

Design of High Efficiency Step-Down Converter for Electro Chemical Energy Conversion

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Abstract
Recently the research interest in power electronics interface for fuel cell has increased. And the static characteristics of fuel cells show more than a 30% difference in the output voltage between no-load to full-load conditions. Thus inevitable decrease, which is caused by internal losses, reduces the utilization of fuel cells at low loads. Fuel cell is a electrochemical energy conversion device which directly produces electricity. Thus, a step-down converter is required to transfer from a high input voltage to an efficient and constant low level voltage. Maintaining high efficiency under a wide loading range is important in fuel cell.The aim of this work is to design a stepdown converter with DCM operation under light load not only can reach high efficiency in heavy-load, but also has great improvement in light-load efficiency. The output accuracy and the output ripples obtained are better than other converters under light-load and as good as a normal PWM converter under heavy-load. Circuit simplicity and high reliability are the major advantages of the proposed converter. Using this technique, the utilization factor and efficiency of the fuel cell is increased. And this paper, focuses on the simulation and implementation of DC-DC converter fed fuel cell. Validation of the proposed model is verified through simulation.
Keywords: Fuel cell, Stepdown converter, PWM

I .INTRODUCTION
The last few years has witnessed a growing interest in the field of fuel cell technology. The stimulus for this interest is provided by the fact that Fuel Cells are a source of clean and efficient source of electricity. They have a wide range of applications ranging from the transportation industry to utility industries. Environmental concerns about global warming has risen to become an important issue providing the impetus to reduce C_{O2} emissions which is one of the many advantages of using a Fuel Cell. Fuel cells have became a very active research field today and the need of step-down converters is required for validation and system integration.

Fuel cells are a source of DC voltage but majority of applications both industrial and domestic require AC supply and hence inverter circuit fed by a fuel cell is employed. Multilevel inverter is a promising topology that enables us to generate output waveforms close to that of a sine wave. High efficiency and low electromagnetic interference due to low frequency control method makes this setup perfectly suitable for high power motor drives. Besides MLI uses separate DC sources to synthesize an output that is far closer to sinusoidal waveform. Thus better quality outputs can be achieved. The step-down converter is required to transfer energy from a high input voltage to an efficient and constant low level. Maintain high efficiency under a wide loading range is important in fuel cell.

Pulse width modulated DC-DC converters for Fuel cell, employing semiconductor power switches, have developed rapidly in recent years. The switch mode operation subjects the control switches to high switching stress and high switching power losses. To maximize the performance of switch-mode power electronic conversion systems, the switching frequency of the power semiconductor devices needs to be increased, but this results in increased switching losses and electromagnetic interference. To eradicate these problems, soft switching methods are presented and investigated. Zero voltage switching (ZVS) and Zero current switching (ZCS) techniques are two conventionally employed soft - switching methods. These techniques lead to either zero voltage or zero current switching, significantly decreasing the switching losses and increasing the reliability for the Fuel cells.

II FUEL CELL MODEL
Fuel cell model is a electrochemical energy conversion device which directly produces electricity, water and heat by processing hydrogen and oxygen. Generally DC voltage generated by a fuel cell stack varies widely, low in magnitude and the voltage is between 20V and 50V at full load. The step-down converter is responsible for absorbing power from the fuel cell, match the fuel cell ripple current specifications and should not conduct any negative current.

The fuel cell directly converts chemical energy into electrical energy. It reacts with hydrogen and oxygen to produce electricity, water and heat, according to the following overall chemical reaction.

$$2H_2+O_2 \longrightarrow H_2O+\text{Electricity}+\text{Heat}$$

The following figure illustrates the principle of operation of a fuel cell

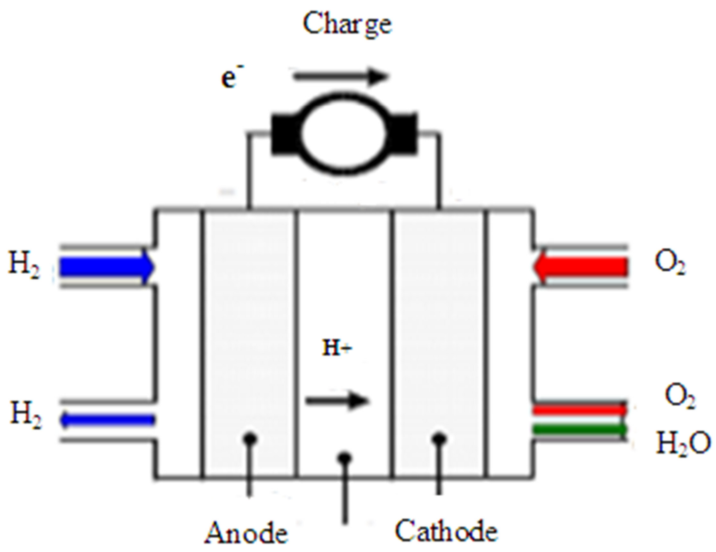


Fig.2.1 Fuel cell Structure

Fuel cell consists of an anode, cathode and an electrolyte providing conducting medium for current to flow. The actual reaction taking place is reverse electrolysis. In reverse electrolysis hydrogen and oxygen are recombined and electric current is produced which flows through the electrolyte.

