A Multi Module Fuel cell Power System Feeding DC Load

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Abstract— *The conventional energy resources present in nature are limited and exhaustible, if it would be used with the rate at which it is being used in today's era then it will be vanished up. So we have to go with the alternative i.e.it is necessary to promote nonconventional energy resources as main source of energy. Fuel cell power generation systems (FCPGS) are going to play an important role for future applications. Fuel cells convert chemical energy into electrical energy. Output voltage of fuel cell is very small, almost less than 1 volt, so number of fuel cell connected in series i.e. stacked in order to increase its voltage level. In this paper the authors has studied the voltage current and power voltage characteristics of proton exchange membrane fuel cell (PEMFC). Low voltage output of fuel cell stack (FCS) is connected to a step up chopper which boost the voltage level. The output of the chopper is fed to a DC load. The results are presented in tabular form as well as waveforms. All the studies are simulation based, and the simulations are performed in MATLAB/Simulink*.

Keywords: **Proton exchange membrane fuel cell (PEMFC), Step up chopper, Fuel Cell stack (FCS), Fuel cell power system (FCPS).**

I. INTRODUCTION

The conventional energy resources coal, petrolium, gasoline etc are exhaustible in nature. They are going to be vanish in upto 200 years. Fuel cell has become the most promissing renewable energy resource to meet the future demand of power. Fuel cell system generally operates on pure hydrogen and oxygen to produce electricity with water and heat as the bio-products. Fuel cell is modular in construction and their efficiency is independent of size. A fuel cell requires continuous supply of a fuel and oxidant to produce D.C. electric power. In conventional steam power plant, the chemical energy of fuel cell is converted into heat energy by burning and heat energy is, then, converted into electrical energy. The efficiency of this conversion process is limited by the limitation of Carnot cycle. In fuel cells the chemical energy of the reaction is converted into electrical energy as an isothermal process so heat is not involved in the conversion process and high conversion efficiency is possible.

The advantages of fuel cells are that they are simple and safe, they have no moving parts, they are pollution free, and they are compact in size and also lighter in weight.

Another reason for the interest in fuel cells is that their efficiency and cost per KW of power are independent of size or the rating of fuel cell. This advantage makes the prospects of the fuel cells is very attractive as portable power plants for space-crafts, locomotives etc.

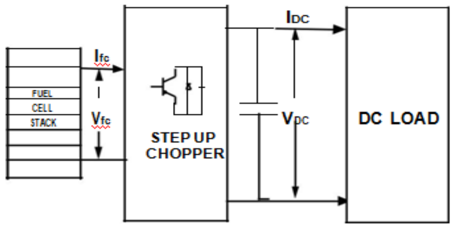

Fig.1. Block diagram of fuel cell power system

Fig.1 shows the block diagram of fuel cell based power system in which a large number of fuel cells are connected in series to get higher voltage. The output voltage of FCS is given to a step up DC-DC converter, which boosts the dc voltage up to the desired value of output voltage. A large number of DC-DC converters have been proposed in literature [1]. In this paper the authors have studied the PEMFC characteristics and step up chopper is connected to enhance the voltage of FCS.

II. FUEL CELL CHARACERISTICS

Fuel cell current keeps on increasing with increasing load its output terminal voltage keeps on decreasing up to its maximum operating point. The operation of fuel cell is divided in mainly three regions named as Activation region, Ohmic region and mass transport region [3]. For a 45V 6kW PEMFC the V-I and P-I characteristics are drawn using a time varying load.The simulation circuit is shown in fig.2. The voltage-current and power-current characteristics for 6KW 45 V PEMFC Stack are shown in fig.3. The former y-axis represents the voltage and the later one represents the power in kilowatts. Voltage current characteristics are given by blue colored curve and power (kW) current characteristics are given by green colored curve. From fig.3 it is observed that the fuel cell draws 6000W under rated conditions and 8325W at maximum power tracking conditions.

