IJIREEICE
ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526
INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 3, Issue 12, December 2015

Grid Integration of Fuel Cell with MPPT under Variable Air Flow Rate

Gitanjali Pandove[1], **Mukhtiar Singh**[2]

Associate Professor, Electronics & Communication Engg, DCRUST, Murthal, Hrayana, India[1]

Registered Scholar at Dr. K. N. Modi University, Newai, Rajasthan, India[1]

Associate Professor, Electrical Engg, DTU, Delhi [2]

Abstract: In the proposed work a proton exchange membrane fuel cell (PEMFC) with variable air flow rate has been presented. Here, the main objective is to extract maximum power out of fuel cell at different air flow rates. The proposed scheme consists of DC-DC buck-boost converter with grid interfacing inverter. The DC-DC converter is controlled to perform maximum power point tracking under varying fuel cell conditions while grid interfacing inverter is controlled to evacuate the generated output power from fuel cell. It has also been demonstrated that the grid interfacing inverter may also be helpful in meeting the reactive power demand of nearby local loads so that grid always exchange power at unity power factor. Finally, detailed modelling and simulation results under MATLAB/SimPowerSystem environment have been presented to validate the proposed control algorithms.

Keywords: Fuel Cell, MPPT, Grid Integration, Inverter Control, DC-DC Converter, Renewable energy sources, Reactive power compensation.

I. INTRODUCTION

There has been renewed interest in developing advanced technologies for the alternate energy sources due to various disadvantages related to conventional power generation [1-3]. Recently, the fuel cell based energy sources are gaining lot of popularity not only for automotive transportation but also as energy storage option in the form of hydrogen and then reconversion at desired location or site of use.

The output energy from FC depends on various parameters and system operating conditions, e.g. Cell temperature, gas flow rate, humidity, pressure at anode and cathode, dry gas mole fraction, stoichiometry etc. These parameters not only vary the output of fuel cell but also the voltage at its terminals. In order to extract maximum power under all these aforementioned conditions, it is very much important to have an efficient means of maximum power point tracking (MPPT).

The MPPT in fuel cell may be performed in two different stages: 1. Optimal control of fuel cell parameters such as gas flow, air flow and pressure, 2. Optimal control of fuel cell terminal voltage and current. In the proposed work, the second option of MPPT has been explored by controlling the buck-boost converter.

The output from Fuel cell may vary as per the load connected on its terminals. There is nonlinear relationship between terminal voltage and current drawn from fuel-cell, which further makes the output power as nonlinear function of loading current. Therefore, there is only one unique operating point at which the fuel cell may deliver maximum power. The maximum power point (MPP) may vary with system temperature, pressure, air and fuel flow rate. Therefore, it is a great challenge to perform MPPT under different operating conditions.

Lot of research have taken place in past and different MPPT algorithms are available in literature. Some of the common MPPT methods such as Hill-climbing/ Perturb and Observe (P&O), incremental conductance, fractional open-circuit voltage, fractional short-circuit current may be found in abundance. Further, the intelligent techniques based on fuzzy logic control, neural network, ripple correlation control, sliding mode control current etc. have also been proposed and all these techniques are generally implemented for photovoltaic system. Since, the output profile of photovoltaic systems is similar to fuel cell and hence, most of these MPPT techniques may be easily adopted for fuel cell also. MPPT methods vary in complexity, hardware implementation, convergence of speed and sensed parameters [4]. Some of the MPPT methods applied to fuel cells are primarily based on P&O [5-9], adaptive MPPT control [10], moto compressor based control technique [11], adaptive neuro-fuzzy logic controller and sliding mode [12-14], MPPT algorithm based on resistance matching between the direct methanol fuel cells internal resistance and the tracker’s input resistance [15], voltage and current based MPPT [16], adaptive extreme seeking control [17].

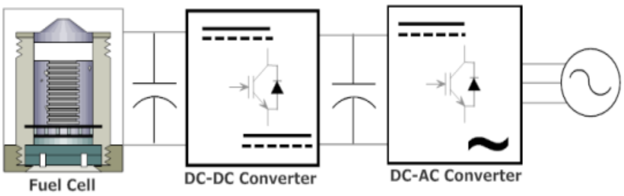

Fig.1 Block Diagram of Proposed Scheme

In the proposed work, the MPPT based on fuel cell terminal voltage and current has been implemented with the help of DC-DC converter. Besides this, the grid side inverter is also controlled to perform multiple roles simultaneously. The proposed scheme as shown in Fig. 1

DOI 10.17148/IJIREEICE.2015.31203

is able to extract maximum power under varying operating conditions. The main characteristics of the proposed approach are its good transition response, low tracking error, very fast dynamic system response against set point, fuel cell airflow rate, robustness as well as its low complexity. The rigorous simulation study has been carried out to evaluate the performance and accuracy of the proposed algorithm.

