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Unified Power Quality Conditioner (UPQC) for the Mitigations of Power Quality Problems in Distribution System

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Abstract— The Unified Power Quality Conditioner (UPQC) is a versatile device which could function as both series filter and shunt filter. The main concern in this paper is to introduce a new concept of UPQC for mitigating different power system problems. The new concept is known as the UPQC-S, in which the series inverter of UPQC is controlled to perform the simultaneous voltage sag/swell compensation and load reactive power sharing with shunt inverter. The reference voltage signal for controlling the series inverter is generated using the UPQC controller based on PAC approach. The Active Power Control approach is integrated with the theory of Power Angle Control approach to perform the two functions simultaneously. The controlling of shunt inverter of UPQC-S is done using PSO based fuzzy logic controller. 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

Power Quality (PQ) related issues are of most concern nowadays. Electrical Power quality is the degree of any deviation from the nominal values of the voltage magnitude and frequency. From the customer perspective, a power quality problem is defined as any power problem manifested in voltage, current, or frequency deviations that result in power failure or disoperation of customer of equipment[1]. The waveform of electric power at generation stage is purely sinusoidal and free from any distortion. Many of the Power conversion and consumption equipment are also designed to function under pure sinusoidal voltage waveforms. However, there are many devices that distort the waveform. These distortions may propagate all over the electrical network.

The widespread use of electronic equipment, such as information technology equipment, power electronics such as adjustable speed drives (ASD), programmable logic controllers (PLC), energy-efficient lighting, led to a complete change of electric loads nature. These loads are simultaneously the major causers and the major victims of power quality problems .

Mainly there are different power quality problems. Voltage sag, voltage swell, harmonics, very short interruptions, long interruptions, voltage spike,noise, voltage unbalance these are the main PQ problems in power system. A wide diversity of solutions to power quality problems is available for both the distribution network operator and end user. The measure of power quality depends upon the needs of the equipment that is being supplied.

Custom Power devices is a better solution for these Power Quality related issues in distribution system[2]. Out of these available power quality enhancement devices, the UPQC has better sag/swell compensation capability. Controlling methods has the most significant role in any power electronics based system. It is the control strategy which decides the efficiency of a particular system. The efficiency of a good UPQC system solely depends upon its various used controlling algorithm. [2]The UPQC control strategy determines the current and voltage reference signals and thus, decides the switching times of inverter switches, so that the expected performance can be achieved. In this proposed work Particle Swarm Optimization is used as the control algorithm and the effect of this controlling method based UPQC in a 14 bus test systems is presented. In the proposed control method, load / source voltages and source voltage /current are measured, analyzed, and tested under unbalanced and distorted load conditions.

II. OVERVIEW OF UPQC-S CONCEPT

At distribution level UPQC is the most attractive solution to compensating many power Quality problems. 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 system configuration of a UPQC is shown in fig.1.

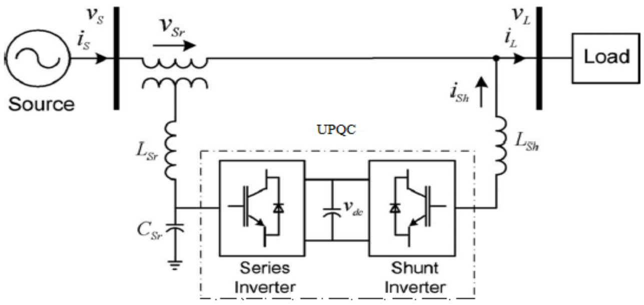

Fig. 1 System Configuration of a UPQC

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

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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[3].

Mainly 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, which is known as VA_{min}. The VA loading in UPQC-VAmin is determined on the basis of voltage sag, may not be at optimal value. The voltage sag/swell on the system is one of the most important power quality problems in distribution. In the paper [9], the authors have proposed a concept of power angle control (PAC) of UPQC. 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.

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.

III. POWER ANGLE CONTROL APPROACH

The voltage sag on the distribution network can be effectively compensated by reactive [8], as well as the active power. With the reactive power control approach the load-reactive power can be compensated by certain percentage along with the voltage sag compensation. In such an approach, the series voltage is injected in such a way that it maintains the quadrature relationship with source current, i.e., no active power involvement[3]. From this paper with proper control of the power angle difference between the source and load voltage, the series APF can also help in compensating the load-reactive power demand without putting extra active power burden on the source during the normal steady-state operating condition. 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. The phasor representation of the Power Angle Control approach under a rated steady-state condition is shown in figure 2.

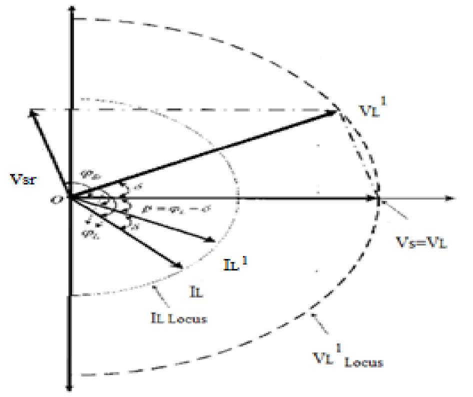

Fig. 2 Concept of PAC of UPQC

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 V_S and resultant load V_{L1} voltages maintaining the same voltage magnitudes[4]. This power angle shift causes a relative phase advancement between the supply voltage and resultant load current I_{L1} 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[11].

