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Optimal Utilization Of Custom Power Devices For The Mitigation Of Power System Problems And Load Reactive Power Compensation

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Abstract: **The modern power distribution system is highly vulnerable to different power quality problems. At distribution level UPQC is a most attractive solution to compensate these problems. The Unified Power Quality Conditioner (UPQC) is a versatile device which could function as series active filter and shunt active filter. The main concern in this paper is to introduce a new concept for the optimal utilization of UPQC. The series inverter of UPQC is controlled to perform simultaneous voltage sag/swell compensation and load reactive power sharing. The active power control approach is integrated with the theory of Power Angle Control to coordinate the load reactive power between two inverters. The reference voltage signal for controlling the series inverter is generated using the UPQC controller based on PAC approach. Particle Swarm Optimization is used as an optimization technique. The controlling of series inverter of UPQC-S is done using PSO based fuzzy logic controller. Using this the reference voltage signal for series inverter is obtained. Computer simulation by MATLAB/ SIMULINK has been used to support the developed concept.**

Index Terms—**power angle control (PAC), power quality, reactive power compensation, Active power filter (APF), unified power quality conditioner (UPQC), voltage sag and swell compensation, PSO(Particle Swarm Optimization), VAloading, Fuzzy Logic Controller.**

I. INTRODUCTION

Electric Power quality is a term which has captured increasing attention in power engineering in the recent years. A wide diversity of solutions to power quality problems is available for both the distribution network operator and end user. The power processing at source ,load and for reactive and harmonic compensation by means of power electronic devices is becoming more prevalent due to the vast advantages offered by them. The measure of power quality depends upon the needs of the equipment that is being supplied. Electric power quality means different things for different people. To most of the electric power engineers, the term refers to a sufficiently high grade of electric service but beyond that there is no universal agreement. Usually the term power quality refers to maintaining a sinusoidal waveform of bus voltages at rated voltage and frequency. In industrial, commercial and utility networks quality problems are common.

Natural phenomena, such as lightning are the most frequent cause of power quality problems. This type of switching phenomena results oscillatory transients in the electrical power supply. Consider example of a switched capacitor, it also contribute power quality disturbances, which is substantially high. Also, the high power non-linear loads contributes to the generation of current and voltage harmonic components in the system. Among the different voltage disturbances that can be produced, the most critical and significant power quality problems are voltage sags and swell, which produces high economical losses. Short-term voltage drops (sags) can trip electrical drives or more sensitive equipment, and this leading to costly interruptions in the production field. A flexible and versatile solution to power quality problems is offered by active power filters.

Currently they are based on PWM converters and connect to low and medium voltage distribution system. They can be connected either in series or in parallel. The Series active power filters must operate along with shunt passive filters in order to compensate load current harmonics. Shunt active power filters and series active power filters operates as controllable current source and controllable voltage source. This two schemes are implemented preferable with voltage source PWM inverters. Also having a dc bus and a reactive element such as a capacitor. The voltage sag/swell on the system is one of the most important power quality problems. The voltage problems can be effectively compensated using a dynamic voltage restorer, series active filter, UPQC. Out of these available power quality enhancement devices, the UPQC has better sag/swell compensation capability.

II. OVERVIEW OF UPQC-S CONCEPT

The widespread use of power electronic based systems has generates harmonics in voltages and currents along with increased reactive current. The term active power filter (APF) is a widely used in the area of electric power quality improvement. APF s have the ability to mitigate some of the major power quality problems effectively. The UPQC is one of the APF family members where shunt and series APF functionalities are integrated together to achieve superior control over several power quality problems simultaneously. The UPQC is a combination of series active filter and shunt active filter linked through a common DC link capacitor. Series active filter and shunt active filter compensate the power quality problems of the source voltages and load currents, respectively. In order to improve the power quality of the system, UPQC has to inject required amount of Volt Ampere (VA) into the distribution system. For cost effectiveness, the VA loading of the UPQC need to be minimized. The general block diagram representation of a UPQC-based system is shown in Fig. 1. It basically consists of two voltage source inverters connected back to back using a common dc link capacitor. This paper deals with a novel concept of optimal utilization of a UPQC.

