POWER QUALITY ENHANCEMENT OF UPQC BY EMPLOYING FUEL CELL UNIT FOR A THREE PHASE SYSTEM

VODAPALLI PRAKASH
Kakatiya Institute of Technology and Science
Warangal, Telangana, India, prakash289@gmail.com

Dr. T. RAMA SUBBA REDDY
Vignan Institute of Technology and Science
Hyderabad, Telangana, India, trsr72@gmail.com

Dr. S. TARA KALYANI
Jawaharlal Nehru Technological University
Hyderabad, Telangana, India, tarakalyani@gmail.com

Dr. P.B. KARANDIKAR
Army Institute of Technology
Pune, Maharashtra, pkarandikar@aitpune.edu.in

Abstract-*This research work depicts the addition of Unified Power Quality Conditioner (UPQC) with the Fuel cell system for enhancing the power quality at the main side irrespective of type of generation. This work reports the various power quality issues normally occurred in a distribution system. How successfully overcome the voltage sag, voltage swell, unbalanced load issues, reduction of harmonic content with UPQC described here. Usage of different industrial loads causes numerous types of voltage unbalances and severe effect on performance. The conditions which are created in the distribution system follow the magnitude of parameters yields to unsymmetrical sag and swells.*

The effective working of UPQC with fuel cell under different conditions is simulated and the expected outcome is achieved. This distinguished method presents a UPQC for remunerating power quality conditions for three phase system that incorporates DC/DC converter contribute by a fuel cell at the DC link. The suitable series-shunt controller is engaged for managing the UPQC under linear, non-linear load conditions is also monitored. The functioning of the presented method is simulated in MATLAB interface.

Key words—Power, quality, Fuel cell, Converter, Harmonics

1. Introduction

The power quality problems are growing every day and are become headache for distribution engineers as well customers [1]. The integrated power electronic devices that are generally used in our daily life are very delicate and yields to harmonics as well as voltage problems with low power factor. Diverse types of disturbances arise due to the unwanted things happened over the network. These disturbances create an impact on the voltage profile voltage of the network and break down of devices which spoil the delicate loads. The diminution of these on both the sides is crucial to amplifying the performance on the system.

UPQC is the device best suitable for versatile solutions to linear and non-linear loads that are delicate to the frequent operations in the system. The UPQC has a single frame that arrange series active power filter and shunt active power filter sharing a combined DC link. These two are successively connected. Shunt active power filter remunerates current associated issues distortions and series active power filter remunerates voltage allied issues [2-5].

Execution of the filters is based on voltage source converter technique. The shunt compensator accountable for compensation reactive power, current harmonic, load unstable. The series compensator responsible for voltage accompanying issues. The fuel cell can be used as battery stuff over the DC link for short-term spans.

The permitted costs at which fuel cells will become competitive are calculated by the market sections, by the costs of the recent technologies and the economic developments, to bring down cost spent on the fuel cell systems, various steps have to be taken into account as improved fuel cell stack design, used lower cost materials etc.

Fuel cell observe applications in electric vehicles, hybrid electric vehicles UPS, various medical diagnostic equipment in hospitals, military and IT centers [6-7]. The discharge rate is gentle in batteries because of mild chemical reactions. Use of fuel cells is recommend in UPQC collection as it is specify by high energy conversion efficiency, flexi design, very low pollution, less mass, less volume and maintenance. Due to less emission, easy start and good power density Proton exchange membrane fuel cells (PEMFCs) are used in power distribution systems. Fuel cells for the residential applications will supply power in the range of 1 kW to 10 kW. As different places having numerous demands for which various applications depends on the category of the customer [8].

The three phase, three wire design with a non-linear burden of diode-bridge rectifier with R-C load in the DC side studied in paper [9]. In paper [10-11] information is about employment of Bi-directional full bridge DC-DC converters in UPQC. For effective working conditions, the THD of source current should be inside an IEEE 519-1992 standard accessible limit of 5% [12]. Various control methods such as fuzzy logic for fuel cell based modeling have been studied [13],[14]. Fuel cell in DC distribution system has been extensively studied and can be controlled effectively run in parallel even in the upset of a grid or grid connected system [15]-[17]. In stationary applications, cost issues are not quite as strict as in mobile applications. Residential applications have to fulfill higher standards because in typical applications, higher stack lifetimes are demanded and the high electric efficiencies of the competing technologies will require operating the systems at much lower current densities than in mobile applications. Unified Power Quality Conditioner (UPQC) with the Fuel cell system for enhancing the power quality at the main side with photovoltaic generation is widely studied [18], [19]. Application of supercapacitor in enhancing power quality of UPQC for three phase balanced/unbalanced loads has been investigated [20]. Voltage sags are mainly caused by symmetrical or asymmetrical faults in the power transmission or distribution systems [21].

This consolidate system is prepared to upgrade the potential of the UPQC, DC/DC converter and fuel cell system for any kind of generation system. To repay the harmonic pertaining to currents, voltage issues and adjustment of power factor at the point of installation. It also curtailment of THD value. The operation of the system was simulated in the course of MATLAB domain. Experimentation of this kind of module is very costly due to high cost of fuel cells.

The important contribution carried out in this work can be recapitulated as follows,

1. For three phase distribution system to enhance the different problems like voltage sag, voltage swells in the presence of an unbalanced nonlinear load by integrating UPQC with Fuel cell.
2. The successful compensation of currents under unbalanced load conditions at the different instants of time.
3. With the effective utilization of combined fuel cell integrated UPQC reduce the harmonic distortion in the system
4. Correction of power correction can be done, without any additional equipment.

This research work depicts the addition of Unified Power Quality Conditioner (UPQC) with the Fuel cell system for enhancing the power quality at the main side irrespective of type of generation. This work is ordered as: Section 2; explains the fuel cell based UPQC. Section 3; explains the series and shunt converter control method. Section 4; convey the fuel cell system and DC-DC converter. Section5; shows results analysis. Section 6; presents conclusion. Section7; give out the addendum.

2. Fuel cell based UPQC

The circuit diagram of the improved UPQC with fuel cell design shown in Fig 1. The active filters are using a dc link connected to a fuel cell taken up by a sharing dc capacitor. The voltage source inverter form of shunt active filter is able to limit the harmonics belongs to input side as well variations in the burden on the system. The transformers are used for injecting voltage and also used to clearing the ripples in the series active filter. The voltage source inverters for mutually the series and shunt compensators are perform with insulated gate bipolar transistors (IGBTs). The Fig.2 presents the Simulink model of the offered system.

In this work, synchronous reference frame established technique for the UPQC in addition with DC/DC converter to govern voltage at the fuel cell for achieving the expected result. Synchronous reference frame implements Park's and Inverse Park's transformation for generation of reference signal. This method has a proper response under unbalanced loads. In the implemented technique. to monitor load side, source side voltages as well currents are recorded in case of unbalanced load scenario using MATLAB interface and the details of the network mentioned in the Addendum.

