Harmonic Analysis of Fuel Cell System Connected to Grid and Harmonic Elimination by using Passive Filter

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Abstract - *This paper deals with the modelling, analysis and control scheme of grid connected fuel cell system with single stage DC-AC link. The output of the Fuel Cell system is connected to the DC side of the Voltage Source Inverter (VSI) for interfacing to the utility Grid. Fuel cell system supply active power as well as reactive power compensation to utility grid having local load. The behaviour of a fuel cell by varying DC link voltage which makes change in the output of the active power has been investigated. Analysis for THD due to variation in DC link power of grid connected fuel cell system has been carried out. Behavior of passive filter to eliminate the harmonic generated by fuel cell is also studied in this work. Passive filter may lead to power losses, which will be overcome by using optimal value of R, L, and C. Variable active/reactive power flow can be made as per requirement of the local load. The entire system is modelled 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, filter and power*

1. Introduction

According to the rate of the increasing population our requirement of everything is also increased. To meet the basic necessities the large number of sources is required to fulfill our all needs. The resources of energy are not much sufficient according to our increasing requirement day by day. Now a day we require large amount of resources by which we can generate desired energy to fulfill the present and future needs. There is various way of generating energy; it may be by taking help of renewable source of energy or by the help of nonrenewable source of energy. So we required more and more types of renewable sources by which, we can generate energy with more efficiency and more economically, clean and pollution free.

Now a day we use various types of source of energy such as solar energy, nuclear energy, hydropower energy, and geothermal energy. According to our present requirement we suggest to utilize the fuel cell in the form of energy generation. It will give better generation of energy among all others various resources [5, 11]. This form of energy is highly efficient, economical, and flexible and pollution free.

Fuel cell is device which is used for the conversion of chemical energy into electrical energy with the help of electrochemical reaction. 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 [6]. It has various merits due to which it is used, it has high energy density due which it have low working temperature, have high efficiency and it has simple structure.

2. Modeling of Fuel Cell

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

$$V_{FC} = E_{rev} - \eta_{act} - \eta_{ohmic} - \eta_{log}$$

E_{rev}= Reversible voltage

η_{act}=Voltage loss due to activation polarization

η_{Ohmic} =Voltage drop due to Ohmic polarization.

η_{l}= Drop produced by concentration polarization.

Modeling PEMFC obtains by using the following equation:

$$V_{FC} = E_{rev} - \frac{2,3RT}{onF} \ln\left[\frac{I_{fc}}{I_o}\right] - R_{int} - I_{FC} - \frac{R_{int}}{\alpha F}\left[1 - \frac{I_{FC}}{Il}\right]$$

Parameters

R= Gas constant

F =Faraday's constant

T=Stack temperature

γ = Transfer coefficient

N = Number of electrons

I_{fc}= Fuel cell current

R_{int}=Total sum of all resistances

I_o = Exchange current

I_f = Fuel Cell limiting current

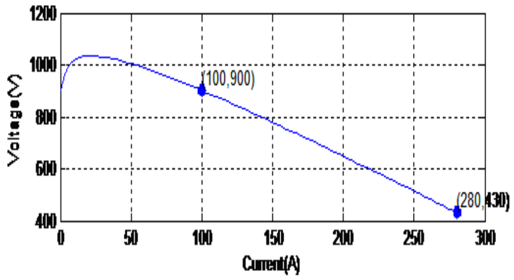


Fig.1.1 (a) Stack Voltage v/s Current

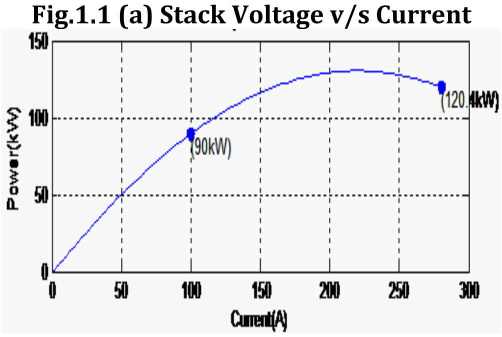


Fig. 1.1(b) Stack Power v/s Current

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 figure1.2 represents the graph of changing the voltage of fuel cell with respect to time. 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

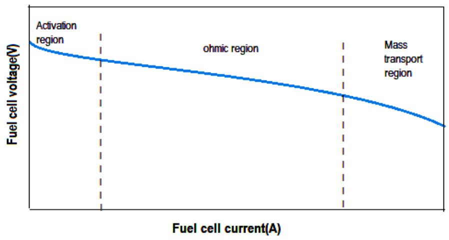


Fig.1.2 Polarization Curve of Fuel Cell

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 [13, 14] 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 [5, 11]. Control scheme abc to dqo , dqo to abc conversion scheme, P- I controllers and SPWM technologies has been used[7].

