Analysis and Elimination of Harmonics in Fuel Cell System Connected to Grid by using Passive filter

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Abstract - *This paper presents study and analysis of fuel cell system connected to grid. Fuel cells are basically electro-chemical energy conversion device. Fuel cells use pure hydrogen and are carbon free device. Fuel cell generation becomes popular due to cleanliness, portability and suitability for electricity and heat generation.. The modeling process and stability analysis of each part are presented in this thesis. This dissertation focuses on grid connected fuel cell power system (FCPS) which can be used as a backup power source for household and commercial units. Behavior of passive filter to eliminate the harmonic generated by fuel cell is also studied. The harmonics are normally eliminated by passive LC or RLC filters. Passive filter may lead to power losses, which will be overcome by using optimal value of R, L, and C. Variable. The entire system is modeled in MATLAB/Simulink environment and various simulation results are presented for the proposed grid connected fuel cell system.*

Key Words: DC link, Fuel Cell, harmonics, passive filter, grid connection

1. INTRODUCTION

Fuel cells (FC) convert chemical energy directly into electrical energy without any intermediary processes, differing from combustion engines that need to convert chemical energy into thermal energy, then into electrical energy, and have their efficiency limited by the Carnot Cycle [1]. Fuel cells have potential to supply electrical energy while being supplied with reactants, like hydrogen and oxygen, making them a very interesting technology to help substitute oil for other less pollutants fuels. An interesting fuel for our country and others is the sugar-cane alcohol, that is rich in hydrocarbons, which can be converted into hydrogen using a fuel reformer. It gives better generation of energy among all others various resources. This form of energy is highly efficient, economical, and flexible and pollution free. The power filters are conventionally used to balance the harmonic current by injecting sinusoidal grid current.

The objective of this paper is to propose and report full experimental results of a grid-connected FC system. This work is analyzed by passive filtering techniques for reducing the harmonic current ripple effect[3]. A large signal model of is used to evaluate the current ripple. The current harmonics level is dependent by filtering capacitance value and the harmonics number is given by using different techniques. Filters are main parts of a renewable energy system. In power distribution system the occurrence of harmonics takes place by distortion of normal electric current waveforms.

Passive filters are made of inductance, resistance and capacitance tuned to harmonic frequencies that are to be attenuated.[2] The elimination of harmonics is done by suppressing harmonic current and decrease voltage distortion appearing in sensitive parts of the system. There are various types of fuel cell such as Aqueous Alkaline fuel cell (AAFC), Phosphoric acid fuel cell (PAFC), Molten carbonate fuel cell (MCFC), and Solid oxide fuel cell (SOFC), Proton exchange membrane fuel cell (PEMFC) .From all kind of fuel cell the PEMFC is mostly used for the large generation of the power supply.

2. Modeling of Fuel Cell

Fuel Cell parameters in the following equation, through which output voltage model simulated are:

V(Fuel cell)=E(RSV)- η act - η ohmic - ηlog
E(RSV)=Reversible voltage
ηact=Voltage loss due to activation polarization
η Ohmic =Voltage drop due to Ohmic polarization.
ηl= Drop produced by concentration polarization.
Modeling PEMFC obtains by using the following equation:
V(FUEL CELL)=E(RSV)-2.3RT/onF*In[Ifc/Io]-R(int)-I(FC)-Rint/ηF[1-I(FC)/ η]

Parameters
R= Gas constant
F =Faraday's constant
T=Stack temperature
γ = Transfer coefficient
N = Number of electrons
I(FC)= = Fuel cell current
Rint=Total sum of all resistances
Io=exchange current
I f=fuel cell limiting current

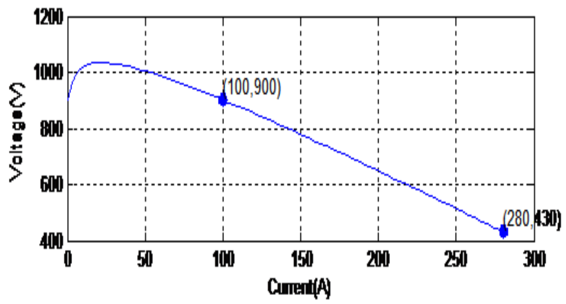

Fig -1.1: (a) Stack Voltage v/s Current

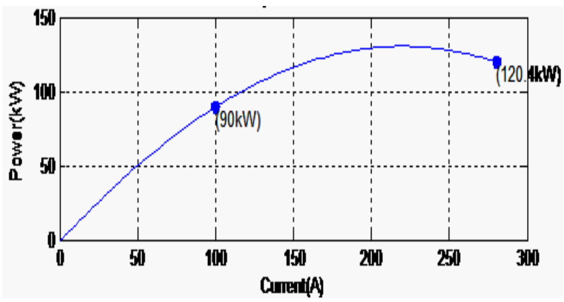

Fig -1.1: (b) Stack Power v/s Current

The above graphs in figure 1.1(a) and (b) shows the variation of stack voltage and stack power with respect to current respectively and the figure 1.2 represents the graph of changing the voltage of fuel cell with respect to time[4]. As in figure at the starting the wattage is very high and our time goes increasing and the rating is getting decreasing. We can calculate the nominal and maximum operating point by this polarization curve. This curve divided into following three Region activation region, ohmic region and Mass transport region.