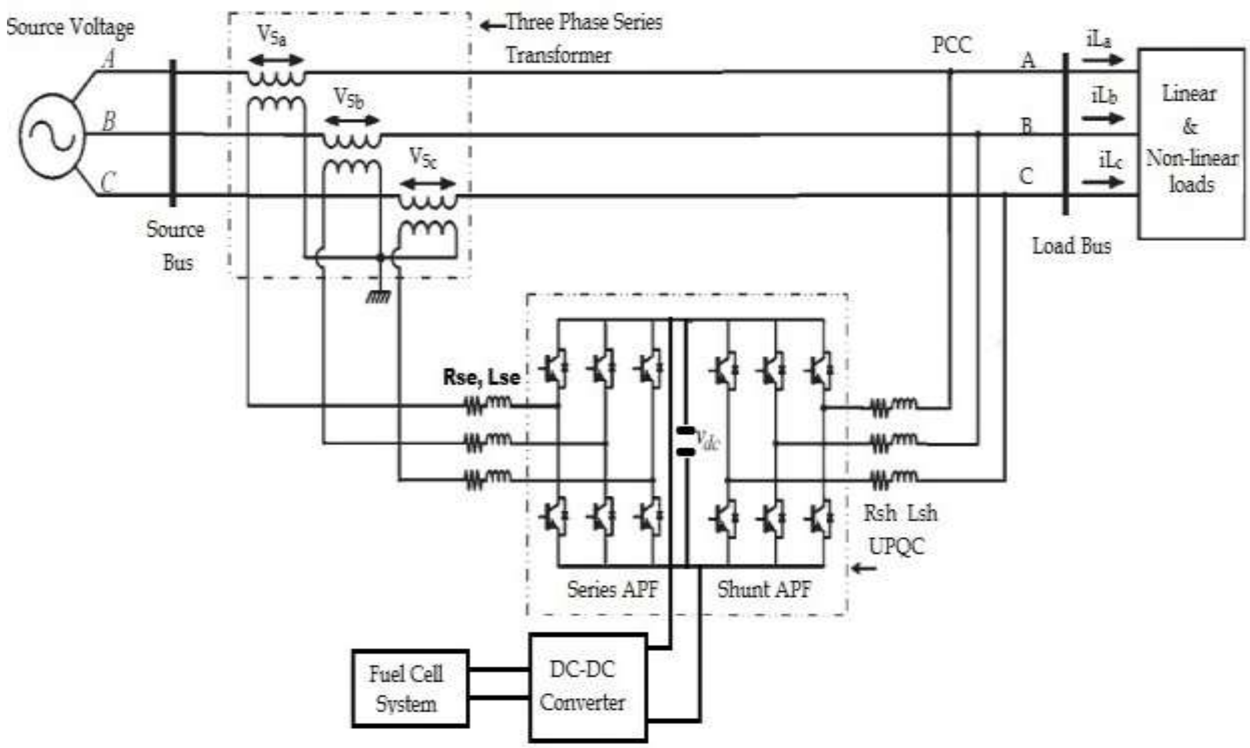


Fig 1.Circuit Diagram of Enhanced UPQC [18].

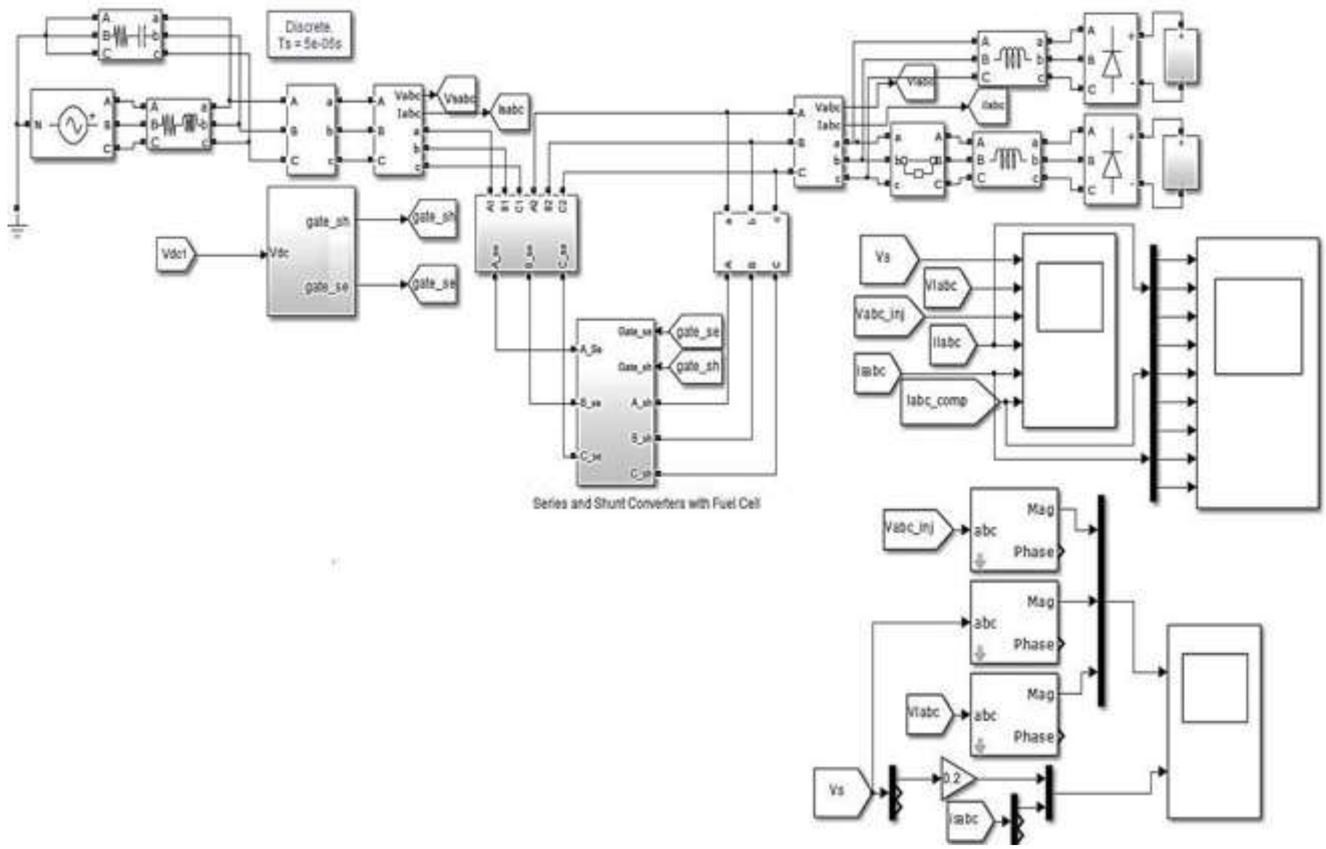


Fig 2. Simulink Diagram of the Enhanced UPQC

3. Control Scheme of Series and Shunt Converter

Synchronous Reference Frame method is also called as direct-quadrature axis method. This method has commanding response when linear, non-linear burdens on the system.

i. Control method for Series Converter

The purpose of the series converter is to filter out harmonics and to regulate the reactive power balance to the system. The series active power filters are employed to remove voltage harmonics. It is also useful to regulate the terminal voltage and to improve voltage balance in three-phase systems. The main target of control method of a series Active Power Filter (APF) is to produce the reference value for both voltage and currents. The control scheme of the series APF is shown in Fig 3. The phase locked loop is employed to establish match with the supply voltage [17].Three phase disturbed supply voltages are sensed and given to point of common coupling which generate two unit vectors (sinθ, cosθ).

