Power Quality Improvement by Solar Photo-voltaic/Fuel cell Integrated System Using Unified Power Quality Conditioner

Sarita Samal*, Prakash Kumar Hota **‡

* Department of Electrical Engineering,Veer Surendra Sai University of Technology, Burla, odisha, India
** Department of Electrical Engineering,Veer Surendra Sai University of Technology, Burla,odisha,India

(saritaruchy@gmail.com, p_hota@redifmail.com)

‡ Sarita Samal, Department of Electrical Engineering,Veer Surendra Sai University of Technology, Burla, odisha
Tel:+91 8908081827, saritaruchy@gmail.com

Received: 29.04.2017 Accepted:16.07.2017

Abstract-The actual problems in reduction of Power Quality (PQ) occurs due to the fastdevelopment of nonlinear load which leads to sudden decrease of source voltage for a few seconds i.e sag, swell, harmonics in source and load current, voltage unbalance and so on. All these PQ problems can be compensated by using Unified Power Quality Conditioner (UPQC). However, the operation of UPQC depends upon the available voltage across thr capacitor present in dc link. If the capacitor voltage is maintained constant then it gives satisfactory performance. The proposed research is basically on designing of Photo Voltaic (PV) and Fuel cell fed system which will maintain proper voltage across the dc link capacitor of the UPQC. The proposed technique is the combination of shunt and series Active Power Filter (APF) to form UPQC which is fed from PV and fuel cell system and connected to grid for improved response in the output. The said model is simulated in MATLAB and results are verified by using First Fourier Transfer (FFT) analysis. In this paper**,** the simulation model of series APF, shunt APF, UPQC, PV-UPQC and Fuel cell with UPQC are design in MATLAB software. In case of shunt active filter the "*d-q* theory" and hysteresis current controller is proposed as its control technique and park's transformation method is used for series active filter**.** The proposed PV/Fuel cell-UPQC is design for reduction of voltage sag, swell, interruption, harmonics in load current and compensation of active and reactive power.

Keywords- Fuel cell, Harmonics, Power quality, Solar PV, Unified Power Quality Conditioner.

1. Introduction

The use of electricity is increasing very rapidly so the necessity of renewable energy based source is required for interconnection to the distribution network. The main drawbacks of the renewable sources are the power generation is not continuous and it is season based. To overcome these disadvantages numbers of renewable sources are interconnected[1,2].The Energy management system (EMS) ensures reliable and continuous power supply to various local loads and enables the bidirectional real power transfer between Microgrid and utility grid while maintaining the grid standards at point of common coupling [3]. For maintaining the power quality problem power electronics switches with advance controller mechanism are used [4].The theory, modeling and application of a unified power quality conditioner has been described by Chen *et al.* [5].The modeling and simulation of solar photovoltaic cell usig MATLAB/SIMULATION and validate the result in experimentally has been explain in [6-7].Femia *et al.* [8] have developed a scheme for maximum power point tracking (MPPT) of solar PV system using perturb and observe method.Hind *et al.* [9] have explained application of an active power filter on a photovoltaic power generation system. Basu *et al.* [10] have made a comparative evaluation of two models of UPQC for suitable interface to enhance power quality. Montero *et al.* [11] have developed number of method for shunt active power filters used in three-phase system. Lee *et al.* [12] described the control techniques of series active power filters compensating for source voltage unbalance and current harmonics. An efficient voltage sag recognition procedure for a dynamic voltage restorer has been developed by Fitzer *et al.* [13]. The simulation and experimental design of shunt active power filter for harmonics and reactive power compensation have been described by Jain *et al.* [14].Kano*et al.* [15]have presented the comparison of the converter arrangements between series and shunt converters in UPFC in view of the control method and the converter capacity.Yallamilli *et al.* [16] have proposes the topology consists of a three phase dual voltage source inverter (DVSI) which transfers the active power between grid and Microgrid based and offering ancillary services such as harmonic mitigation, reactive power support at the point of common coupling (PCC).The purpose of fuel cell is to transform the chemical energy of fuel to electric energy. A fuel cell is environmental friendly, noise free, high efficiency as compare to other sources as and it can be interfaced with AC and DC distribution system using different power electronics devices described by Noroozian *et al.* [17]. Nergaard *et al.* [18] has design 48V fuel cell with inverter application and ultra capacitor for energy storing purposes. Bucci *et al.*[19] has described the various types of fuel cell technology with Matlab modeling and implementation of Proton Exchange Membrane (PEM) fuel cell. Jayalakshmi *et al.* [20] presented the modeling and control of photovoltaic/fuel cell/supercapacitor hybrid power system for stand-alone applications. Elgammal *et al.* [21] have presented a low cost DC and AC active power filters to enhance the power quality of hybrid Fuel Cells (FC) and Photovoltaic arrays (PV) renewable energy system through reducing the complexity of design and control of active harmonic filters that effectively mitigate power system harmonics.

The advantage of the above method is that it maintains the dc link voltage constant and when there is no sun light fuel cell can provide necessary power to the UPQC for its operation. The major disadvantage of UPQC is that it cannot compensate the voltage interruption but proposed method can perform all the function as UPQC can and also compensate the voltage interruption.

This paper is presented in following approach. In section 2, modeling and simulation of PV/Fuel cell UPQC system where 2.1 sections about the modeling and simulation of solar PV, section 3, modeling and analysis of fuel cell with simulation result. In section 4, UPQC system is simulated with solar PV and Fuel cell. Finally the implementation results are discussed in section 5.

2. Solar PV-Fuel Cell Integrated UPQC Circuit and its Functions

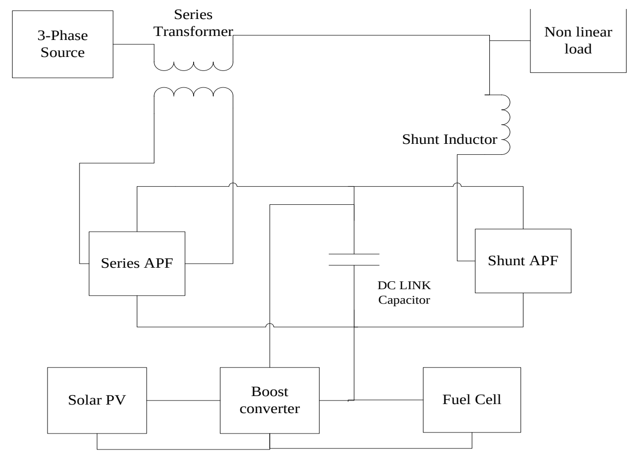

Fig. 1. Basic Block diagram for PV/Fuel- UPQC system.

