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IRP Theory based UPQC for Power Quality Profile Enhancement in Distribution System

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Abstract: ***Power system network will never operate under ideal conditions but contains power quality problems. FACTS based controllers like DVR, DSTATCOM and APF (active power filter) are some of the compensating devices used to improve power quality. UPQC (unified power quality conditioner) is a back-to-back converter topology with common DC-link voltage employed to improve power quality. This paper presents multi-level (three-level) UPQC as power quality conditioner in distribution system. The pulses from hysteresis control trigger UPQC where reference currents are generated using IRP (instantaneous reactive power) control theory for shunt controller and SRF theory for series controller. Analysis is presented with the conditions like UPQC as series compensator conditioning source voltage, UPQC as shunt compensator compensating harmonics in source current and UPQC as (series and shunt) compensator conditioning source voltage and harmonics. System proposed is build and analysis is presented using MATLAB/SIMULINK software.***

Key words: ***Current compensation, Harmonics compensation, IRP theory, Power quality, UPQC, Voltage compensation.***

I. INTRODUCTION

There is a huge dependency on electrical energy in this mature technological world. Supplying qualified power to the utility goods is as important and is a challenging to power sector. Most of the industrial and commercial load applications demand uninterrupted power supply with superior quality.The ability of grid or electrical network to deliver clean and stable power is power quality. However, qualified clean power generates a power supply which is always available and consisting of very low noise. Clean supply refers to sinusoidal wave shape and is voltage and frequencies within acceptable tolerance. With energy demand ever increasing, loads connected to power network induce disturbances on grid side and make grid parameters deviate from ideal conditions [1-5]. Variation of source Conventional passive filters as power quality conditioners can improve the power quality but their size, source impedance, resonance problem affect their usage and side parameters makes reduces equipment performance, energy loss and unwanted breakdowns.

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Reactive power issues, harmonic issues, network unbalance, transients, voltage variations, flickers, oscillations are some of the power quality problems. Poor power quality [6] makes system to experience stalled production, increased energy consumption, reduction in production pace, malfunctioning of equipment, reduced efficiency, reduction in life time of equipment.

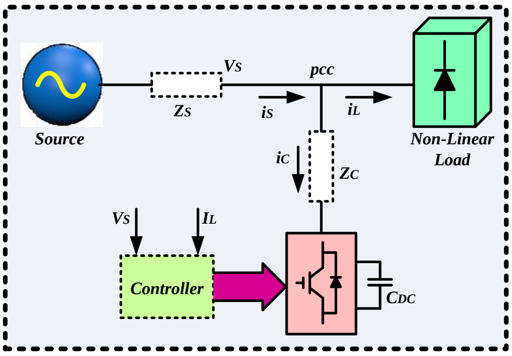

Fig. 1. Shunt Compensator

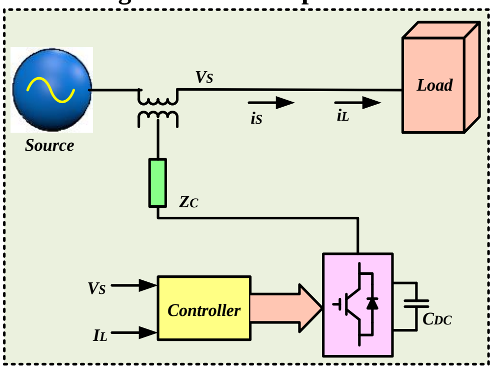

Fig. 2. Series Compensator

performance. FACTS based compensators are alternatives to conventional methods to condition the power. FACTS controllers are many types out of which shunt compensators, series compensators and series-shunt combinational devices are used widely. Shunt compensator model and series compensator model are shown in Figure 1 and Figure 2 respectively. Shunt compensators are connected in parallel to the power system and series compensators are placed in series to the power line. Shunt compensators generally induce currents to compensate voltage or to eliminate the affect of harmonics. Series compensators induce voltage to power line to compensate voltage in the system. DSTATCOM (static compensator in distribution system) is an example of shunt compensation methods and DVR is an example of series compensator. UPQC [6-9] is a FACTS device which is a combinational compensator with both series and shunt converters connected back-to-back with a common DC-Link voltage source.

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This paper presents three-level UPQC as power quality conditioner in distribution system. UPQC is triggered by the pulses from hysteresis control from where reference currents are generated using IRP (instantaneous reactive power) control theory for shunt controller of UPQC and series controller of UPQC is controlled from SRF theory. Analysis is presented with the conditions like UPQC as series compensator conditioning source voltage, UPQC as shunt compensator compensating harmonics in source current and UPQC as (series and shunt) compensator conditioning source voltage and harmonics. System proposed is build and analysis is presented using MATLAB/SIMULINK software.

