a DC to DC converter operating in buck mode to get the desired terminal voltage of the storage device and then it charges the storage device. The AC supply and the final filtered DC supply also supplies energy to the load in their respective sides. The block diagram representation of charging modes is mentioned in figure 6 given below

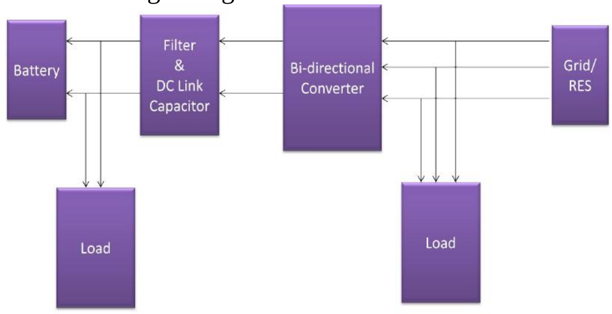

Fig.6 Block Diagram for Charging Mode

In discharging mode, the energy storage device acts as the source and the grid side acts as the sink. In this mode the bi directional converter act as a three phase inverter and converts the fixed DC supply the stepped AC supply of grid frequency, this converter stepped AC supply waveform is smoothened to sinusoidal waveform with the help of filter circuit before connecting to the grid side. The fixed DC supply input and the output sinusoidal AC supply energies the load in their respective sides. The block diagram representation of discharging modes is mentioned in figure 7 given below. In both above mentioned modes the design of filter plays an important role. The flow chart representation of the above mentioned logic is given in the figure

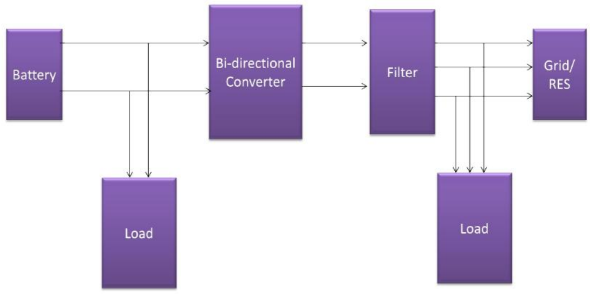

Fig.7 Block diagram for discharging mode

IV. FILTER DESIGN

The design of LC filter for the above mentioned topology decides the converter size. Since the presence of current ripples is to be avoided for charging and discharging modes in the energy storage system. Thus the above said requirement can be satisfied with proper design of filter. There are various types of filter and in this project we have considered LC filter. The function of this LC filter is to reduce the frequency harmonics produced by the MOSFET in the inverter mode. In converter mode 6-pulse rectifiers are most commonly used as a front end rectifier.

The design of proper filter may reduce the size and cost of the system. The estimation of overall size of the inductance and capacitance filter is discussed below. Figure 9 shows simplified circuit diagram for 6-pulse rectifier [4].