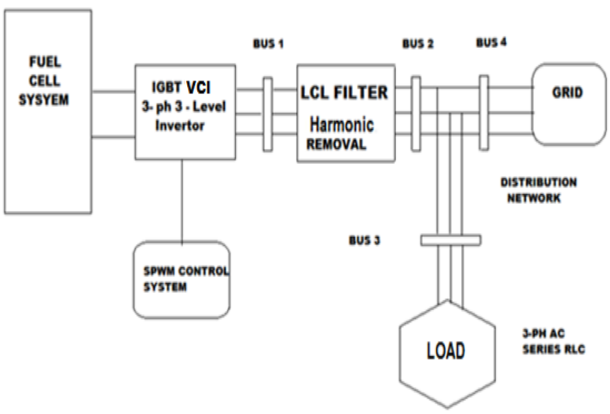


Fig.1.3 Block Diagram of Complete Power Conversion System of Fuel Cell

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 I_d and actual value of I_d are compare and similarly I_q reference value is compare with I_q actual given to current regulation. The figure 1.4 shows the flow diagram of complete control schemes as;

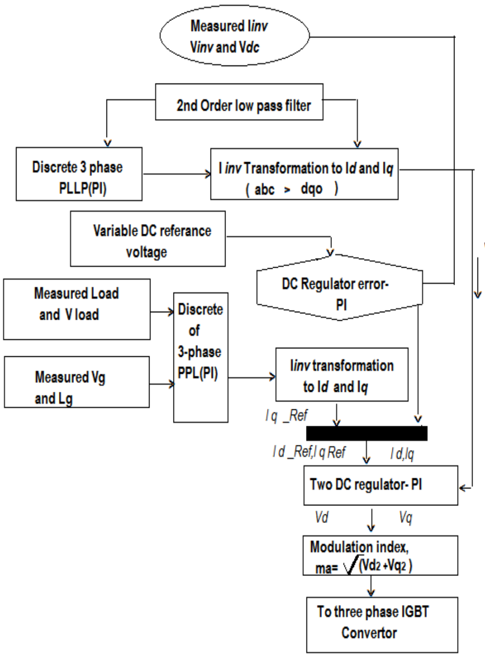


Fig. 1.4 Algorithm of Control Scheme of Grid Connected Fuel Cell System.

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	1500	440 V	440 V

Table1.2 Control System Parameters

Parameter	K_p	K_i
DC Voltage control(volts)	0.2	0.6
Current control(A)	10	10

The Active power flow depends upon the power angle between invertor 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 controled 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.(power quality improvement.09)[9]

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

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

For unity power factor operation at, β = 0, assuming R is very small for

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

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

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 $Vinv$ .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 fig no.13 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.

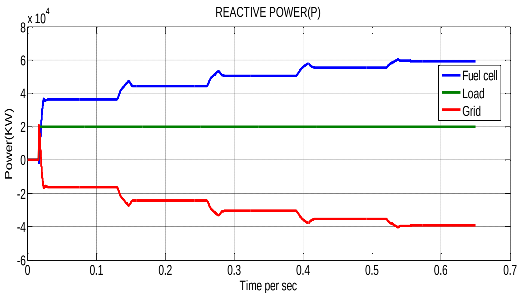


Figure 1.5 shows the Behavior of Reactive Power (P) with Time per Sec

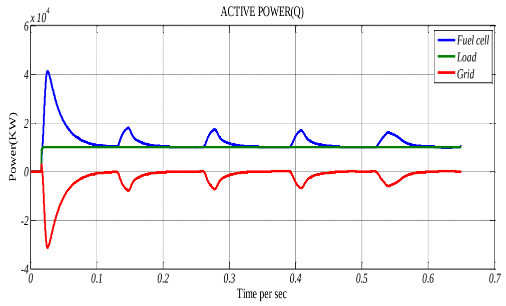
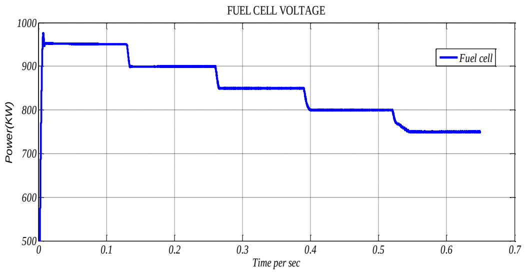


Figure 1.6 shows the Graph of Active Power (Q) with respect to Time per Sec



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 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.

Table 1.5 Power Output and Harmonic by Varying Resistance and Inductance

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 Risistance 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).

