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A Fuzzy Logic Controlled Multi input Direct Current to Direct Current Converter for Parallel Connected Sources

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Abstract:
This paper presents an efficient topology and fuzzy control strategy for hybrid system which utilizes multiple type of power sources such as photovoltaic systems, rechargeable batteries and fuel cells. The proposed topology works only with four switching elements controlled by fuzzy controller for simultaneously performing multiple tasks such as charging the battery, supplying the load and using the rechargeable battery in case of primary source are unavailable or fails to supply required amount of power. Furthermore the system is capable of tracking the maximum power point for PV panel to extract maximum power from it and also regulating the output voltage. The fuzzy controller is opted for the controlling the switching of transistors because it reduces the complexity involved with traditional PID controllers with improved overall performance. Finally, the performance of the proposed converter and its control are verified by simulating it on Simulink environment with different operational conditions and the simulation results validates the effectiveness of proposed system.

Keywords: *Direct current to direct current boost converter, hybrid converters, fuzzy logic controller.*

1. Introduction

Battery powered electronic and electrical devices, such as laptops, ultra mobile Pc's, cellular phones, battery powered or hybrid electrical vehicles, are now nearly essential and unavoidable necessities for our daily lives. Hence the rechargeable batteries are now gaining increasingly significant role in different applications. Even with a number of advantages its applicability partially restricted by the recharging requirements, which requires a dedicated charging system for continuous operation. Although in many applications the recharging can be performed by utilizing the alternate source available such as fuel cell in hybrid vehicles and solar panels in field operations.

Essentially the power converters are utilized to condition the available electrical power for the load specific requirements. The simplest converters uses one input and one output, which converts the level of input voltage, however for the complex task where more than one inputs with their different characteristics are needed to supply multiple loads of different requirements makes the designing of such converters very complex task which involve the designing of topologies with minimum number of switching components and their controlling strategies. There are a number of controlling techniques have been already proposed to control such power converters, and the most common approach is either traditional proportional-integral (PI) controllers or linear negative feedback controllers. But these approaches have limited scope because they either required linear system (which is not always possible) or require the linearization procedure for nonlinear controlled system which is further complex task and produces only approximate model. Other design methods, such as one-cycle control and sliding mode variable structure control, utilizes the pulsed and nonlinear properties of switching converters and capable of achieving instantaneous control of the average value of the voltage or current by chopping. The objective of this paper is to develop a simple and efficient approach, for developing the multiple input converters with at least one rechargeable source, and to overcome the problems discussed earlier, we introduced a simple topology with fuzzy controller. The remainder of this paper is organized as follows. Section II presents a literature review followed by the converter topology and operation modes explanation in Section III. The dynamic modeling of the proposed converter is given in Section IV. Section V describes the control system of the proposed converter. Section VI represents the simulation and experimental verifications and Section VII concludes this paper.

2. Literature Review

Since a number of hybrid power systems with various power electronicnconverters have been already proposed in this section some of them are discussed. Farzam Nejabatkhah*et al.* [i] proposed a simple topology for three input DC-DC converter with only four switching elements and efficient controller modeling.

Asystematic technique to create multi-input converters (MICs), is presented in [v]. The paper deals with two different types of MICs: first type is with only ones ource at a time can transfer energy to the load,and in the second type, all the input sources can transfer power to the load. Similarly another fundamental research in MICs, is presented in [vi] in which consideration, limitations, and conditions used in analyzing MICs are explained, and finally it concluded some basic rules that facilitates to predict feasibility and unfeasibility of input cells that can realize MICs from their single input variants. Two different multiple input converters utilizing flux addition in a multi-winding transformer are presented in [vii] and [viii].Both of them are not appropriate for hybrid systems because of restricted unidirectional operation structure of[vii], and complexity and power limitations of [viii]. In [ix], a three input bidirectional converter with two series-resonant tanks circuits and three active full bridges is proposed. The circuit uses a three winding high frequency transformer which in comparison with only inductors and Diode Bridge at the load side, gives reduced switching losses due to soft-switching operation with higher boost gain. H. Tao et al. [x] present a number of derivable multi port converters based on dc link and magnetic coupling combination and utilizing half-bridge boost converters. The system contains minimum conversion steps, cheaper, and compact solution. In [xii] [xiii] and [xiv], three MICs topologies are proposed based on dc–dc boost converter. In [xii] the dc–dc boost converter is useful for combining multiple energy sources with different power capacity and voltage levels. The MICs dc–dc converter proposed in [xiii] facilitates operating in buck, boost, and buck–boost converter topologies without any additional transformer. A three-input dc–dc boost converter is presented in [xiv] which combines a PV, an FC (Fuel Cell), and a battery under a simple unified structure also a complete power controlling algorithm is developed to operate PV source in maximum power point (MPP) of the PV source and set the FC in its optimal power operation range. A three-port isolated full-bridge topology for hybrid FC/battery system is proposed in [iii],with aim of feeding a small autonomous load. This topology has the advantage of bidirectional power flow provided by active full-bridges in each port. Using the similar transformer the three transformer-coupled half-bridge converters presented in [xv] are studied.

3. Topology of the Proposed Converter

The structure of the proposed three-input DC–DC boost converter is shown in Figure1. The converter uses two unidirectional ports for two input power sources V_1 and V_2, and a bidirectional port for rechargeable battery. The V_1 and V_2 can be supplied with PV (Photo-voltaic Cell), FC (Fuel Cell), or wind turbine sources at port 1 and port 2 Therefore, V_1 and V_2 are modeled as dependent power sources because their output characteristics are depends upon the type of power sources.