In the proposed method the design and development of the PV-Fuel cell-UPQC system is described. By using instantaneous *d-q* control theory techniques along with proportional-Integral (PI) controller and hysteresis band controller, the mitigation of voltage sag and swell under different balance and unbalanced load conditions are simulated. The use of a PV array and Fuel cell for retaining fixed DC link voltage is another distinguishing feature of the PV-Fuel cell-UPQC system. With these functions, the proposed method is suitable for connecting atPoint of Common Coupling (PCC). The proposed configuration with UPQC is shown in Fig.1.where voltage interruption reimbursement and active power injection to grid in addition to the other regular UPQCoperation can be achieved.

2.1 Modeling of solar PV

Solar photo-voltaic system works on the principle that when a light energy falls on solar cell it converts it to electrical energy. The Fig.2 shows here is an equivalent model of solar PV system representing single diode model. It consist of a photo current I_{ph} which depends on temperature and irradiation, the series resistance represent the internal resistance due to which current I flows and the shunt resistance describe the flow of I_{sh} which is a leakage current. The I-V and P-V curve is shown in Fig.3.

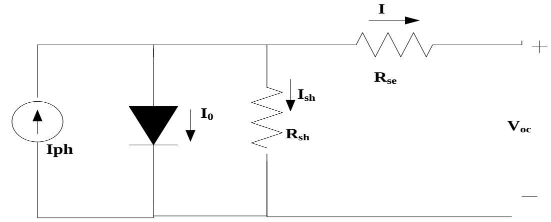

Fig. 2.Solar cell single diode model.

The load current, photo current and other equation are given below from Eq. (1) to Eq. (5)

$$I = I_{Ph} - I_0 - I_{sh} \quad (1)$$

$$I_{Ph} = [I_{sc} + K_i(T_k - T)] \times \frac{G}{1000} \quad (2)$$

$$I_{RS} = \frac{I_{sc}}{[exp(q \times V_{oc}/N_s \times k \times A \times T) - 1]} \quad (3)$$

$$I_0 = I_{RS}\left[\frac{T}{T_r}\right]^3 exp\left[\frac{q \times E_{g0}}{Ak}\left\{\frac{1}{T_r} - \frac{1}{T}\right\}\right] (4)$$

$$I_{PV} = N_P \times I_{Ph} - N_P \times I_0\left[\exp\left\{\frac{q \times V_{PV} + I_{PV}R_{se}}{N_s \times AkT}\right\} - 1\right] (5)$$

where
I_{PV}-Diode photo current
I_O-Reverse saturation current of diode
I_{sh}- Leakage Current.
V_{pv}-Diode voltage,
V_{oc} - Open circuit voltage
R_{se}-Series Resistance
R_{sh}-Shunt resistance
I_{sc}- Short circuit Current.

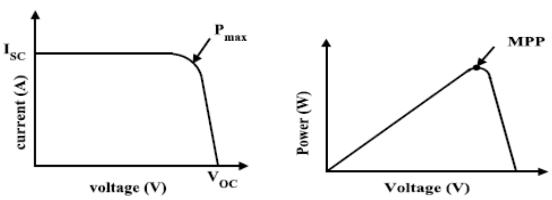

Fig. 3. PV system I-V & P-V characteristics

2.3 Maximum Power Point Tracking System

The solar panel efficiency is increased by the use MPP technique. The MPPT is the application of maximum power transfer theorem which state that the load will obtain maximum power when the source impedance is equal to load impedance. The MPPT is a device that extracts highest power from the solar cell and changes the duty cycle of the boost converter so as to match the load impedance to the source**.**

2.4 Perturb & Observe (P&O) MPPT

There are many method of MPPT out of which Perturb & Observe (P&O) technique is mostly used by the researcher due to its simplicity and cost effective. This method works on an algorithm that first PV panel terminal voltageV (n) and current I (n)are calculated and related value of power is measured denoted by P (n). The detail flow chart is shown in Fig.4 which describes the algorithm for designing the MPP system using P&O technique.

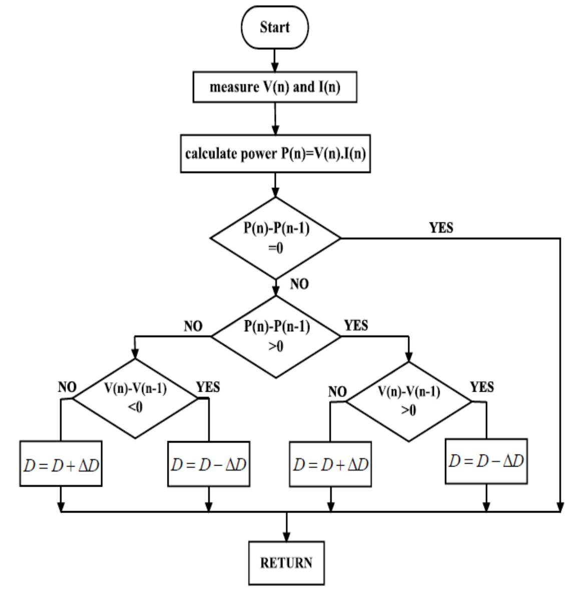

Fig. 4. Flowchart of P & O MPPT algorithm

In this algorithm, the module voltageis periodically given a perturbation and the corresponding output power P(n) is compared withthe previous perturbing cycle P (n-1). In this algorithm a slight perturbation is introduce tothe system. If the powerincreases i.e P (n) - P (n-1) > 0due to the perturbation then the perturbation is continued in the same direction and the duty cycle of the boost converter will increase or decrease depending upon PV panel voltage i.e D+ΔD for V (n)-V (n-1) >0 and D-ΔD for the case V (n)-V (n-1) < 0. After the peak power is reached the power at the MPP is zero i.e at P (n) - P (n-1) = 0 and next instant power decreasesand hence after that the perturbation reverses.
where
V (n) - PV panel terminal voltage
V (n-1) – Voltage due to perturbation
I (n) - PV panel current
P (n) – PV panel power
P (n-1) - Power due to perturbation
D- Duty cycle of boost converter
ΔD- Change in duty cycle

2.5 DC/DC Step up Converter

A step up or boost converteris a devicewhich increases the input voltage to desired output voltage as required by load. The configuration is shown in Fig.5, which consists of a inductor *L*, switch *S*, diode D_1, capacitor *C* for filter, load resistance R and DC input voltage Vin.