I. THREE-LEVEL UPQC

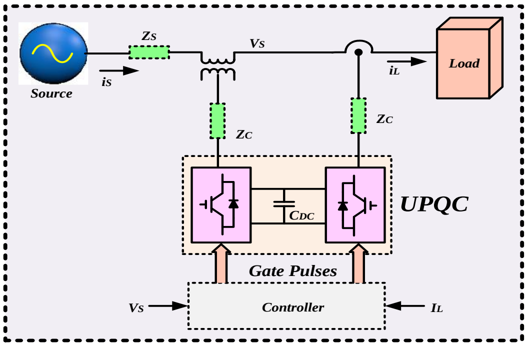

Fig. 3. Model of UPQC

UPQC is a combinational series-shunt compensator, which can condition current harmonics, load voltage and reactive power issues in power system. Figure 3 illustrates the basic single-line model of unified power quality conditioner. Zs is the source impedance, Vs is the source voltage, Zc is filter impedance and I_L is load current. As mentioned, UPQC is a series-shunt combinational conditioner consisting of two static converters connected with a common DC-Link voltage source as shown in Figure 3. Series compensator is in series to power line connected through series transformer. In UPQC, series converter (compensator) is used to condition the voltage such that the load voltage is kept constant (with constant magnitude) at load side ensuring voltage is balanced with constant peak at load side which is a basic requirement for sensitive loads. Shunt compensator placed in parallel to the power line ensures the current waveform is nearer ideal sinusoidal in shape, minimizing the harmonics in source current. The voltage source converters (VSI or VSC) of both series and shunt converters of UPQC uses IGBT's as power switches to generate and inject required compensating signals when triggered. Filter impedance consists of inductors to smoothen the output signal of converters. The converter gives out three-level output and output signals of converters are conditioned to make sinusoidal using filters.

II. CONTROL OF UPQC

A. Control of shunt compensator of UPQC

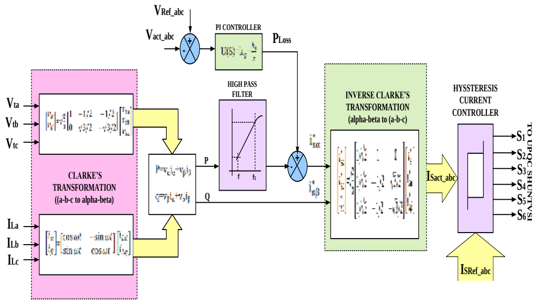

Fig. 4. IRP theory for shunt compensator of UPQC

IRP theory is employed to control the shunt converter of UPQC. H. Akagi first proposes the Instantaneous Real-Reactive Power (IRP) theory in the year of 1983. The formal IRP theory is most suitable for current compensation in a three-phase power system using shunt-VSI structure and regulates DC-link voltage as a constant. The active-reactive power consignments are well with-in this orthogonal coordinated frame. The basic schematic view of formal IRP theory is depicted in Figure 4.A precise measurement of input variables are source voltage (V_{sabc}), load currents (I_{Labc}) are fed to Clarke's transformation process. This process generates the voltage-current quantities in-terms of orthogonal coordinates ($V_{\alpha\beta}, I_{\alpha\beta}$). The instantaneous active (P) & reactive (Q) power quantities are calculated based on the above specified co-ordinates by relevant equations. Three-phase to two co-ordinate transformation of source voltage and load current is done using equations (1) & (2) as:

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \cdot \begin{bmatrix} v_{ta} \\ v_{tb} \\ v_{tc} \end{bmatrix} \qquad (1)$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \cdot \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \qquad (2)$$

Active power (P) and reactive power (Q) calculation from two co-ordinate system is given by (3) as:

$$\begin{bmatrix} P \\ Q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \qquad (3)$$

On the other-hand, authentic DC voltage is evaluated alongside its reference parameter and routed to PI controller to generate power loss component from which $i_{s\alpha}^*$ is generated. Inverse transformation of these source reference signals produces three-phase reference signals.

$$\begin{bmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1 & 0 \\ 1/\sqrt{2} & -1/2 & \sqrt{3}/2 \\ 1/\sqrt{2} & -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_0^* \\ i_{s\alpha}^* \\ i_{s\beta}^* \end{bmatrix} \qquad (4)$$

Where, i_0^* is represented as the zero-sequence current component, which should be zero in three-wire three-phase system.