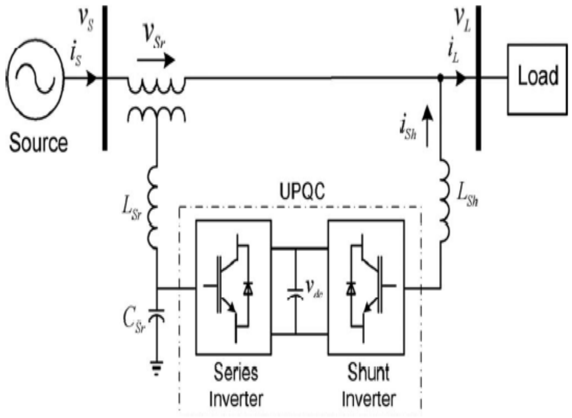

Figure. 1. Unified power quality conditioner (UPQC) system configuration.

Three significant control approaches for UPQC can be found to control the sag on the system: 1) active power control approach in which an in-phase voltage is injected through series inverter , popularly known as UPQC-P; 2) reactive power control approach in which a quadrature voltage is injected, known as UPQC-Q; and 3) a minimum VA loading approach in which a series voltage is injected at a certain angle, in this paper called as UPQC-VAmin. Among the aforementioned three approaches, the quadrature voltage injection requires a maximum series injection voltage, whereas the in-phase voltage injection requires the minimum voltage injection magnitude. In a minimum VA loading approach, the series inverter voltage is injected at an optimal angle with respect to the source current. Besides the series inverter injection, the current drawn by the shunt inverter, to maintain the dc link voltage and the overall power balance in the network, plays an important role in determining the overall UPQC VA loading.

The reported paper on UPQC-VAmin is concentrated on the optimal VAload of the series inverter of UPQC especially during voltage sag condition. A detailed investigation on VA loading in UPQC-VAmin considering both voltage sag and swell scenarios is essential. In the paper , the authors have proposed a concept of power angle control (PAC) of UPQC. The Power Angle Concept suggests that with proper control of series inverter voltage the series inverter successfully supports part of the load reactive power demand, and thus reduces the required VA rating of the shunt inverter. Most importantly, this coordinated reactive power sharing feature is achieved during normal steady-state condition without affecting the resultant load voltage magnitude. The optimal angle of series voltage injection in UPQC-VAmin is computed using lookup table or particle swarm optimization technique. These iterative methods mostly rely on the online load power factor angle estimation, and thus may result into tedious and slower estimation of optimal angle. On the other hand, the PAC of UPQC concept determines the series injection angle by estimating the power angle δ. The angle δ is computed in adaptive way by computing the instantaneous load active/reactive power and thus, ensures fast and accurate estimation.

In this paper, the concept of PAC of UPQC is further extended for voltage swell and sag conditions. This modified approach is utilized to compensate voltage sag/swell while sharing the load reactive power between series and shunt inverters. Since the series inverter of UPQC in this case delivers both active and reactive powers, it is given the name UPQC-S (S for complex power). The series inverter of the UPQC-S is controlled using a Particle Swarm Optimization based fuzzy logic controller. Here PSO is used as an optimization technique to find the optimum value of reactive power with different constraints.

The key contributions of this paper are outlined as follows.

1) The series inverter of UPQC-S is used for the simultaneous voltage sag/swell compensation and load reactive power compensation in coordination with shunt inverter.

2) In UPQC-S, the available VAloading is utilized to its maximum capacity, with the prime focus is to minimize the VA loading of UPQC during voltage sag condition.

3) The concept of UPQC-S can be used for both voltage sag and swell condition.

III. POWER ANGLE CONTROL APPROACH

In UPQC-S concept the Active power control approach is integrated with the theory of Power Angle Control approach. The PAC concept suggests that with proper control of series inverter voltage the series inverter successfully supports part of the load reactive power demand, and thus reduces the required VA rating of the shunt inverter. Most importantly, this coordinated reactive power sharing feature is achieved during normal steady-state condition without affecting the resultant load voltage magnitude.

