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Multiple-Input Converter with Neural and Fuzzy control as Power Conditioner For Fuel Cell Based Grid Interactive Power Supply

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Abstract: *This paper presents a topology of the multiple-input converter (MIC) which is used as the power conditioner that can integrate the various renewable energy sources to make best use of their operating characteristics and obtain better reliability than that could be obtained by single power source. This paper also presents simulation of a grid interactive multiple-input converter with inputs from fuel cell, AC supply and battery and delivers AC supply to the load. The multiple input converters generally use an intelligent controller for efficient power management which suitably connects the sources based on instantaneous load condition. The power conditioner houses a battery bank which is suitably connected by the controller to sink or source the input power based on the instantaneous load requirement.*

Keywords: *Fuel cell, Multiple – Input Converter, Power Conditioner and Renewable Energy Integration.*

1. Introduction

India is facing an acute energy scarcity which is hampering its industrial growth and economic progress. India with 17 per cent of the world population and just 0.8 percent of the world's known oil and natural gas resources is facing serious energy challenges and it continues in the coming decades as well. Besides India is world's 6th largest electrical energy consumer, accounting 3.4% of global energy consumption.

2. Multiple - Input Converter

A multiple input converter is the one which has many input terminals and receives energy from various sources, integrates with in itself and supplies energy to a single load or multiple loads. The integration of electrical power is done at the point of common coupling (PCC) in the converter either as AC or DC voltage. Universally, the electrical energy to the various loads is supplied from a single energy source, which is mostly the utility, PV panel, wind turbine generator or fuel cell. On the other hand certain loads defined as critical loads are powered by two sources such as uninterruptable power supplies (H.Tao et al, 2008; J.L. Duarte et al 2007). Here an effort has been made to integrate the power from fuel cell and the grid supply with battery as an external leveling agent that can maintain an interruption less supply of power (H.Krishnaswami et al, 2009) for the load which can be mainly used for the remote electrification of military installations and rural electrification.

3. AC Based Integration

In the AC based integration shown in figure 1, the energy from various sources is combined in a high frequency transformer. The high frequency AC can be generated using a suitable inverter. The power conditioner can be designed as a standalone power supply without utility as one of the input or the grid interactive power supply with the utility as one of the input to the converter, where the converter is suitably operated by a suitable intelligent controller to achieve the maximum usage of fuel cell power rather than grid energy. For the standalone system, if the demand is greater than the sum of generation the excess power requirement will be met with the battery.

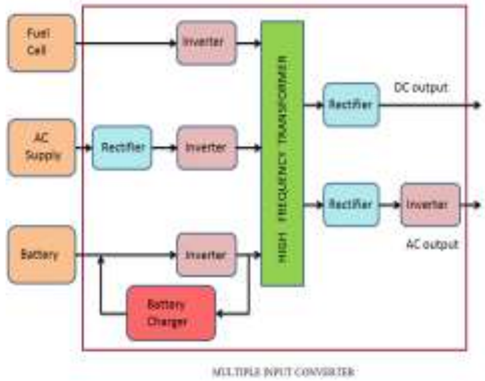

Fig. 1: Schematic of Proposed Multiple-Input Converter

3.1 . Controller

The controller for the proposed system is done using a logical decision based on the regulated DC output voltage due to load variation. The logic for the controller is developed based on the fact that, the mean output voltage of the rectifier decreases as the load increases due the source and system impedance. Hence the reference voltage pertaining to the mode selection i.e., charging or discharging of the battery is set based on the magnitude of the DC voltage at the output of the rectifier.