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The final reference current is compared to actual current for deriving the optimal switching states with the help of hysteresis current controller (HCC) which produces gate pulses to back-to-back power converters of UPQC.

B. Control theory for series compensator of UPQC

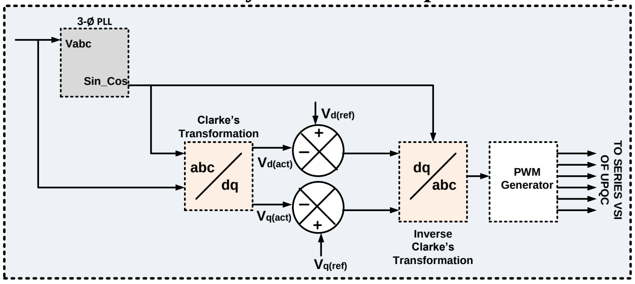

Fig. 5. Control theory for series compensator of UPQC

The series controller of UPQC mainly stabilizes or conditions the load voltage which is main criteria for sensitive loads. The control circuit to generate gate pulses to series converter of UPQC is shown in Figure 5. The three-phase source voltage is fed to three-phase phase locked loop (PLL) to get the information of phase angle. The phase angle obtained from PLL and the three-phase source voltage signal is processed to Clarke's transformation block where corresponding equations transform three-phase source voltage signals in to two co-ordinate signals in 'd-q' terms thus obtaining actual d-coordinate of voltage signal and actual q-coordinate of voltage signal. The actual values are compared to reference 'd-q' signals and the error is processed to PI controller which yields reference signals. These voltage reference signals in 'd-q' coordinates along with phase angle information from PLL are processed to inverse transformation where again 'd-q' coordinates are transformed back to 'abc' signals. The three co-ordinates signals are fed to PWM generator to generate triggering pulses to switches of series converter of UPQC. The over-all diagram of UPQC with control circuit is illustrated in Figure 6. Table I indicates system parameters used in simulation analysis

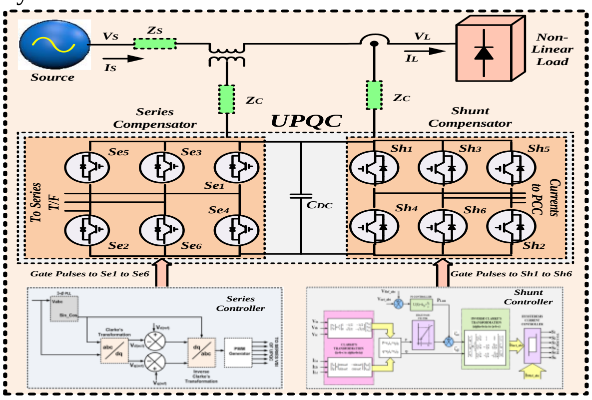

Fig. 6. Over-all diagram of UPQC with control circuits

Table I: System Parameters

Parameter	Value
Source Voltage	415 V, 50 Hz
Source impedance	0.1 Ohms, 0.9mH
Filter impedance	0.001Ohms, 10mH
DC-Link Voltage	600V

III. RESULT ANALYSIS

Case-1: UPQC only as series compensator

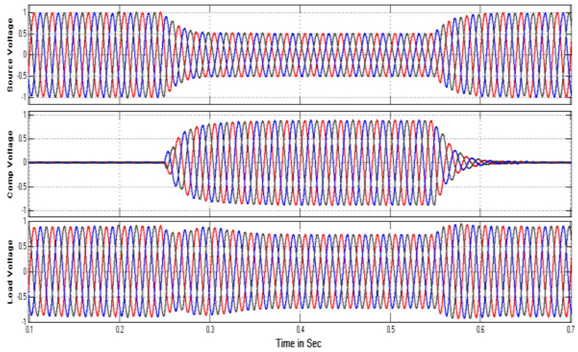

Fig. 7. Source voltage, Compensating voltage and load voltage of power system

Figure 7 illustrates the system behavior with UPQC acting only as series compensator conditioning load voltage. Figure 7 shows source voltage, compensating voltage from UPQC (series compensator) and load voltage of power system. Source voltage is programmed to contain sag in voltage during 0.25 seconds to 0.55 seconds. During this particular sag period, the load also should be affected with sag but UPQC (series converter) injects compensating signals to power system through injecting series transformer and conditions the voltage to load. The load voltage is not affected with sag and is maintained at constant peak.