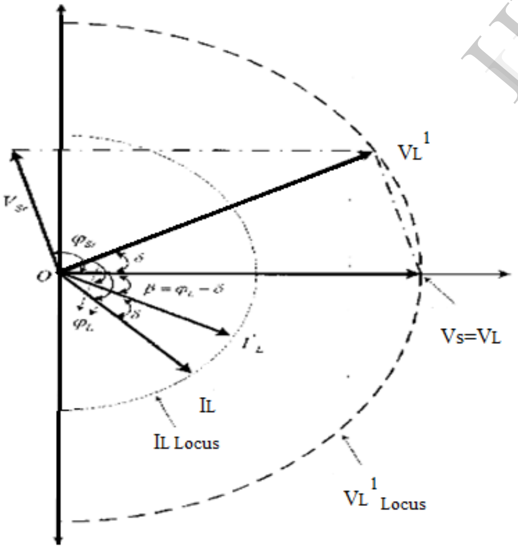

Figure 2. Concept of PAC of UPQC.

The phasor representation of the Power Angle Control approach under a rated steady-state condition is shown in figure 2.According to this theory, a vector V_{Sr} with proper magnitude V_{Sr} and phase angle ϕ_{Sr} when injected through series inverter gives a power angle δ boost between the source VS and resultant load V_L^1 voltages maintaining the same voltage magnitudes. This power angle shift causes a relative phase advancement between the supply voltage and resultant load current IL^1 denoted as angle β. In other words, with PAC approach, the series inverter supports the load reactive power demand and thus, reducing the reactive power demand shared by the shunt inverter. For a rated steady-state condition,

$|V_S| = |V_L| = |V_L^*| = |V_L^1| = k.$

phasor $\overrightarrow{V\mathrm{Sr}}$ can be defined as,

$$V_{Sr} = |V_{Sr}|\angle\phi_{Sr}$$
$$=k.\surd 2.\surd 1 - \cos\delta\angle\{180^\circ - \tan{-1}(\_\sin\delta/1 - \cos\delta)\}$$
$$=(k\cdot\surd 2\ \surd 1 - \cos\delta\cdot)\angle(90^\circ + \delta/2)$$

Where

$\delta = \sin{-1}(Q_{Sr}/PL)$

IV. SERIES INVERTER PARAMETER ESTIMATION UNDERVOLTAGE SAG

In this section, the series inverter parameters that required to achieve simultaneous voltage sag compensations and load reactive power are computed. Figure 3 shows a detailed phasor diagram to determine the magnitude and phase of series injected voltage for UPQC-S.

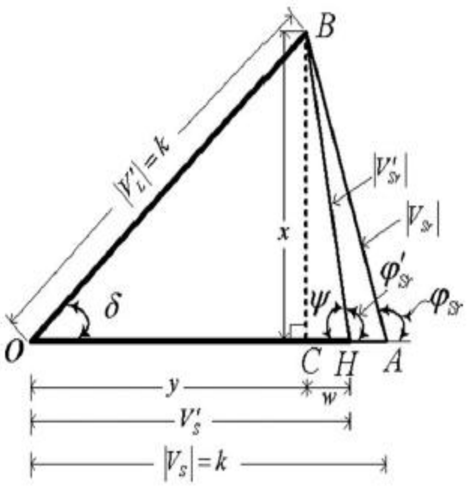

Figure 4. Phasor Diagram to Estimate the Series Inverter Parameters For the Proposed UPQC-S Approach Under Voltage Sag Condition

The voltage fluctuation factor kf which is defined as the ratio of the difference of instantaneous supply voltage and rated load voltage magnitude to the rated load voltage magnitude is represented as

$kf = (V_S - V_L^*)/ V_L^*$

Representing (10) for sag condition under PAC
$kf = (V_S^1 - V_L^1)/V_L^1 = (V_S^1 - k)/k$
Let us define
$1 + kf = nO$
To compute the magnitude of $\overrightarrow{V_{Sr}^1}$, from ΔCHB in Fig.
$w = l(CH) = nO \cdot (k - y)$

$|V_{Sr}^1| = \cdot\sqrt{(k \cdot \sin\delta)2 + \cdot (nO \cdot k - k\cos\delta)2}$

$|V_{Sr}^1| = k. \cdot\sqrt{1 + nO^2 - 2 \cdot nO \cdot \cos\delta}.$
To compute the phase of $\overrightarrow{VSr^1}$
$\angle CHB = \angle\psi = \tan{-1}(x/w) = \tan{-1}(\sin\delta/(nO - \cos\delta))$

Therefore, $\angle\phi_{Sr} = 180^\circ - \angle\psi$

The above Equations give the required magnitude and phase of series inverter voltage of UPQC-S that should be injected to achieve the voltage sag compensation while supporting the load reactive power under PAC approach.