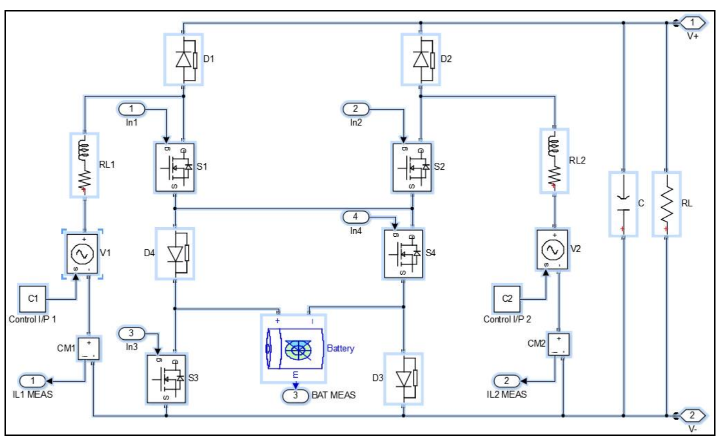

Figure 1: Circuit Diagram of the proposed Converter

The two inductors L_1 and L_2 connected with in series of V_1 and V_2 make the input ports as current sources and filters the dc currents from the input power sources. The R_L is the equivalent to feeding load resistance. Four switching devices S_1,S_2,S_3 and S_4 are the main elements that can used to control the power flow of the hybrid power system.

According to the switching combination the converter can be operated in three different modes as follows:

1. Supplying the load when battery not available.
2. Supplying the load when battery available.
3. Supplying the load while battery is charging.

3.1. Supplying the Load When Battery Not Available

Since the battery is not available which means there is no need to flow (supply or draw) current through battery. The condition can be easily achieved in the proposed converter by simply turning off the S_3 Turning off the S_3 opens the path of current through battery from S_1 and S_2, however there is a path through S_1 and D_1 but can only be followed if S_4 be off while S_1 remains on and hence when controlling this condition must be avoided.

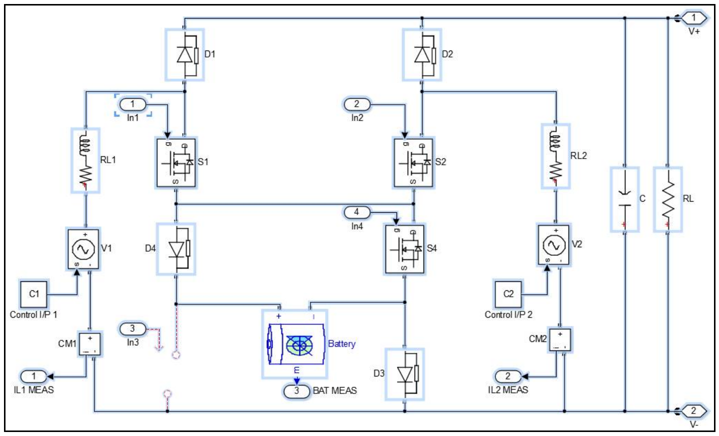

Figure 2(a): converter in mode 1, with S_3 turned OFF.

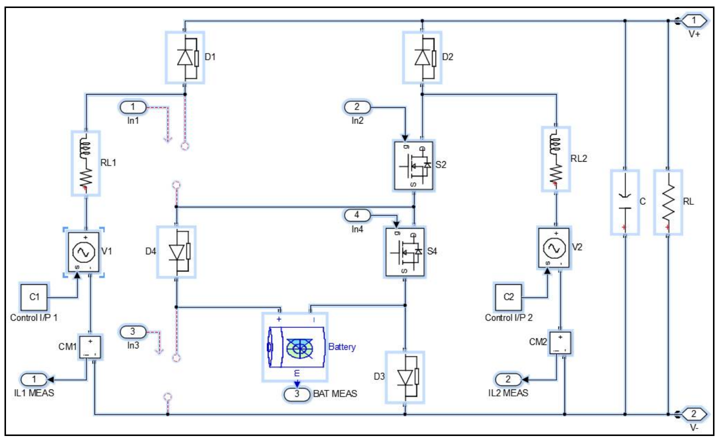

Figure 2(b): converter in mode 1, with S_1 and S_3 turned OFF.

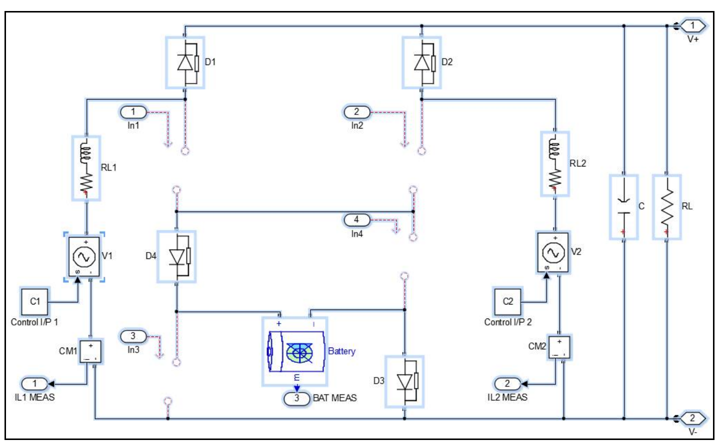

Figure 2(c): converter in mode 1, with S_1,S_2,S_3 and *S_4 are turned OFF.*

The behavior of the circuit could be explained according to the figures 2(a), 2(b) and 2(c). The figure 2(a) shows when the switch S_3 is open and all other switches are ON in such case the inductors L_1 and L_2 will store the energy and current will flow only through internal loop not through load R_L (assuming voltage hold by C is greater). Now if the switch S_1 is also turned OFF (figure 2(b)) the current of L_1 will flow through the load while the L_2 will continue to store energy. Now if all switches are turned OFF (figure 2(c)) then both the inductors will flow current through load.