Case-2: UPQC only as shunt compensator

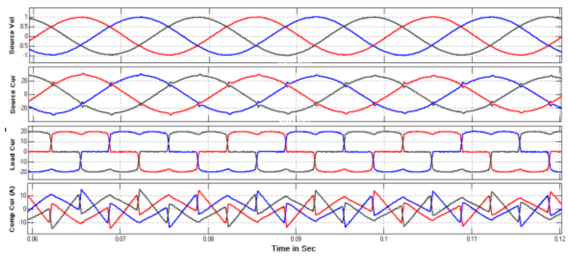

Fig. 8. Source voltage, source currents, load currents and compensating currents of power system

Figure 8 shows the system parameters when UPQC acting only as shunt compensator. Source voltage, source currents, load currents and compensating currents of power system are shown in Figure 8. As load is non-linear type, load current draws non-linear currents, which affect source currents. Compensating signals from UPQC (shunt compensator) nullifies the affect of harmonics on source parameters. Source current is nearer sinusoidal with very less distortion and load current is non-linear in nature.

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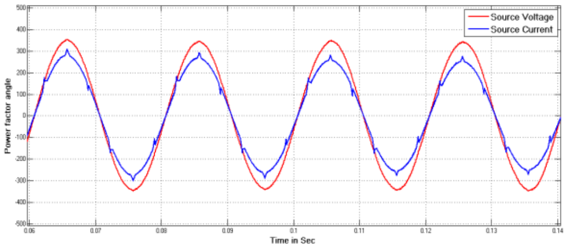

Fig. 9. Power factor of system

Figure 9 illustrates the power factor on source side of power system. Source voltage and source current have almost the same phase and power factor tends to unity. Current signal is added with gain (to increase the amplitude) for better visualization.

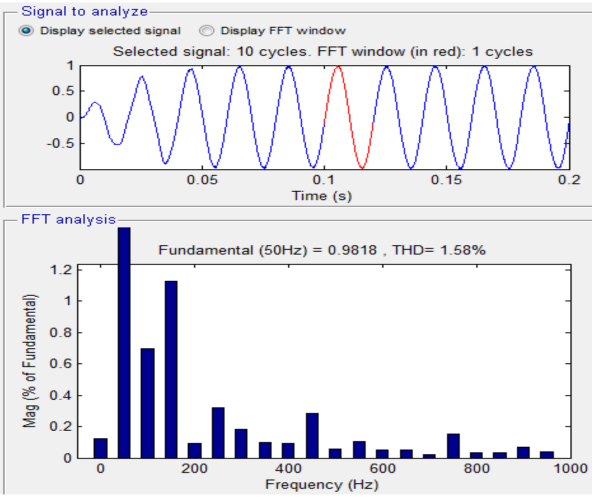

Fig. 10. THD in source current

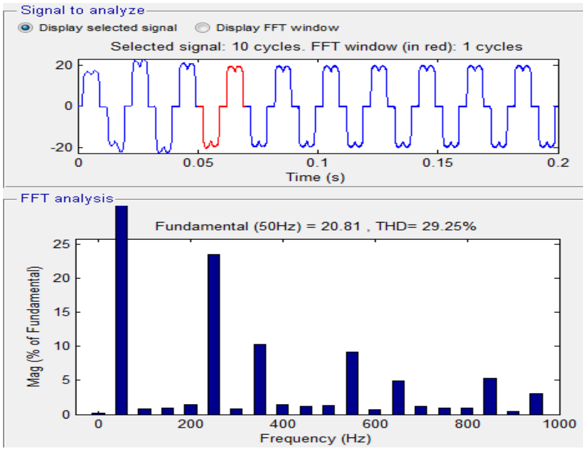

Fig. 11. THD in load current

Figure 10 and Figure 11 shows the harmonic distortion analysis in source current and load current. Source current is deviated by 1.58% and load current by 29.25%. The source current is distorted less.

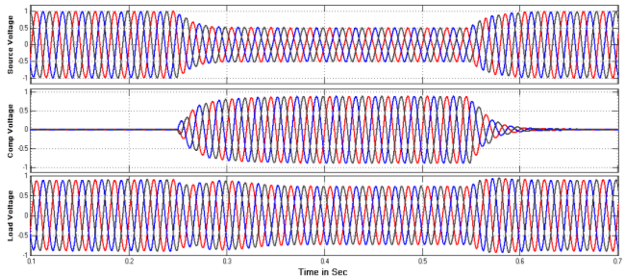

Fig. 12. Source voltage, Compensating voltage and load voltage of power system when UPQC acting as series and shunt compensator

Figure 12 shows source voltage, compensating voltage from UPQC and load voltage of power system. Source voltage is programmed to contain sag in voltage during 0.25 seconds to 0.55 seconds. During this particular sag period, the load also should be affected with sag but UPQC injects compensating signals to power system through injecting series transformer and conditions the voltage to load. The load voltage is not affected with sag and is maintained at constant peak with UPQC. Simultaneous operation of series and shunt converters condition, though series converter is responsible for compensating voltage.