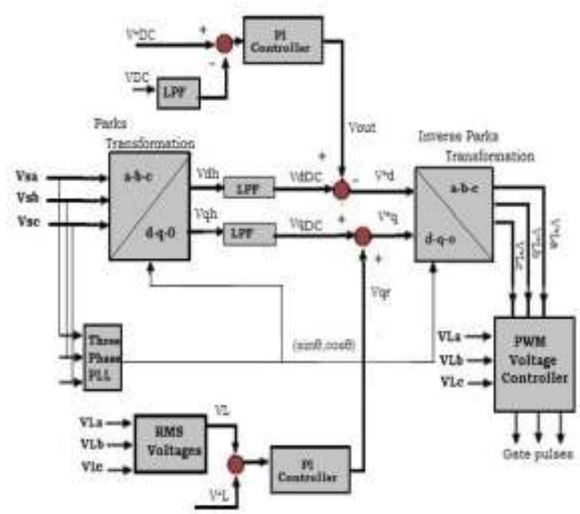


Fig 3. Control method of Series APF [17].

The source voltages V_{sa}, V_{sb}, V_{sc} are transformed into d-q-0 from abc, shown in equation (3.1).

$$\begin{bmatrix} V_{Sd} \\ V_{Sq} \\ V_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \sin\theta & \sin\left(\theta - 2\pi/3\right) & \sin\left(\theta + 2\pi/3\right) \\ \cos\theta & \cos\left(\theta - 2\pi/3\right) & \cos\left(\theta + 2\pi/3\right) \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix} \begin{bmatrix} V_{Sa} \\ V_{Sb} \\ V_{Sc} \end{bmatrix} \quad (3.1)$$

The low pass filters are removes the harmonic components. The sections of voltages in V_{dh}, direct-axis and V_{qh}, quadrature-axis consists of fundamental component, ripple or harmonic components are shown in equation (3.2) and (3.3).

$V_{dh}= V_{dDC} + V_{dAC}$(3.2)

$V_{qh}= V_{qDC} + V_{qAC}$ (3.3)

To hold the DC bus voltage of the series filter, a proportional–integral (PI) controller is used and the output is taken as the voltage (V_{out}) for meeting the losses.

The reference of direct -axis and quadrature-axis are V^*_d, V^*_q are given by,

$V^*_d= V_{dDC} - V_{out}$(3.4)

$V^*_q= V_{qDC} + V_{qr}$(3.5)

Reference and actual source voltage will generate the three phase RMS voltage. This will helps to establish the suitable injected voltage by the same for the compensation of voltage losses. To get the required compensation reactive component of voltage, use average RMS voltage and reference voltage from the PI controller.

V_{qDC} is reactive component and with V_{qr} values are maintained to get the appropriate voltage at the converter of series APF, so that it can be needful to retain the RMS voltage at point of inter connection due to RMS voltage loss by load reactive power. The two reference voltage values (V^*_d, V^*_q) are used to produce the reference load voltages, to adjust the amount of voltage at series APF.

The Inverse Park transformation is applied for producing the reference voltages which is given in equation (3.6) is to change reference load voltage (V^*_{Labc}) are transform d-q-0.

$$\begin{bmatrix} V^*_{La} \\ V^*_{Lb} \\ V^*_{Lc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \sin\theta & \cos\theta & 1/\sqrt{2} \\ \sin\left(\theta - 2\pi/3\right) & \cos\left(\theta - 2\pi/3\right) & 1/\sqrt{2} \\ \sin\left(\theta + 2\pi/3\right) & \cos\left(\theta + 2\pi/3\right) & 1/\sqrt{2} \end{bmatrix} \begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix} \quad (3.6)$$

ii. Control method for Shunt Converter

Shunt active power filter is focused to manage the DC link voltage and to remunerate the load current under reactive, non-linear loads. This control scheme of the shunt active power filter is shown in Fig4.

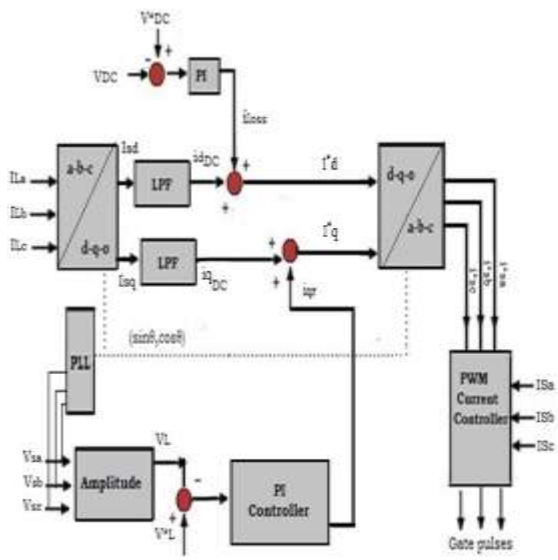


Fig 4. Control scheme of Shunt APF [17].

The source currents should be sinusoidal irrespective of the load conditions with the help of shunt APF by the current controller design. Three phase disturbed currents are sensed and added to point of common coupling which produce two quadrature unit vectors (sinθ, cosθ). The reference currents of direct axis, quadrature axis are I^*_d, I^*_q values are shown in equation in (3.7), (3.8).

$$I^*_d= i_{dDC}+ i_{out} \quad (3.7)$$

$$I^*_q= i_{qDC} + i_{qr} \quad (3.8)$$

Where i_{dDC}, i_{qDC} direct-axis and quadrature-axis fundamental currents, i_{out} are the output of the PI controller. The load currents in the three phases are transformed into d-q-0 from abc using the mentioned equation (3.9):

$$\begin{bmatrix} i_{ld} \\ i_{lq} \\ i_0 \end{bmatrix} = \sqrt{\tfrac{2}{3}} \begin{bmatrix} \sin\theta & \cos\theta & \sqrt{\tfrac{1}{2}} \\ \sin\left(\theta-\tfrac{2\pi}{3}\right) & \cos\left(\theta-\tfrac{2\pi}{3}\right) & \sqrt{\tfrac{1}{2}} \\ \sin\left(\theta+\tfrac{2\pi}{3}\right) & \cos\left(\theta+\tfrac{2\pi}{3}\right) & \sqrt{\tfrac{1}{2}} \end{bmatrix} \begin{bmatrix} i_{la} \\ i_{lb} \\ i_{lc} \end{bmatrix} \quad (3.9)$$

The two reference currents (i^*_d, i^*_q) are used to generate the reference load currents, to correct the current magnitude at shunt APF. The reference source currents are produced by Inverse Park transformation given by equation 3.10.

$$\begin{bmatrix} i^*_{sa} \\ i^*_{sb} \\ i^*_{sc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos\theta & -\sin\theta & 1/\sqrt{2} \\ \cos\left(\theta-\tfrac{2\pi}{3}\right) & -\sin\theta\left(\theta-\tfrac{2\pi}{3}\right) & 1/\sqrt{2} \\ \cos\left(\theta+\tfrac{2\pi}{3}\right) & \sin\left(\theta+\tfrac{2\pi}{3}\right) & 1/\sqrt{2} \end{bmatrix} \begin{bmatrix} i_d^* \\ i_q^* \\ i_0^* \end{bmatrix} \quad (3.10)$$

The control process of the filter senses the current values and is investigated with the reference currents in a hysteresis current controller to produce switching pulses.