The advantages of fuel cell are

1. On a comparative scale fuel cells are 85% as efficient as combustion engines and hence they are important in case of generating power systems.
2. A reduced moving part ensures high reliability and a long life.
3. Zero emission can be achieved because pure water is the only by-product when hydrogen is the fuel. Thus they are very useful in case of vehicular emission control.

A. Characteristics of Fuel Cell

The general V-I polarization curve of a fuel cell shows a reduction of the fuel cell voltage with load current density. This unavoidable decrease is due to internal losses which in turn affects the utilization factor of fuel cell at low loads.This voltage reduction is mainly due to three losses. At low current densities the loss is mainly due to the sluggishness of reactions taking place at the electrodes, which is termed as activation loss.

Ohmic losses are caused by the flow of electrons through the electrolyte and through the electrodes. The electrolyte should only transport ions through the cell, however a small amount of fuel diffusion and electron flow occurs. Ohmic losses are essentially linear, that is proportional to the current density. Decreasing the electrode separation and enhancing the ionic conductivity can reduce the ohmic losses. The final loss component is the gas transport loss at higher current densities. As the reactant is consumed at the electrode, the concentration of the surrounding material reduces because not enough reactants and products are being transported to and from the electrodes. The output voltage decreases with the decrease in the concentration.

III BUCK CONVERTERS UNDER LIGHT AND HEAVY LOAD CONDITION

A. Losses of PWM converters under light-load

Figure 3.1shows the schematic of a PWM step down converter and the waveforms. In steady-state condition, the level of inductor current (IL) will be constant. The PWM controller is designed to maintain the constant IL level under steady state condition, when the converter is operating under light-load condition, the IL level will be lower and some part of IL might be lower than zero. This part is a huge waste under light-load, it is the only defect that PWM converters operating under light-load.

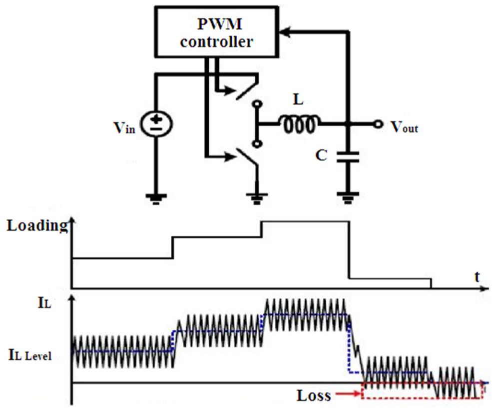


Fig 3.1 PWM Step down converter and Waveform.

The switching frequency of a conventional PWM converter is usually about 200KHz to 1MHz, no matter under heavy-load or light-load.This frequency is not a problem when the converter operates under heavy-load, but in the case of light-load, the switching loss becomes critical and the loss under this frequency greatly decreases the efficiency. The conduction loss is also a problem when converters operate under light- load.

B. Losses of PFM converters under heavy-load

Figure 3.2 shows the PFM Step down converter and waveforms. A PFM Step down converter is usually used for operating under light-load, because PFM converters operate in DCM mode and have lower switching frequency. These two characteristics make PFM converters very efficient under light-load. But a conventional PFM converter operating under heavy load is not as efficient as PWM convertor operating under heavy load because of the large energy needed for heavy- load.

It is because the charge level of a conventional PFM is constant. For a wide- range PFM converter, the charge level is more for light-load. DCM mode also limits the output power of a conventional PFM converter, so the conventional PFM converters are not usually used for heavy- load condition.

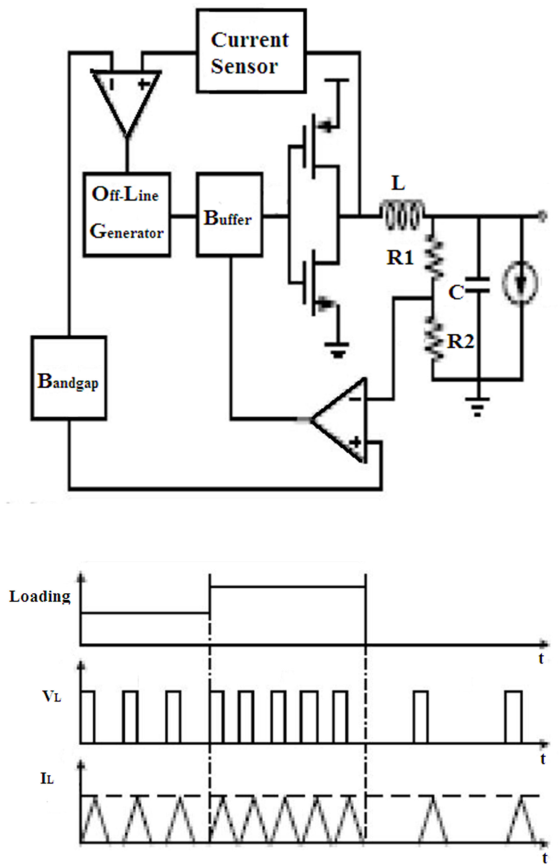


Fig 3.2 PFM Step down converter and Waveform.