3.2. Supplying the Load When Battery Available

If the battery is fully charged and can be used to supply load then the converter can be operated in mode 2.

The operation can be explained in four phases.

3.2.1. Energy Storing Phase
In this phase the energy from all three sources are drawn and stored in L_1 and L_2 however during this phase the load is supplied by the capacitor C as shown in figure 3(a).

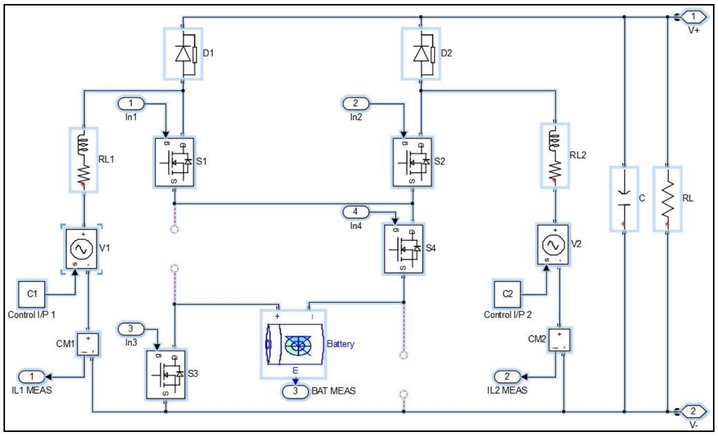

Figure 3(a): converter operating in mode 2 and phase 1 (Energy storing phase)

3.2.2. Battery Elimination Phase
In this phase the battery is disconnected from the main circuit however the energy supplied by the battery is still stored in inductor L_1 and L_2

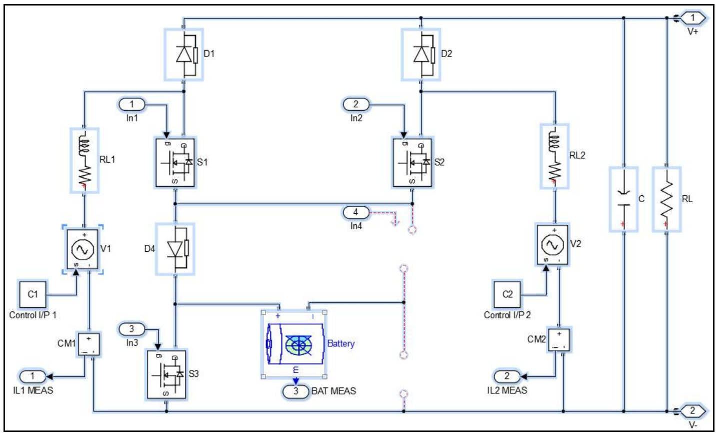

Figure 3(b): converter operating in mode 2 and phase 2 (Battery Elimination Phase)

3.2.3. Series Load Supplying Phase
In this phase the sources are connected in series to supply the load.

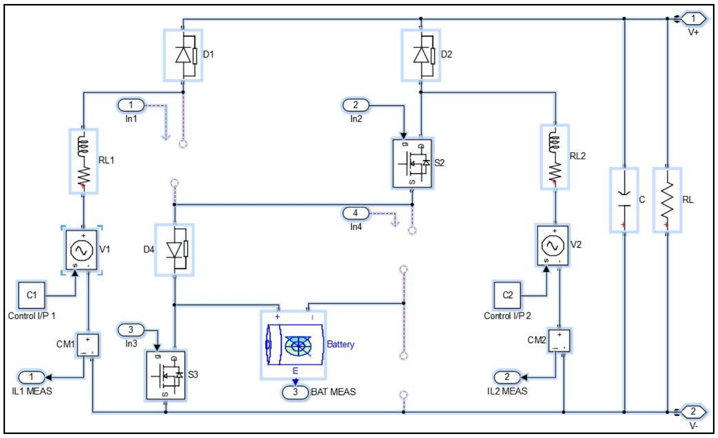

Figure 3(c): converter operating in mode 2 and phase 3 (Series Load Supplying Phase)

3.2.4. Parallel Load Supplying Phase

In this phase the load is supplied by the L_1 and L_2 independently and in parallel.

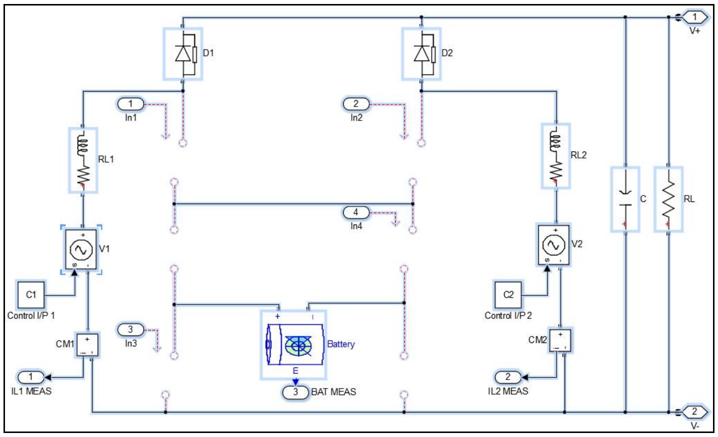

Figure 3(d): converter operating in mode 2 and phase 3 (Parallel Load Supplying Phase)

3.3. Supplying the Load While Battery Is Charging

This mode helps when the battery needed to be charged while load also needed supply. In this mode the battery charging and load supplying is performed in two different phases, however the complete operation can be divided in four phases.

3.3.1. Energy Storing Phase

In this phase the energy from the sources V_1 and V_2 is stored in L_1 and L_2 respectively. However the current from both inductors are added up by connecting in parallel. This helps in providing the larger current to battery for charging in next phase.