II. FUEL CELL MODELLING

A fuel cell is a device that converts the chemical energy in to the electrical energy. The fuel cell in which chemical reaction takes place due to the combination of hydrogen with oxygen in the presence of suitable oxidizing agent is similar to battery. The major difference between them is the fuel cell's capability of producing electricity is dependent on continuity of fuel supply or in other words the continuity of electricity may be maintained as long as fuel is supplied. The fuel cell may be a promising technology for our future energy demand, and may be helpful in catering the heat and electricity requirements. The energy released from the chemical reaction between hydrogen and oxygen is the basic principle of the fuel cell [18-20]. At the anode of an electrolyte, the electrons are released by the ionization of hydrogen gas and H^+ ions are generated.

$$2H_2 \rightarrow 4H^+ + 4e^-$$

At the cathode, the combination of oxygen, electrons from electrode and H^+ions from electrolyte yields water as given below.

$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$$

Thus for continuous chemical reaction, the electron from anode to cathode through electric circuits and hydrogen ions through electrolyte should keep on flowing. The typical model of PEMFC is shown in Fig.2.

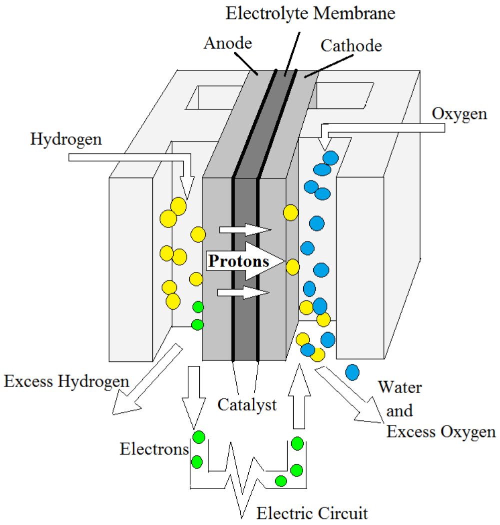

Fig.2. PEM Fuel Cell

Electrical Equivalent Model of Fuel Cell: The output voltage of fuel cell (V) mainly depends on four different kind of voltages and represented as

$$V = V_{rev} - V_{act} - V_{ohm} - V_{conc}$$

Where V_{rev} represents the reversible voltage; $V_{act}$is the voltage drop due to the activation of the anode and cathode; V_{ohm} is a measure of ohmic voltage drop; V_{conc}represents the voltage drop resulting from the concentration or mass transportation of the reacting gases. The theoretical reversible voltage which sometimes also referred as fuel cell's open circuit voltage may be calculated as

$$V_{rev} = V_{0,rev} + \frac{RT}{2F}\ln\left[P^*_{H_2} \times \sqrt{P^*_{O_2}}\right] - V_{d,rev}$$

Where R is a gas constant, T is temperature in Kelvin, F is Faraday's constant, and P* is the partial pressure of the noted species, all of which are positive. Further

$$V_{0,rev} = V^0_{0,rev} - k_E(T - 298)$$

where$V^0_{0,rev}$ is the reference potential at standard Temperature and pressure (298 K, 1 atm), and k_E is a constant.

$$V_{d,rev}(t) = \lambda_e I(t)\left[1 - e^{-t/t_e}\right]$$

whereλ_e is a constant, I(t) is the cell current, and t_e is fuel and oxidant flow delay.

Similarly, the activation voltage drop is nothing but loss of potential due to slow electrochemical reaction taking place at the electrode surface especially under low power demands and can be represented as

$$V_{act} = \eta_0 + a(T - 298) + bT\ln(I)$$

Where a, b and η_0 are constants.
The loss of potential due to electrical resistance exerted by polymer membrane between membrane and electrodes and among electrode themselves is known as ohmic voltage drop and may be represented as

$$V_{ohm} = IR_{ohm}$$

Where

$$R_{ohm} = R_{ohm\,0} + k_{RI}I - k_{RT}T$$

Here, R_{ohm0}, k_{RI}, and k_{RT} are all positive constant.
The concentration voltage drop generally happens during high load current, where the system is unable to supply enough reactants and remove products at faster rate for the complete chemical reaction.