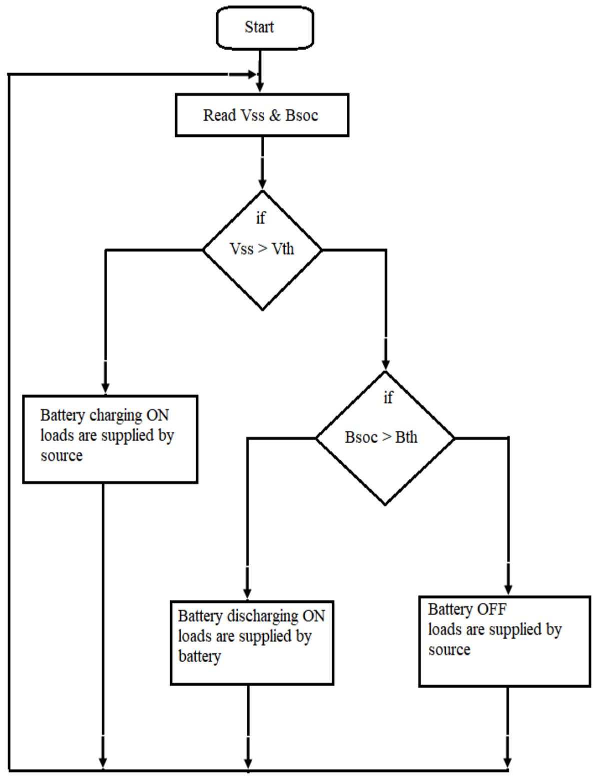

Fig.8 Flow Chart of Charging and Discharging Battery

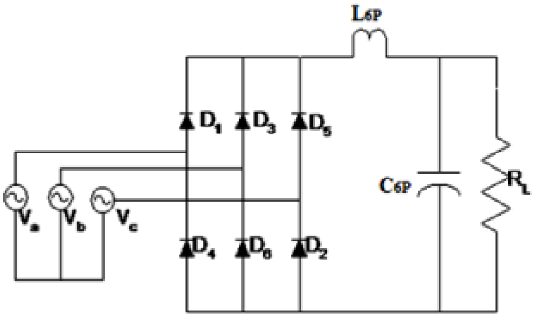

Fig.9 Circuit Diagram for 6-Pulse Rectifier

When a capacitor filter or an inductor filter is used individually, the equation to calculate the reactive components with some assumption is present. But, when both the reactive components are used in a combined manner there is no proper equation to define the component values. A compute model of filter components when used together for controlling the ripple has been developed under specified values to find out the values.

A LC filter greatly helps in improving the reduction of ripple in rectified voltage and current waveform. The capacitor or the inductor alone cannot perform filter action satisfactorily. However, a high quality of ripple free dc voltage and current waveform can be generated if both the reactive components are working in a combined manner. The LC filter finds its application in high power applications, since they provide a very uniform flow of current in the system. In order to meet harmonic requirement a 6-pulse rectifier is used. It is also used to remove unwanted ripples generated in the system. Since the ripple factor is directly proportional to the load resistance, in inductance filter and the ripple factor is inversely proportional to the load resistance, in capacitive filter. Thus if we use the combination of LC filter the ripple factor will become independent of load resistance. They are the key components in many electronic devices. It is located in between the bi-directional converter and grid. The grid side parameters are fixed by the regulatory authorities, thus it is mandatory and required to design and construct an proper control strategy for the operation of bi-directional converter.

Since filter inductor and capacitor constitute bulkier components of the overall converter, it is possible to minimize the overall size [3].

V. FUZZY LOGIC CONTROLLER

The term “fuzzy” is referred to the fact of logics which cannot be expressed as “completely true” or “completely false” rather it’s “partially true” or “partially false”. Fuzzy logic which is widely used in machine controls which tracks down the output voltage of a converter for a given reference. The block diagram of Fuzzy logic Controller with the DC-DC buck boost Converter is shown below. The output voltage of a buck-boost converter is controlled by changing the switching duty cycle. Fuzzy Logic can make development and implementation much simpler [2].

Figure 10 displays the general block diagram of fuzzy based buck boost converter. Fuzzy controller consist of 1) an input stage where it maps sensors or other inputs using appropriate member functions and truth value,2) a processing stage which checks and generates results for each and every appropriate rules and then combines the rules and 3) an output stage which then converts the combined results of fuzzy subset back to its specific output value. The input variable of a fuzzy system is basically being tagged by array of member functions represented as fuzzy set. Hence the method of changing the real data values referred as input to fuzzy values is known as "fuzzification". To control the rule and linguistics values decision making is done accordingly using the rule base to achieve a good control in the system. Then the interference values has been taken and converted into actual values which are known as "defuzzication". The voltage at the output of the bi-directional DC-DC converter is being tuned to desired value by varying the duty cycle of the switch.