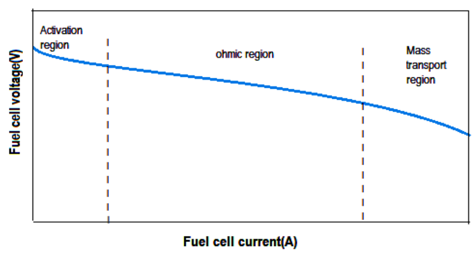

Fig -1.2: Polarization Curve of Fuel Cell

3. Power Conservation System of Fuel Cell

The figure 1.3 shows the block diagram of complete power conversion scheme. This system consists of fuel cell connected to inventor, then to local load and further to the grid. In this scheme 3 Phase -3 levels VSI inverter [3, 4] is used with LC filter to reduce harmonics. Rating of fuel cell is nearby local load demand and also reactive power compensation is provided as per local load demands [6, 10]. Control scheme abc to dqo , dqo to abc conversion scheme, P-I controllers and SPWM technologies has been used[7].

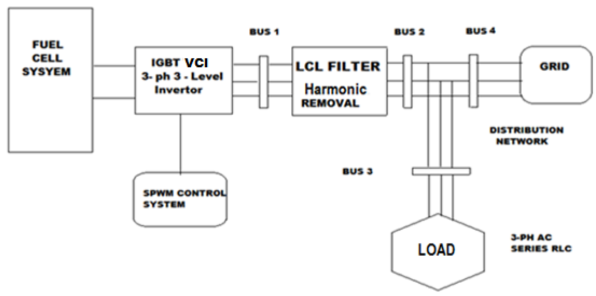

Fig -1.3: Block Diagram of Complete Power Conversion System of Fuel Cell

4. Control Scheme

The complete control scheme consists of different PI controller to control the dc link voltage& active power and reactive power flow. To control dc link voltage reference value of dc link voltage are predefined for a particular output power requirement [1, 2]. Reference and actual value of dc link voltage are compared and given to dc voltage regulator(PI controller) which is further to current regulator(PI controller).To control active power reference value of Id and actual value of Id are compare and similarly Iq reference value is compare with Iq actual given to current regulation. The figure 1.4 shows the flow diagram of complete control schemes as

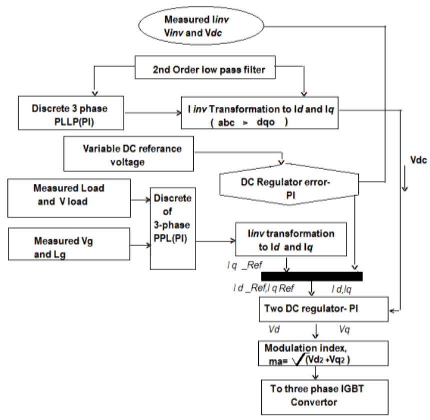

Fig -1.4: Algorithm of Control Scheme of Grid Connected Fuel Cell System

4.2 Power Circuit Parameters and their Analysis

Table 1.1 Various Power Circuit Parameters

F grid	V dc	C dc	V grid	V inv
50Hz	**Variable**	**1600**	**440V**	**440V**

Table1.2 Control System Parameters

Parameter	Kp	Ki
DC Voltage control(volts)	0.3	0.8
Current control(A)	12	12

The Active power flow depends upon the power angle between inverter voltage and grid voltage. Reactive power flow depends upon the voltage magnitude[1,2] .The reactive power generation is obtained with grid connected convertor due to which the impact of absence of active power and convertor losses get controlled and obtain regulated DC voltage. When active power is not present than DC link capacitor get charged and by inserting required reactive power to voltage level get maintained.

$$P = \frac{Vinv^2}{z} Cos\varnothing - V\frac{Vinv}{z} V_g Cos(\delta - \beta + \varnothing) \quad \text{---------------} \quad (1)$$

$$Q = \frac{Vinv^2}{z} Sin\varnothing - \frac{Vinv}{z} V_g Sin(\delta - \beta + \varnothing) \quad \text{--------------} \quad (2)$$

$$P = \frac{Vinv^2}{X} V_g \sin\delta$$

$$Q = \frac{Vinv}{z}(V_{inv} - V_g Cos\varnothing),$$

Convertor current,

$$I_{inv} = \frac{\sqrt[3]{2}\sqrt{P^2+Q^2}}{Vg} \quad \text{------------------} \quad (3)$$

From equation no 3 we can analysis this thing that value of real power is dependent on the value of δ, and the value of reactive power is dependent on the Value of .This shows that both positive and negative real power plays a role to supply active power to grid system and drawing power from the grid system respectively.