C.The Proposed Technique For Duality In Pwm Converters

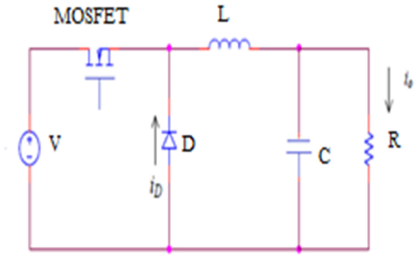


Fig 3.3 Step down converter and Waveform.

The proposed Step - down converter with two operating modes is presented in fig 3.3. The first mode is CCM mode and the second mode is DCM mode. In CCM mode the converter works like a normal PWM converter to exhibit the best characteristics of a PWM converter under heavy-load, such as high efficiency, high accuracy, low output ripple and stable output voltage. The peak efficiency of this mode is about 90%. In DCM mode the switching frequency will decrease and the IL current below zero will be ignored. By adding these two characteristics, the efficiency under light-load will be highly increased. The peak efficiency in DCM mode is about 96%.

IV SIMULATION RESULTS

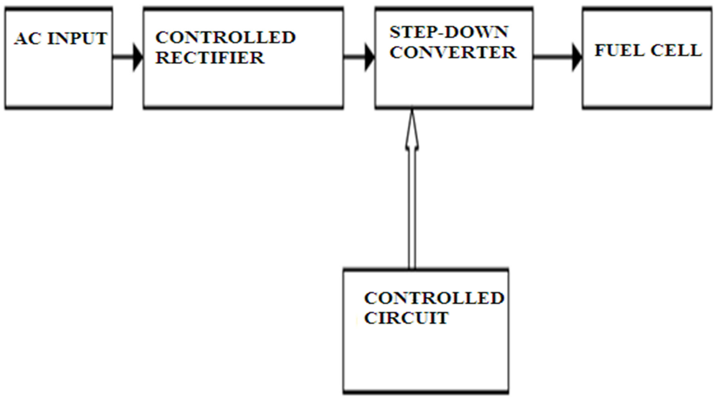


Fig 4.1 Block diagram of step-down converter

The Block diagram 4.1 consists of AC power input of 230V and it is given to the controlled rectifier. The controlled rectifier will convert AC to DC . The output of the controlled rectifier is given as input to the Step-down converter and the fuel cell is charged by the output voltage of step-down converter. The step-down converter switches are controlled by the controlled circuit.

The Step-down converter is simulated in Matlab/Simulink with the following parameters:

PARAMETER	VALUE
Resonant Inductor	40µH
Resonant Capacitor	22µF
Filter Inductor	20mH
Filter Capacitor	400 µF
Switching Frequency	20kHz
Load Resistance	50Ω
Diode on resistor	0.006Ω
Mosfet on resistor	0.005Ω
Diode	IN4007
Mosfet	IRF840

The simulation is done using Matlab simulink and results are presented. Scope is connected to display the output voltage.