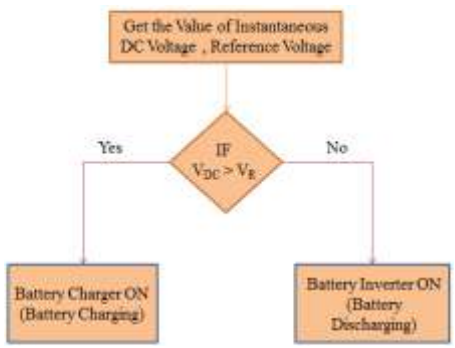

Fig. 2: Flowchart

3.2 . Simulation Results

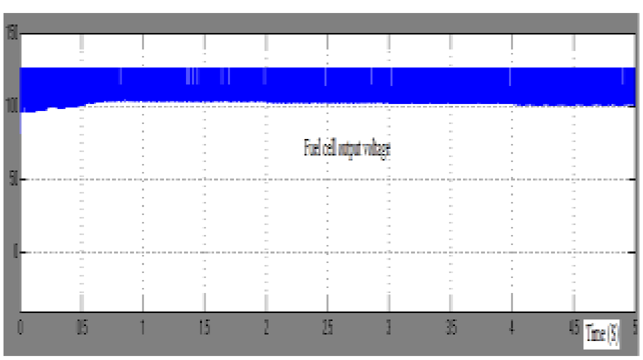

Fig. 3(a): Fuel Cell Output Voltage

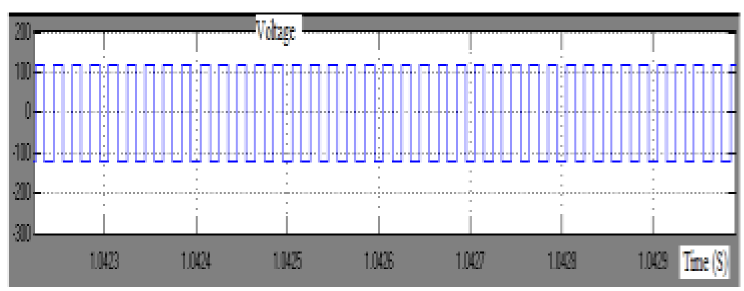

Fig. 3(b): Inverter Output Connected to Fuel Cell

Fig. 3(c): Variation of Output Voltage with Increasing Load.

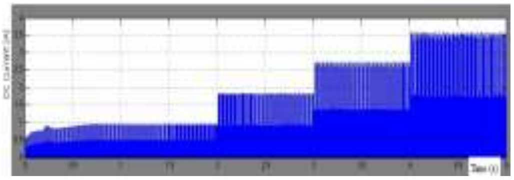

Fig. 3(d): Variation of Output Current with Increasing Load.

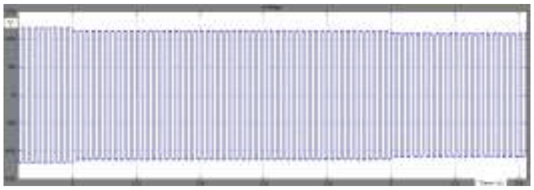

Fig. 3(d): AC Output Voltage at Power Frequency (50Hz)

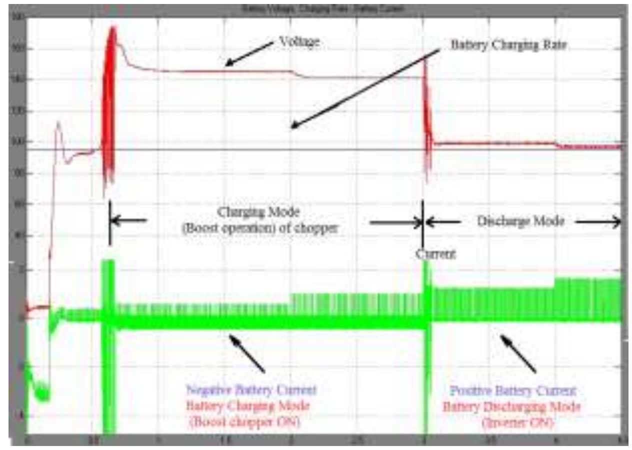

Fig. 3(e): Mode Selection of the Controller (Charging / Discharging) Based on Load Variation

4. DC Based Integration

In the DC based integration, the energy from the various sources is integrated at the point of common coupling (PCC) after the voltage being stepped up in the DC-DC converter. Due to the nature of the various sources i.e., differences in the V-I characteristics of the sources, the drop in the output voltage due to inclusion of the load may be different which leads to the large circulating current within the sources which need to be avoided, hence each DC-DC converter generally uses a controller exclusively to maintain a constant voltage at point of common coupling on the event of variation of load.

4.1. Bi –Directional Converter

The Bi-Directional Converter (BDC) (H.Al-Atrash et al, 2007; N.D. Benavides, 2005) connects the battery with the Point of Common Coupling, it can transfer the energy on both the directions. Since the voltage difference between the PCC and battery is less, a non – isolated BDC is used. The Buck / Boost BDC is generally used which operates in the boost mode to discharge the battery and operates in the buck mode to charge the battery.

