Analysis of UPQC with Advanced Control Scheme under Different Situations

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***Abstract*—Power quality has become an important factor in power systems, for consumer and household appliances with proliferation of various electric and electronic equipment and computer systems. The main causes of a poor power quality are harmonic currents, poor power factor, supply-voltage variations, etc. In recent years unified power quality conditioner (UPQC) is being used as a universal active power conditioning device to compensate both harmonics as well as reactive power. In this work, UPQC has been modeled for both active and reactive power compensation using different control strategies. The behavior of UPQC has been analyzed with sudden switching of R-L loads, and R-C loads as well as occurrences of different shunt faults. The simulation results based on Matlab/Simulink are discussed in detail in this paper.**

***IndexTerms*—Power quality, shunt active filter, series active filter**

I. INTRODUCTION

The modem power distribution system is becoming highly vulnerable to the different power quality problems [1-2]. The extensive use of non-linear loads is further contributing to increased current and voltage harmonics issues. Furthermore, the penetration level of small/large-scale renewable energy systems based on wind energy, solar energy, fuel cell, etc., installed at distribution as well as transmission levels is increasing significantly.Unified power quality control was widely studied by many researchers as an eventual method to improve power quality of electrical distribution system [1-3]. The function of unified power quality conditioner is to compensate supply voltage flicker/imbalance, reactive power, negative-sequence current, and harmonics. In other words, the UPQC has the capability of improving power quality at the point of installation on power distribution systems or industrial power systems. Therefore, the UPQC is expected to be one of the most powerful solutions to large capacity loads sensitive to supply voltage flicker/imbalance [2] . The UPQC consisting of the combination of a series active power filter (APF) and shunt APF can also compensate the voltage interruption if it has some energy storage or battery in the dc link [3] . The shunt APF is usually connected across the loads to compensate for all current-related problems such as the reactive power compensation, power factor improvement, current harmonic, compensation, and load unbalance compensation (3,4)whereas the series APF is connected in a series with the line through series transformers. It acts as controlled voltage source and can compensate all voltage related problems, such as voltage harmonics, voltage sag, voltage swell, flicker, etc.

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In this work, UPQC has been modeled for both active and reactive power compensation using different control strategies. The system has been modeled using MATLAB/SIMULINK 7.5. The analysis has been carried out with non-linear loads using sudden switching of RL loads and RC loads. The analysis has also been carried out with different types of shunt faults.

II. MODELING OF UPQC

The simplified diagram of UPQC with series and shunt active filters has been shown in Fig. 1(a) and its equivalent circuit is shown in Fig. 1(b). In this section, the UPQC modeling has been presented considering the equivalent circuit of UPQC. The compensation strategy, basic control function,series and shunt converter controls have been explained for UPQC model development.

A. *Compensation Strategy*

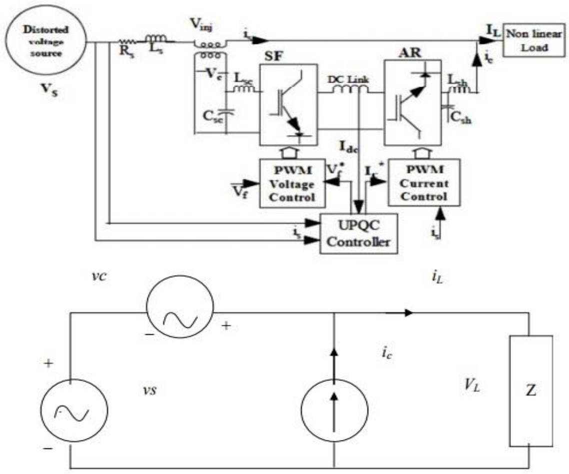

Fig. 1(a),1(b) Simplified UPQC Diagram and equivalentcircuit diagram of UPQC

As shown in Fig.1,vsis the supply voltage. vc, Icare the series compensation voltage, shunt compensation current and vL, iL are the load voltage and current respectively. The sourcevoltage may contain negative, zero as well as harmonic components. Per phase voltage of the system can be expressed as:

$$V_{sa} = V_{1pa}(t) + V_{1na} + \sum_{k=2}^{\infty} V_{sk}(t) \quad (1)$$

$$V_{sa} = V_{1p}\sin(\omega t+\theta_{1p}) + V_{1n}\sin(\omega t+\theta_{1n}) + \sum_{k=2}^{\infty} V_{sk}(k\omega t+\theta_{kn}) \quad (2)$$