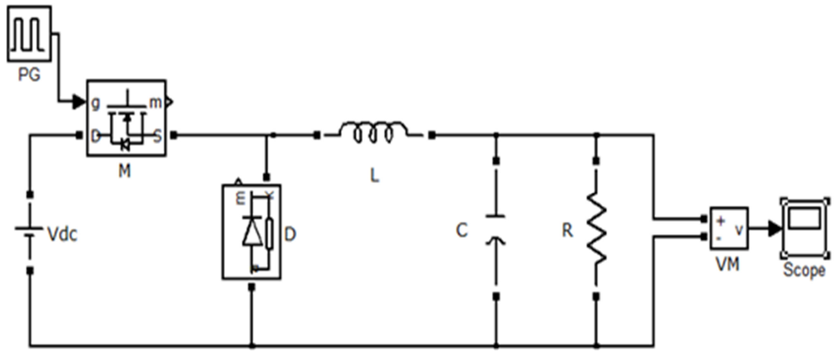


Fig 4.2 Simulated diagram of step-down converter

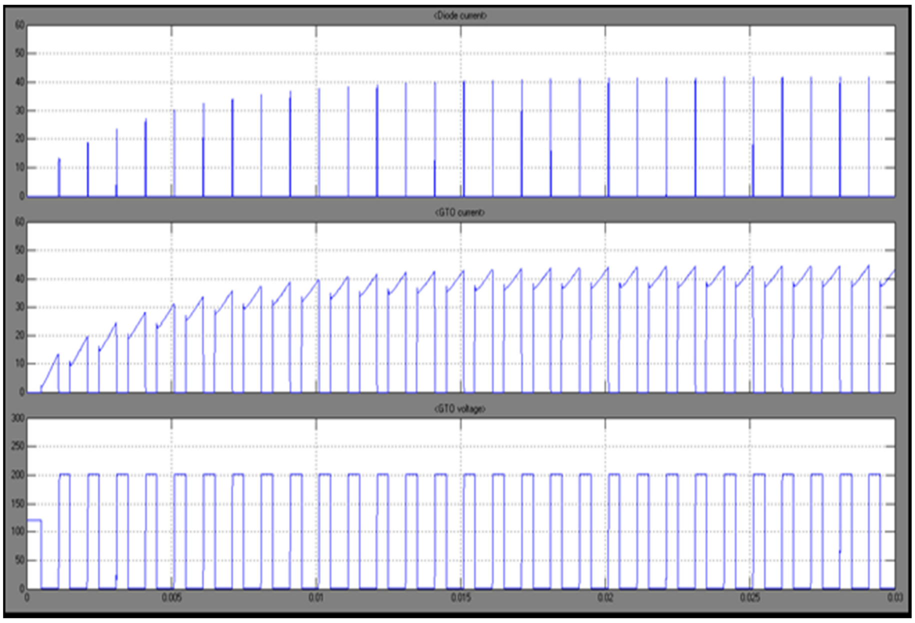


Fig 4.3 Voltage and Current output of step-down Converter