4. Fuel cell system and DC-DC Converter

Fuel cells convert chemical energy into electricity. Fuel cells are most commonly classified by the based on type of electrolyte being used. These include proton exchange/polymer electrolyte membrane fuel cells (PEMFCs), alkaline fuel cells (AFC), phosphoric acid fuel cells (PAFC), solid oxide fuel cells (SOFC), zinc air fuel cells (ZAFC), molten carbonate fuel cells (MCFC), direct methanol fuel cells (DMFC), and photonic ceramic fuel cells (PCFCs), which vary widely in their required operating temperature. PEMFC is considered for the presented research work in this paper.

Due to the low operating temperature, long life, fast start up, flexible design, these as well as in offices and residences. The electrolyte in fuel cell is an ion exchange membrane i.e. fluorinated sulfonic acid polymer or other similar polymer which is an excellent proton conductor. The liquid in this fuel cell is water; hence, corrosion problems are minimal [7] and [19].

Fuel cells have short response that are much slower than the dynamic responses of the standard conditioner and load from where it is taken. The slower the fuel cell's response, the larger the amount of energy storage that is needed with the attendant increases in its size, weight, and cost; it also reduces the number of proper energy storage options such as ultracapacitor, flywheel, battery, etc.) [7].

The generation of electricity from fuel cell unit is taken in this research are two principal elements that generates using electrochemical action. The fuel cell is modelled as a combination of reformer and stack, the equivalent form of the fuel cell unit is shown in Fig.5 [13]. The parameters of fuel cell model are resistance of the reformer (R_r), capacitance of the reformer (C_r), resistance of the stack (R_s), capacitance of the stack (C_s). Time constant of the reformer $\tau_r = R_rC_r$ and time constant of the stack $\tau_s = R_sC_s$ and in general τ_r is the bigger than τ_s.

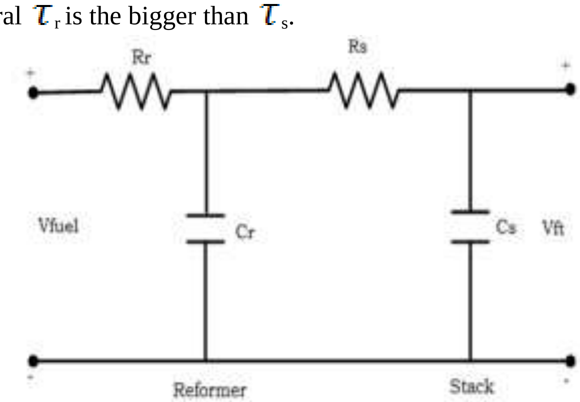


Fig 5.Equivalent circuit of a Fuel cell unit [13].

The fuel cell is a system which produces electricity from the chemical process of oxygen and hydrogen. The reformer produces usually hydrogen from fuels and then pushes it to the stacks. The stacks produce DC electric power by electrochemical reaction of oxygen and hydrogen which is available in the air [14-15]. The reformer is taken as first order equation, its transfer function is shown in equation (3.11).The stack is also shown by a first order time delay equation with transfer function is shown in equation (3.12)[18].

$$\frac{V_{cr}}{V_{fuel}} = \frac{\frac{1}{C_r S}}{R_s + \frac{1}{C_r S}} = \frac{1}{1 + R_r C_r S} = \frac{1}{1 + \tau_r S} \qquad (3.11)$$

$$\frac{V_{cs}}{V_{cr}} = \frac{\frac{1}{C_s S}}{R_r + \frac{1}{C_s S}} = \frac{1}{1 + R_s C_s S} = \frac{1}{1 + \tau_s S} \quad (3.12)$$

The DC/DC converter with two full-bridges used [16], it can function in bi-directional mode. The converter has a wide voltage conversion range with simple control. The operational voltage of the fuel cell is in the range between 65-80V, while the dc link voltage is about 700V.

The DC/DC converter enhances the fuel cell voltage up to the nominal DC link voltage in discharge mode. The fuel cell voltage is governed between 65-80V by controlling the gas flow rate in the unit. Control of this gas flow in fuel cell play crucial role in the effective implementation of this in power system application. DC link voltage increases up to about 700V. The DC/DC converter decreases the nominal DC-link voltage down to the level of fuel cell voltage in the charge mode. Cost of fuel cell system is not a hurdle as it cost very less in terms of percentage cost of complete power system generation, transmission and distribution.

5. Results analysis

Fig.6 shows the combined fuel cell - UPQC implemented system for disturbances like voltage and current related issues and load unbalance.

(a) Sag-Swell Compensation

A balanced sag of the source voltage (Vs) is entered during 0.3 sec to 0.38 sec as shown in Fig.7(a).The source voltage (V_S), Load Voltage (V_L), Voltage injected ($V_{\_inj}$), Load current (I_{Labc}), Source current (I_{sabc}) and shunt remunerating current ($I_{\_Comp}$) are shown in the Fig.7(a).The RMS value of per phase injected voltage ($V_{\_inj}$), supply voltage (V_S), Load voltage (V_L) is shown in the Fig.7(b). To support the load voltage, the fuel cell is supplying the suitable remunerating power through the series compensator and it can be monitored that the load voltages retain the same. Likewise a balanced swell is applied during 0.5sec to 0.58sec and the corresponding remunerating voltage and the instantaneous waveforms of voltage (V_S), Load Voltage (V_L), Voltage injected ($V_{\_inj}$), Load current (I_{Labc}), Source current (I_{sabc}),shunt compensation current ($I_{\_Comp}$) are shown in the Fig.8(a), (b)

(b) Load Compensation

The execution of integrated fuel cell-UPQC for load stabilizing is shown in Fig.9 where the load is not balanced. From 0.7 sec to 0.8 sec, an unbalance is created by opening one of the phase. Fig.10 shows the waveform of Load current (I_{Labc}), Source current (I_{sabc}) and shunt compensation current ($I_{\_Comp}$). These results show acceptable performance of the implemented integrated fuel cell-UPQC system used.