The below figure shows us the power output of the fuel cell. In this we can see the output graph of fuel cell active power, graph of active power of load and graph of grid active power.

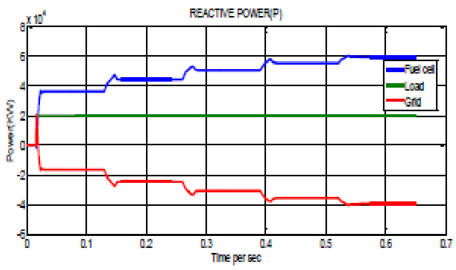

Fig -1.5: Shows the behavior of Reactive Power (P) with Time per sec

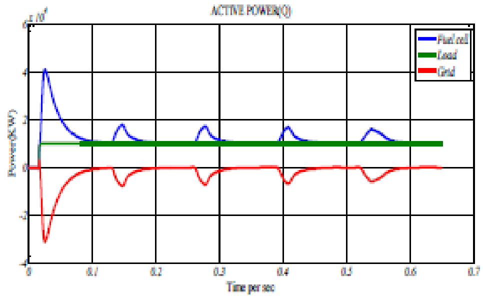

Fig -1.6: Shows the Graph of Active Power (Q) with Time per sec

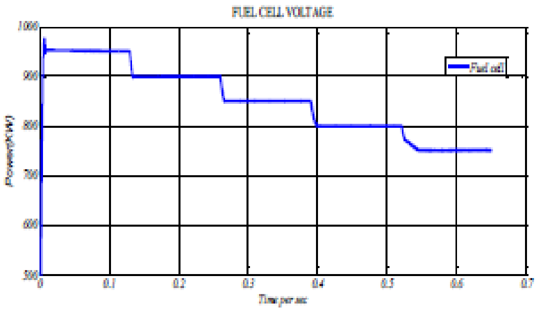

Fig -1.7: Fuel Cell Voltage Graph

5. RESULTS & ANALYSIS

We have to decide value of L and R for LC filter .In this we analysis harmonic for different values L&R at different level of Fuel Cell output power. All results are shown in table given below.

Case 1 Inductance 1500 Henry and by changing the value of Resistance

Table 1.3 Power Output and Harmonic by Varying Resistance and Inductance

Case 1(a) R=0.01ohms L=1500 mH				
DC Voltage	950	900	850	800
Power Output X(10^4 Watts)	3.64	4.48	5.111	5.612
Harmonic	1.91	1.55	1.35	1.21
Fundamental harmonics	0.7631	0.9163	1.041	1.138

Case 1(b)	R=0.05ohms		L=2000mH	
Power output X(10^4 Watts)	3.60	4.435	5.057	5.542
Harmonic	1.94	1.57	1.36	1.23
Fundamental harmonics	0.7576	0.9085	1.03	1.125

Case 1(c)	R=0.5ohms		L=2500mH	
Power output X(10^4 Watts)	3.292	4.044	4.567	4.968
Harmonic	2.16	1.81	1.62	2.39
Fundamental Harmonics	0.7081	0.8341	0.9352	1.014

Above result show that by increasing the value of resistance harmonic distortion increased and power output gets decreased. In order to reduce harmonic distortion the value of R should be low as described in above results. Here the value of inductor 1500 Henry. When resistance gets changed from 0.01 to 0.05 Ohms the output of power decreases. Again by increasing the value of R from 0.05 to 0.5 the power output will decrease. And other variation, when the DC voltage is decreased than the power output get better whose comparison is shown in Case 1(a), Case (b) and Case1(c).

Case 2 Inductance 2000 Henry and by changing the v value of Resistance

Here by changing the value of inductor I= 2000, and then keeping the value of inductor constant and by varying the value of resistance as same as in our above case the harmonic get decreased which is shown below and the output power also get improved by decreasing the dc voltage

Table 1.4 Power Output and Harmonic by Varying Resistance and Inductance

Case 2(a)	R=0.01ohms	L=2000 mH		
DC Voltage	950	900	850	800
Power output X(10^4 Watts)	3.661	4.484	5.113	5.608
Harmonic (%)	1.46	1.17	1.02	0.92
Fundamental harmonics	0.7636	0.9168	1.04	1.138
Case 2(b)	R=0.05ohms	L=2000mH		
Power output X(10^4 Watts)	3.611	4.438	5.058	5.542
Harmonic (%)	1.48	1.19	1.04	0.94
Fundamental Harmonics	0.7636	0.9088	1.031	1.125

Case 2(c)	R=0.5ohms	L=2000mH		
Power output X(10^4 Watts)	3.292	4.042	4.563	4.963
Harmonic (%)	1.64	1.37	1.23	2.12
Fundamental Harmonics	0.7114	0.8341	0.9353	1.014

Case 3 Inductance 2500 Henry and by changing the value of Resistance

By increasing the value of inductor I= 2500 H from 2000 H, and by taking the minimum value of resistance the power output and harmonic get better.