Where v1pais the fundamental frequency positive sequence components,v1na is fundamental frequency negative sequence components respectively. V1pis the positive sequence voltage amplitude and V1nis the negative sequence voltage amplitude. The last term of equation represents the harmonic content in the voltage. In order for the load voltage to be perfectly sinusoidal and balanced, the series filter should produce a voltage of:

$$V_{ca} = (\text{v-}v_{1p})\sin(\omega t+\theta_{1p}) - V_{1na}(t) - \sum_{k=2}^{\infty} V_{ka}(t) \quad (3)$$

The functions of the shunt active filter is to provide compensation of the load harmonic current, load reactive power demand and also to maintain dc link current constant. To provide load reactive power demand and compensation of the load harmonic and negative sequence currents, the shuntAPF acts as a controlled current source and its output components should include harmonic, reactive and negativesequence components in order tocompensate these quantities in the load current [13]. The per phase load current of shunt active filter is expressed as:

$$I_{al} = I_{1p}\sin(\omega t+\theta_{1p}) + I_{a1nl} + \sum_{k=2}^{\infty} I_{alk} \quad (4)$$

B. Shunt converter control

The shunt APF compensates currentharmonics in addition to maintaining the dc link current at a constant level. To achieve this, dc link current of the UPQC is compared with a constant reference current of magnitude equal to peak of harmoniccurrent [14]. The error between measured dc link current and reference current is processed in a PI controller. The output of PI controller is added to real power loss component to derive reference source current given as:

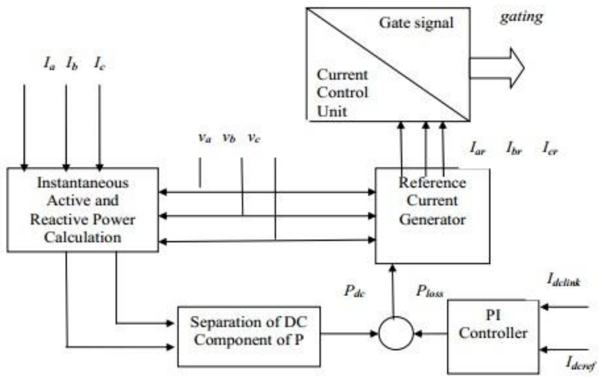

Fig.2 Control block diagram of shunt filter controller

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \begin{bmatrix} 1/2 & -1/2 & -1/2 \\ 0 & \sqrt{3/2} & -\sqrt{3/2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (5)$$

$$\begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} = \begin{bmatrix} 1/2 & -1/2 & -1/2 \\ 0 & \sqrt{3/2} & -\sqrt{3/2} \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \quad (6)$$

$$P(t) = v_\alpha(t)\, I_\alpha(t) + v_\beta(t)\, I_\beta(t) \quad (7)$$

$$q(t) = -\, v_\beta(t)\, I_\alpha(t) + v_\alpha(t)\, I_\beta(t) \quad (8)$$

In matrix form it is given as:

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} \quad (9)$$

From equation 9 the values of p and q can be expressed in terms of dc components plus the ac components as follows:

$$P = \bar{p} + \breve{p}\ , \ q = \bar{q} + \breve{q} \quad (10)$$

Where: $\bar{p}$ is the dc component of the instantaneous power p, and is related to the fundamental active current. To compute harmonic free unity power factor, three- phase currents, compensating powers p_c and q_c are selected as:

$$p_c = p_{\bar{d}c} + p_{loss} \quad (11)$$

$$q_c = 0 \quad (12)$$

Where, p_{loss} is the instantaneous active power corresponding to the switching loss and resistive loss of UPQC.The orthogonal components of the fundamental current are obtained as follows:

$$\begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} p_c \\ q_c \end{bmatrix} \quad (13)$$

C. Series converter control

The load voltage to be perfectly sinusoidal and balanced, the series filter should produce a voltage equal to equation (3). The reference load voltages are obtained bymultiplying the unit vector templates with a constant equal to peak amplitude of fundamental input voltage. The compensation signals for series filter are thus obtained by comparing these reference loadvoltages with actual source voltage using equation (14).