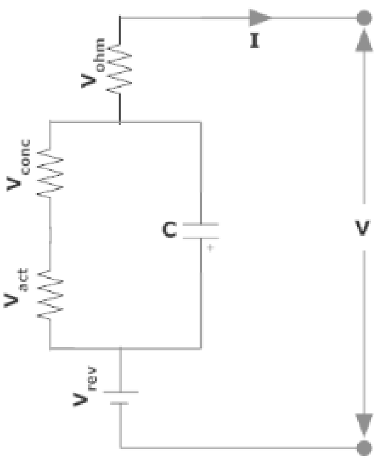

Fig.3 Electrical Eqv. Model of Fuel Cell

The concentration polarisation or potential loss is defined as

$$V_{conc} = -\frac{RT}{zF}\ln\left(1-\frac{I}{I_{lim}}\right)$$

Where, z is the no. of participating electrons and I_{lim} is the maximum current limit. The fuel cells are normally designed to avoid during such operating conditions. The electrical equivalent model of Fuel Cell is shown in Fig. 3. [21-22]

III. CONTROL DESCRIPTION

The power processing equipment are major components of proposed system consisting of DC-DC converter and grid interfacing inverter. The DC-DC converter is controlled to extract maximum power out of fuel cell while the grid interfacing inverter is controlled to evacuate the fuel cell generated power and inject it into the grid. The control of proposed system is divided into two parts: 1. Fuel Cell side control, 2. Grid side control.

A. Fuel Cell side control

The main role of DC-DC converter is to control the fuel cell output power as a function of its output current in compliance of P-I curve as shown in Fig. 4.

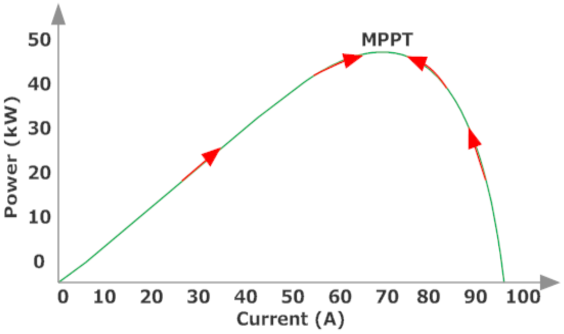

Fig.4. Power-Current curve of Fuel Cell

Since the output power is the function of fuel cell current, there is always one point at which maximum power can be extracted at a given condition.

Accordingly, under different operating points, the controller is designed to perform MPPT as per the flow chart shown in Fig. 5. Here, the output power and current are compared with their values at previous instant and as per their sign the operating modes are divided in to four categories. Depending on the mode of operation the amount of current drawn from fuel cell is decided and incremented/decremented as shown in Fig. 5.