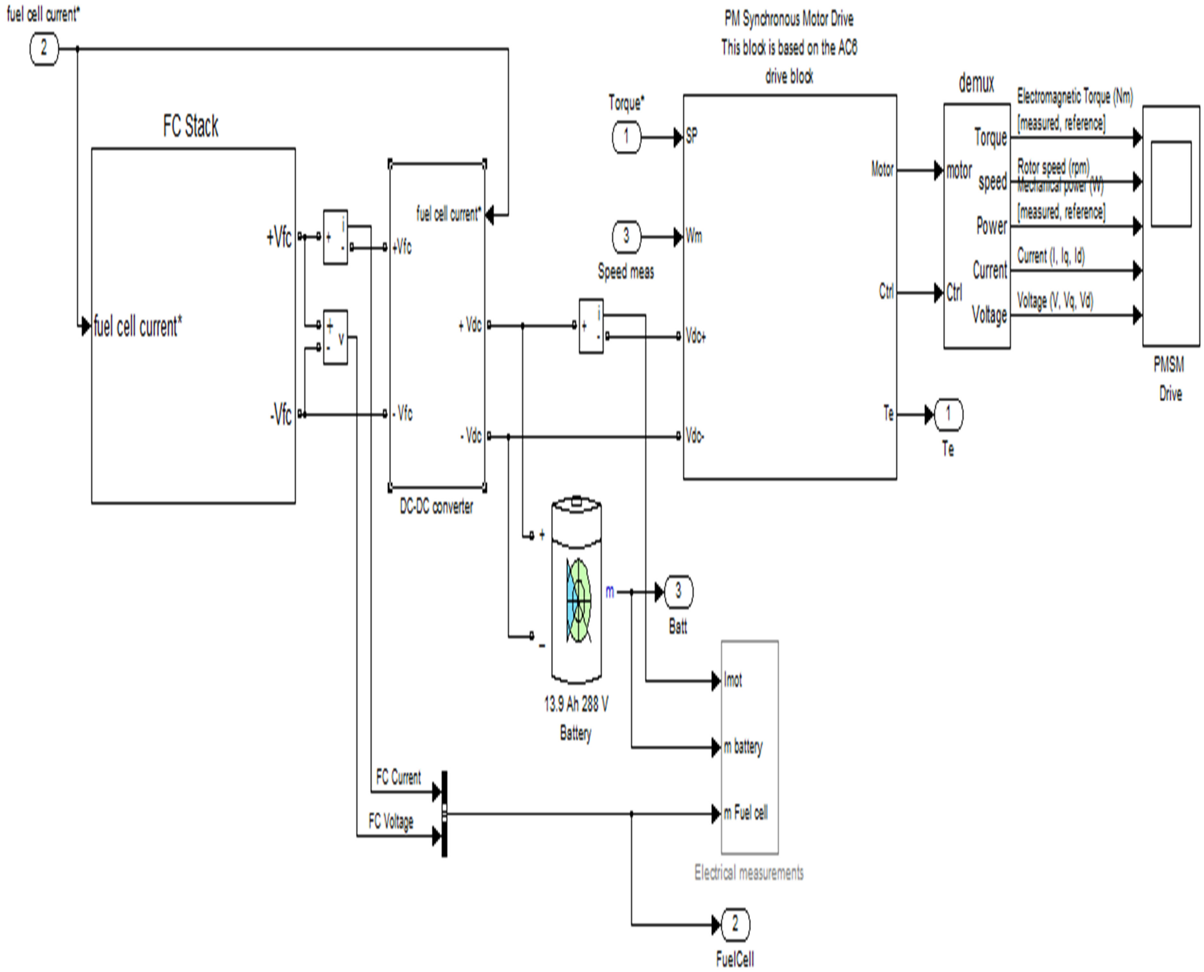


Fig 4.4 Simulated diagram of Fuel cell

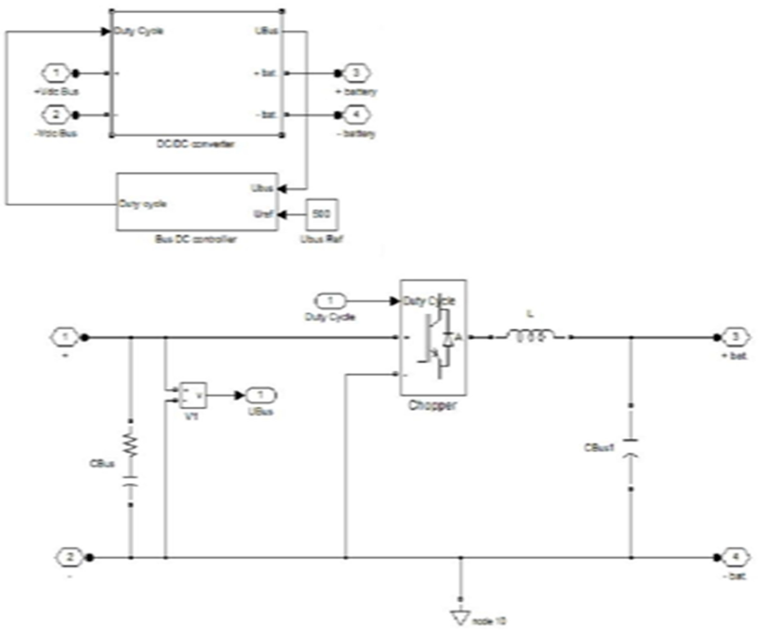


Fig 4.5 Simulated diagram of Fuel cell connecting DC-DC converter block