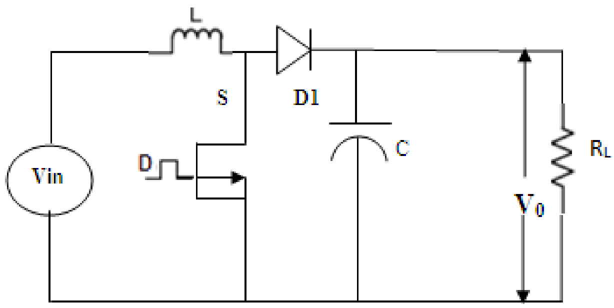

Fig. 5. Basic circuit for Boost converter

The boost inductor stores the energy fed from the input voltage source as the switch D is on by applying switching pulse and during this time the load current is maintain by the charged capacitor so that the load current should be continuous.

During the switch off period the input voltage and the stored inductor voltage will appear across the load hence the load voltage is increased. Hence, the load voltage is depends upon weather switch S in ON or OFF and this is depends upon the duty cycle (*D*).Duty cycle is the ratio of T_{ON} to T.Where T_{ON} and T denotes the on time and time period of firing pulse respectively.Science the switch conducts with a duty cycle (*D*) and then the output DC voltage is given by Eq. (6)

$$\frac{V_0}{V_s} = \frac{1}{1-D} \quad (6)$$

The minimum value of duty cycle Dmin and maximum value of duty cycle Dmax used for a lossless boost converter is given by the Eq. (7) and Eq. (8)

$$D_{max} = 1 - \frac{V_{in-min}}{V_o} \times \eta \quad (7)$$

Where, D_{max} is the maximum duty cycle required to keep the converter in Continuous Conduction Mode (CCM).CCM is one of the modes of operation of boost converter.

$$D_{min} = 1 - \frac{V_{in\_max}}{V_o} \times \eta \quad (8)$$

Where, D_{min} is the minimum duty cycle required to keep the converter in CCM.

2.6 Matlab /Simulation of PV System

In general the efficiency of a PV unit is extremely low, therefore it is essential to operate the PV unit at its peak point so that the highest power can be provided to the load at any condition. A step up converter which is located next to the PV unit extracts maximum power with the help of P&O MPPT method which matching the impedance of the circuit to the impedance of the PV unit Impedance matching is possible by changing the duty ratio of the boost converter. The simulation of solar PV with P&O MPPT and Boost converter is shown in Fig.6. The P-V and I-V characteristic of PV unit is shown in Fig.8 and Fig.7 and the boost converter output voltage is shown in Fig.9.

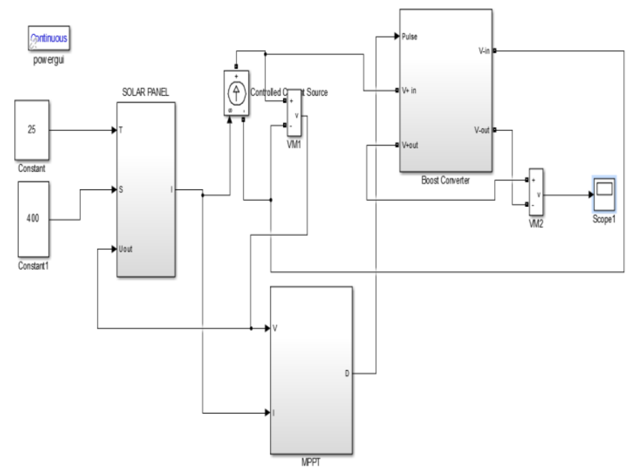

Fig. 6. Simulation of PV with MPPT and Boost converter

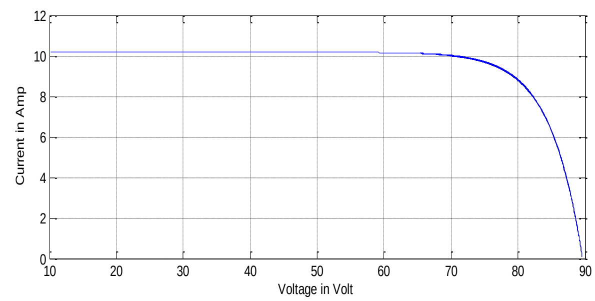

Fig.7. I-V Characteristics of PV module

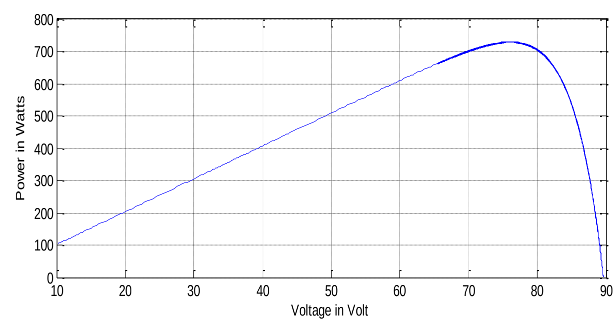

Fig.8. P-V Characteristics of PV module

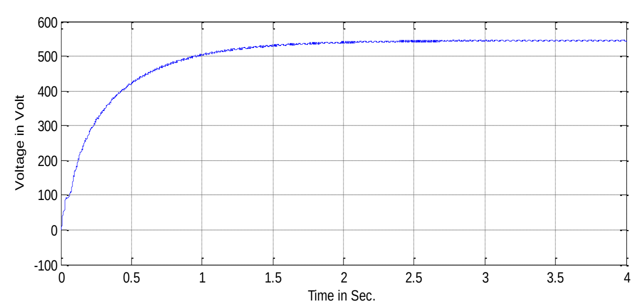

Fig.9. Output voltage of Boost converter

3. PEM Fuel Cell Model

The fuel cell system considered in this paper is consisting of a fuel cell reformer and stack which generate electricity due to electrochemical reaction of hydrogen and oxygen as shown in Fig.10.

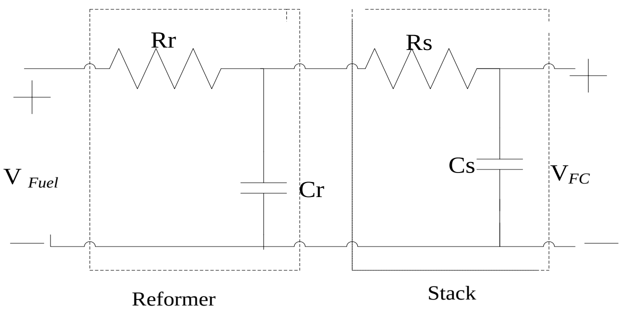

Fig.10. Fuel cell equivalent circuit.