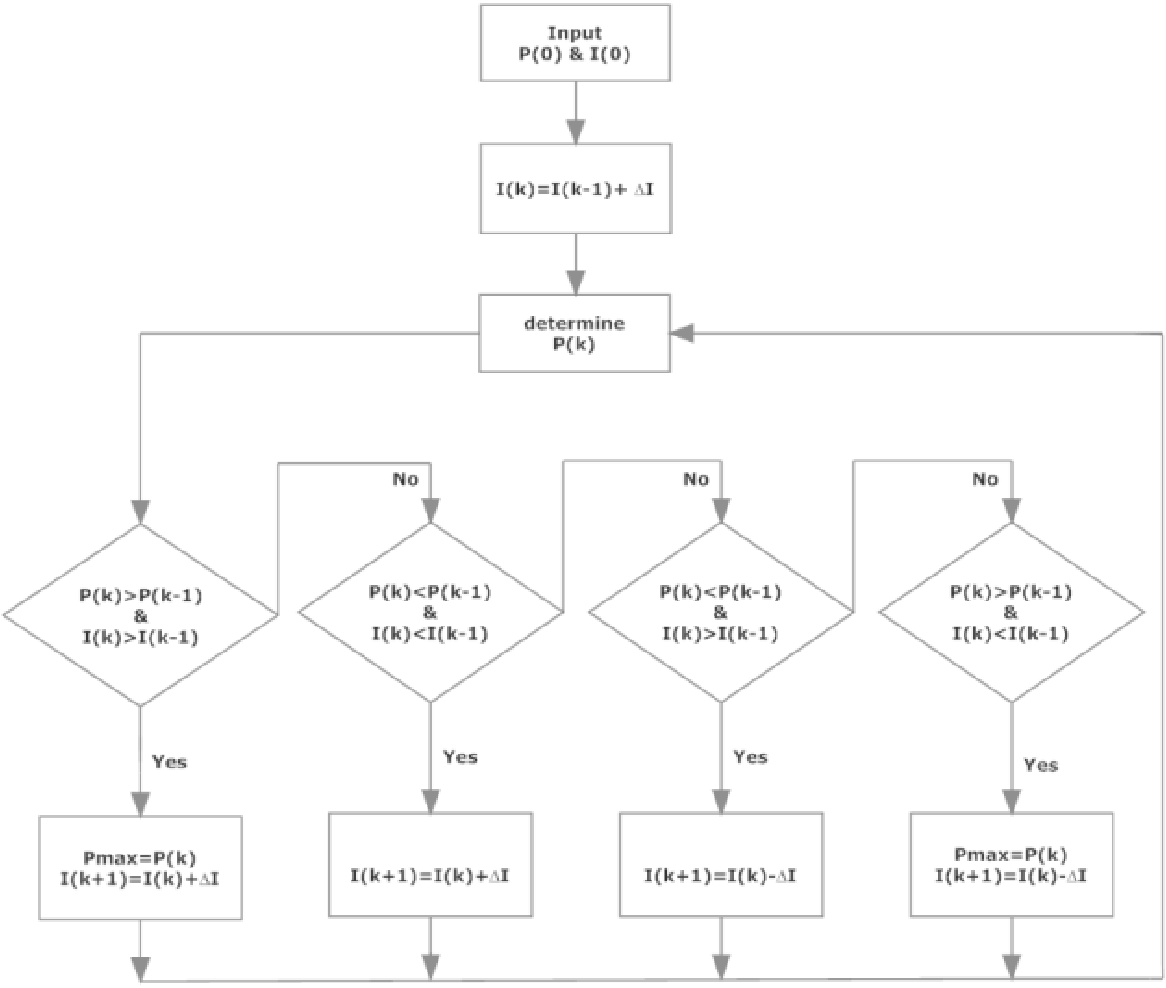

Fig.5. Flow Chart of MPPT Control Algorithm

DOI 10.17148/IJIREEICE.2015.31203

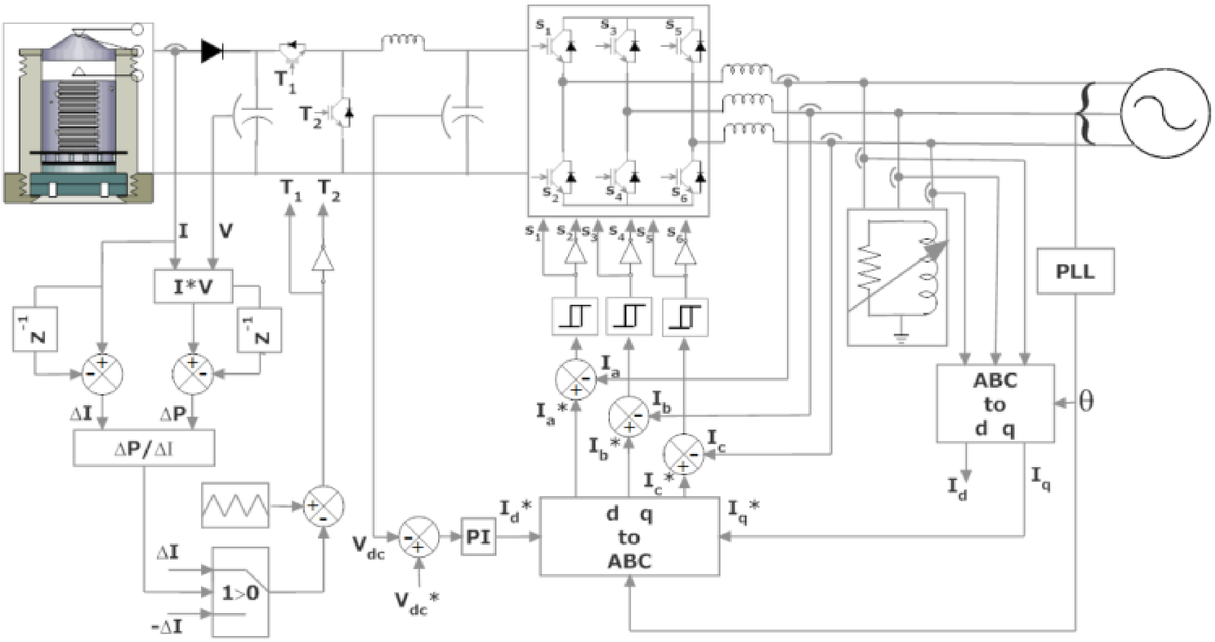

Fig .6 Control Diagram of proposed system

B. Grid Side Control

The main purpose of grid interfacing inverter is to inject the fuel-cell output power into the grid. However, in the proposed work the inverter is also utilised to feed the reactive power demand of local loads connected at point of common coupling (PCC). The control algorithm is mainly divided into two control loops: Outer Voltage loop and Inner current loop. The outer loop maintains the DC voltage close to its reference value and sets the reference active current demand for inverter current. The load reactive current is directly taken as reference reactive component of inverter current. Once, the active and reactive current components of Inverter are known then its equivalent 3-phase components may be easily determined with the help of Park's transformation which is also referred as d-q to ABC transformation. Here it is pertinent to mention that the phase lock loop (PLL) is utilised to determine synchronizing angle for the grid interfacing inverter. The complete control diagram is shown in Fig.6.

IV. RESULTS AND ANALYSIS

The proposed system consisting of fuel cell, DC-DC converter and grid interfacing inverter is developed in MATLAB Simulink and extensive simulation study has been carried out to validate the proposed control algorithm. The simulations are carried out for variable input air flow with Resistive and Resistive-Inductive load at PCC.

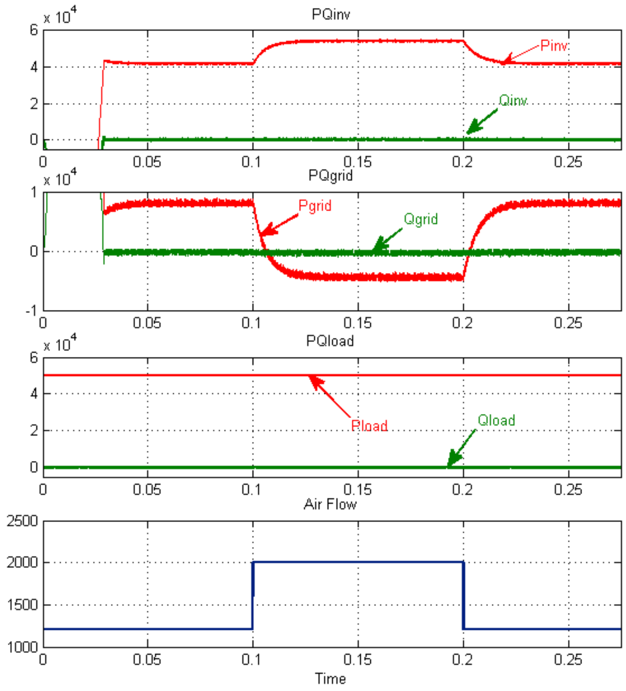

Fig.7. P-Q traces of Inverter, Grid and Resistive load

A. Results with Resistive load