(c) Harmonics Compensation and PF Corrections

Fig. 10(a)–(d) shows the harmonics of load current, source current, source voltage and the load voltage. From Fig.10 (a), (b) it can be observed that the total harmonic distortion of the phase ‘b’ of load current is 29.85%. The source current has the THD of 2.2%. From Fig.11 (c) and (d) the THD of the source voltage and load voltage are 1.31% and 1.03%. The power factor is also corrected after compensation of reactive power which is shown in Fig.11.

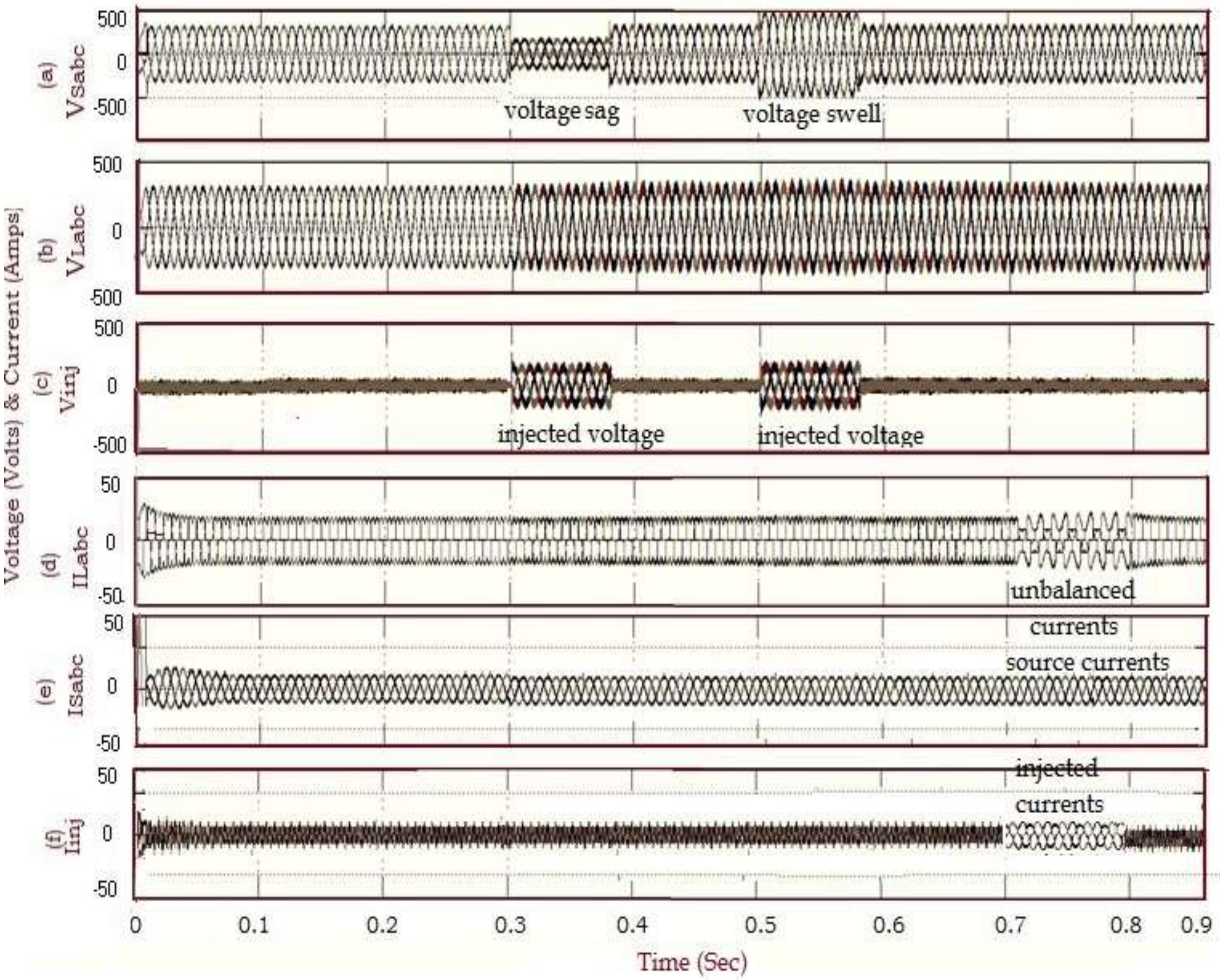
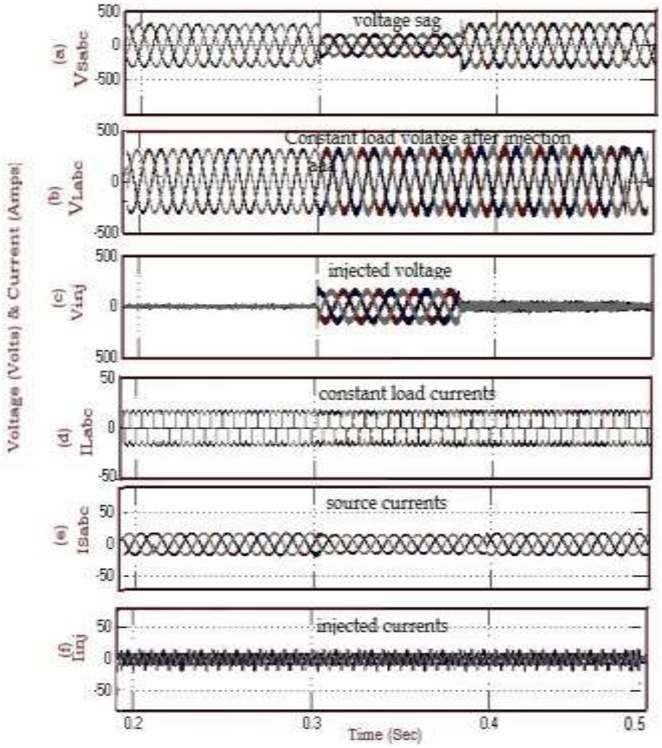
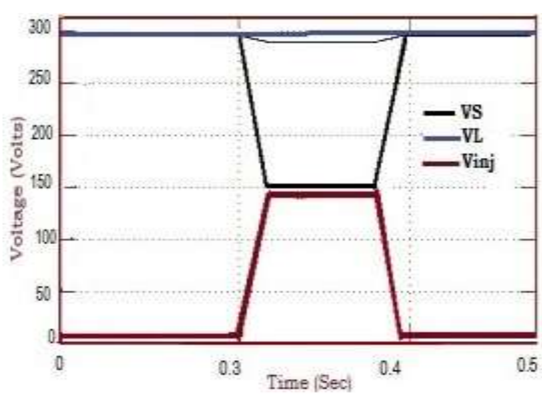