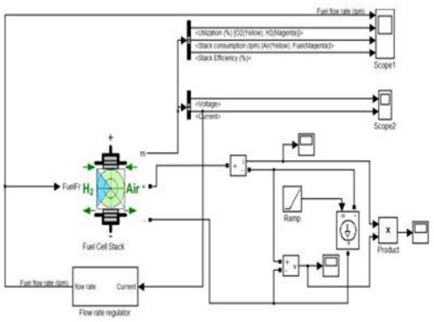

Fig.2. Simulation circuit for plotting V-I and P-I characteristics

The simulation circuit is shown in fig.2. The voltage-current and power-current characteristics for 6KW 45 V PEMFC Stack are shown in fig.3. The former y-axis represents the voltage and the later one represents the power in kilowatts. Voltage current characteristics are given by blue colored curve and power (kW) current characteristics are given by green colored curve. From fig.3 it is observed that the fuel cell draws 6000W under rated conditions and 8325W at maximum power tracking conditions.

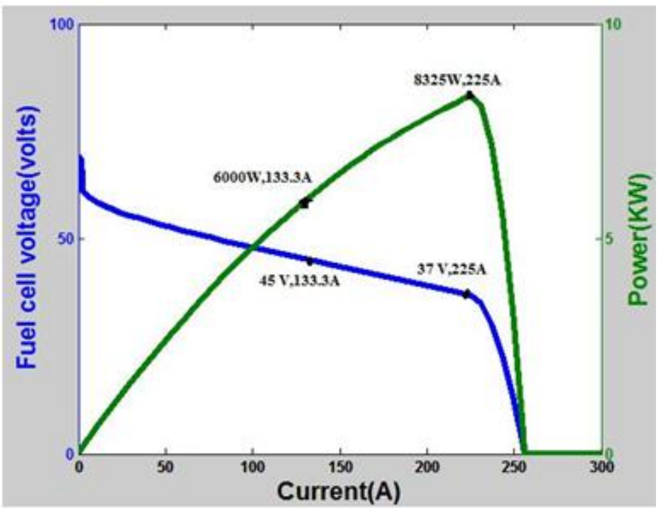

Fig.3. V-I and P-I characteristics of fuel cell

From fig.3 we observe that fuel cell operation starts at 70V and it falls to 60V at no load so this region is activation region. On increasing the load we get Ohmic region of fuel cell where the fuel cell current starts to rise and the fuel cell voltage starts falling. The voltage falls from 60V to 37V giving optimum power of 6KW at 45V, 133.3A and a maximum power of 8.325KW at 37V, 225A but at maximum point the fuel cell operation becomes unstable. On further increment of load the fuel cell enter the mass transport region where the output voltage eventually falls to zero.

III. STEP-UP CHOPPER

Step-up chopper is one in which average Output Voltage (V_0) is greater than Input Voltage (V_s). Fig.4 illustrates an elementary form of step-up chopper. In this chopper a large inductor L in series with source voltage is essential as shown in fig.4. When the switch (CH) is on, inductor stores energy. When CH is off the inductor current cannot get died on instantaneously. This current is forced to flow through the diode and load for OFF time. As the current tends to decrease, polarity of the emf induced in L is reversed. As a result, voltage across the load, given by, exceeds the source voltage. In this manner, it acts like a step-up chopper and the energy stored in L is released to the load. Let the ON period of the switch is T_{on} and the OFF period of the switch is. During T_{on} period the current through the inductance L would increase from I_1 to I_2 and during the current would fall from I_2 to I_1.

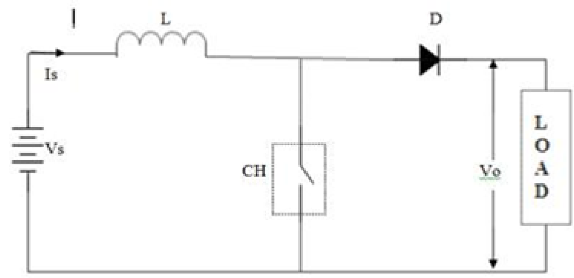

Fig.4. Circuit diagram of step-up chopper

Now the energy input to the inductance during the period, is W_{on} (Voltage across L)(average current through L)T_{on}

= T_{on} (1)

During the time, when chopper is OFF, the energy released by inductor to the load is

(Voltage across L) (Average current through L)

= (-) (2)

Considering the system to be lossless, these two energies given by equations will be equal

(-)

= –.

= (+)

= = = (3)

Here α is known as the duty cycle, and its value is always less than 1. Hence Output Voltage increases with increase in α.