The fuel cell is a device which produces electricity from the chemical reaction of hydrogen and oxygen. The reformer is presented by a first order equation and the corresponding transfer function is shown in equation (9), the stack is also represented by a first order time delay equation with transfer function is shown in equation (10),

$$\frac{V_{cr}}{V_{in}} = \frac{\frac{1}{C_r S}}{R_r + \frac{1}{C_r S}} = \frac{1}{1 + R_r C_r S} = \frac{1}{1 + \tau_r S} \qquad (9)$$

$$\frac{V_{cs}}{V_{cr}} = \frac{\frac{1}{C_s S}}{R_s + \frac{1}{C_s S}} = \frac{1}{1 + R_s C_s S} = \frac{1}{1 + \tau_r S} \quad (10)$$

The electrochemical equivalent model of fuel cell is shown in Fig.11. The mathematical model for design of PEM fuel cell by different set of equation is shown below.

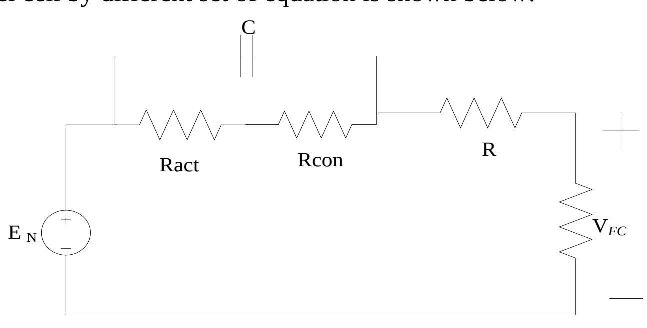

Fig.11. Simplified model of the PEM for only one cell.

$$E_N = 1.229 - 0.00085(T - 298.15) + 4.31 \times 10^{-5} \times T \times \left[\ln(P_{H2}) + \frac{1}{2}\ln(P_{O2})\right] \qquad (11)$$

$$V_{FC} = E_N - V_{act} - V_{Ohmic} - V_{con} (12)$$

$$V_{act} = -[\xi 1 + \xi 2 \times T + \xi 3 \times T \times \ln(CO_2)] (13)$$

$$C_{O2} = \frac{P_{O2}}{5.08 \times 10^6 \times e^{-\left(\frac{498}{T}\right)}} \qquad (14)$$

$$V_{Ohmic} = i_{FC}(R_M + R_C) \qquad (15)$$

$$R_M = \frac{\rho_M \times \lambda}{A} \qquad (16)$$

$$V_{con} = \ln\left(1 - \frac{J}{Jmax}\right) \times (-B) \qquad (17)$$

$$V_s = K \times V_{FC} \qquad (18)$$

Where

E_N - Open circuit thermodynamic potential of the cell

Each cell model coefficients of parametric are representing by ξ1, ξ2, ξ3, ξ4 and ψ.

The ohmic voltage drop is represented by V_{ohmic}

R_M - Proton conduction equivalent membrane resistance.

R_C – Electron conduction Equivalent contact resistance.

V_{con}- Concentration over potential.

k- no. of cells connected in series

A- Membrane Area in sq.cm,

Λ- Thickness in cm.

R_C-Contact resistance in ohm,

C-Capacitance in Farad

ξ's-Model coefficients,

Ψ-Empirical parameter

Jmax-Maximum current density in A/cm2,

Pressure of hydrogen P_{H2} (atm),

Pressure of oxygen P_{O2} (atm),

Temperature T (K).

3.1 Matlab Simulation of Fuel Cell with Boost Converter

A simple fuel cell typically produces output voltage in the range of 0.5–0.9 V. Since this low voltage becomes insufficient for real-time applications, a stack of fuel cells are arranged in series and a step up converter is connected to so that the required voltage can be attained. The simulation diagram of Fuel cell with boost converter is shown in Fig.12. The I-V and P-V characteristics of Fuel cell is shown in Fig.14 and output voltage of boost converter is shown in Fig.13.

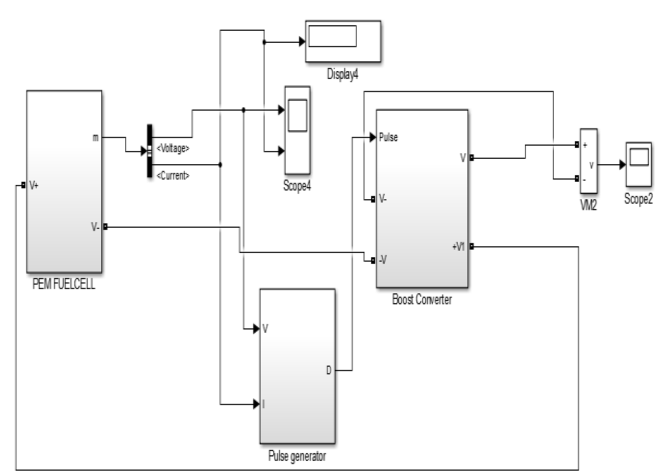

Fig.12. Fuel cell with boost converter.

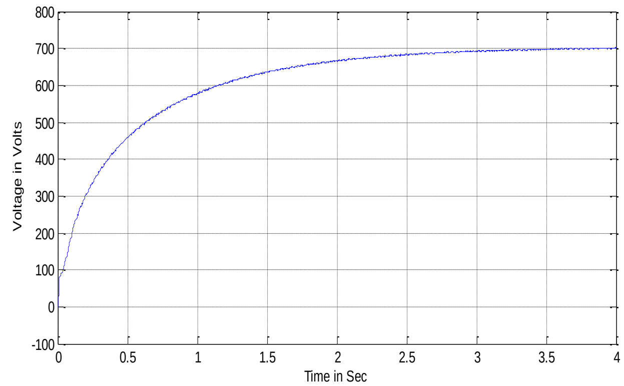

Fig. 13. Output voltage of boost converter.

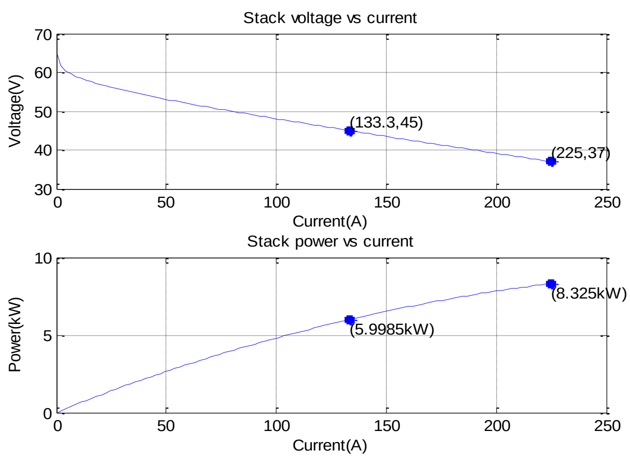

Fig.14. I-V and P-V characteristics of Fuel cell.