V. PREPOSED UPQC-S CONTROL SCHEME

A detailed controller for UPQC based on PAC approach is developed. The series inverter maintains the load voltage at desired level, the reactive power demanded by the load remains unchanged (assuming load on the system is constant) irrespective of changes in the source voltage magnitude. Furthermore, the power angle *δ* is maintained at constant value under different operating conditions. The reactive power shared by the series and shunt inverters can be fixed at constant values by allowing the power angle *δ* to vary under voltage sag/swell condition. The control block diagram for series inverter operation is shown in Fig.6

The instantaneous power angle *δ* is determined. Based on the system rated specifications, the value of the desired load voltage is set as reference load voltage *k*. The instantaneous value of factors kf and nO is computed by measuring the peak value of the supply voltage in real time. The magnitudes of series injected voltage VSr and its phase angle ϕSr are then determined using equations. A phase locked loop is used to synchronize and to generate instantaneous time variable reference signals vSr^*,a , vSr^*,b , vSr^*,c .The reference signals thus generated give the necessary series injection voltages that will share the load reactive power and compensate for voltage sag/swell as formulated using the proposed approach. The error signal of actual and reference series voltage is utilized to perform the switching operation of series inverter of UPQC-S. The control diagram for the shunt inverter is as given in [15].

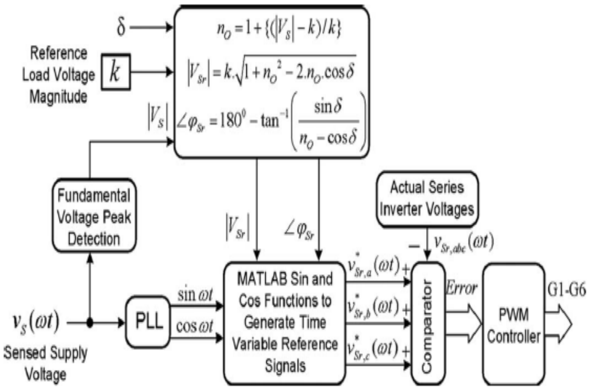

Figure 5 Reference Voltage Signal Generation For the Series Inverter Of the Proposed UPQC-S Approach.

VI. PSO AND FUZZY LOGIC CONTROLLER

A. Fuzzy Logic Controller

The performance of UPQC mainly depends upon how quickly and accurately compensation signals are derived. Control schemes of UPQC based on PI controller has been widely reported. The PI control based techniques are simple and reasonably effective. However, the tuning of the PI controller is a tedious job. Further, the control of UPQC based on the conventional PI control is prone to severe dynamic interaction between active and reactive power flows. The FC is basically nonlinear and adaptive in nature. The results obtained through FC are superior in some cases. For example the place where the effects of parameter variation of controller are also taken into consideration. The FC is based on linguistic variable set theory and does not require a mathematical model. Generally, the input variables are error and rate of change of error. If the error is coarse, the FC provides coarse tuning to the output variable and if the error is fine, it provides fine tuning to the output variable.

In Basic control action of fuzzy controller is determined by a set of linguistic rules. These rules are determined by the system. Here the numerical variables are converted into linguistic variables, mathematical modeling of the system is not required here. The FLC consist of three parts: fuzzification, interference engine and defuzzification.

The FC is characterized as:
1) Corresponding to each input and output there are seven fuzzy sets.
2) For simplicity Triangular Membership functions.
3) Fuzzification.
4) Mamdani‟‟s „„min‟‟ operator for implication
5) Defuzzification using the Average height method.