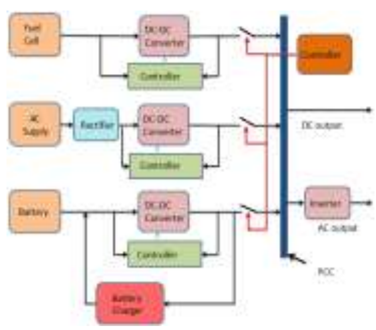

Fig. 4: Multiple-Input Converter with DC Based Integration.

4.2. Battery

Battery is used as the external leveling agent to sink/ source the power based on the instantaneous load condition. The lead acid batteries are preferred for standalone applications as the maintenance and the initial costs are less.

$$I_{BuckBDC} = 0.1 \times C_B = 0.1 \times 20 = 2A$$

4.3 Slip-In and Slip-Out

The slip-in and slip-out of the battery from conduction is an important function which is performed by the power management controller. The point of slip-in and slip-out of battery from conduction is generally done based on the instantaneous load condition by sensing the voltage at PCC.

4.4 SOC of Battery

The state of charge (SOC) is defined as the available capacity expressed as a percentage of its rated capacity. The SOC of the battery is so important for the selection of various modes of operation by the controller. Of the various methods such as specific gravity, direct measurement and voltage based methods, the voltage based SOC estimation is used in the work as it is convenient from simulation perspective.

The voltage based estimation of SOC for lead acid battery is done in the proposed work shown in table 1. The slip in and slip out battery for conduction is set at 80% SOC, as continuous discharge of batteries to about 70 - 80% of its capacity shall damage the battery even it is a deep cycle battery.

TABLE I: SOC Vs Battery Voltage

S. No	SOC	V_{Bat}
1	100	105.83
2	95	105.21
3	90	104.83
4	85	104.33
5	80	103.83

5. Simulation

The simulation of the multiple-input converter is done in MATLAB/Simulink.

5.1 Fuel Cells

Fuel cells produce direct current electricity using an electromechanical process similar to battery. As a result, combustion and the associated environmental side effects are avoided. Natural gas or coal gas is cleaned in a fuel cell and converted to a hydrogen rich fuel by a processor or internal catalyst. The gas and the air then flow over an anode and a cathode separated by an electrolyte and thereby produce a constant supply of DC electricity, which is converted to high quality AC power by a power conditioner.

5.2 Controller

The proposed system uses two controllers i.e., a neural controller for voltage and a fuzzy control for the power management.

5.2.1. Neural Controller

The function of the neural controller is to maintain a constant DC voltage at the point of common coupling (PCC) is shown in Figure 8. When the sources are connected in parallel at PCC through DC-DC converters the output voltages have to be maintained constant and the magnitude of all output voltages need to be same, so as to limit the circulating current.

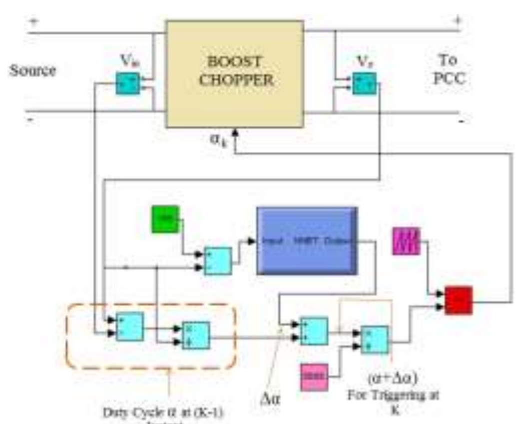

Fig. 5: Implementation Diagram of the Neural Network Controller

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5.2.2 Fuzzy Controller

The controller for the proposed system is programmed to take the logical decision based on the instantaneous load demand, power availability of the fuel cell and present SOC of the battery. The maximum deliverable power rating of the fuel cell at stable state is 1.25 kW; similarly the 20Ah battery at its nominal discharge current i.e., ($0.2C_B$) can deliver 400W continuously, also at its peak discharge current i.e., ($0.5C_B$ - $0.7C_B$) the battery can deliver 1kW to 1.4kW for a shorter period of time if demanded by load.

TABLE II: Modes of Operation of Controller.