In Fig.7., the traces of active and reactive power for inverter, grid, load with variable air flow are shown. Initially, a load of 50kW with no reactive power demand has been connected in the system where the air flow rate is varied in between 1200-2000 m/s. Under the given circumstances, the fuel cell generates almost 42kW as evident from the active power injected by the inverter in to the grid and the reactive power is zero due to no requirement of reactive power from load at PCC. Here it can be easily noticed that the deficit active power of 8kW is supplied from grid in order to meet the total load active power demand of 50kW. At 0.1Sec., the air flow is suddenly increased from 1200 to 2000m/s which results in increased power generation from Fuel cell and accordingly the power injected from inverter reaches up to 54kW. Since, the fuel cell generates the power in excess to the load power demand of 50kW at PCC, the rest of the power of 4kW is being absorbed by the grid as indicated by the profile of grid active power, where it suddenly changes its sign from 8kW to -4kW with sudden increase in air flow rate. At 0.2Sec., the air flow rate is dropped to its initial value and the system again restores itself to its initial stage.

The traces of grid voltage, grid current, load current, inverter injected current and DC-link voltages are shown in Fig.8. Here, it can be easily noticed that the initially the current drawn by load is more than the current injected by inverter and hence, grid has to supply the deficit amount of current. Since, the load is resistive in nature, the grid voltage and currents are in same phase. However, at 0.1 Sec., the grid current becomes in opposite phase to grid voltages, which indicates the current is being injected in to grid as now the current supplied from inverter is more than the current drawn by load. At 0.2Sec., the grid current again changes its phase as the current supplied from inverter falls to its initial value due to drop in air flow supplied to fuel cell and consequently drop in its output power. Here, it may be noticed that the DC-link voltage is always maintained to its reference value of 1000 V, despite of variations in operating conditions of the whole system.