Fig6.Results showing voltage and current disturbances

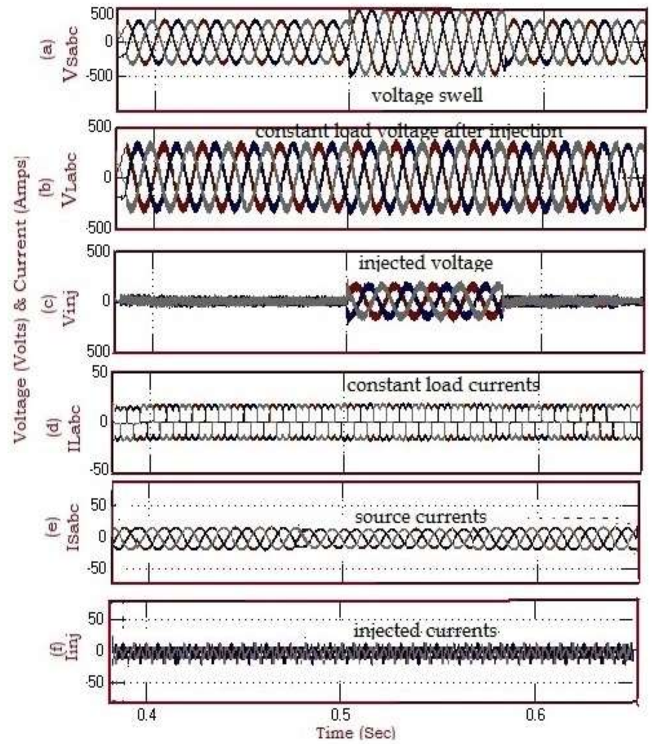


(a)



(b)

Fig 7. (a) Results showing V_{sabc}, V_{Labc}, $V_{\_inj}$, I_{Labc}, I_{sabc}, $I_{\_Comp}$ during sag condition (b) Result showing the magnitude of per-phase Source Voltage –Vs (Black), Load Voltage-VL (Blue) and Injected Voltage-Vinj (Pink).



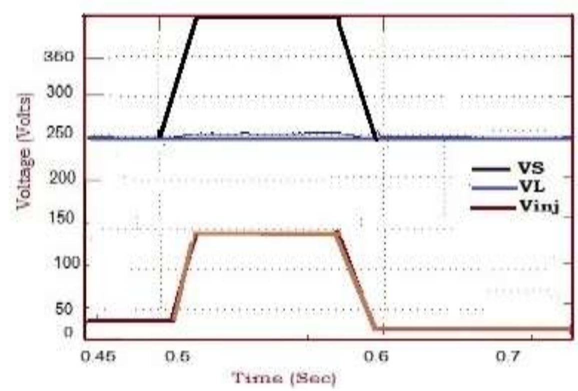


Fig 8. (a) Results showing V_{sabc}, V_{Labc}, V_inj, I_{Labc}, Isabc, I_Comp during swell condition (b) Result showing the magnitude of per-phase Source Voltage –Vs (Black), Load Voltage-VL (Blue) and Injected Voltage-Vinj (Pink).

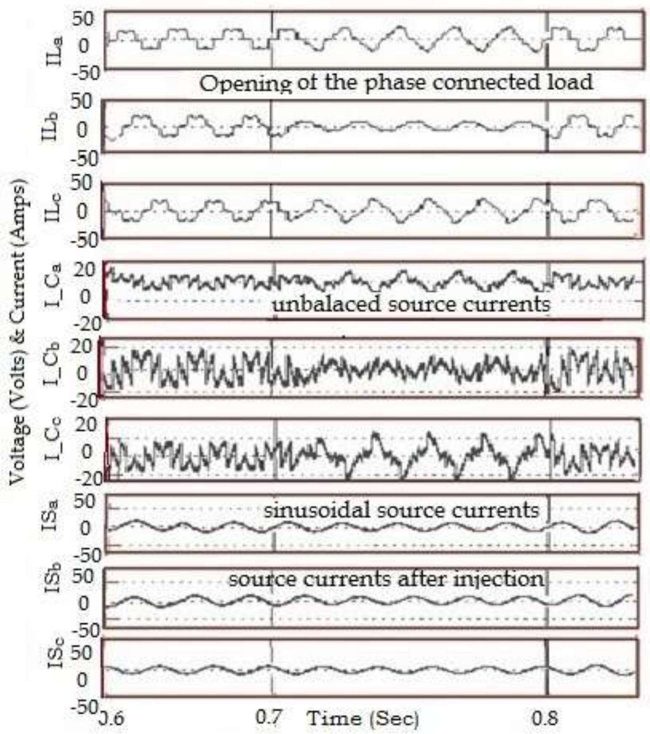
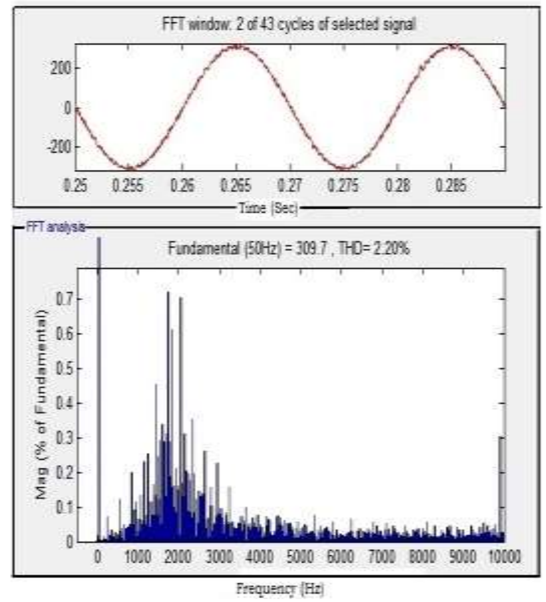
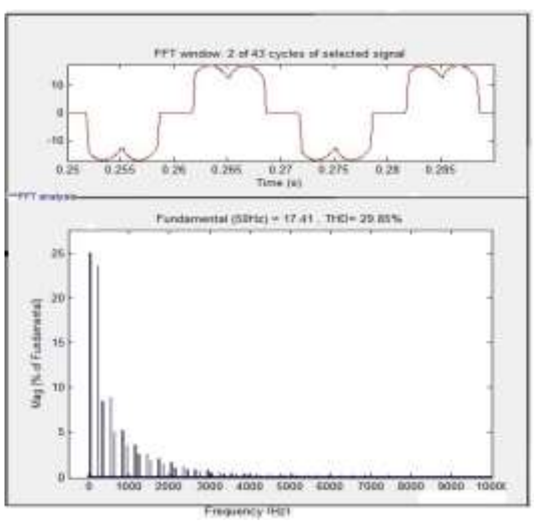