Mode	Source	S_1 (Fuel Cell)	S_2 (BDC - Battery Charging)	S_3 (BDC - Battery Discharging)	S_4 (AC Supply)
1	Fuel Cell alone	On	Off	Off	Off
2	Fuel Cell and Battery (Charging)	On	On	Off	Off
3	FC and Battery (Discharging)	On	Off	On	Off
4	Fuel Cell, Grid and Battery (Charging)	On	On	Off	On

6. Modes of Operation

6.1. Mode 1

When the Fuel Cell stack generates sufficient power ($P_{Fuel\ Cell} > P_{Load}$) and the battery is nearly fully charged, i.e., state of charge of the battery is more than 80% (SOC > 80%), all the power produced by the Fuel Cell stack will be used to supply loads.

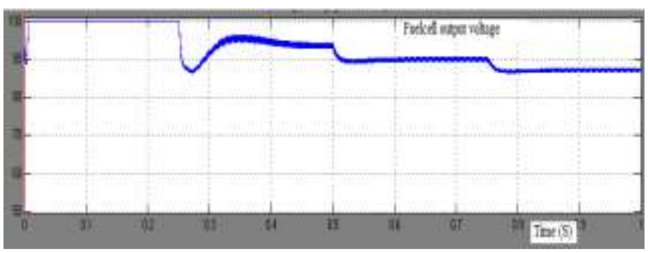

Fig. 6(a): Fuel cell Output Voltage

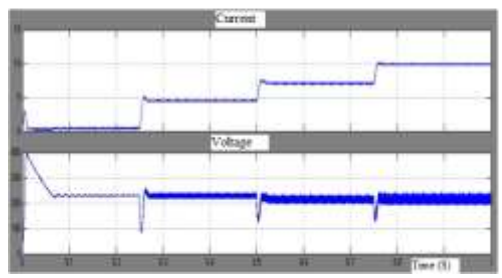

Fig. 6(b): Fuel cell Current (top) and Voltage (bottom) at the output of DC Converter

6.2. Mode 2

When the power generated by the Fuel cell stack is more than the load demand and the battery doesn't have enough power i.e., ($P_{Fuel\ Cell} > P_{Load}$ and SOC < 80%), the Fuel cell stack is used to supply the load shown in figure 12(a) and also charges the battery with remaining power, revealed in the figure 12(b).

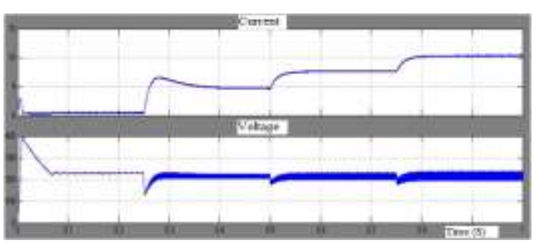

Fig. 7(a): Fuel cell Output Current and Voltage

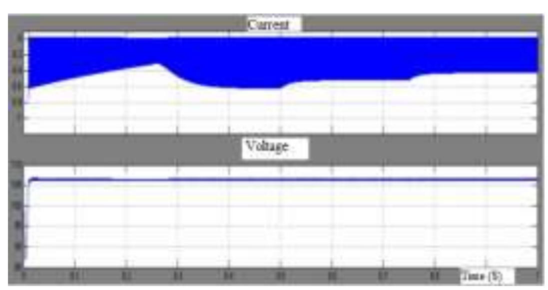

Fig. 7(b): Battery Current (-ve) and Battery Voltage

6.3. Mode 3

When the deliverable power of the Fuel cell stack is less than the load demand and the state of charge of the battery is more than 80%. i.e., ($P_{Fuel\ Cell} < P_{Load}$ and SOC > 80%).