IV. MODULAR FCS

Fuel cell produces very low voltage, less than 1 V, so a number of fuel cells are connected in series to increase the voltage level. The problem occurs with it, that if only one fuel cell in the stack start underperforming, all the other fuel cells in the stack also come under operation, as they are connected in series. So, to overcome this problem it is required to connect the FCS in small modules in series to obtain better efficiency.

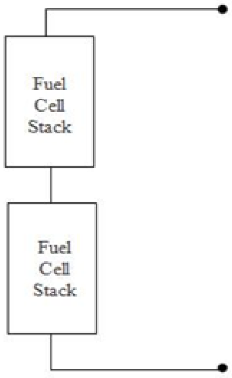

Fig.5. Block diagram of two Module FCS

Here authors took two modules of 6 KW, 45 V FCS and connected them in series to increase the efficiency of fuel cell stack. Fig.5 shows two modules of FCS connected in series.

V. FUEL CELL POWER SYSTEM (FCPS)

Fuel cell power generation systems (FCPGS) are now playing very important role in power generation. Fuel cell converts the chemical energy of fuel into the electrical energy. Here authors have taken the Proton Exchange Membrane Fuel Cell (PEMFC), in which hydrogen and oxygen molecules get inserted during operation and as a result of chemical reaction energy is produced and also water and heat are produced as byproducts. Output voltage of fuel cell is very small, so number of fuel cells are connected in series or stacked to increase the output voltage. Here authors took two modules of FCS, Both the FCS contains 65 fuel cells connected in series in it. Now, both the modules of FCS are connected in series in order to increase the voltage level. Two modules FCS connected across the step-up chopper feeding the DC load are shown in Fig: 6.

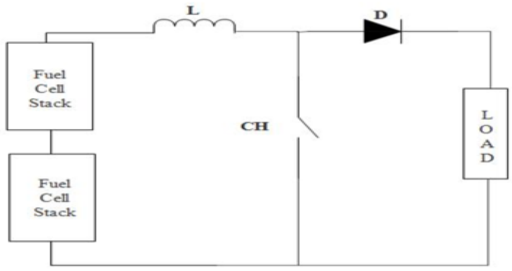

Fig.6: Fuel Cell Power System

Here, low voltage of FCS is connected through a step-up chopper. Step-up chopper is one in which the output voltage is greater than input voltage hence it boosts the voltage obtained from FCS. In this chopper a large inductance L is connected in series with the FCS. When switch (CH) is on, inductor stores energy. When CH is off the inductor current cannot be died on instantaneously. This current starts flowing through diode and load for OFF time. As the current tends to decrease, polarity of the electromotive force (emf) induced in L is reversed. As a result, voltage across the load, given by, exceeds the input voltage. The output of the chopper is then fed to a DC load.

VI. SIMULATION AND REULTS

Two modules of FCS are connected in series to get higher voltage and to enhance the reliability and efficiency.

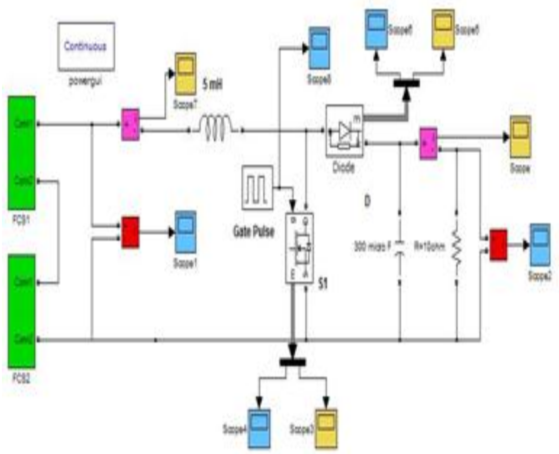

Fig.7. Simulation diagram of FCPGS

The input voltage at optimum working condition of FCS will be 45V for each module so for both the modules the output voltage will be 90V, but the working voltage may be any value between 45V to 37V in its working region.