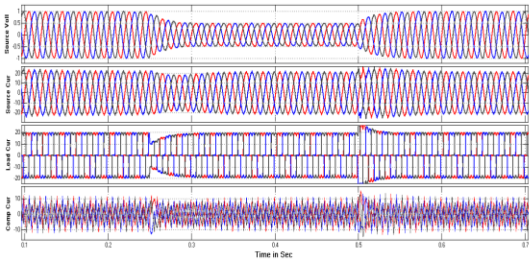

Fig. 13. Source voltage, source currents, load currents and compensating currents of power system when UPQC acting as series and shunt compensator

Figure 13 shows the system parameters when UPQC acting both as series and shunt compensator. Source voltage, source currents, load currents and compensating currents of power system are shown in Figure 13. As load is non-linear type, load current draws non-linear currents, which affect source currents. Compensating signals from UPQC nullifies the affect of harmonics on source parameters. Source current is nearer sinusoidal with very less distortion and load current is non-linear in nature. Sag observed in source voltage of Figure 13 is compensated by UPQC and load voltage doesn't have sag as illustrated in Figure 12.

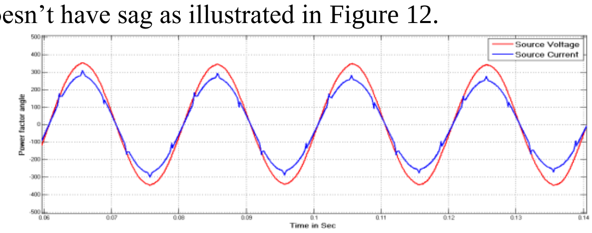

Fig. 14. Source Power factor

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Figure 14 illustrates the power factor on source side of power system. Source voltage and source current have almost the same phase and power factor tends to unity. Current signal is added with gain for better visualization.

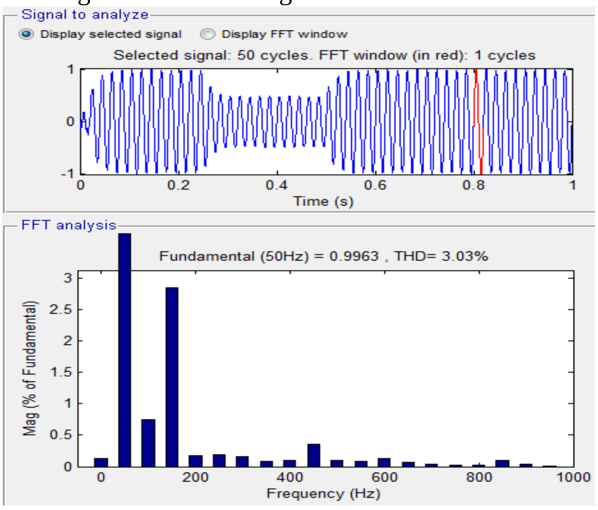

Fig. 15. THD in source current

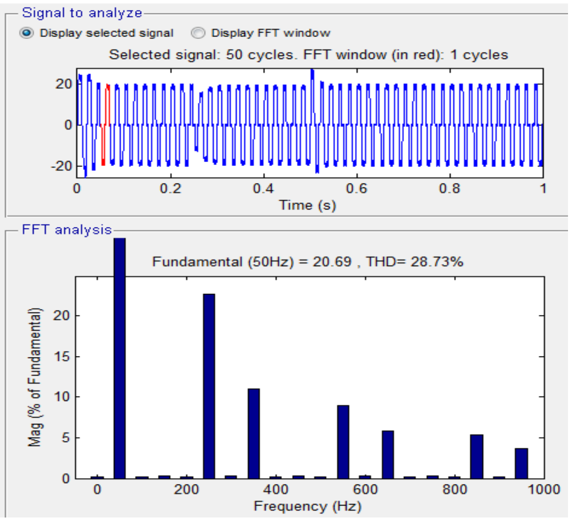

Fig. 16. THD in load current

Figure 15 and Figure 16 shows the harmonic distortion analysis in source current and load current. Source current is deviated by 3.03% and load current by 28.73%. Source current is not much distorted and is within nominal limit of 5%.