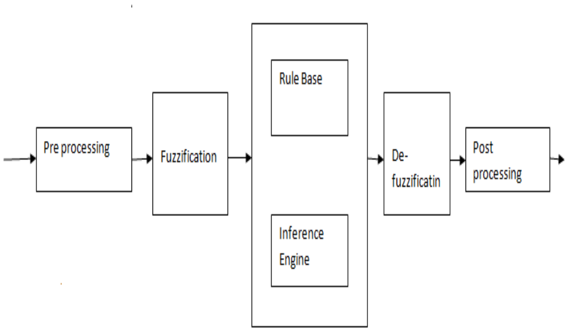

Fig.6 Fuzzy Logic Controller

(1) Fuzzification

Membership function values are assigned to the linguistic variables, using seven fuzzy subsets: NB (Negative Big), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM (Positive Medium), and PB (Positive Big). The fuzzy subsets partition and the shape of membership function gives the shape to the appropriate system. *E(k)* is the value of input error and *CE(k)* is the change in error. Both are normalized by an input scaling factor. Here the input scaling factor has been designed such that input values are between -1 and+1. In this arrangement the triangular shape of the membership function presumes that for any particular input there is only one dominant fuzzy subset.

(2) Inference Method

Several composition methods such as Max–Min and Max-Dot have been proposed in the literature. In this paper Min method is used. The output membership function of each rule is given by the minimum operator and maximum operator.

(3) De fuzzification

The output of fuzzy controller is a fuzzy subset. As the actual system requires a non fuzzy value of control, defuzzication is required. The center of area (COA) algorithm is used for defuzzification of output control parameter. Consequently, it is our point of view that a defuzzification method should be structured in a way so as to assist in the appropriate translation of expert's knowledge and minimize the possibility of errors in this translation. This can be done by introducing design guidelines (related to the components of the fuzzy controller) which would render the task of achieving design objectives systematic and simpler. In this paper the controlling of series inverter UPQC is done using Particle Swarm Optimization based fuzzy logic controller.PSO is used as the optimization technique for minimize the reactive power. The reference signal generation and controlling of series inverter voltage is done using fuzzy logic controller. Fig.7 shows the control scheme using the fuzzy logic controller.

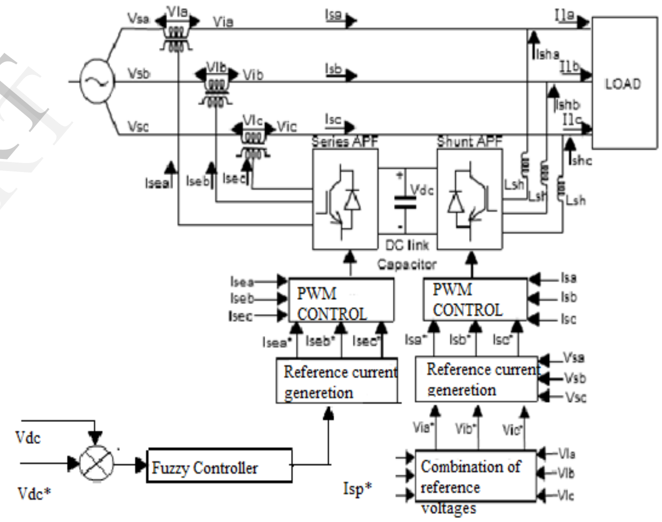

Fig.8 Series APF Control Using Fuzzy Controller

A. Particle Swarm Optimization

Particle Swarm Optimization (PSO) is a population based stochastic optimization technique developed by Dr.Ebehart and Dr.Kennedy in 1995 ,inspired by the social behavior of bird flocking or fish scooling.PSO shares many similarities with evolutionary computation techniques such as Genetic Algorithms(GA). However, unlike GA,PSO has no evolution operators such as cross over and mutation. In PSO ,the potential solutions, called particles, fly through the problem space by following the current optimum particles. The detailed information will given in the following sections. When comparing with the Genetic Algorithm, the PSO has some advantages. The main advantages of PSO are that PSO is very easy to implement and there are few parameters to adjust.

PSO optimizes a problem by having a population of swarm of particles and moving these particles around in the search-space according to simple mathematical formulae over the particle's position and velocity. The movement of each particle's is influenced by its local best known position and is also guided toward the best known positions in the search-space. These positions are updated as better positions. And is expected to move the swarm toward the best solutions. The algorithm is initialized with a group of random particles(solutions) and then search for optima by updating generations. In every iteration, each particle is updated by following two best values. The first one is the best solution(fitness) it has achieved so far. This value is called pbest .Another best value is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the population. This value is known as global best and called as g-best. When a particle takes part of the population with its topological neighbors, the best value is known as local best and is called p-best. After finding the values of pbest and gbest, the velocity and positions of the particle is updates.