4. Control Strategies of the UPQC System

There are several control strategies available to find out the reference values of the voltage and the current of UPQC. The Fig.15 shows the block diagram for control strategies of UPQC system. The concept of instantaneous active power (p) and reactive power (q) and its application in shunt filter reference current generation, the synchronous reference frame theory, the fuzzy logic control (FLC) for the control of UPQC method are some of the above mentioned control strategies. Based on the above discussion, d-q theory with hysteresis current control mode is suitable for parallel mode operation of UPQC system and d-q theory with Pulse Width Modulation (PWM) voltage control mode is suitable for interruption mode operation.

The hysteresis control method is simple to implement and it has enhanced system stability, increased reliability and mitigates power quality problems.

UPQC consists of two main controllers as follows:

I. Series Active Power Filter
II. Shunt Active Power Filter

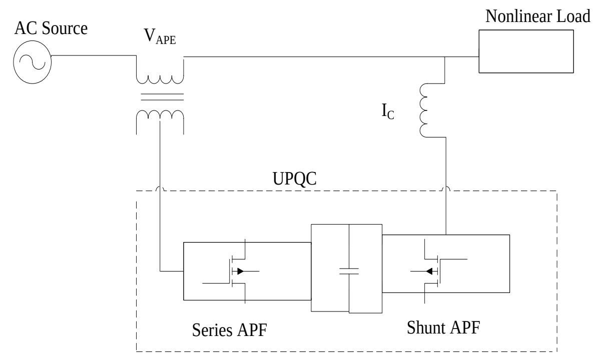

Fig.15. Block diagram of UPQC.

4.1 Control Scheme of Series active Power Filter

The block diagram for series APF control scheme is shown in Fig.16 where Park's transformation method is used for generation of unit vector signal. The actual voltage and the reference are converted to *dq0* from *abc* coordinates and both are compared in *dq0* reference frame. After the comparison both are again converted to *abc* reference frame. From Phase Locked Loop (PLL) $\varnothing$ can be generated which is required for Park's transformation and inverse Park's transformation. The switching pulses required for Voltage Source Inverter (VSI) conduction are generated from the comparison of selected output voltage (Vc*) with the sensed series APF output voltage (Vc) in a hysteresis voltage controller. Fig.17 shows the related simulation diagram.

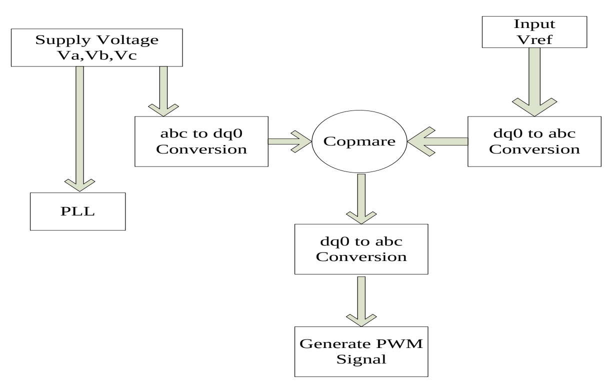

Fig.16. Control scheme of series Active Filter

The Park's transformation and inverse Park's transformation are given below

$$\begin{bmatrix} v_q \\ v_d \\ v_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\varnothing & \cos(\varnothing-120) & \cos(\varnothing+120) \\ \sin\varnothing & \sin(\theta-120) & \sin(\varnothing+120) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}$$

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} \cos\varnothing & \sin\varnothing & 1 \\ \cos(\varnothing-120) & \sin(\varnothing-120) & 1 \\ \cos(\varnothing+120) & \sin(\varnothing+120) & 1 \end{bmatrix} \begin{bmatrix} v_q \\ v_d \\ v_0 \end{bmatrix}$$

4.2 Simulink Model of Series Active Filter Control scheme.

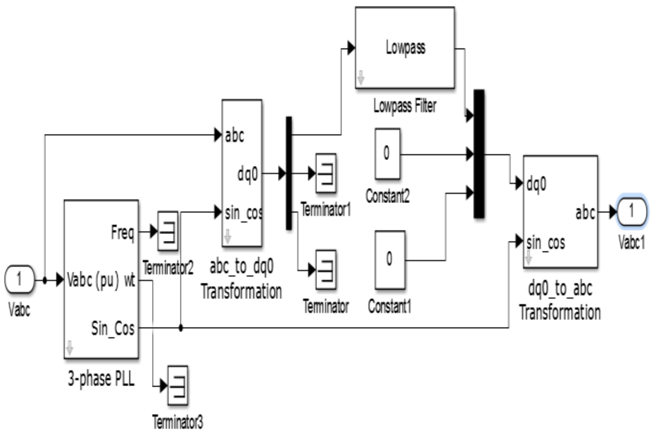

Fig.17. Simulation of Series Active Filter Controlscheme

4.3 Shunt Active Power Filter Control Scheme.

The shunt (APF) is usually joined in parallel to the system which indicates the harmonics content. To eliminate the harmonics, the equal amount of harmonic compensating current is injected in opposite phase w.r.t the harmonic current. The control scheme shown in Fig.18 includes the transfer of source current from *a-b-c* to *d-q* frame. In nonlinear load the source current includes both oscillating as well as dc component. The dc component is only positive sequence component but the oscillating component includes positive, negative and zero sequence components. To maintain the DC link voltage this active filter will absorb some active power from the power system. The Matlab simulation of control scheme for shunt active filter is shown in Fig.20.

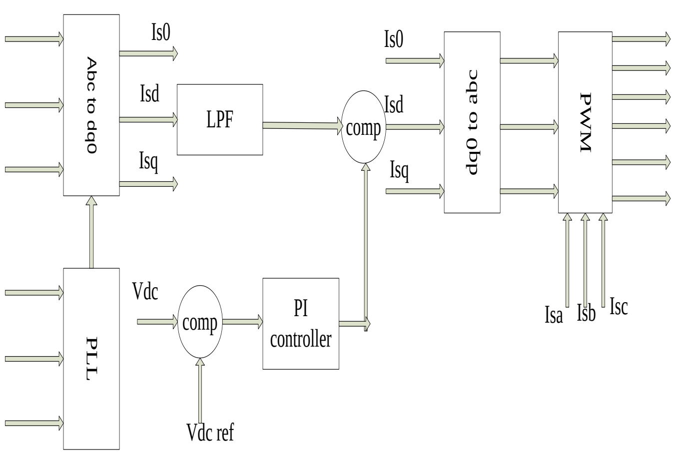

Fig.18. Control scheme of Shunt Active Power Filter

4.4 Design of Shunt APF

(i) *DC link capacitor*:-The active and reactive power flow to the system is provided by the link capacitor when it is required.