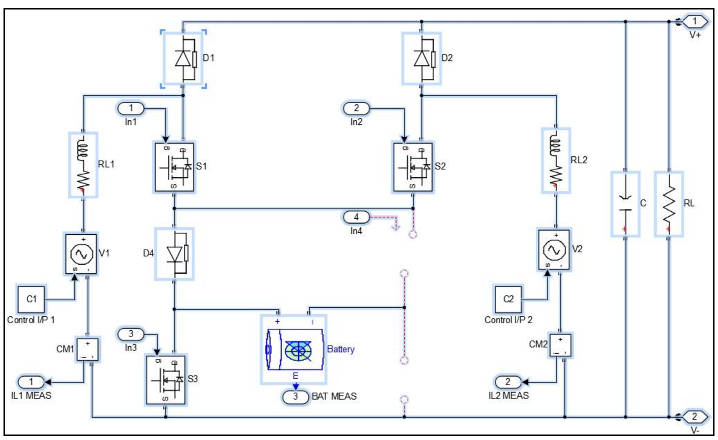

Figure 4(a): converter operating in mode 3 and phase 1 (Energy storing phase)

3.3.2. Battery Charging Phase

Once the energy is stored in L_1 and L_2 the battery charging can be performed by directing the current of these inductors through battery here this is performed by simply turning OFF the switch S_3.

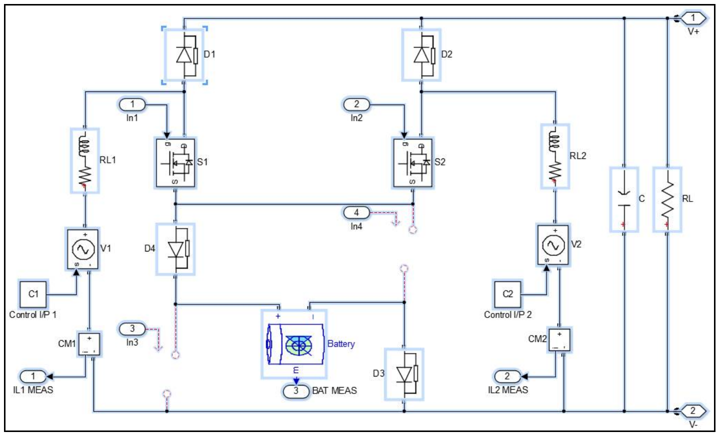

Figure 4(b): converter operating in mode 3 and phase 2 (Battery Charging Phase)

<u>3.3.3. Battery Charging with Load Feeding Phase</u>

In this mode the load is supplied by the L_1 only while the L_2 is still supplying the battery. The operation is performed by directing the current of L_1 to load and breaking its path through battery.

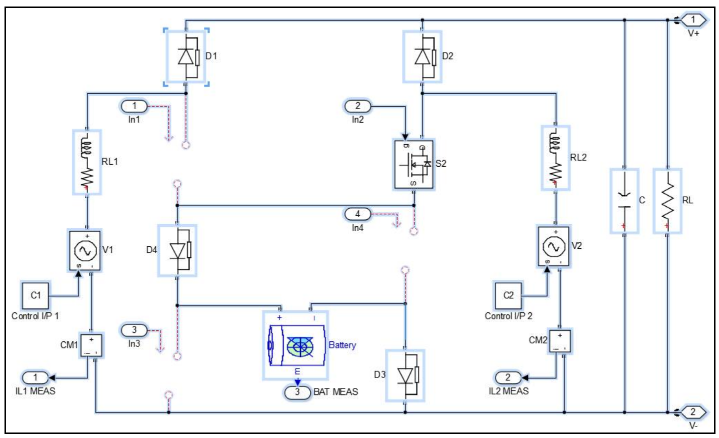

Figure 4(c): converter operating in mode 3 and phase 3 (Battery Charging with Load Feeding Phase)

<u>3.3.4. Only Load Feeding Phase</u>

In this phase all the current sources are directed towards R_L and breaking the paths through battery.

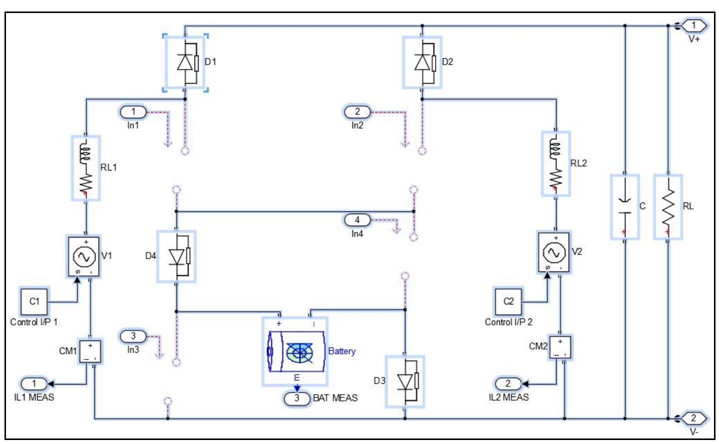

Figure 4(d): converter operating in mode 3 and phase 4 (Battery Charging with Load Feeding Phase)

4. Controlling of the Converter

The controlling of the converter required to control the switching duration of each switch depending upon the mode converter in operating and the phase of operation undergoing.

In our work we proposed a fuzzy logic based control system for the controlling of converter.

Fuzzy logic is a logical decision system which uses the fuzzy set theory. The basic idea behind the fuzzy logic is to utilize the natural language terms for estimation of decision instead of quantitative terms. It is found very useful in modeling of decision system where the information cannot be defined precisely, instead some widely varying definitions can be formed.
Since the fuzzy logic needs linguistic behavior explanation only it removes the complex mathematical computation for generating the decisions. Hence it provides a simple and effective for controlling complex systems.
A basic architecture of FLC (Fuzzy Logic Controller) can be described by the figure 5.