VII. SIMULATION RESULTS

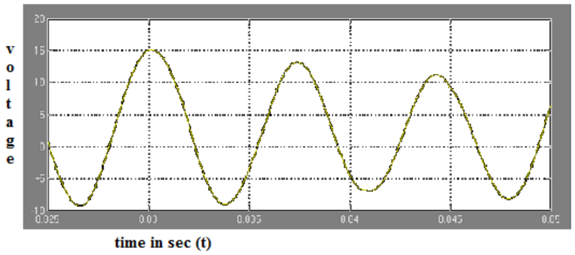

Fig. 9 (a)

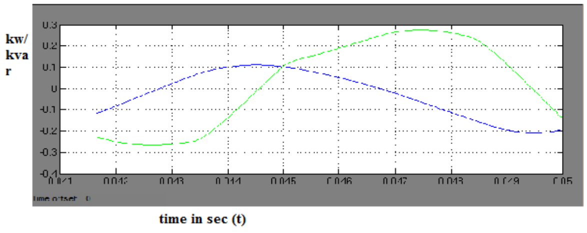

Fig. 9(b)

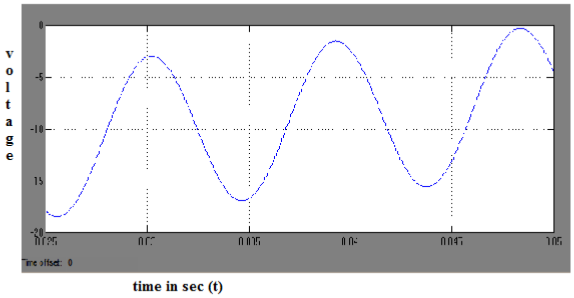

Fig. 9(c)

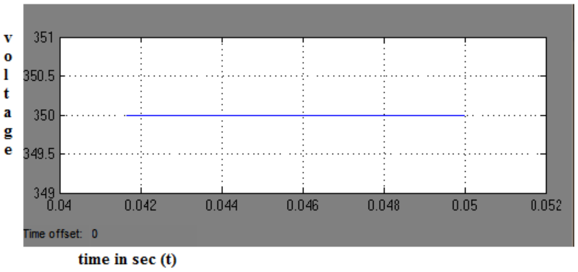

Fig. 9(d)

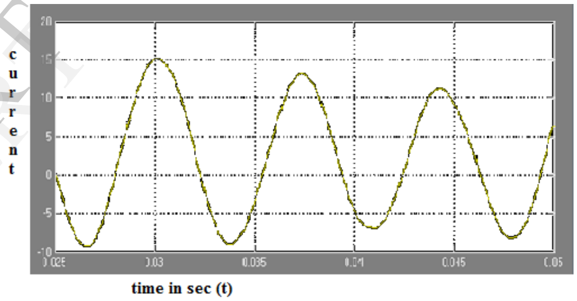

Fig 9(e)

The simulation results for the proposed UPQC-S approach under voltage sag and swell conditions are given in Fig.9. Here Fig.(a) represents load voltage, Fig.(b) shunt active and reactive power fig.(c) represents the series injected voltage ,fig (d) self supporting dc bus voltage and fig.(e) the load current wave form.

VII. CONCLUSION

In this paper a new concept for the optimal utilization of UPQC is introduced. The complex power (simultaneous active and reactive powers) controlling through series inverter of UPQC is proposed and named as UPQC-S. The proposed concept of the UPQC-S approach is mathematically formulated and analyzed for voltage sag and swell conditions. The developed mathematical equations for UPQC-S can be used to estimate the angle and magnitude of series injection voltage and the overall VA loading both under voltage sag and swell conditions. Here the controlling of series inverter of UPQC is done using the PSO based fuzzy logic controller. The modeling of proposed UPQC system can be done using MATLAB and implemented on higher bus system. The significant advantages of UPQC-S over general UPQC applications are: 1) series inverter can be used to compensate voltage variation (sag, swell, etc.) while supporting load reactive power.