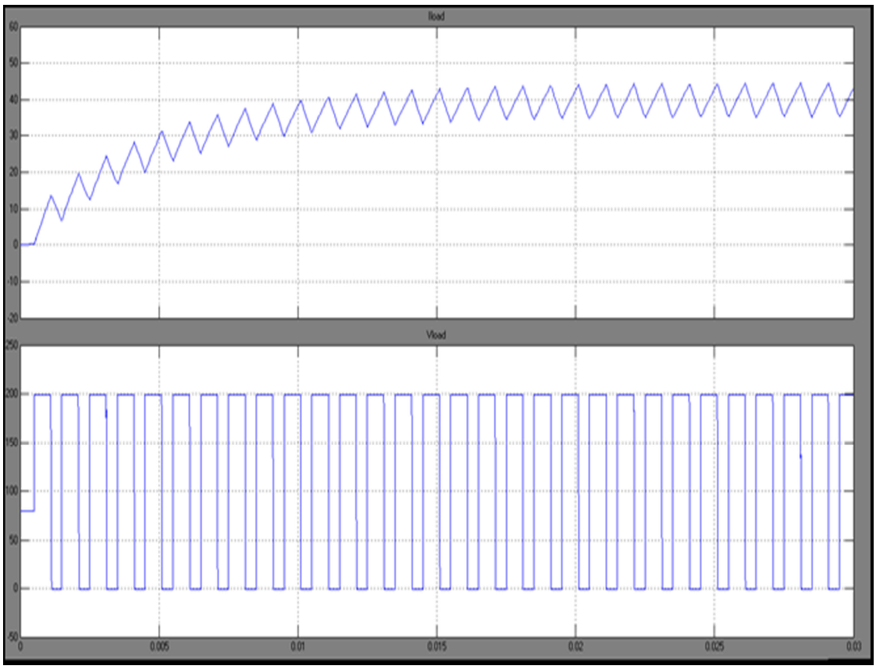


Fig 4.6 Voltage and current output of fuel cell

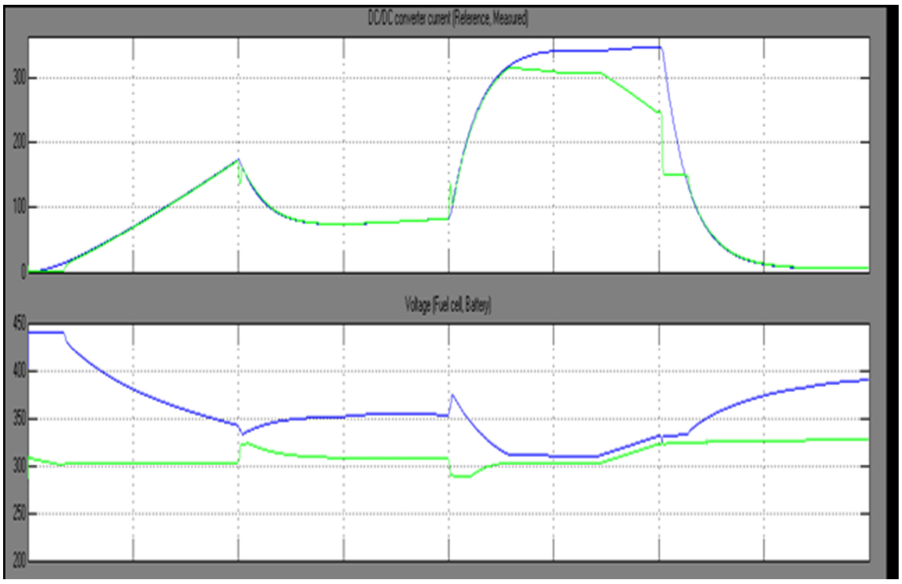
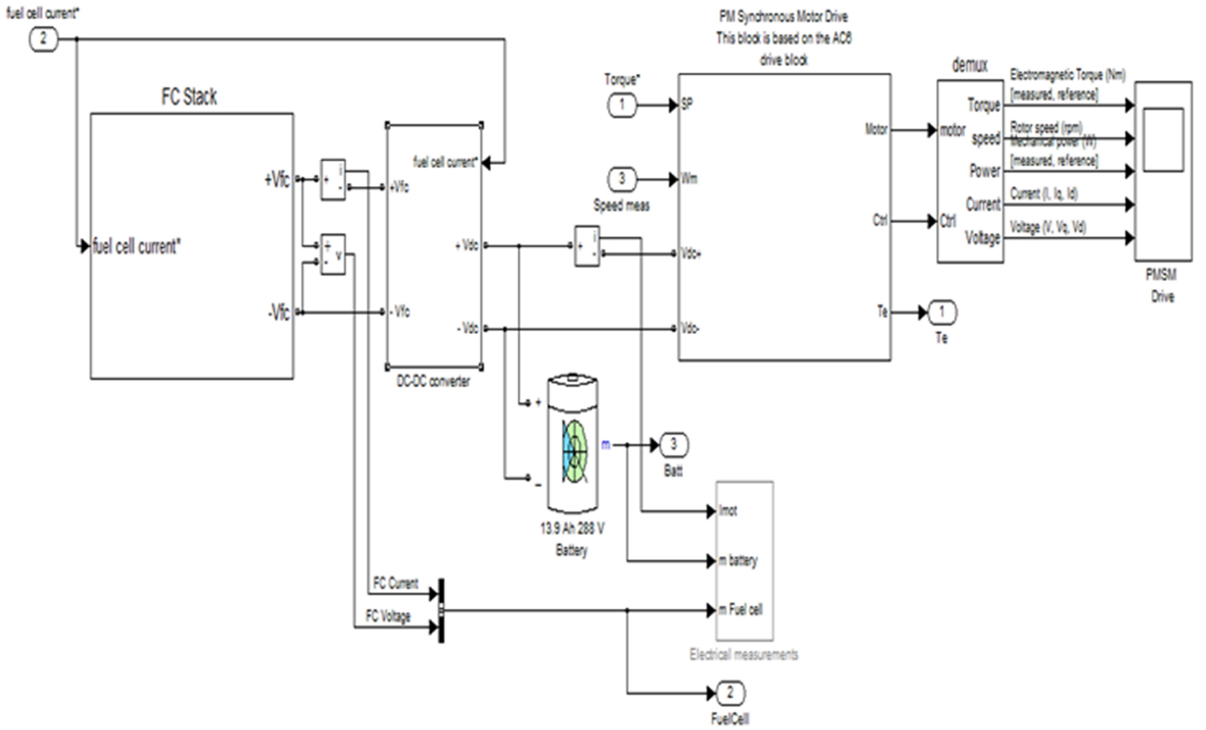