(ii) *Voltage source inverter:*-The electronics device which converts direct current to alternating current when Pulse Width Modulation (PWM)voltage is given to the gates of itsInsulated Gate Bipolar junction Transistor(IGBT) or Gate Turn-off Thyristor (GTO) etc. Here the main function of the VSI is to compensate the source current harmonics present by injecting the equal and opposite current to the system.

(iii) *Hysteresis Current Controller:*-Hysteresis current controller shown in Fig.19generates PWM signal by comparing the reference signal w.r.t to the actual signal the figure below shows the generation of PWM signal by comparing the two current signals.

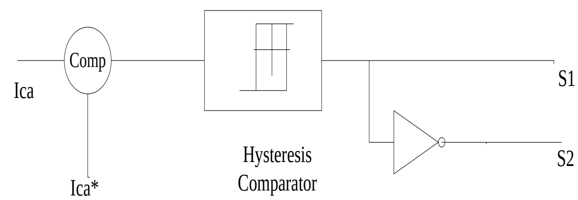

Fig.19. Principle of hysteresis current controller

4.5 Shunt Active Power Filter Control scheme.

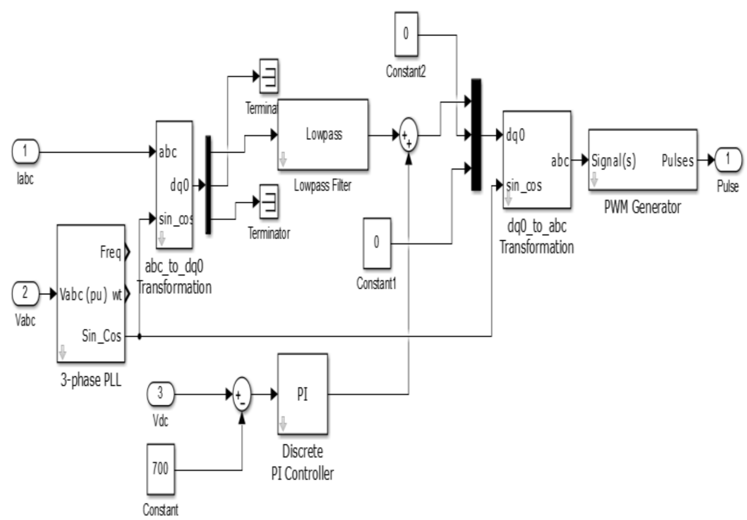

Fig.20. Shunt Active Filter Control Scheme

5. Solar PV/Fuel cell - UPQC System Simulink Model

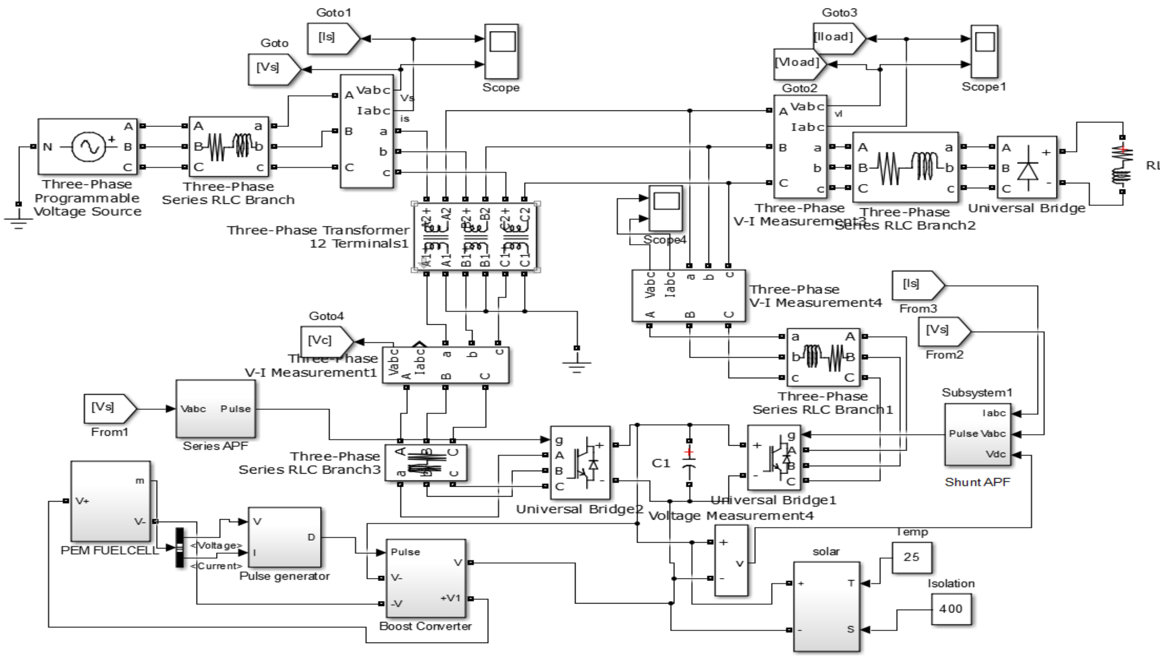

Fig. 21. Simulation of Control scheme of Shunt Active Filter

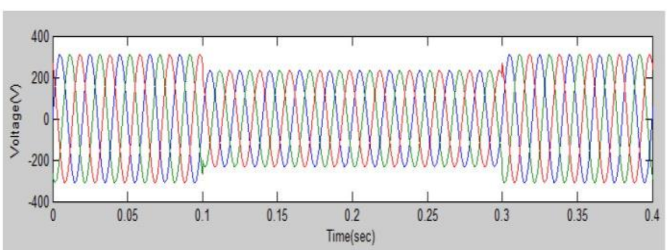

Fig.22. Load Voltage without SAF

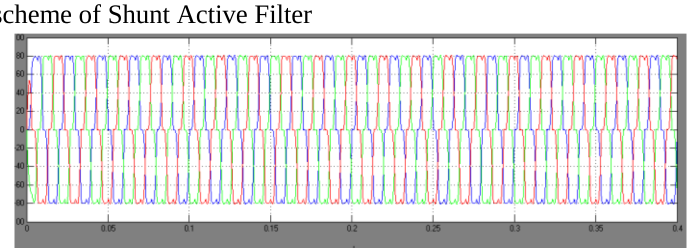

Fig.25. Load current before compensation

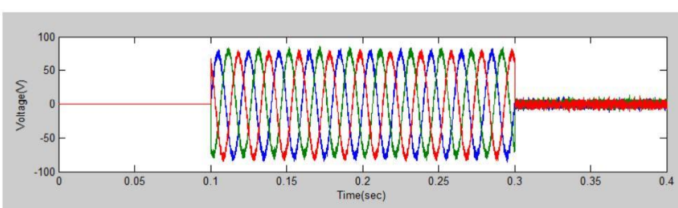

Fig.23. Injected Voltage

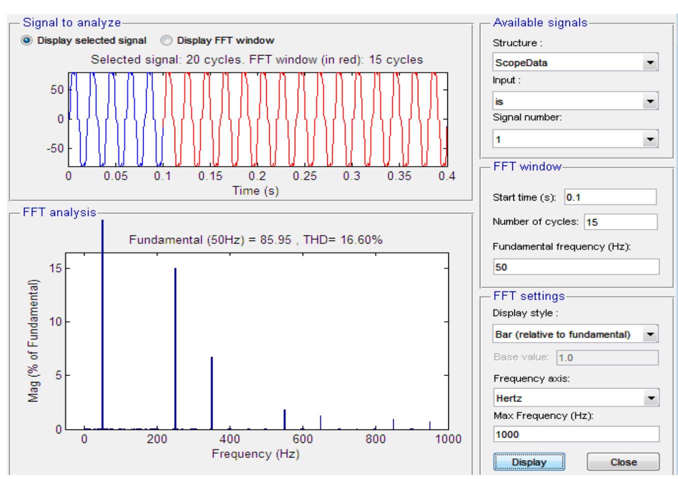

Fig.26. Harmonics analysis without shunt APF

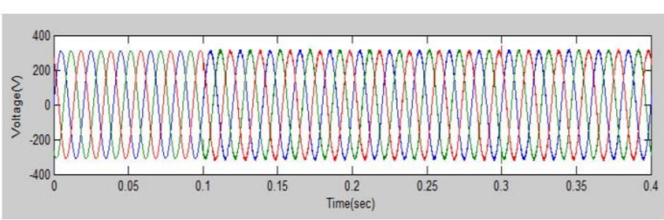

Fig.24. Load Voltage with SAF

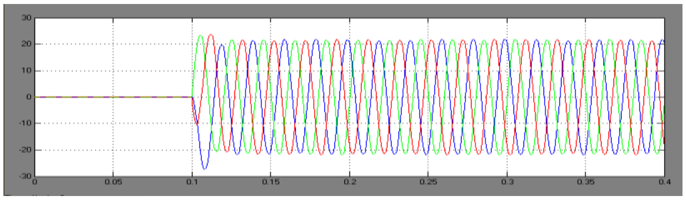

Fig.27. Current Injected by shunt active filter

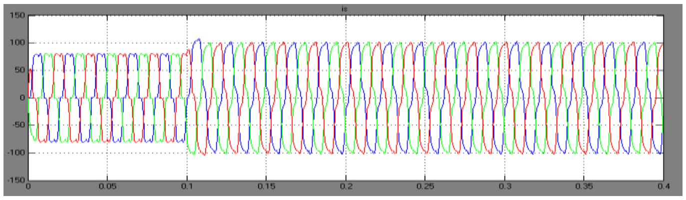

Fig.28. Load current with shunt APF

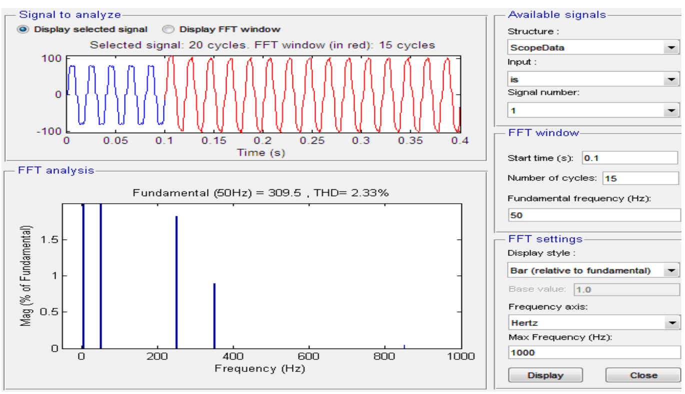

Fig.29. Harmonics analysis with shunt APF