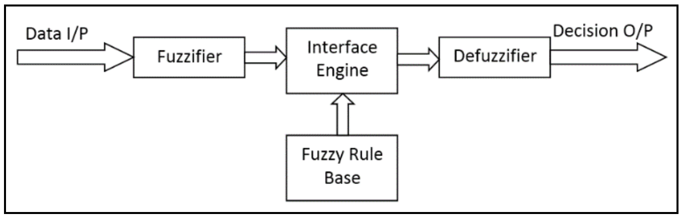

Figure 5: The Basic Structure of Fuzzy Controller

The complete FLC comprises of four different components:

A. FUZZIFIER: is the input interface for FLC with external environment this block split the input quantity to different base categories depending upon the membership function.
B. FUZZY RULES: are the rules (in linguistic form) created by the designer to control the system.
C. INFERENCE: is the block responsible for making a logical judgment based on the provided input and decision rules.
D. DEFUZZIFIER: is used to convert the processed information into the required output format.

4.1. Controlling Algorithm

This section presents the proposed algorithm to operate the converter in all operating modes which has detailed in earlier sections. The controller uses the fuzzy logic to achieve required goals.
The proposed algorithm can be explained as follows:
Start:

1. Input the operating mode.
2. Input the operational requirements like (Regulated Voltage or Current at the Output, Battery Charging Current etc.)
3. Sense the voltage across the load and current flowing through L_1, L_2 and R_L.
4. Apply these observation to FLC;
5. Control the switching according to FLC output;
6. Go to step 1.

End
Explanation FLC: used in step 4 of main algorithm
Start:

1. Apply fuzzy logic with measured and $I_{L_1}, I_{L_2}, I_{R_L}, V_{R_L}$ and required V_{req} in the following way.
   1. $\Delta V^t = V^t_{R_L} - V^t_{req}$
   2. $\Delta A^t = \Delta V^t - \Delta V^{t-1}$
   3. $use\ (\Delta V)\ AND\ (\Delta A) for\ FLC\ as\ Input$
   4. $use\ the\ FLC\ output\ control\, S_1, S_2, S_3\ and\ S_4.$

End

5. Simulation Results

The simulation for the proposed converter with fuzzy controller is obtained by using MATLAB/Simulink.
The results of the simulation under different operating conditions are present in this section.
Operating conditions:
$V_1 = 12\ Volts, V_2 = 12\ Volts,$
$Battery\ Voltage = 12\ and\ full\ charged,$
$R_L = 2ohms, V_L(Output) Ragulated\ at\ 15\ Volts.$

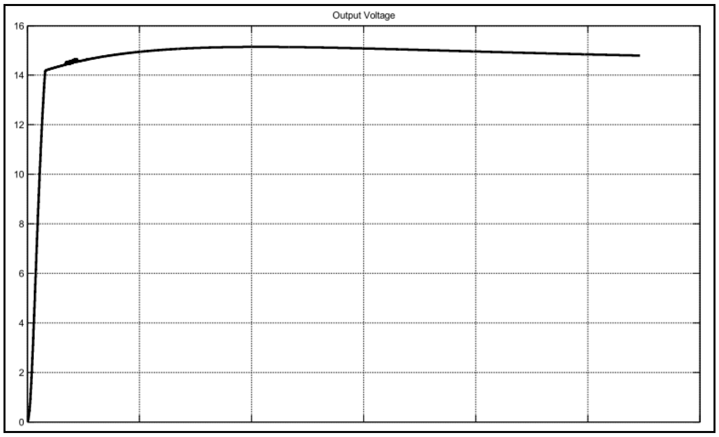

Figure 6: shows the output voltage when all three sources are supplying the load.

Operating conditions:

$V_1 = 12\ Volts, V_2 = 12\ Volts,$

$Battery\ Voltage = 12\ and\ only\ 10\%\ charged,$

$R_L = 2ohms, V_L(Output) Ragulated\ at\ 15\ Volts.$

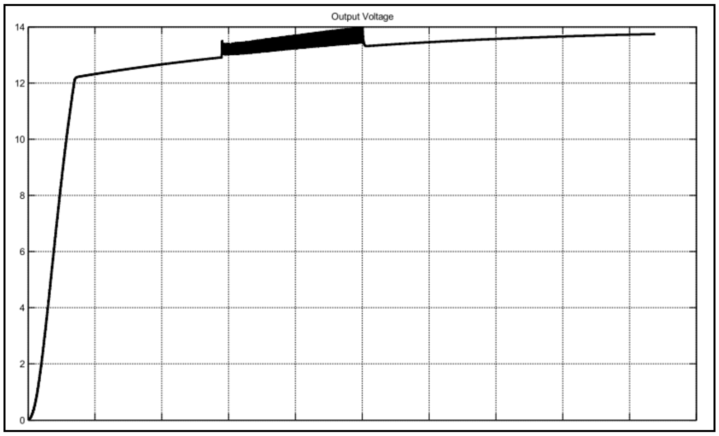

Figure 7: shows the output voltage when battery and load both are supplied by the sources V_1 and V_2.