$$\begin{bmatrix} v_{fa}^* \\ v_{fb}^* \\ v_{fc}^* \end{bmatrix} = \begin{bmatrix} v_{sa} - v_m v_a \\ v_{sb} - v_m v_b \\ v_{sc} - v_m v_c \end{bmatrix} \quad (14)$$

The series-APF should behave as a controlled voltage source and its output should follow the pattern of voltage given in equation (2). This compensating voltage signal can be obtained by comparing the actual load terminal voltage with the desired value. These compensation signals are compared with actual signals at the terminals of series filter and the error is taken to hysteresis controller to generate the required gating signal for series filter as shown in Fig. 3.

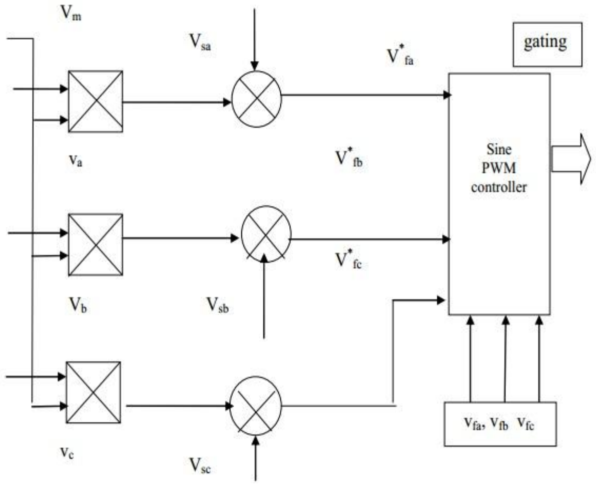

Fig. 3 Control block diagram of series-APF

III. SIMULATION RESULTS

An ideal three-phase sinusoidal supply voltage of 11kV, 50Hz is applied to the non-linear load (diode rectifier feeding an RL load) injecting current harmonics into the system.

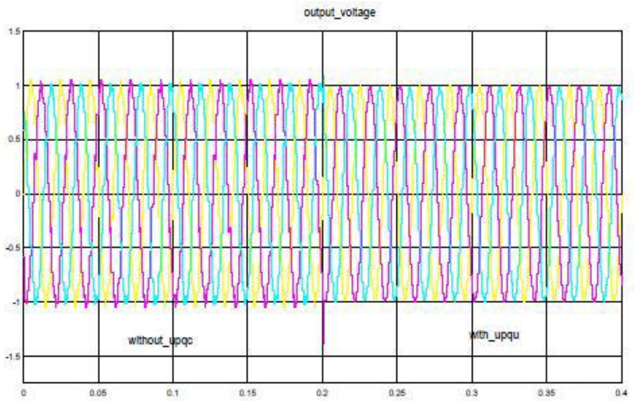

Fig. 4(a)

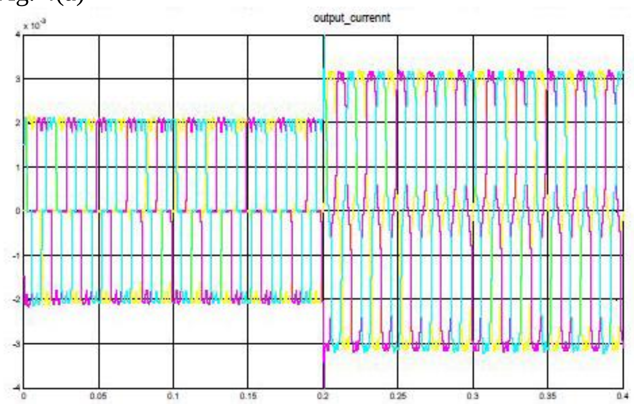

Fig. 4 Simulated results of UPQC (a) Load Voltage (b) Load current with the switching of RL Load

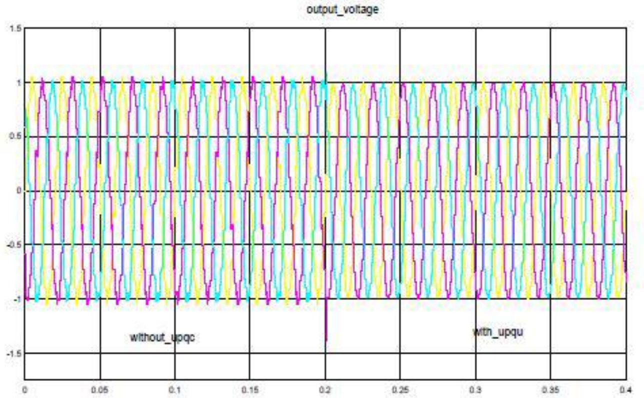

Fig. 5(a)