Table No.1 Different parameters and their ratings to carry out the simulation work of solar PV and Boost converter.

Parameters	Ratings
No.of Cells in series	36
Cells in Parallel	01
Solar Type	Silicon Solar PV
Short Circuit Current	10.2A
Open circuit Voltage	90.5V
Voltage at maximum Power	81.5V
Current at maximum Power	8.6A
Supply Voltage	380 V at 50 Hz frequency
Inductance at source side	0.2 mH
Capacitance at load	1150 µF
Inductance at load	2 mH
Load resistance	5 Ω
DC link capacitor	1100 µF
Filter inductor	1.5 mH
Filter capacitor	20 µF

Table No.2 Different parameters and their ratings to carry out the simulation works of Fuel cell.

Parameters	Ratings
Voc	65V
No.of Cell	65
Stack efficiency	55%
Air flow rate	300IPM
Fuel cell resistance	0.70833Ω
Load resistance	5 Ω
One cell voltage	1.128V
H2	99.56%
O2	59.3%

5.1 Result analysis

The simulink models of PV/Fuel cell -UPQC are simulated in MATLAB is shown in Fig.21 which consist of series APF, shunt APF, solar PV, Fuel cell and boost converter. The different parameter for performing the simulation work is shown in Table No.1 and Table No.2

- The simulation result shown in Fig.22 is without series filter where voltage sag is clearly shown from 0.1sec. to 0.3sec. When the series active filter injects voltage from 0.1sec.to 0.3sec shown in Fig.23, the load voltage is compensated to actual value as shown in Fig.24.
- Figure.25 shows the simulation result load current before compensation and Fig.26 shows the harmonics content i.e. 16.6% by using FFT analysis. When the shunt active filter injects current from 0.1sec.to 0.4sec as shown in Fig.27. The load current harmonics is reduce to 2.33% as shown in the FFT analysis Fig.29 for which the load current is nearly sinusoidal as shown in Fig.28.