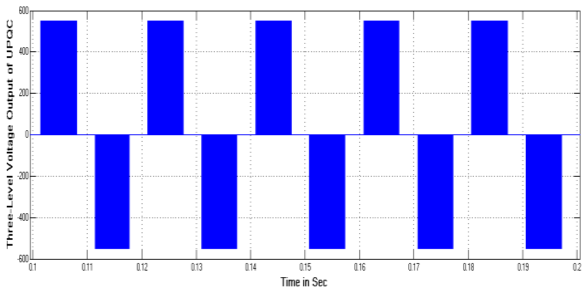

Fig. 17. Three-level output of UPQC

Figure 17 shows the three-level output of UPQC. The output of UPQC is leveled with Vdc, 0 and –Vdc as shown in Figure 16. Table II shows the harmonic distortion analysis in currents of power system with different operating conditions

Table II: Harmonic analysis

THD	Source Current	Load Current
UPQC acting as only shunt controller	1.58 %	29.25 %
UPQC acting as both series and shunt controller	3.03 %	28.73

IV. CONCLUSIONS

Delivering power with quality to the customers is at prior with the loads being sensitive to disturbances in system parameters. FACTS based controllers are found prominent in improving power quality. The paper presents analysis in different operating conditions of UPQC. Performance of UPQC to condition the load voltage when sag is present in source voltage when UPQC acting only as series compensator, performance of UPQC compensating harmonics in source currents with non-linear load power system when UPQC acting only as shunt compensator and performance of UPQC when acting as both series and shunt compensator is verified in this paper. Shunt controller of UPQC is controlled with IRP theory and IRP control generates required compensating signals to condition source current without harmonics. Conventional SRF theory is employed to trigger series compensator of UPQC to nullify sag in load voltage. Harmonic analysis is tabulated which illustrates that when UPQC working only as shunt controller and when UPQC working as both series-shunt controller, distortion in source current is limited within nominal limit of 5%. Three-level output of UPQC is shown. Power factor of system is well maintained as illustrated in result analysis.

REFERENCES

1. Hirofumi Akagi, "New trends in active filters for power conditioning," *IEEE Trans. Industry Applications*, vol. 32, no. 6, Nov/Dec 1996.
2. Mauricio Aredes, Klemens Heumann, Edson H. Watanabe, "An Universal Active Power Line Conditioner," IEEE Trans. Power Delivery, vol. 13, no. 2, April 1998.
3. Hideaki Fujita, Hirofumi Akagi, "The Unified Power Line Conditioner: The Integration of Series- and Shunt-Active Filters," IEEE Trans. Power Elelctronics, vol. 13, no. 2, March 1998.
4. Zainal Salam, Tan Perng Cheng and Awang Jusoh, "Harmonics Mitigation Using Active Power Filter: A Technological Review", ELEKTRIKA, VOL. 8, NO. 2, 200.6, 17-26.
5. S.Khalid, B.Dwivedi, "Comparative Critical Analysis of Advanced Controllers used for Active Power Filter," National Conference on Power Electronics and Renewable Energy Systems, PEARES, Kalavakkam, 2009.
6. S. Shen, H. Zheng, Y. Lin and W. Zhao, "UPQC Harmonic Detection Algorithm Based on Improved p-q Theory and Design of Low-Pass Filter," 2018 Chinese Control And Decision Conference (CCDC), Shenyang, China, 2018, pp. 5156-5160

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7. S. A. O. d. Silva, L. B. Garcia Campanhol and V. d. Souza, "Dynamic Performance Evaluation of a dual UPQC Operating Under Power Quality Disturbances," PCIM Europe 2018; International Exhibition and Conference for Power Electronics, Intelligent Motion, Renewable Energy and Energy Management, Nuremberg, Germany, 2018, pp. 1-8.
8. Muneer, J. Sukumaran and A. Bhattacharya, "Investigation on reduced DC link voltage based UPQC for harmonic compensation under unbalanced load," 2017 International Conference on Technological Advancements in Power and Energy (TAP Energy), Kollam, India, 2017, pp. 1-6
9. J. Ye, H. B. Gooi and F. Wu, "Optimal Design and Control Implementation of UPQC Based on Variable Phase Angle Control Method," in IEEE Transactions on Industrial Informatics, vol. 14, no. 7, pp. 3109-3123, July 2018.

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