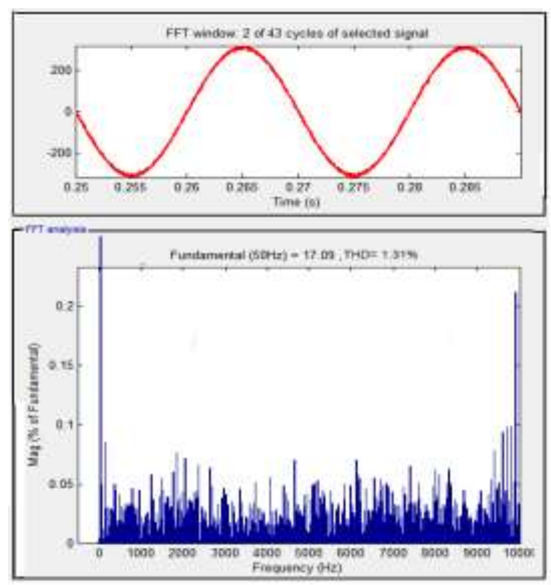
Fig 9. Results showing thedisturbance in the load currents



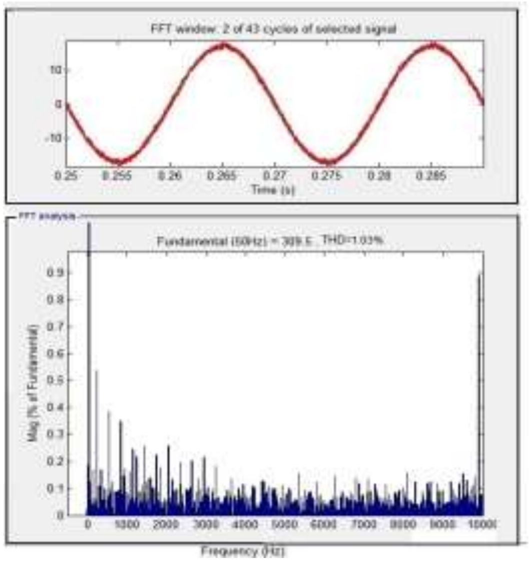
(b)



(a)



(c)



(d)

Fig 10. Shows the % THD values of a) Load Current b) Source Current c) Source Voltage d) Load Voltage of a distribution system.

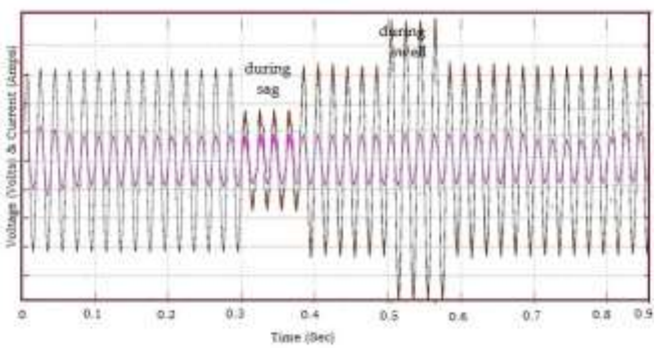


Fig 11. Results showing the power factor correction

TABLE I
RESULTS UPQC WITH FUEL CELL

Control Technique	Parameter	%THD
UPQC with Fuel cell	Source Voltage (Volts) (V_{Sabc_rms})	1.31%
	Load Voltage (Volts) (V_{Labc_rms})	1.03%
	Source Current (Amps) (i_{Sabc_rms})	2.2%
	Load Current (Amps) (i_{Labc_rms})	29.85%

There are various types of loads are present in the network is an amalgamation of linear and non-linear loads. In implemented system a versatile compensating device UPQC is integrate with fuel cell. The presented system is able to mitigate the voltage and current related problems. Because of the harmonic content due to non-linear character of voltage as well currents, the THD of load current THD is high. The controller is able to reduce the THD of source current and load voltage. The THD value of source current, load voltage is curtailed in fuel cell as compared to super capacitor. In all most in all cases, symmetrical voltage sags due to sudden stating/stopping of large rated motors and three-phase faults. Based on the parameters like voltage and current magnitudes in the system, the sag and swells can be identified, the effect of unsymmetrical sags in case of ground faults. Voltage sags are mainly caused by symmetrical or asymmetrical faults in the power transmission or distribution systems.

6. Conclusions

This paper presented combined configuration of UPQC along with the fuel cell irrespective of type of generation and type of load which is main contribution of the work carried out. Depends on the variation of different quantities, time duration, type of device or equipment and its location may results in unsymmtrical sag and swells. These types of disturbances will create more loss to consumers. This information is more important in re-structured systems. Fuel cells can be used in many applications, such as transportation, material handling, stationary, portable, and power system applications. Fuel cells have many advantages over the conventional combustion based technologies used in many generating stations. Cost of fuel cell will come down in coming years and it will be extensively used in addressing power quality issues in power system. Experimentation in conducting application based research of fuel cells is hard to do due to availability of resources. Hence, results obtained in simulation are checked with standard limits set by authorities As the result The UPQC addresses the current, voltage issues.

For effectual working conditions, the THD of source current has been found within an IEEE 519-1992 permissible range of 5%. The THD of the source current is 2.2%. The system has an improved working under linear, non-linear load conditions. It is essential to mention that the presented system still having the opposition to mitigate source current harmonics pertaining to source side disturbances. The functioning of presented system was monitored through simulation with MATLAB domain.

7. Addendum

Circuit and load parameters:			
Parameter	Value	Parameter	Value
Source Voltage (V_s)	440V	DC link capacitance (C_{dc})	4700uF
Frequency (f)	50Hz	Source resistance (R_{se})	0.01Ω
Load resistance (R_L)	10Ω	Source inductance (L_s)	60mH
Load inductance (L_L)	25mH	Shunt inductance (L_{sh})	10mH
DC link voltage (V_{dc})	700V	Series inductance (L_{se})	2.4mH
Preset Model PEMFC			
Fuel	1.5bar	Fuel cell Resistance	0.65704Ω
Nominal air flow rate	2050 lpm	Normal Operating Voltage	625V
Normal Operating Current	78A	Exchange Current	0.086683A
Open circuit voltage (Voc)	900V	Max.operating point	280A
Nominal stack efficiency	55%	Voltage of one cell	1.1379V
Nominal Utilization H2	99.25%,	Air	1.2 bar
Oxygen [O_2]	58.67%	Exchange Co-efficient	0.25821
Fuel Signal Variation Parameters			
Oxidant Composition [O_2]	21.1%	Fuel Composition [H_2]	99.25%

Acknowledgment

I would like to articulate my profound gratitude and indebtedness to my Head of the Department Professor Dr. C.Venkatesh and Principal Professor Dr.K.Ashoka Reddy, for their constant motivation, support and constructive suggestions in a wide angle. I express my sincere gratitude to Management KITS, Warangal for providing the research facilities and encouragement all through the research work.

References

1. Sangepu, Raghavendra & Muni, Vijay, “Effect of Power Quality Issues in Power System and Its Mitigation by Power Electronics Devices”, ISSN 2278 – 5469 , 2015, vol. 28, issue no.105, pp. 72-79.

2. Aredes, M, K. Hemnn and E.H. Watanabe, “An Universal Active Power Line Conditioner,” IEEE Trans. on Power Delivery, vol.13, issue no.2, April 1998, pp.545-551.