Case3(a) R=0.01 L=2500				
DC Voltage	950	900	850	800
Power Output X(10^4 Watts)	3.683	4.494	5.115	5.613
Harmonic (%)	1.81	0.95	0.82	0.75
Fundamental	0.765	0.9188	1.04	1.138
Case3(b) R=0.05 L=2500				
Power Output X(10^4 Watts)	3.628	4.455	5.08	5.568
Harmonic (%)	1.27	1.00	0.87	0.80
Fundamental	0.7628		1.034	1.131
Case3(c) R=0.5 L=2500				
Power Output X(10^4 Watts)	3.219	4.041	4.598	4.976
Harmonic (%)	1.35	1.11	1.00	2.14
Fundamental	0.7139	0.8341	0.935	1.015

By observing all three cases find that by taking the minimum Value of resistance (0.01ohms)and by taking the maximum value of Inductance (2500Henry) maximum power output obtained. As same by making same change in our parameter by taking minimum value of Resistance and maximum value of inductance our harmonic distortions get improved. And other variation we can see when we change the DC voltage, when the DC voltage is decreased than the power output get increased as per comparison in Case 1(a), Case1(b), and Case1(c)

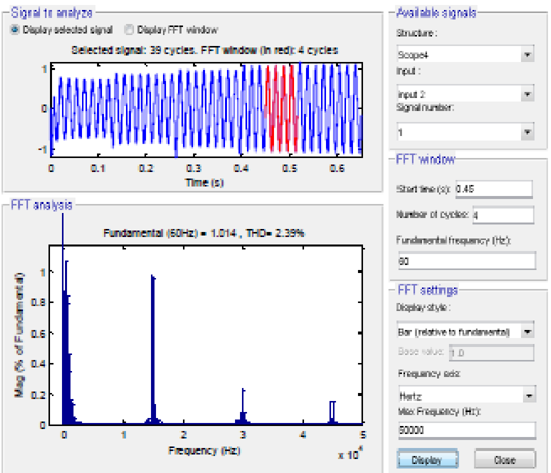

Fig -1.8 : Shows the output of power and Harmonics, when R= 0.5 and I= 1500H

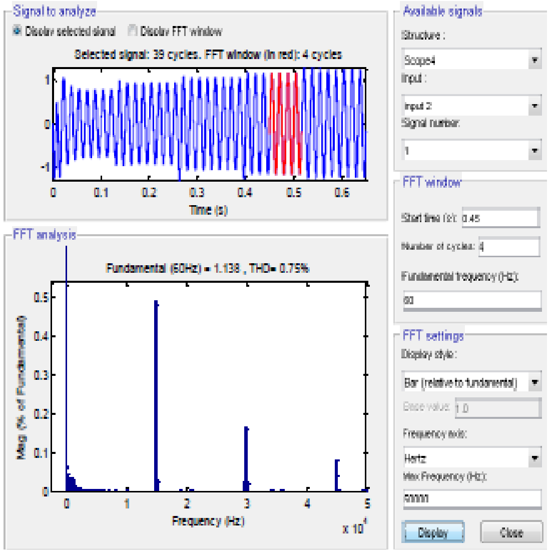

Fig -1.9 : Shows the output of power and Harmonics, when R= 0.01 and I= 2500H

We concluded that when R=0.5 which is maximum value of resistance and I= 1500 which is minimum value of inductance than the harmonic is more which is 1.21%, and power output is less which is 4.968 W as showed in Case 1(c). By taking minimum value of resistance R=0.01 and maximum value of inductance I=2500 than less harmonic distortion is obtained which is 0.74%, and more power output (5.289W) which showed in Case 3(a) showed in below figure 4.3(b)

6. CONCLUSION

This paper represents a simple control scheme in which output power of fuel cell is varied by varying dc link voltage. This system can control the active power as well as reactive power as per demand of the load .Harmonic analysis has been done for different value of output power of fuel cell system. To reduce the harmonic system is analyzed for different value of LC filter parameter inductor and resistance value of LC filter is varied in such a manner that harmonic reduces to minimum value. From this analysis optimum value of R&L is obtain.

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