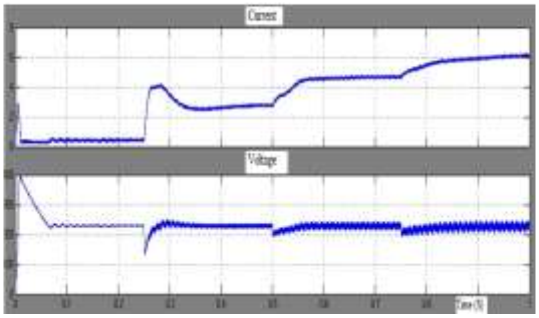

Fig. 8(a): Fuel cell Output Current and Voltage at PCC

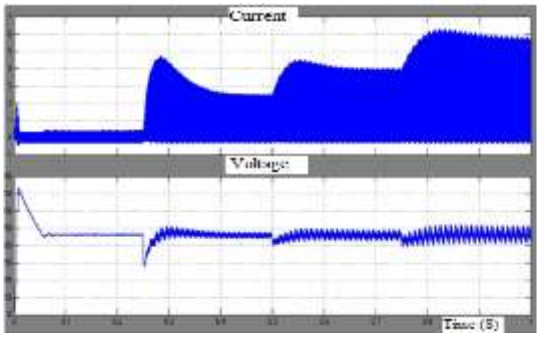

Fig. 8(b): Battery Output Current and Voltage at PCC

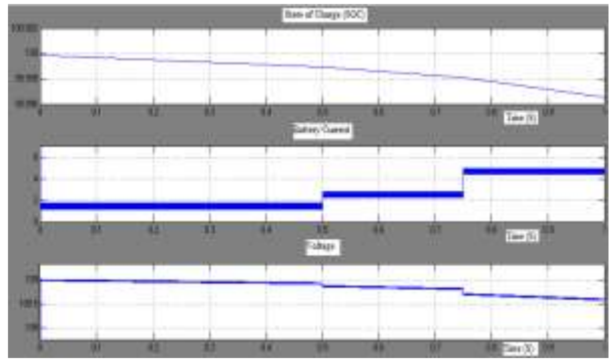

Fig. 8(c): Battery Discharge Characteristics

6.4. Mode 4

Once the power generated by the fuel cell stack is insufficient to meet the load and the SOC of the battery is very less i.e., ($P_{Fuel\ Cell} < P_{Load}$ and SOC < 80%), the power generated by the fuel cell is fully supplied to the load (shown in figure 14(b)) and the excess demand alone is met through the grid supply by suitably adjusting the duty cycle of the boost converter connected to the grid so as to supply the necessary power alone from the grid shown in figure 14(a).

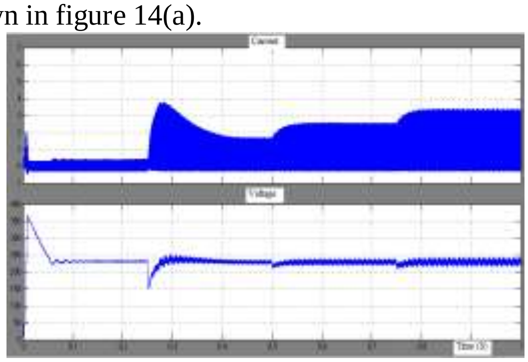

Fig. 9(a): Output current and voltage of Grid at PCC

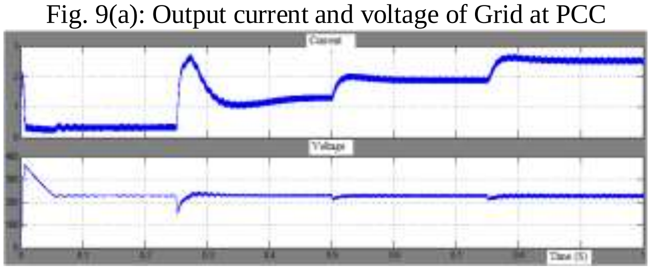

Fig. 9(b): Fuel cell Discharge at PCC

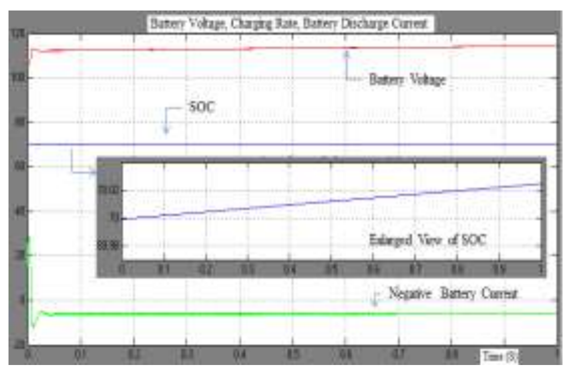

Fig. 9(c): Battery Charging Characteristics

7. Conclusion

The simulation and performance analysis of multiple-input converter is done and the analysis shows a better performance which can be confirmed from the waveforms. The scope of the above work is immense in the area of renewable energy applications for rural electrifications and remote installations.

8. References

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