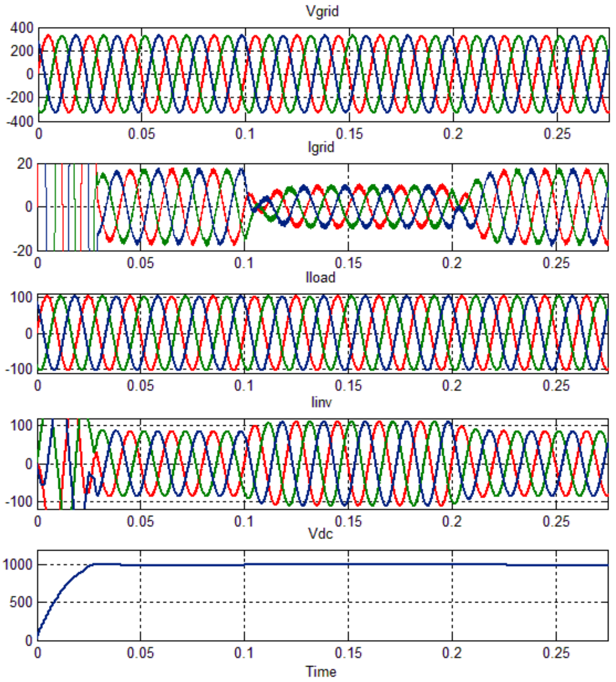

Fig.8. Traces of Grid Voltage, Grid, Inverter, Load Currents and DC-Link voltage with Resistive load

B. Results with Resistive-Inductive load

The Fig. 9 shows the traces of active and reactive power of grid, load and inverter with variable air flow rate applied to fuel cell having RL load connected at PCC. Here, the main purpose is to control the grid interfacing inverter to supply not only the active power generated from fuel cell but also the reactive power demand of load at PCC in order to have grid unity power factor (UPF) operation.

From Fig.9, it can be easily noticed that the load demands almost 50kW active power and 20kVAR of reactive power. The inverter supplies the whole reactive power demanded by load as also evident from grid side zero reactive power, while the load active power is shared by both inverter and grid as discussed in case of simulation results with resistive load.