Conclusion

The advantage of Photo Voltaic /Fuel Cell System is to retain a constant voltage of 700 volts across the DC-Link capacitor. In this work the solar PV with boost converter output is obtaining 700V and fuel cell with boost converter output is also 700Vand simulation of PV/Fuel cell -UPQC maintains constant voltage of 700V when Sag, Swell and Interruption occur. It also reduces the harmonics content to 2.33% if any nonlinear load is associated. Hence the proposed scheme can regulate active and reactive power injection to the grid and compensate voltage interruption in addition to the other usual operation of UPQC.

References

[1] J.M. Carrasco, L.G. Franquelo, J.T. Bialasiewicz, E. Galván, R.C PortilloGuisado, M.M. Prats, J.I. León,and N. Moreno-Alfonso, "Power-electronic systems for the grid integration of renewable energy sources A survey*",. IEEE Transactions on industrial electronics,* Vol.4 pp.1002-16.Jun 2006.(Article)

[2] I.H., Altas, and A. M. Sharaf, "A photovoltaic array simulation model for matlab-simulink GUI environment", *Clean Electrical Power, ICCEP'07,* International Conference on IEEE, pp.341-345, 2007.(Conference Paper)

[3] S. Kotra, and M. K. Mishra, "Energy management of hybrid Microgrid with hybrid energy storage system", In *Renewable Energy Research and Applications (ICRERA), International Conference on*, pp. 856-860. IEEE, 2015**.**

[4] M. Davari, S.M. Ale-Emran., H.Yazdanpanahi.and G.B. Gharehpetian.,"Modeling the combination of UPQC and photovoltaic arrays with Multi-Input Single-Output DC-DC converter",*InPower Systems Conference and Exposition, PSCE'09*, pp. 1-7, 15 March 2009, IEEE. (Conference Paper)

[5] Y. Chen, X. Zha, J. Wang, H. Liu, J. Sun,andH. Tang.,"Unified power quality conditioner (UPQC): The theory, modeling and application",. *InPower SystemTechnology,Proceedings.PowerConInternational Conference on IEEE*,Vol.3, pp. 1329-33,2000

[6] T. Salmi, M. Bouzguenda, A.Gastli, and A.Masmoudi, "Matlab/simulink based modeling of photovoltaic cell", *International Journal of Renewable Energy Research (IJRER)*. Vol.2, No. 2, pp. 213-218, 2012.

[7] M. T, Ahmed, T. Gonçalves, and M. Tlemcani, "Single diode model parameters analysis of photovoltaic cell", In *Renewable Energy Research and Applications (ICRERA), IEEE International Conference on* , pp. 396-400, 2016

[8] N.Femia, G.Petrone, G. Spagnuolo and M.Vitelli, "Optimization of perturb and observe maximum power point tracking method", *IEEE Transactions on Power Electronics*, Vol.20, No.4, pp.963-973, July 2005.(Article)

[9] C.Rachid, B. Yahia, and D. Hind, "Application of an Active Power Filter on Photovoltaic Power Generation System",*International Journal of Renewable Energy Research (IJRER)* Vol.2, No. 4 pp.583-590, 2012

[10] M.Basu, S.P.Das, K.Gopal, A.Dubey, "Comparative evaluation of two models of UPQC for suitable interface to enhance power quality", *Electric Power Systems Researc*, Vol.77, No-7, pp.821-30, May, 2007.

[11] M.I.M.Montero, E.R.Cadaval, and F.B.Gonzalez, "Comparison of control strategies for shunt active power filters in three-phase four-wire systems", *IEEE Transactions on Power Electronics*, Vol.22, No.1, 2007, pp.229-236.

[12] G.M.Lee, D.C.Lee, and J.K.Seok, "Control of series Active Power Filters compensating for source voltage unbalance and current harmonics", *IEEE Transactions on Industrial Electronics.*, Vol.51, No.1, pp.132-139, February, 2004

[13] C.Fitzer, M.Barnes, and P.Green, "Voltage Sag Detection Technique for a Dynamic Voltage Restorer", *IEEE Transactions on Industry Applications*, Vol.40, No.1, pp.203-212,Jan/Feb.,2004

[14] S.Jain, P.Agarwal, and H.O.Gupta, "Design simulation and experimental investigations on a shunt active power filter for harmonics and reactive power compensation", *Electrical Power Components and Systems*, Vol.32,No.7, pp.671-692, July, 2003.

[15] M. Kano, T. Maekawa, T. Takeshita, and Y. Kunii, "Comparison of converter arrangement of series and shunt converters in UPFC for distribution system control",In *Renewable Energy Research and Applications (ICRERA),IEEE International Conference on*, pp. 431-436, *2016.*

[16] R. S. Yallamilli, and M. K. Mishra, "Power management of grid connected hybrid microgrid with dual voltage source inverter", In *Renewable Energy Research and Applications (ICRERA), IEEE International Conference on* ,pp. 407-412,2016

[17] R. Noroozian, M. Abedi, G. B. Gharehpetian, and A. Bayat. "On-grid and off-grid operation of multi-input single-output DC/DC converter based fuel cell generation system." In *Electrical Engineering (ICEE), 18th Iranian Conference on* IEEE, pp. 753-758, 2010.

[18] T.A. Nergaard, J.F. Ferrell, L.G. Leslie, and J.S. Lai., "Design considerations for a 48 V fuel cell to split single phase inverter system with ultra capacitor energy storage", *InPower Electronics Specialists Conference,.* P*ESC* 02, *IEEE* , Vol.4, pp. 2007-2012,2002

[19] G. Bucci, F. Ciancetta, E. Fiorucci, F. and Vegliò. "An experimental approach to the modeling of PEM fuel cells in dynamic conditions", *InPower Tech, IEEE Lausanne*, pp. 1094-99, July,2007.

[20] N.S. Jayalakshmi, D.N. Gaonkar, and P.B. Nempu, "Power Control of PV/Fuel Cell/Supercapacitor Hybrid System for Stand-alone Applications", *International Journal of Renewable Energy Research (IJRER)* Vol.6, No. 2 pp.672-679, 2016

[21] A.Elgammal, and D. Ali, "Self-Regulating Active Power Filter Compensation Scheme for Hybrid Photovoltaic-Fuel Cell Renewable Energy System for Smart Grid Applications", *International Journal of Renewable Energy Research (IJRER)* Vol.7, No. 2 pp.513-524, 2017