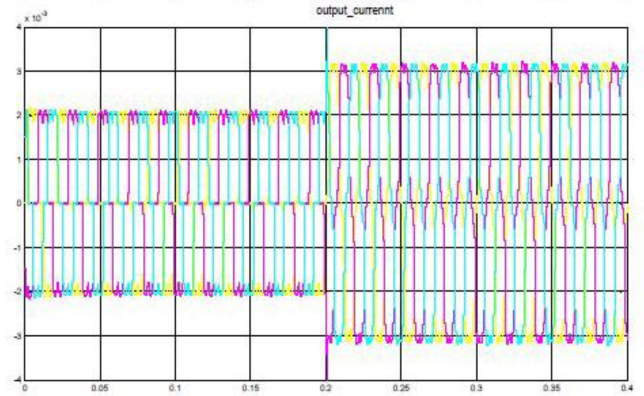

Fig. 5 Simulated results of UPQC (a) Load Voltage (b) Load current with the sudden switching of RC load

The power transfer capability of long transmission lines isusually limited by their thermal capability. Utilizing theexisting transmission line at its maximum thermal capability is
possible with UPQC. The series inverter injects voltage ofvariable magnitude and phase into the transmission line at the
point of its connection, there by controlling real and reactivepower flow through the line. For the shunt fault conditions the UPQC is switched on at the time interval between 0.3s to 0.4s respectively.

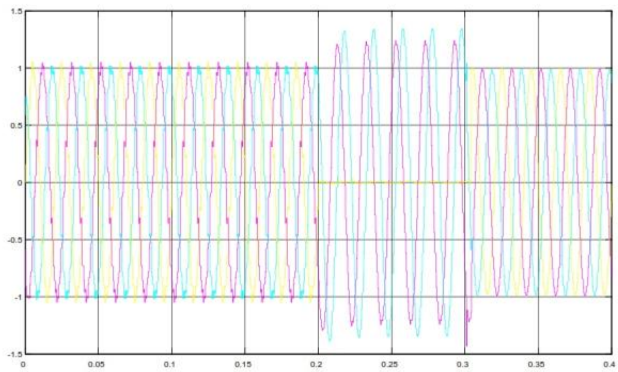

Fig. 6(a)

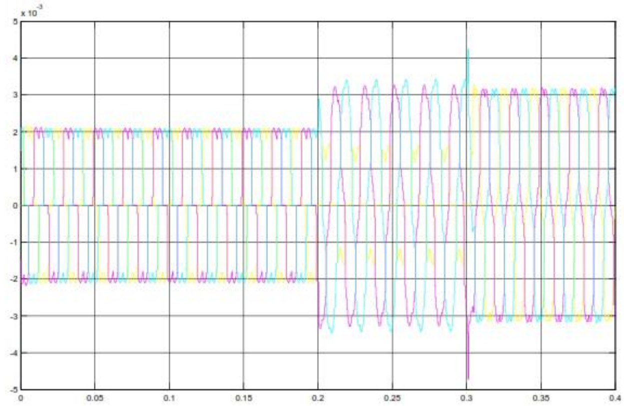

Fig. 6 Simulated results of UPQC (a) Load Voltage (b)load current with the sudden occurrence of LG fault

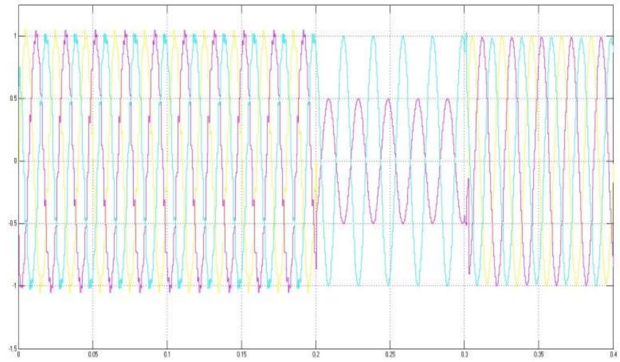

Fig.7 (a)