3. H. Akagi, Y. Kanazawa and A. Nabae, "Instantaneous Reactive Power Compensators Comprising Switching Devices without Energy Storage Components," in *IEEE Transactions on Industry Applications*, vol.IA-20, issue no. 3, May 1984, pp.625-630.

4. B. Han, B. Bae, H. Kim and S. Baek, "Combined operation of unified power-quality conditioner with distributed generation," in *IEEE Transactions on Power Delivery*, vol. 21, issue no. 1, Jan. 2006, pp. 330-338.

5. T.A. Nergaard, J.F. Ferrel, 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,” in Proc. IEEE/PESC,Cairns, Australia, June 23-27,vol.4, 2002, pp.2007-2012.

6. https://www.fuelcellstore.com

7. Bei Gou, Woon Ki Na, Bill Diong,”FUEL CELLS Modeling, Controland Applications”, CRC Press, 2010, pp 2.

8. X. Yu, M. R. Starke, L. M. Tolbert and B. Ozpineci, “Fuel cell power conditioning for electric power applications: a summary”IET Electric Power Applications, vol.1,issueno. 5, Sept. 2007, pp.643-656.

9. Yang Zhang, Shengfa Zhang, Jiahong Chen,“ The Applications of Bidirectional Full-bridge DC-DC Isolated Converter in UPQC”, Electrical Machines and Systems, ICEMS 2008, Oct. 2008, pp.1916 – 1921.

10. P. MadhavaSarma, S. Arulkumar,M. SrideviP.Veeraragavan and SrinivasanAlavandar, “An advanced implementation of the voltage level monitoring and control using soft sensor methods for unified power quality conditioner”, Journal of Electrical Engineering,vol. 18, edition 4, 2019.

11. V. Khadkikar and A. Chandra, “A New Control Philosophy for a Unified Power Quality Conditioner (UPQC) to Coordinate Load-Reactive Power Demand Between Shunt and Series Inverters,” in IEEE Transactions on Power Delivery, vol. 23, issueno. 4, Oct. 2008, pp. 2522-2534.

12.Ali M. Eltamaly, YehiaSayed, Abou-Hashema M. El-Sayed and Amer Nasr A. Elghaffar,”Voltage Sag Compensation Strategy Using Dynamic Voltage Restorer for Enhance the Power System Quality”, Journal of Electrical Engineering, ISSN No:1582-4594, issue no 3, vol.19, 2019, Article 19.3.31.

13.Y. Kim, S. Kim, " An Electrical modeling and Fuzzy Logic Control of a Fuel Cell Generation System", IEEE Transactions on Energy Conversion, June 1999, vol. 14, issueno. 22, pp.239-244.
14.J. Jung, M. Dai, A. Keyhani, "Modeling and Control of a Fuel Cell Based Z-Source Converter," IEEE Applied Power Electronics Conference and Exposition, APEC'05, March 6-10, Austin, TX, 2005, vol.2, pp.1112-1118.
15. M. Mahmoodi, G. B. Gharehpetian, M. Abedi and R. Noroozian, "Novel and Simple Control Strategy for Fuel Cell Converters in DC Distribution Systems," *2006* IEEE International Power and Energy Conference, Putra Jaya, 2006, pp. 358-362.
16. Yang Zhang, Shengfa Zhang and Jiahong Chen, "The applications of bidirectional full-bridge DC-DC isolated converter in UPQC," *2008* International Conference on Electrical Machines and Systems, Wuhan, 2008, pp. 1916-19.
17Bhim Singh, Ambrish Chandra, Kamal Al-Haddad - Power Quality: Problems and Mitigation Techniques, WILEY, February 2015, ISBN: 978-1-118-92205-7.
18. S. Samal and P. K. Hota, "Power Quality Improvement by Solar Photo-voltaic/Fuel cell integrated system using Unified Power Quality Conditioner", International Journal of renewable energy research, 2017, vol.7, issueno.4.
19. Fuel Cell Handbook (Fifth Edition) By EG&G Services Parsons, Inc. Science Applications International Corporation, October 2000, pp.1-3.
20. Prakash Vodapalli, T. Rama Subba Reddy, S. Tara Kalyani, P.B. Karandikar, "Application of supercapacitor in enhancing power quality of UPQC for three phase balanced/unbalanced loads", Journal of Electrical Engineering, 2014, ISSN No:1582-4594, issue no 4, vol.14, 2014, Edition: 4,Article 14.4.50.
21. Ioannis Binas, Marios Moschakis "Voltage Sag Characteristics during Symmetrical and Asymmetrical Faults" World Academy of Science, Engineering and Technology International Journal of Energy and Power Engineering, Vol:14, No:4, 2020
22.Beatriz Alzueta1, Raquel Garde1 and Monica Aguado2 "Residential fuel cells for distributed generation" Fuel Cell and Distributed Generation, 2007: 1-26 ISBN: 978-81-308-0179-7.

Authors

V.Prakash is a research scholar working towards his Ph.D at J.N.T.U Hyderabad and also working as Assistant Professor of Electrical & Electronics Engineering at Kakatiya Institute of Technology & Science, Warangal, T.S. His areas of research interests are power quality, power electronics, drives and Energy storage systems.
prakash289@gmail.com

T.Rama Subba Reddy: Ph.D, M.Tech and B.Tech in Electrical Engineering from J.N.T.University Hyderabad. For the last 25 years, he worked at Rajeev Gandhi Memorial Collage of Engineering and Technology, Nandyal in various positions as Asst.Professor, Associate Professor and Professor from 1996 to 2008.Professor and Head of Electrical & Electronics Engineering, Scient Institute of Technology, Ibrahimpatnam, Hyderabad from 2008 to 2011.Principal, Arjun college of Technology and science, Hyderabad from 2011 to 2013, science 2013 working as Professor & Head of Electrical and Electronics Engineering, Vignan Institute of Technology and Science, Deshmukhi, Hyderabad, T.S.His areas of interest include Power system Analysis and Reliability Evaluation of power system. He has 23 research publications in National and International conferences and journals.
trsr72@gmail.com.

S.Tara Kalyani completed her B.E in Electrical & Electronics Engineering from Osmania University, Hyderabad in the year 1995 and M.E in Industrial drives and control in the year 1999 from Osmania University, Hyderabad. She received the doctoral degree from the J.N.T.University in the 2008. She got 18 years of teaching experience and 11 years of research experience. Presently she is a Professor of EEE at JNTU Hyderabad. She has presented 30 papers in International and National conferences, Also published National and International Journals. She guided M. Tech projects and presently guiding 3 research scholars. Her areas of interest include Power Electronics, FACTS Controllers and Industrial Drives.
tarakalyani@gmail.com

P.B.Karandikar is Ph.D. in Electrical Engineering and ME Electrical from COEP, Pune, India. He is working as Associate Professor in Army Institute of Technology, Pune, India, since last 25 years. He guided 5 PG and 4 PhD students. He published more than 100 papers which includes about 10 are international journal papers. He published one text book. He acquired ten Indian patents in his credit.
pkarandikar@aitpune.edu.in