$V_1 = 12\ Volts, V_2 = 12\ Volts,$

$Battery\ Voltage = 12\ and\ only\ 50\%\ charged,$

$R_L = 2ohms, V_L(Output) Ragulated\ at\ 15\ Volts.$

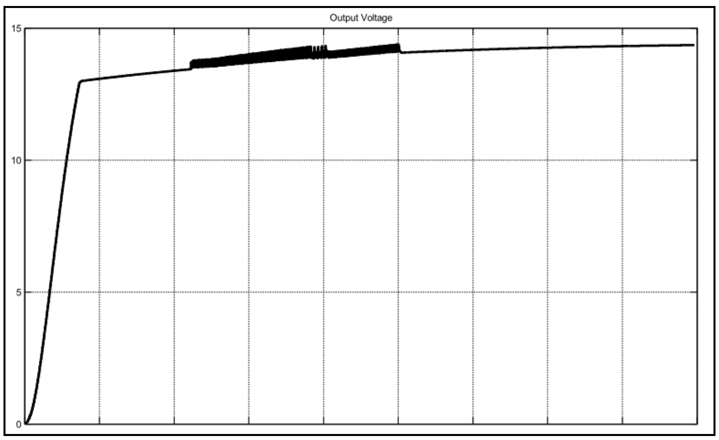

Figure 8: shows the output voltage when battery is half charged and the charging and load feeding both tasks are performed by the sources V_1 and V_2.

6. Conclusion

The novel multi-input fuzzy controlled converter is presented in this paper. The proposed architecture provides a much more cost-effective and simple solution for hybrid systems (such as parallel connected PV and Fuel Cells) compared to the conventional multi-input converters.Using a single converter for all the modes (charging, supplying and battery less operations) reduces the total volume and cost of the converter. The proposed algorithm lies on fuzzy logic controller to estimate the switching activities of the transistors, which eliminates the need for complex system dependent PI controllers and can further reduce the system cost.Overall the simulation results shows that the MISO converter provides satisfying results in different operating conditions and also maintains the output voltage regulation.

7. References

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Annexure

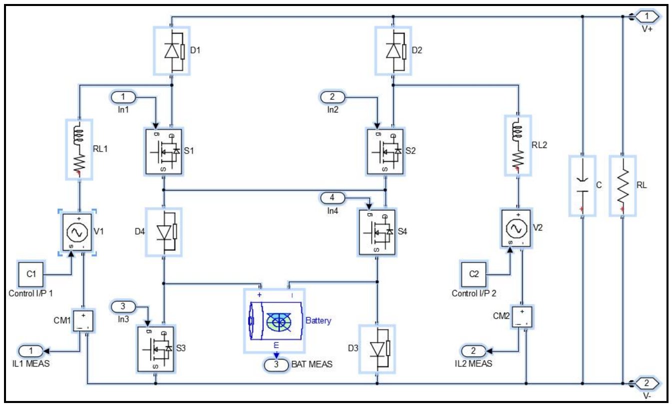

Figure 1: Circuit Diagram of the proposed Converter

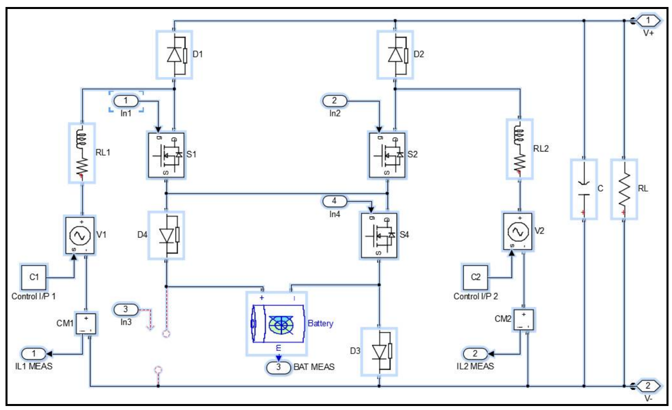

Figure 2(a): converter in mode 1, with S_3 turned OFF

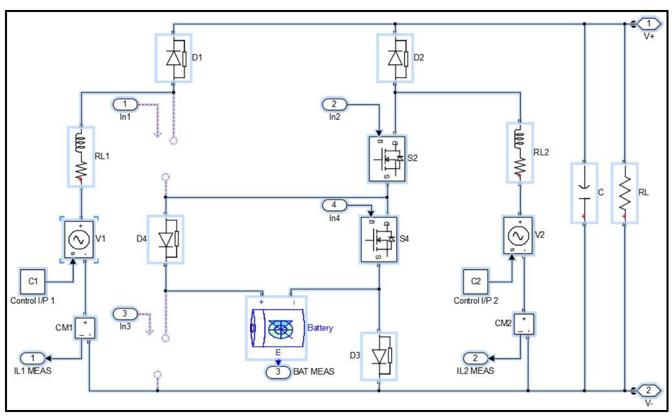

Figure 2(b): converter in mode 1, with S_1 and S_3 turned OFF.

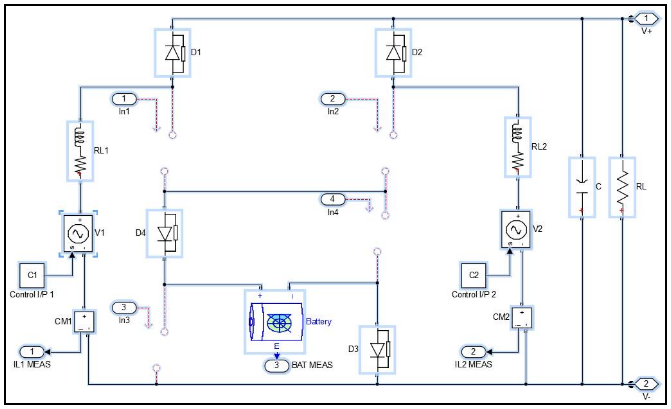

Figure 2(c): converter in mode 1, with S_1, S_2, S_3 and S_4 are turned OFF.