Fig 4.7 Measurement of Power, Voltage from Fuel cell



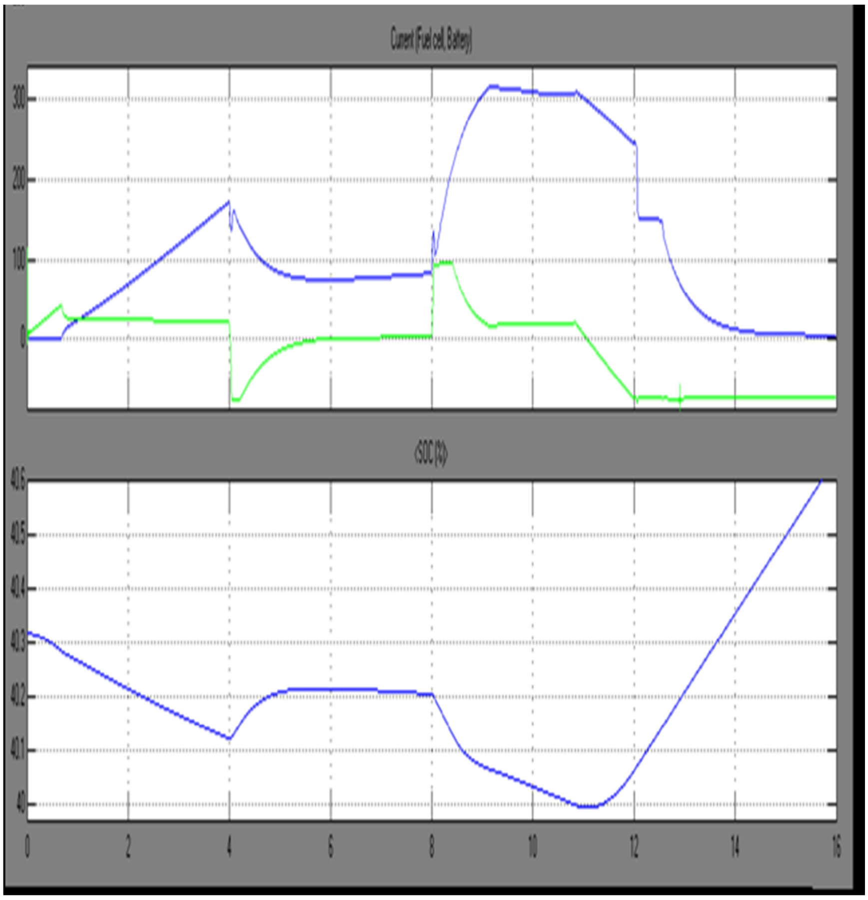


Fig 4.8 Measurement of Current, Torque from Fuel cell

The proposed converter makes the DCM mode be much easier to implement in a PWM DC-DC step-down converter. It also reduces the output ripple and increases the output accuracy. The peak efficiency of a converter using this technique is 96.53% under heavy- load and 90.99% under light-load. Maximum output ripple is only 1.2mV, which is 0.12% of the output voltage. The converter ripple is less than 1 % at different voltage levels. Under these conditions, the step-down converter overall efficiency is around 96%. The step-down converter operates from heavy-load to light- load with high efficiency, high accuracy, low output ripple and stable output voltage.

V EXPERIMENTAL RESULTS

The Step-down Converter is developed and tested in the laboratory. The experimental set-up consists of power supply circuit, gate driver circuit and DC-DC step-down converter circuit. The power supply circuit with input voltage of 220V AC and it is converted into DC supply of 5V and 12V by converter circuit. Here the single phase rectifier circuit and bridge rectifier circuit is used .The filter circuit is used to reduce the distortions and noises in the circuit. The filter circuit is obtained by connecting capacitance in parallel to the output of rectifier circuit. The gate and driver circuit consists of rectifier bridges and it is used to give gate pulse for the switches in step-down converter circuit. The Step-down converter is designed by using MOSFET switch, at a particular time the gate pulse is given to the switch to get the desired output voltage. Pulses required by the MOSFETs are generated by using a ATMEL microcontroller 89C2051.These pulses are amplified by using a driver amplifier.

The following values are found to be a near optimum for the design specifications

PARAMETER	VALUE
Resonant Inductor	100µH
Resonant Capacitor	2200µF,63V
Load Resistance	20Ω
Diode	IN4007
MOSFET	IRF840,10A,10-500V
Regulator	LM7805, LM7812,5-24V
Driver IC	IR2110,+500V or +600V
Crystal Oscillator	230/15V,500mA,50Hz
Microcontroller	AT89C2051,2.7V to 6V,0Hz to 24MHz