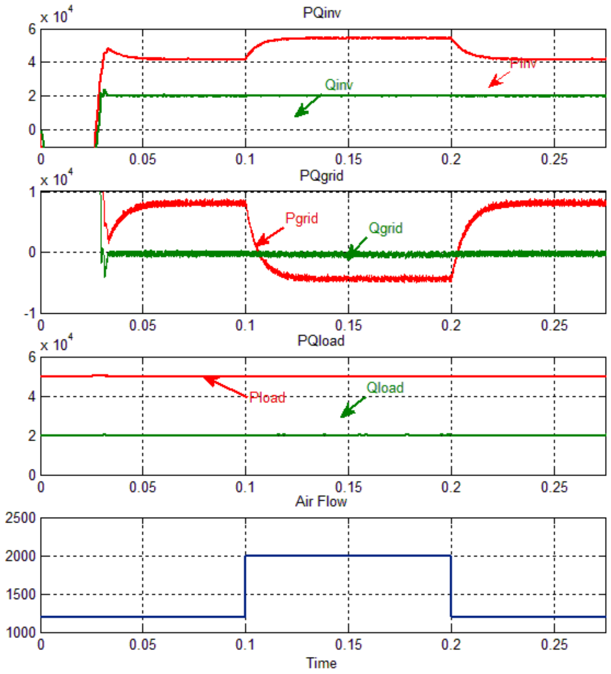

Fig.9. P-Q traces of Inverter, Grid and Resistive-Inductive load

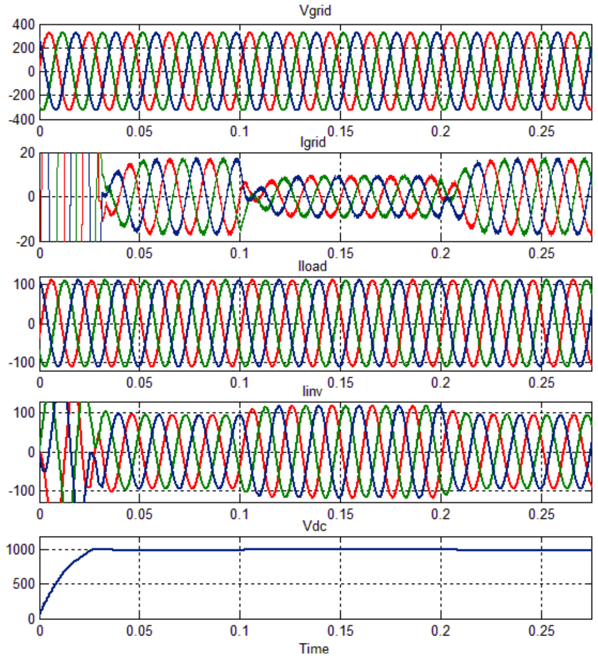

Fig.10. Traces of Grid Voltage, Grid, Load, Inverter Currents and DC-Link voltage with Resistive-Inductive load

Finally, the traces of grid voltage, grid current, load current, inverter current and DC-Link voltage are shown. Here it can be seen that the load current is lagging the grid voltage due to RL load, but grid current always remains in phase or out of phase depending on the active power being drawn from grid or being injected in to grid. Thus from grid side only exchange of active power takes place irrespective of nature of load (R, RL, RLC load etc.) as the reactive power demand is well taken cared by inverter while keep on supplying the generated active power from fuel cell, simultaneously. This confirms the UPF operation

DOI 10.17148/IJIREEICE.2015.31203

of grid which is very much desirable considering the side effect of supplying reactive power demand to be fed from grid.

V. CONCLUSION

In the proposed work, the detailed modeling of fuel cell with MPPT control algorithm has been presented. Besides this, the grid UPF operation has been achieved by controlling the grid interfacing inverter in such a way that it not only supplies the generated active power but also the reactive power demand of nearby loads connected at PCC. The detailed control algorithm with relevant diagrams has been provided to understand the proposed concept. Finally, the detailed simulation study has been carried out and validated by the analysis of simulation results.

ACKNOWLEDGMENT

Many thanks to the D. C. R. University of Science & Technology, Murthal a Govt. of Haryana university for providing me an opportunity to pursue the current research work from Dr. K. N. Modi, University, Newai, Rajasthan.