2)Optimal utilization of series inverter of UPQC.

3) Reduction in the shunt inverter rating due to the reactive power sharing by both the inverters.

In future both inverters can be controlled. The series inverter can be controlled using ANFIS controller with different evolutionary algorithms such as PSO, GA, Ant Colony algorithm etc.

REFERENCES

[1] B. Han, B. Bae, H. Kim, and S. Baek, “Combined operation of unified power-quality conditioner with distributed generation,” *IEEE Trans. Power Del.*, vol. 21, no. 1, pp. 330–338, Jan. 2006.

[2] C. N. Ho and H. S. Chung, “Implementation and performance evaluation of a fast dynamic control scheme for capacitor-supported interline DVR,” *IEEE Trans. Power Electron.*, vol. 25, no. 8, pp. 1975–1988, Aug. 2010.

[3] D. O. Kisck, V. Navrapescu, and M. Kisck, “Single-phase unified power quality conditioner with optimum voltage angle injection for minimum VA requirement,” in *Proc. IEEE Power Electron. Spec. Conf. (PESC)*, Jun. 17–21, 2007, pp. 574–579.

[4] G. S. Kumar, P. H. Vardhana, B. K. Kumar, and M. K. Mishra, “Minimization of VA loading of unified power quality conditioner (UPQC),” in *Proc. IEEE Powereng*, Mar. 18–20, 2009, pp. 552–557.

[5] H. R. Mohammadi, A. Y. Varjani, and H. Mokhtari, “Multiconverter unified power-quality conditioning system:MC-UPQC,” *IEEE Trans. Power Del.*, vol. 24, no. 3, pp. 1679–1686, Jul. 2009.

[6] H. Fujita and H. Akagi *IEEE Trans. Power Electron.*, vol. 13, no. 2, pp. 315–322, Mar. 1998.

[7] I. Axente, J. N. Ganesh, M. Basu, M. F. Conlon, and K. Gaughan, “A 12-kVA DSP-controlled laboratory prototype UPQC capable of mitigating unbalance in source voltage and load current,” *IEEE Trans. Power Electron.*, vol. 25, no. 6, pp. 1471–1479, Jun. 2010.

[8] M. Yun, W. Lee, I. Suh, and D. Hyun, “A new control scheme of unified power quality compensator-Q with minimum power injection,” in *Proc. IEEE Ind. Electron. Soc. (IECON)*, Nov. 2–6,, 2004, pp. 51–56.

[9] M. Basu, S. P. Das, and G. K. Dubey, “Investigation on the performance of UPQC-Q for voltage sag mitigation and power quality improvement at a critical load point,” *IET Generat., Transmiss. Distrib.*, vol. 2, no. 3, pp. 414–423, May 2008.

[10] M. Gon, H. Liu, H. Gu, and D. Xu, “Active voltage regulator based on novel synchronization method for unbalance and fluctuation compensation,” in *Proc. IEEE Ind. Electron. Soc (IECON)*, Nov. 5–8,, 2002, pp. 1374–1379.

[11] M. S. Khoor and M. Machmoum, “Simplified analogical control of a unified power quality conditioner,” in *Proc. IEEE Power Electron. Spec. Conf. (PESC)*, Jun., 2005, pp. 2565–2570.

[12] M. Vilathgamuwa, Z. H. Zhang, and S. S. Choi, “Modeling, analysis and control of unified power quality conditioner,” in *Proc. IEEE Harmon. Quality Power*, Oct. 14–18, 1998, pp. 1035–1040.

[13] S. Subramanian and M. K. Mishra, “Interphase AC–AC topology for voltage sag supporter,” *IEEE Trans. Power Electron.*, vol. 25, no. 2, pp. 514–518, Feb. 2010.

[14] V. Khadkikar, A. Chandra, A. O. Barry, and T. D. Nguyen, “Analysis of power flow in UPQC during voltage sag and swell conditions for selection of device ratings,” in *Proc. IEEE Electr. Computer Eng. (CCECE)*, May 2006, pp. 867–872.

[15] 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,” *IEEE Trans. Power Del.*, vol. 23, no. 4, pp. 2522–2534, Oct. 2008.