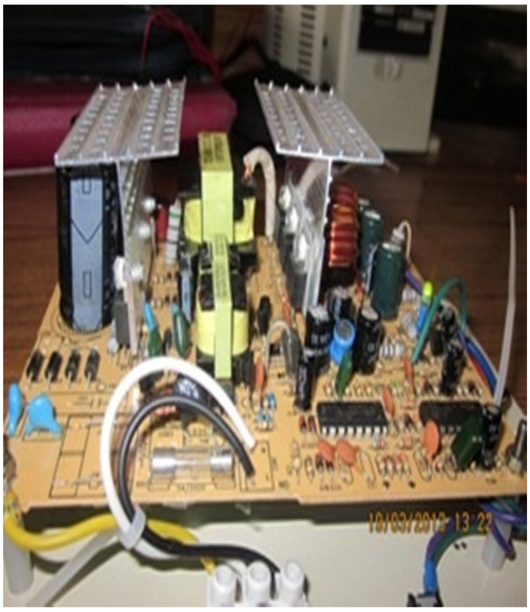


Fig 5.1 Experimental Set Up of Step-down converter in Side View

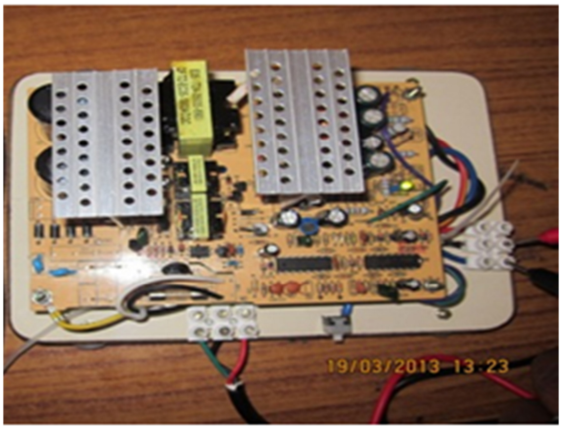


Fig 5.2 Experimental Set Up of Step-down converter in Top View

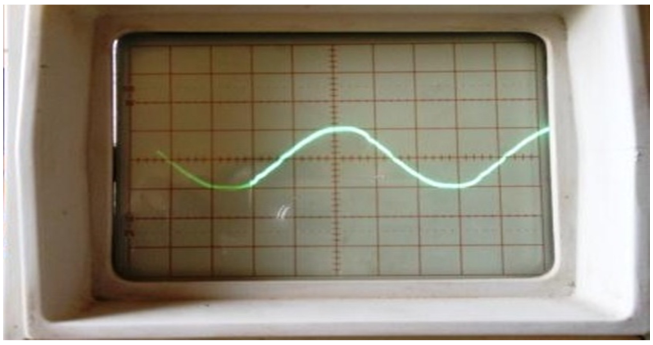


Fig 5.3 Oscillogram of Sine wave for reference input

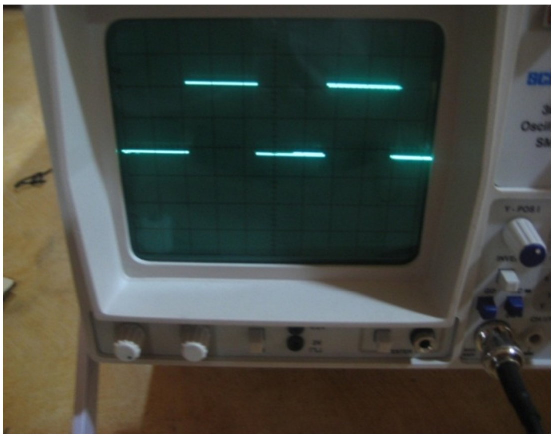


Fig 5.4 Oscillogram of Driving pulses

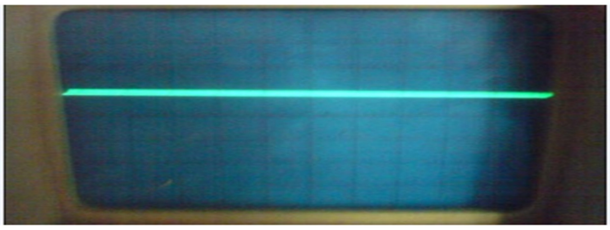


Fig 5.5 Oscillogram of DC output

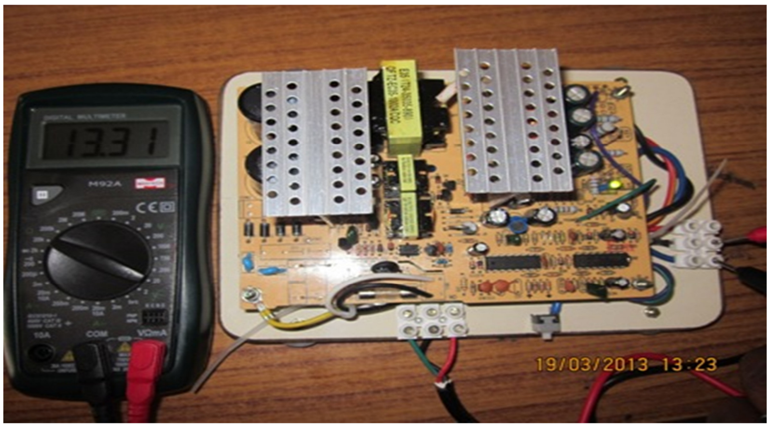


Fig 5.6 Output voltage with switching losses

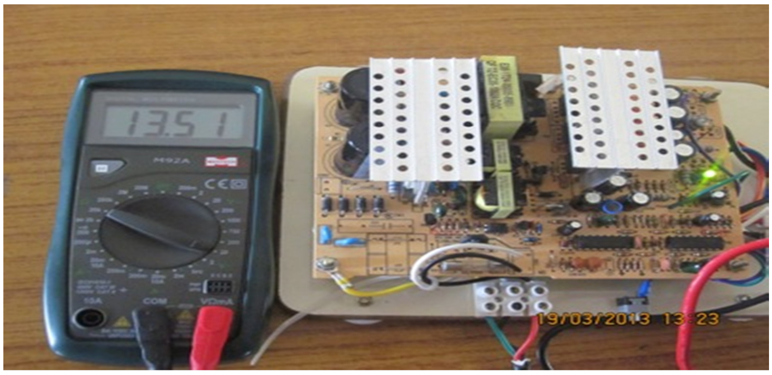


Fig 5.7 Output voltage without switching losses

VI CONCLUSION

In this paper, the approach to integrate fuel cell with step down converter is proposed. The proposed step down converter is operated in DCM mode with constant on-time control to achieve the desired PCM operation. Fuel cell is a electrochemical energy conversion device which directly produces electricity. The step down converter verifies that the DCM technique provides an exact output voltage, low output ripple and high efficiency from 1mA to 500mA loading. Fuel cell dynamic phenomena analysis in different physical domains have been performed and discussed. With the model predicted stack voltage value, the fuel cell stack power output is emulated by step down converter. The converter is designed to meet the real fuel cell dynamic responses. The simulation results are presented and discussed with hardware. The converter output has a very good accuracy compared to the model predicted value.The proposed converter has advantages like high efficiency, high power density, low EMI, reduced switching stresses, high circuit efficiency and stable output voltage.As a result the step down converter delivers selectable output voltages and can be equipped with different fuel cell systems. Thus, the overall fuel cell is validated.

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BIOGRAPHIES

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