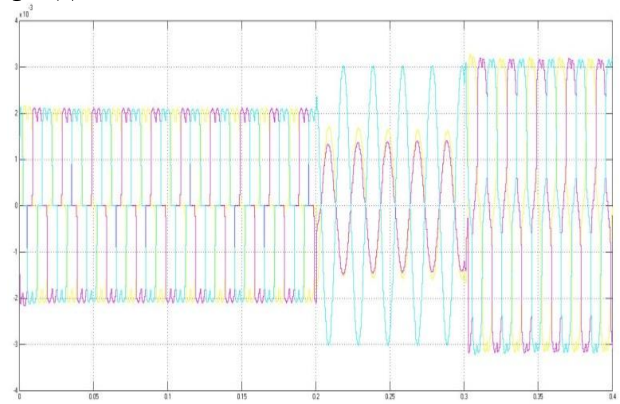

Fig. 7 Simulated results of UPQC (a) Load Voltage (b) Load current with the sudden occurrence of LL fault

IV. CONCLUSION

This paper describes an improved control strategy for UPQC system operation.The performance of UPQC has been studied under different cases of R-L, R-C loads switching and different kind of shunt faults.AC voltage regulation and power factor of the transmission line is also improved.The UPQC provides an improvement in the real and reactive power flow through the transmission line. UPQC provides reliable performance in switching of loads as well as different types of shunt faults.UPQC provides compensation as well as improves power factor.

REFERENCES

[1] C. Sankaran, Power Quality, Boca Raton: CRC Press, 2002, p. 202.

[2] R. A. Walling , R. Saint, R. C. Dugan, J. Burke and L. A. Kojovic, "Summary of Distributed Resources Impact on Power Delivery Systems", IEEE Trans. Power Delivery, vo1.23, no.3, pp.1636-1644, July 2008.

[3] H. Akagi, and H. Fujita, "A new power line conditional for harmonic compensation in power systems, " IEEE Trans. Power Del., vol. 10, no. 3, pp. 1570-1575, Jul. 1995.

[4] H. Fujita, and H. Akagi, "The unified power quality conditioner: The integration of series and shunt-active filters, " IEEE Trans. Power Electron., vol. 13, no. 2, pp. 315-322, Mar. 1998.

[5] H. Akagi, E. H. Watanabe and M. Aredes, Instantaneous Power Theory and Applications to Power Conditioning. Wiley-IEEE Press. April 2007.

[6] D. Graovac, A. Katie, and A. Rufer, "Power Quality Problems Compensation with Universal Power Quality Conditioning System, IEEE Transaction on Power Delivery, vol. 22,no. 2,2007.

[7] B. Han, B. Bae, H. Kim, and S. Baek, "Combined Operation of Unified Power-Quality Conditioner with Distributed Generation," IEEE Transaction on Power Delivery, vol. 21, no. I, pp. 330-338, 2006.

[8] M. Aredes, "A combined series and shunt active power filter, " in Proc. IEEE/KTH Stockholm Power Tech Conf., Stockholm, Sweden, pp. 18-22, June 1995.

[9] Y. Chen, X. Zha, and 1. Wang, "Unified power quality conditioner (UPQC): The theory, modeling and application, " Proc. Power System Technology Power Con Int. Corr!, vol. 3, pp. 1329-1333, 2000.

[10] H. Akagi, "Performance and modeling of a shunt active filter for Installation on power distribution systems," to be presented at the 1996 IEEE-PES International Conference on Harmonics and Quality of Power, Oct. 16-18, 1996.

[11] H. Fujita and H. Akagi, "The unified power quality conditioner: The Integration of series- and shunt active filters," IEEE Trans. Power Electronics, vol. 13, no. 2, pp. 3 15-322, 1998.

[12] H. Fujita and H. Akagi, "The unified power quality conditioner: The integration of series- and shunt active filters," IEEE Trans. Power Electronics, vol. 13, No. 2, pp. 3 15-322, 1998.

[13] H. Akagi, Y. Kanazawa, and A. Nabae, "Instantaneous reactive power compensators comprising switching devices without energy storage
components," IEEE Trans. Ind. App., vol. IA-20, pp. 625-30, May/June 1984.