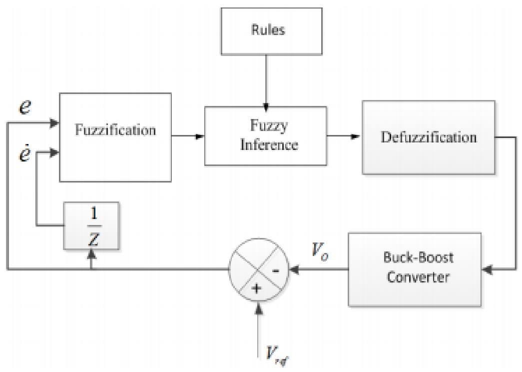

Fig.10 Block Diagram of Fuzzy Logic Controller

In FLC, the difference between the desired voltage and sensed output voltage is called as "error". The error voltage is calculated by;

$e = \varepsilon(k) = r(k) - y(k)$

while the change in error is calculated as ;

$\Delta e = e(k) - e(k-1)$

Here r(k) = desired voltage

y(k)= sensed output voltage

The Error and Change in Error (CE) are changed to generate fuzzy sets. The fuzzifications which convert numeric input into variable linguistic values by means of generated fuzzy sets. Here in this context a gaussian membership function of nine linguistic variables have been used: Negative High (NH), Negative Large (NL), Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Medium(PM), Positive Large (PL) Positive High (PH). The membership functions of Error, Change in Error (CE) and output variable (Duty) of the fuzzy system using nine linguistic variables has been show in figure 11, figure 12 and figure 13. Finally, the resultant is combined with the fuzzy subsets are changed into the crisp values.

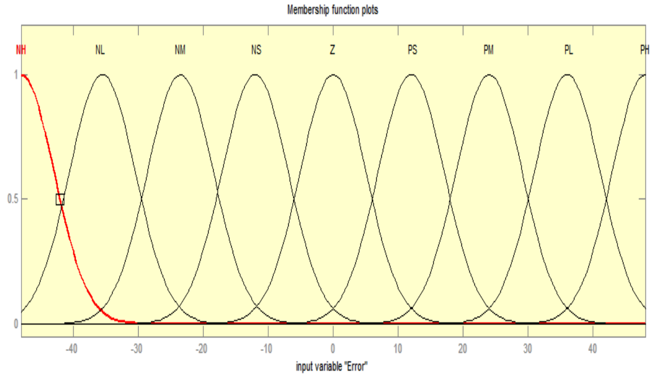

Fig.11 Error Membership function

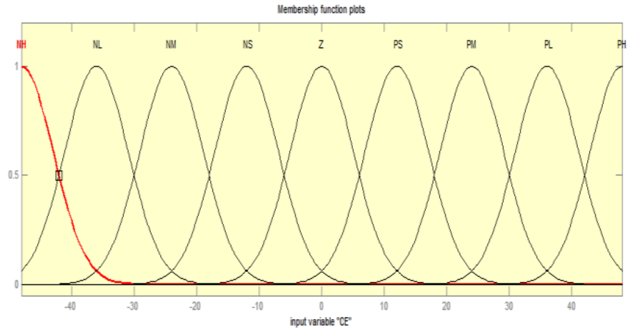

Fig.12 CE Membership function

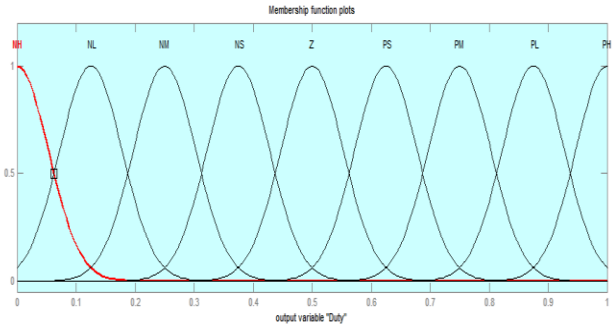

Fig.13 Duty Membership function

Table 1 Component Specification

Component	Specification
Grid / RES source	3 phase 415 V / 20 – 120 V AC supply
Rectifier side filter	L=40 mH, C=24.57 µF
Inverter side filter	L = 2.29 mH, C= 44.98 µF
Battery	150 AH, 96 V lead acid
Buck –Boost chopper L&C	L=69 mH, C=2200 µF