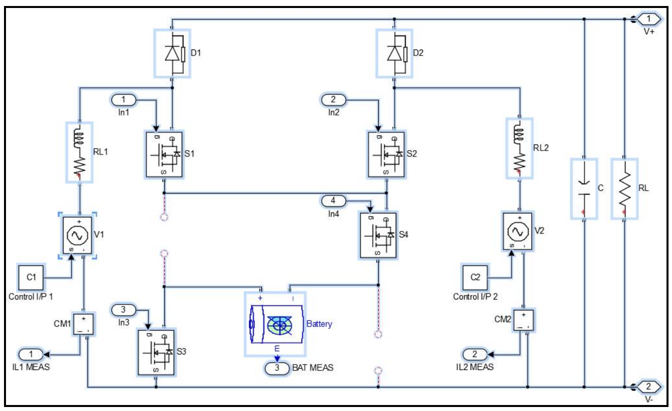

Figure 3(a): converter operating in mode 2 and phase 1 (Energy storing phase)

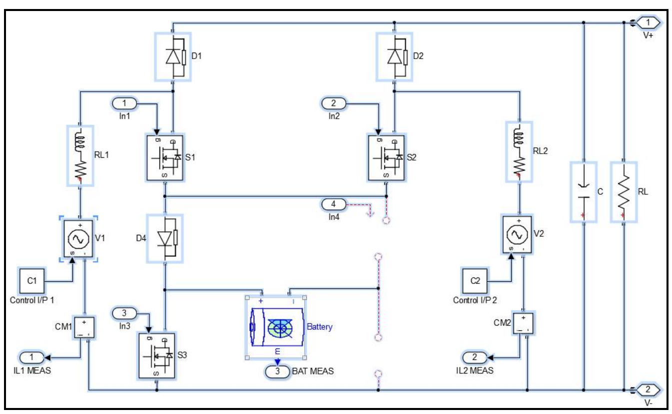

Figure 3(b): converter operating in mode 2 and phase 2 (Battery Elimination Phase)

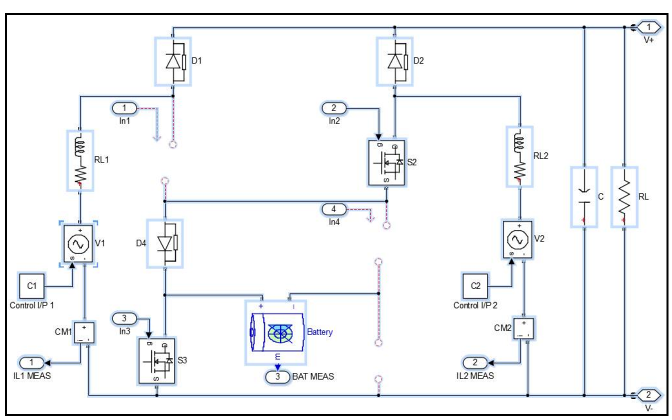

Figure 3(c): converter operating in mode 2 and phase 3 (Series Load Supplying Phase)

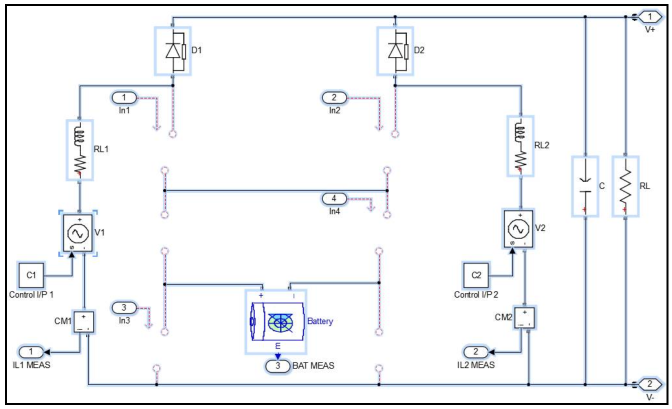

Figure 3(d): converter operating in mode 2 and phase 3 (Parallel Load Supplying Phase)

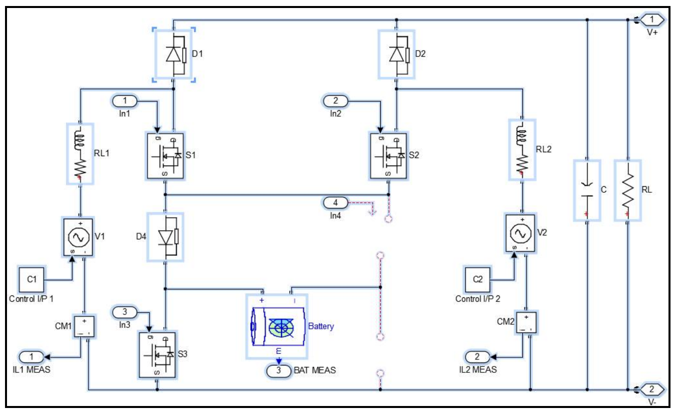

Figure 4(a): converter operating in mode 3 and phase 1 (Energy storing phase)

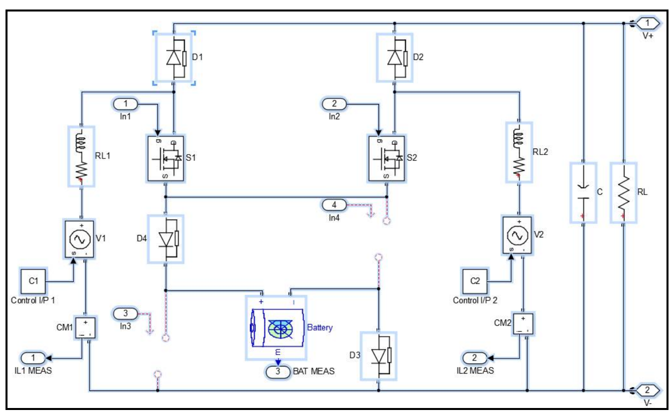

Figure 4(b): converter operating in mode 3 and phase 2 (Battery Charging Phase)