REFERENCES

[1] M. Singh, and A. Chandra, “Real Time Implementation of ANFIS Control for Renewable Interfacing Inverter in 3P4W Distribution Network,” IEEE Trans. Industrial Electron, vol. 60, no.1, pp. 121-128, Jan. 2013.
[2] M. Singh, V. Khadkikar, A. Chandra, and R. K. Varma, “Grid-Interconnection of Renewable Energy Sources at Distribution Level with Power Quality Improvement Features,” IEEE Trans. Power Delivery., vol.26, no. 1, pp. 307-315, Jan. 2011.
[3] G. Pandove, and M. Singh “High-Frequency DC-DC Boost Converter for Residential PV System with Power Factor Correction,” in Proc. IEEE PICONF’2012, 19 –22 Dec. 2012, Murthal, Haryana, India.
[4] O. Wasynczuck, "Dynamic Behavior of a Class of PhotovoltaicPower Systems", IEEE Trans. Apparatus and Systems, 1983.
[5] M. Singh, A. Chandra and B. Singh, “Sensorless Power Maximization of PMSG based Isolated Wind-Battery Hybrid System Using Adaptive Neuro-Fuzzy Controller” In the Proc. of IEEEIASGM-2010, Houston, Texas, USA.
[6] N. Karami, R.Outbib and N.Moubayed, “Fuel Flow Control of a PEM Fuel Cell with MPPT,” In the Proc. ofIEEE ISIC-2012, Croatia.
[7] Sarvi, M.; Barati, M.M.; , "Voltage and current based MPPT of fuelcells under variable temperature conditions," Universities PowerEngineering Conference, Sept. 2010.
[8] C.A. Ramos-Paja, G. Spagnuolo, G. Petrone, R. Giral, A. Romero,"Fuel cell MPPT for fuel consumption optimization," Circuits andSystems (ISCAS), Proceedings of 2010 IEEE InternationalSymposium, June 2010.
[9] K. Hussein, I.Muta, T.Hoshino, M. Osakada, "MaximumPhotovoltaic Power Tracking: An Algorithm for Rapidly ChangingAtmospheric Conditions", lEE Proc.-Generation, Transmission,Distribution, January, 1995.
[10] N. Bizon, "On tracking robustness in adaptive extremum seekingcontrol of the fuel cell power plants", Applied Energy 2010.
[11] M. Becherif, D. Hissel, "MPPT of a PEMFC based on air supplycontrol of the motocompressor group", International Journal ofHydrogen Energy, Vol: 35, Issue: 22, 2010.
[12] Sh. Abdi, K. Afshar*, N. Bigdeli, S. Ahmadi, "A Novel Approach for Robust Maximum Power Point Trackingof PEM Fuel Cell Generator Using Sliding Mode ControlApproach", Int. J. Electrochem. Sci., 7,4192 – 4209, 2012.
[13] J. Jiao, and X. Cui, “Adaptive Control of MPPT for Fuel Cell Power System,” Journal of Convergence Information Technology(JCIT), Vol. 8, No. 4,Feb.-2013.
[14] M. ELSayed Youssef, Moataz H. Khalil, Khairia E. AL-NAdi, “Neural Network Modeling forProton Exchange Membrane Fuel Cell (PEMFC)”, Advances in Information Sciences and ServiceSciences, Advanced Institute of Convergence Information Technology, vol. 2, no. 2, pp. 61-66,2010.
[15] C. Ramos Paja, C. Bordons, A. Romero, R. Giral and L. Martinez Salamero, “Minimum FuelConsumption Strategy for PEM Fuel cells”, IEEE Transactions on Industrial Electronics, vol. 56,no. 3, pp. 685-696, 2009.
[16] Yan Minxiu, Fan Liping, Sun Ping, “Constant Voltage Output in Proton Exchange Membrane FuelCell under Fuzzy Sliding Mode Control”, Advances in Information Sciences and Service Sciences,Advanced Institute of Convergence Information Technology, vol. 4, no. 20, pp. 180-187, 2012.
[17] ZhongZhidan, HuoHaibo, Zhu Xinjian, Cao Guangyi, Ren Yuan, “Adaptive Maximum PowerPoint Tracking Control of Fuel Cell Power Plants”, Journal of Power Sources, vol. 176, no. 1, pp.259-269, 2008.
[18] J. M Correa, F. A Farret, L. N Canha, Marcelo G. Simoes, “An Electrochemical-Based Fuel-CellModel Suitable for Electrical Engineering Automation Approach”, IEEE Transactions onIndustrial Electronics, vol. 51, no. 5, pp. 1103-1112, 2004.
[19] S. Pasricha, and S.R. Shaw, “A Dynamic PEM Fuel Cell Mode”,IEEE Transactions on Energy Conversion, vol. 21, no. 2, June2006.
[20] R. OHayre, S.Cha, W. Colella, F. Prinz ,“Fuel cell fundamentals”,John Wiley and Sons, New York, 2009.
[21] C. Wang, M. H. Nehrir, and S. R. Shaw, “Dynamic Models and ModelValidation for PEM Fuel Cells Using Electrical Circuits,” IEEE Trans.Energy Conv., vol. 20, no. 2, pp. 442-451, June 2005.
[22] P. Famouri and R. S. Gemmen, “Electrochemical Circuit Model of aPEM Fuel Cell,” at Power Eng. Soc. Gen. Meeting, pp. 1440-1444, July 2003.

BIOGRAPHIES

Gitanjali Pandove has done her M.Tech from AMU Aligarh and B. Tech from Nagpur University. Presently, she is working as associate professor in Electronics and Communication Engineering dept. At Deenbandhu Chhotu Ram University of Science and Technology (D.C.R.U.S.T.) Murthal, Sonipat, Govt. of Haryana, India. Her research interest includes, Digital Control, power electronics, Renewable Energy, Optical communication, Image Processing and Digital signal processing.

Mukhtiar Singh received the B.Tech. and M.Tech. Degrees in electrical engineering from National Institute of Technology (formerly known as R.E.C. Kurukshetra), Kurukshetra, India, in 1999 and 2001, respectively. He has done his Ph.D. degree in 2010 from Ecolede Technologie Superieure, Universite du Quebec, Montreal, QC, Canada, under the National Overseas Scholarship, funded by the Government of India. Since 2002, he has been Assistant Professor in the Department of Electrical Engineering, Deenbandhu Chhoturam University of Science and Technology, Murthal, Sonepat, India. Currently, he is working as Associate Professor at Delhi Technological University (Formerly Delhi College of Engineering) Delhi. His research interests include renewable energy sources, power quality, energy storage systems, electric vehicles, and power electronics and drives.