Table 2 Fuzzy Rules

CE / E	NH	NL	NM	NS	Z	PS	PM	PL	PH
NH	NH	NH	NH	NL	NM	NS	NS	Z	Z
NL	NH	NH	NL	NL	NM	NS	NS	Z	PS

NM	NH	NL	NL	NM	NS	NS	Z	PS	PS
NS	NL	NL	NM	NS	NS	Z	PS	PS	PM
Z	NL	NM	NS	NS	Z	PS	PS	PM	PL
PS	NM	NS	NS	Z	PS	PS	PM	PL	PL
PM	NS	NS	Z	PS	PS	PM	PL	PL	PH
PL	NS	Z	PS	PS	PM	PL	PL	PH	PH
PH	Z	PS	PS	PM	PL	PL	PH	PH	PH

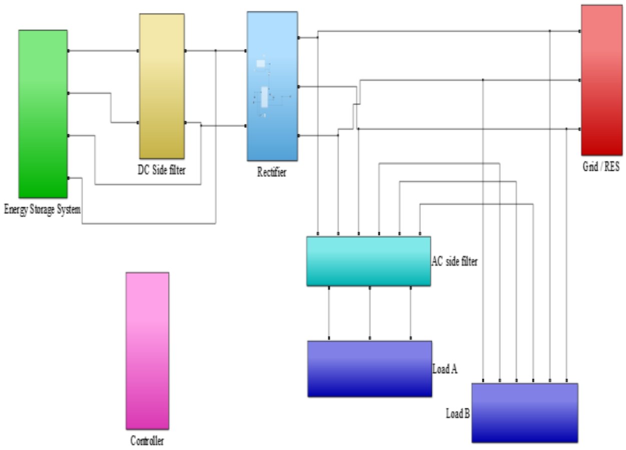

Fig.14 MATLAB Simulink Model of Bidirectional Energy Conversion using Fuzzy Control