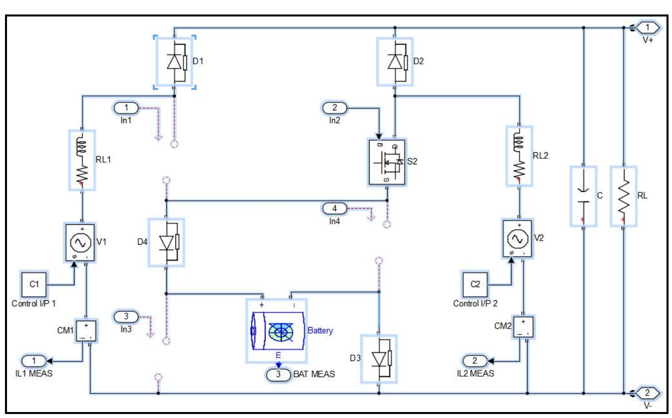

Figure 4(c): converter operating in mode 3 and phase 3 (Battery Charging with Load Feeding Phase)

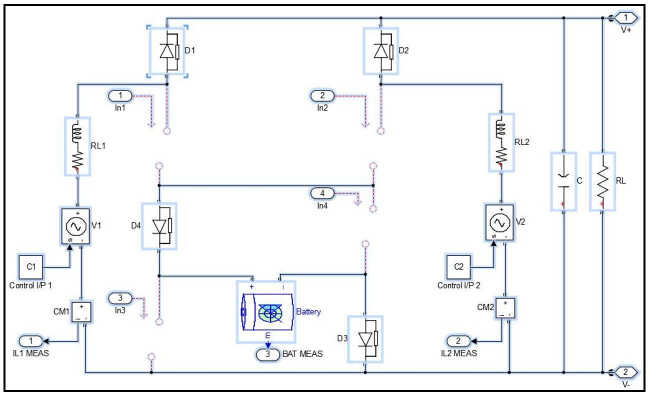

Figure 4(d): converter operating in mode 3 and phase 4 (Battery Charging with Load Feeding Phase)

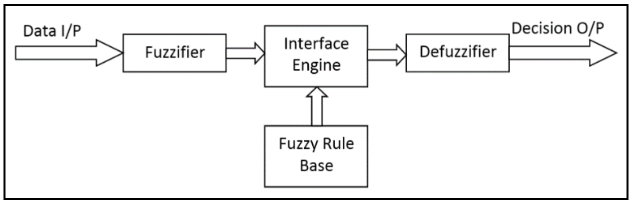

Figure 5: The Basic Structure of Fuzzy Controller

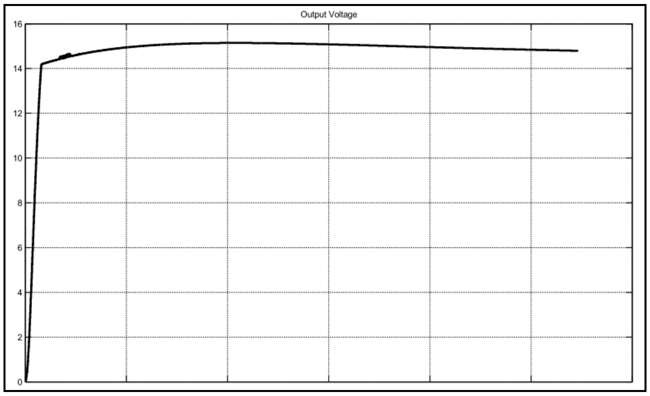

Figure 6: shows the output voltage when all three sources are supplying the load.

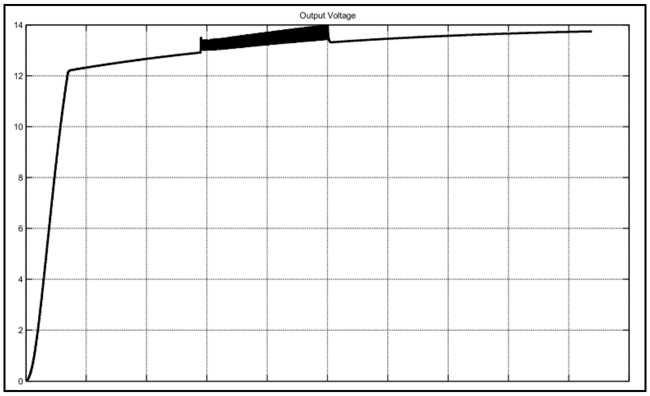

Figure 7: shows the output voltage when battery and load both are supplied by the sources V_1 and V_2.

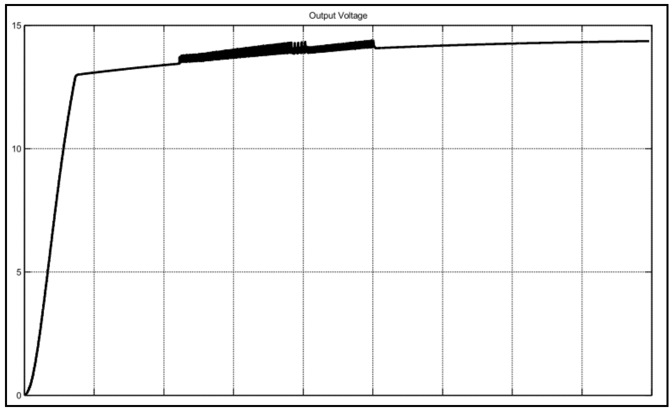

Figure 8: shows the output voltage when battery is half charged and the charging and load feeding both tasks are performed by the sources V_1 and V_2.