	Table.1. Parameters and their values		Value
S. No.	Parameters		
1.	Resistance (R)		10 Ω
2.	Inductance (L)		5 mH
3.	Capacitance (C)		300 µF
4.	Duty Ratio (α)		0.51
5.	Switching Frequency ()		20 kHz

Table.1 shows the values of parameters used in the simulation

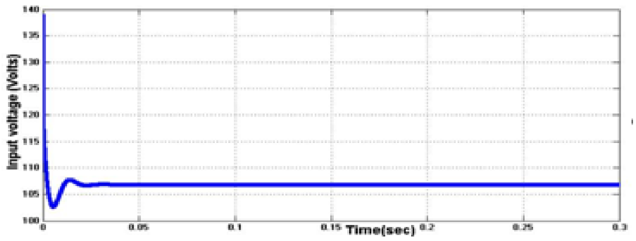

Fig.8: Input voltage of FCPS

Output voltage of two modules FCS is coming 106V and is shown in fig.8.

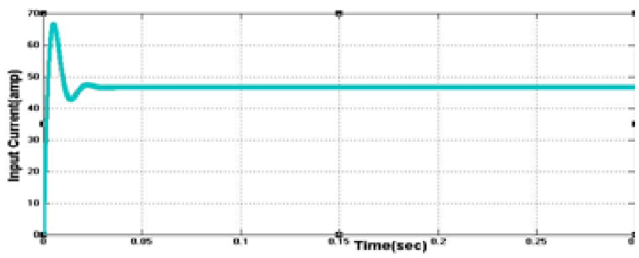

Fig.9: Input current of FCPS

Output current of two modules FCS is coming 46.2 and is shown in fig.9

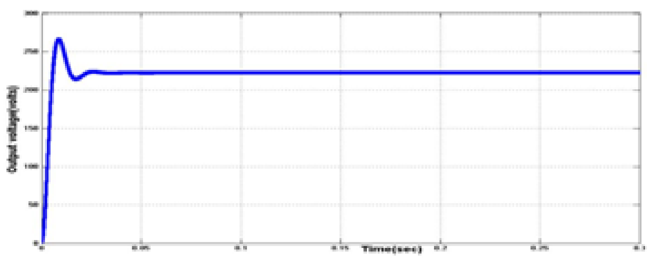

Fig.10: Output Voltage

Output voltage of FCPS is coming 216V and is shown in fig.10.

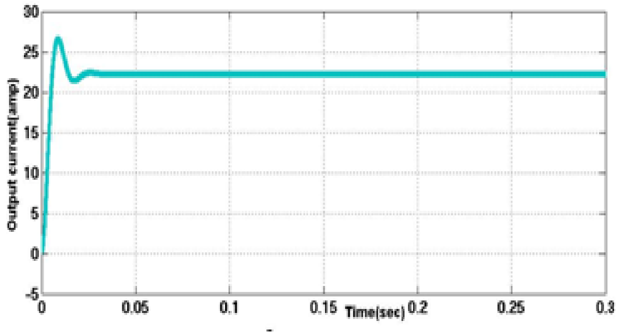

Fig.11: Output current

Output current of FCPS is coming 22.25 A which is shown in Fig.11.

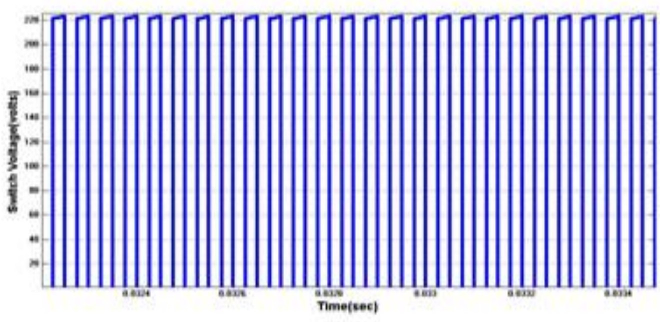

Fig.12: Switch Voltage

Switch voltage is obtained 222 V and shown in Fig.12.

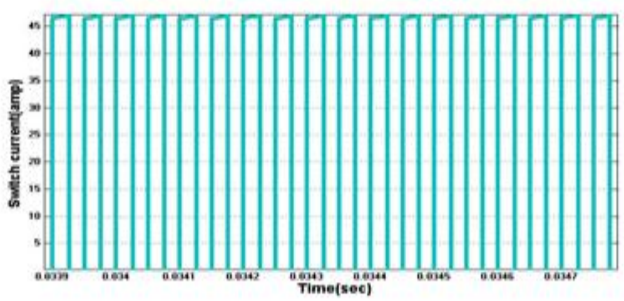

Fig.13: Switch Current

Switch current obtained is 47 A and is shown in Fig.13.