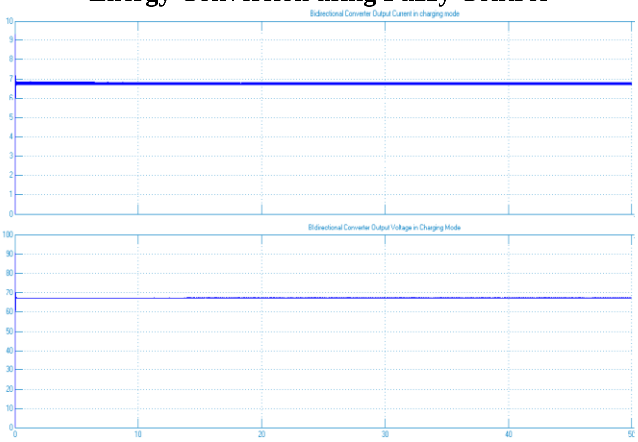

Fig.15 Bidirectional Converter Output in Charging Mode

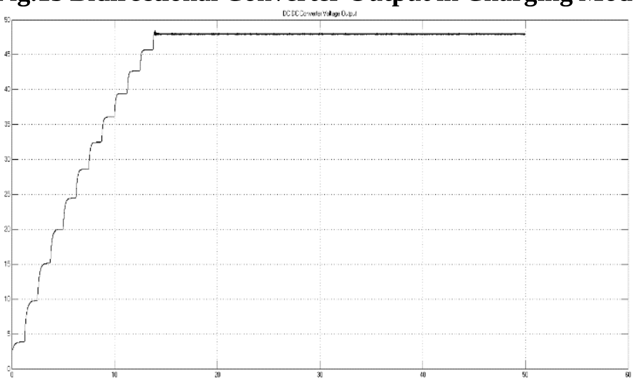

Fig.16 DC-DC Chopper Output in Discharging Mode

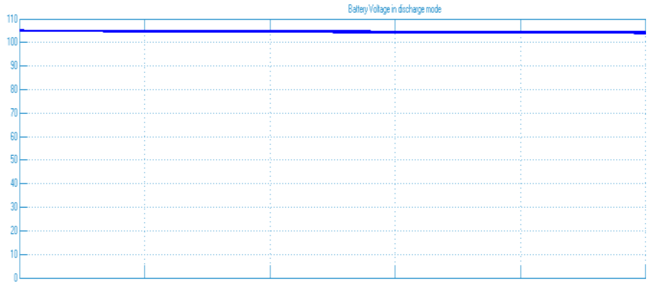

Fig.17 Battery Output in Discharging Mode

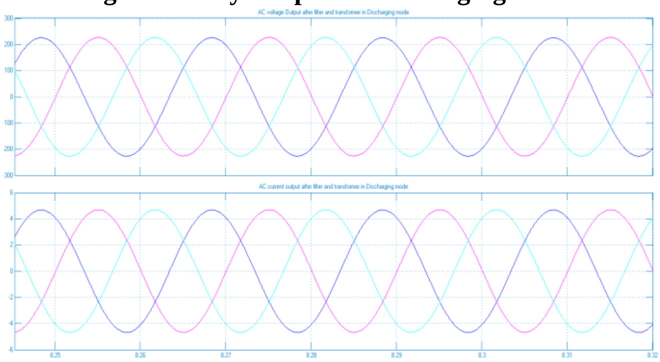

Fig.18 AC Output at Load in Discharging Mode

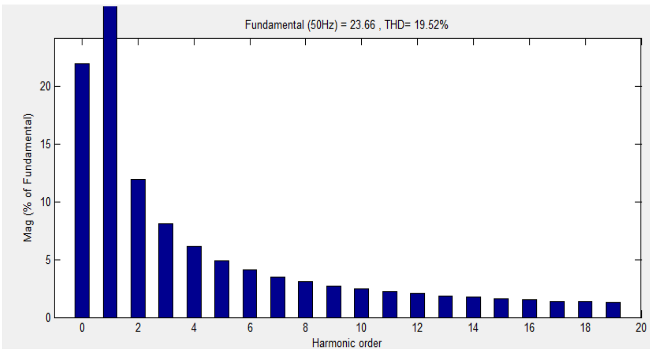

Fig.19 THD of AC Output Voltage at Load in Discharging Mode

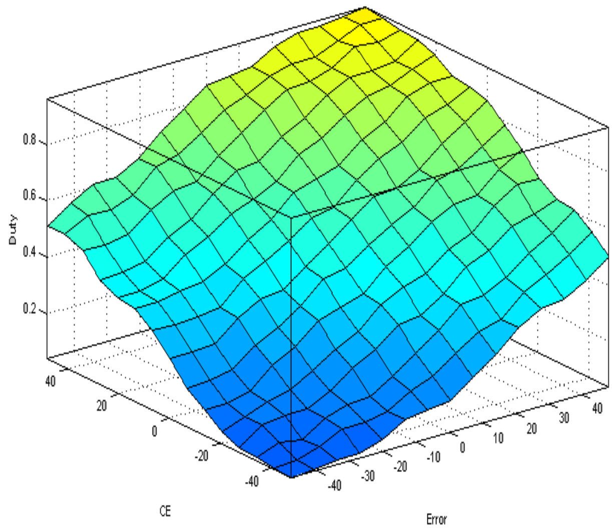

Fig.20 Fuzzy Rules Surface for DC-DC Converter Operation

VI. SIMULATION RESULT

The analysis of the proposed system is done using MATLAB Simulink as shown in figure 14.

The model has AC source representing a grid supply or renewable source followed by three phase bridge converter, buck-boost chopper, battery and three loads. AC and DC side filters are used with respect to the analysis done above in section 3. The three phase bridge converter consists of six IGBT with ant parallel diodes, In rectification mode the bridge act as a three phase diode rectifier and in inverter mode the IGBT's are operated by a high frequency PWM signal. The buck-boost chopper is controlled by a fuzzy block with 9 member function. Relays, contactors and diodes are used were ever required. The output results are shown for the energy transfer from the source side to the battery and load side followed by the transfer of energy from the battery to the load and source side. The simulation results are shown for both charging and discharging mode with fuzzy surface in figure 15 – 20.

VII. CONCLUSION

A fuzzy based bi-directional energy flow form energy storage device by energizing and de-energising through a bi-directional converter is simulated in MATLAB simulink environment with grid/RES system. Both rectifier and DC-DC converter side filter is designed based on the battery as well as grid requirement with THD to minimum. The future scope of this project may deal with an efficient Battery Management System with several load and storage system. In future generation Electric vehicle will be the major means of sustainable transportation system because of its pollution free, its fuel economy and its energy efficiency. Bi-directional converter plays a major role in EVs.

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