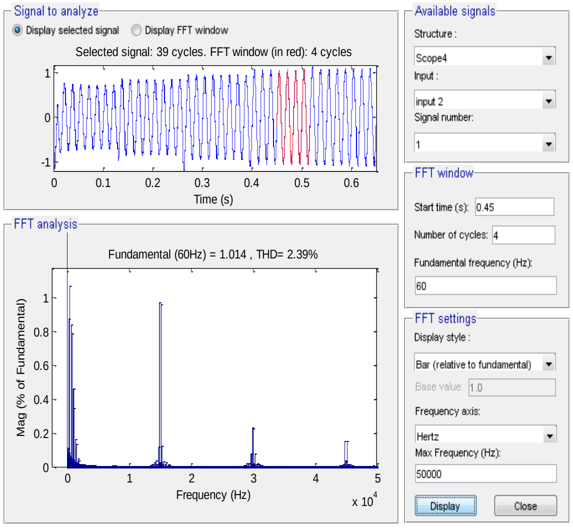
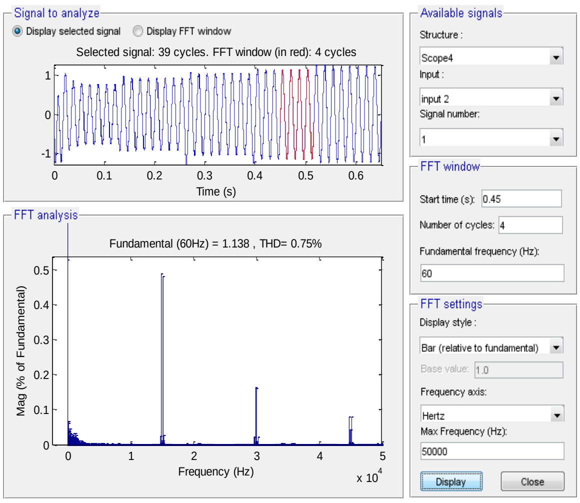


Fig 1.8 shows the Output of Power and Harmonics, when R=0.5 and I=1500 H



Above fig 1.9 shows the Output of Power and Harmonic 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)

7. 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.

REFERENCES

[1] W. Rui, G. Wei and W. Zhi, "Economic and optimal operation of a combined heat and power with renewable energy resources", Automation of Electric Power Systems, vol. 35, pp. 22-27, 2011.

[2] Priyadharshini.R and S.P. Devendran . " Implementation of fuel cell distributed generation system with conventional and fuzzy based PI controllers," *in International Journal of Engineering Research and Applications (IJERA)* Vol. 2, Issue 3, May-Jun 2012, pp. 450-464

[3] Babu Y. Raju * and P. Linga Reddy . "A Three-Phase Grid-Connected Fuel Cell System based on a Boost-Inverter," *Indian Journal of Science and Technology*, Vol 8(23), September 2015, pp. 1-4.

[4] Mehta Gitanjali , S. P. Singh, "Grid-interfacing Fuel Cell System with active and Reactive Power Flow Control ," in Chennai and Dr.MGR University Second *International Conference on Sustainable Energy and Intelligent System*, Dr. M.G.R. University, Maduravoyal, Chennai, Tamil Nadu, India, July, 2011 , pp. 554-559.

[5] Hajizadeh Amin and Masoud Aliakbar Golkar. "Power Flow Control of Grid-Connected Fuel Cell Distributed Generation Systems , " in *Journal of Electrical Engineering & Technology*, Vol. 3, No. 2, 2008 , pp. 143-151.

[6] Kumar Deepak, Kuldeep Singh Bedi and Ankit Goel. "Transformer less Grid Connected Fuel Cell System to Control the Flow of Active and Reactive Power." in *Journal of Engineering Research and Applications,* Vol. No 3, Issue No 6, Nov-Dec, 2013, pp. 1740-1743.

[7] Mehta Viral, Joycee Smith Cooper "Review and analysis of PMC FUEL CELL design and manufacturing" *in Journal of Power Sources* 114 (2003) pp. 32-53.

[8] Gupta Akhil, Saurabh Chanana & Tilak Thakur. "Power quality improvement of solar photovoltaic

transformer- less grid-connected system with maximum power point tracking control ," in *International Journal of Sustainable Energy* (2014), Vol. 33, No. 4, pp. 921–936.

[9] B. Harithai and P. Dhanamajaya. "A Grid Connected Fuel Cell Based on Boost Inverter System" *in International journal of innovative research in Electrical, Electronics, Instrumentation and Control System* Vol. 2, Issue 8, August (2014), pp.1529-1534.

[10] Vijayakumar Ananthu , Vidya M Nair, "Control of Fuel Cell Based Distribution Generation System", *Vol. 2, Special Issue 1,December (2013)*, pp. 242 -251.

[11] PP.Aseeb Nayana and Deepa Sankar . "Grid Connected Photo Voltaic- Hydrogen Fuel Cell Hybrid System." *International Research Journal of Engineering and Technology (IRJET)* e-ISSN: 2395 -0056 Volume: 02 Issue: 04 July-2015 pp. 843-847.

[12]. Bedi Kuldeep Singh. " PV and Fuel Cell Hybrid System Connected to grid with Data Based MPPT Technique," *in International Journal of Advanced Research in Computer Science and Software Engineering* , Volume 3, Issue 11, November 2013 pp . 901-909.

[13] G.R.Rajeshkanna1 and S.Thiagarajan. "A Single-Phase Grid-Connected PV Cell System Based on a Boost-Inverter." in *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering* Vol. 4, Issue 10, October 2015, pp 8360 – 8367.

[14] Mewar University Simulation, "Study of Grid Connected Fuel Cell," *International Journal of Science and Research (IJSR)* ISSN (Online): Index Copernicus Value (2013) pp .1015 – 1018.

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