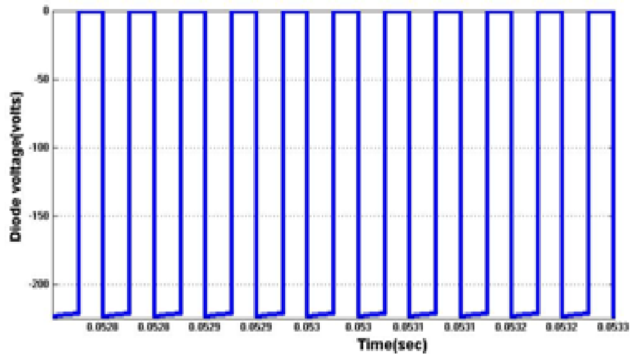

Fig.14: Diode voltage

Diode voltage is obtained -223.5 V as shown in Fig.14.

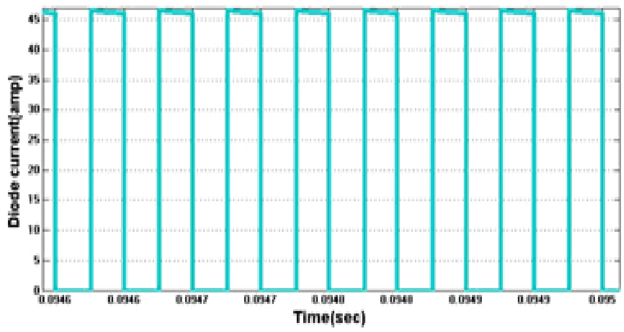

Fig.15: Diode Current

Diode current is obtained 46.5 A as shown in Fig.15

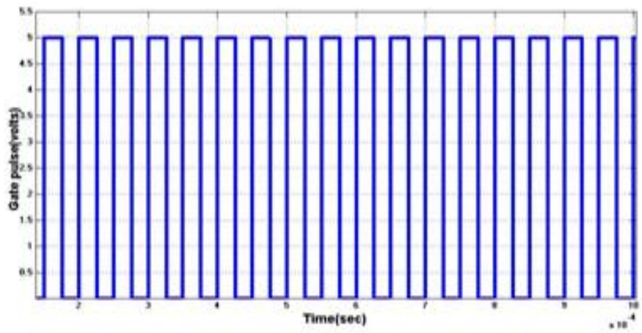

Fig.16: Gate pulse

Gate pulse given to the switch is of 5 V and the duty ratio is 52%, waveform is as shown in Fig.16.

Table.2. various voltages and currents in the circuit

S. No.	Parameters	Value
1.	Input Voltage	106 V
2.	Input Current	46.2 A
3.	Output Voltage	216 V
4.	Output Current	22.25 A
5.	Voltage across Switch	222 V
6.	Current across Switch	47 A
7.	Voltage across Diode	-223.5 V
8.	Current across Diode	46.5 A
9.	Gate Pulse	5 V
10.	Duty Ratio (α)	0.51
11.	Efficiency	98.2%

Table.2 shows the input and output voltage and currents of the FCPS

VII. CONCLUSION

Fuel cells are becoming most promising option for future electricity demands. Since the voltage of one fuel cell is very low so large numbers of fuel cells are stacked to get higher voltage. These FCS are connected in modules to increase reliability and efficiency. In this paper authors has taken two modules of 45V, 6kW PEMFC. Two modules are connected in series to get higher voltage. Each FCS having a wide range of operating region which is shown by drawing V-I characteristics of PEMFC using MATLAB.

A step up chopper is connected to enhance the output voltage further. This DC-DC converter may also be used for reducing ripples in FCPS. A simulation is done using MATLAB in which two modules of FCS are connected in series, whose output is given to a step up converter which is using MOSFET as a switch. Output of this chopper is given to a dc load and all the waveforms are plotted and the results is also shown in tabular form.

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