For the rated steady state condition,

$$|V_S| = |V_L| = |V_{L*}| = |V_{L1}| = k \qquad (1)$$

Phasor V_{Sr} can be defined as,

$$V_{Sr} = |V_{Sr}| \angle \phi_{Sr} \qquad (2)$$

$$= (k \cdot \sqrt{2}\sqrt{1 - \cos\delta}) \angle (90 + \delta/2)$$

Where

$$\delta = \sin - 1 \left(\frac{Q_{Sr}}{P_L}\right) \qquad (3)$$

Where V_S is the source voltage, V_L is the load voltage, δ is the power angle and k is the reference load voltage magnitude.

IV. 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.3.

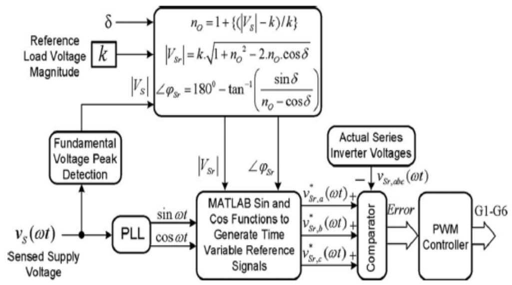

Fig. 3 Control scheme for series inverter of UPQC

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[5]. 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 [9].

V. CONTROLLING TECHNIQUES

A. Fuzzy Logic Controller (FLC)

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[6]. 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 Fuzzy Controller is basically nonlinear and adaptive in nature. The results obtained through FC are superior in some cases.

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.

Fuzzy controllers are mainly of two types:

1.TAKAGI-SUGENO FUZZY Controller

2.MAMDANI FUZZY Controller

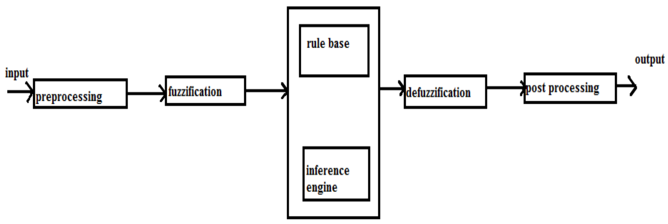

Fig. 4 Fuzzy control system

B. Particle Swarm Optimization (PSO) Algorithm

Particle swarm optimization (PSO) is a computational method that optimizes a problem by iteratively trying to improve a candidate solution with regard to a given measure of quality [12]. This algorithm was simplified and it was observed to be performing optimization. PSO gets better results in a faster, cheaper way compared with other methods. There are only few parameters to adjust. PSO does not use the gradient of the problem being optimized, which means PSO does not require that the optimization problem be differentiable .PSO makes few or no assumptions about the problem being optimized can search very large spaces of candidate solutions.

PSO also used on optimization problems that are partially irregular, noisy, change over time, etc. This new approach features many advantages; it is simple, fast and easy to be coded. Also, its memory storage requirement is minimal. Moreover, this approach is advantageous over evolutionary and genetic algorithms in many ways. First, PSO has memory. That is, every particle remembers its best solution (local best) as well as the group best solution (global best). Another advantage of PSO is that the initial population of the PSO is maintained, and so there is no need for applying operators to the population, a process that is time and memory storage- consuming. In addition, PSO is based on "constructive cooperation" between particles, in contrast with the genetic algorithms, which are based on "the survival of the fittest".

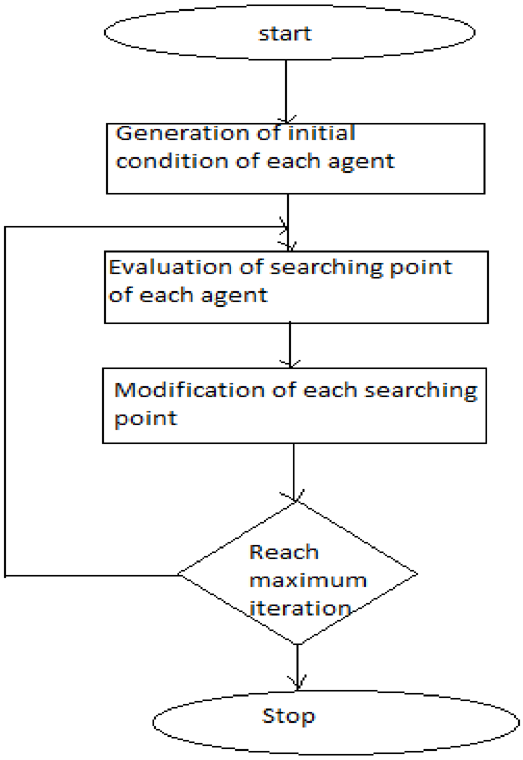

Fig.5 Flow Chart of PSO

VI. SIMULATION RESULTS

The simulation results for the proposed UPQC-S approach under voltage sag and swell conditions are given in Fig.6.

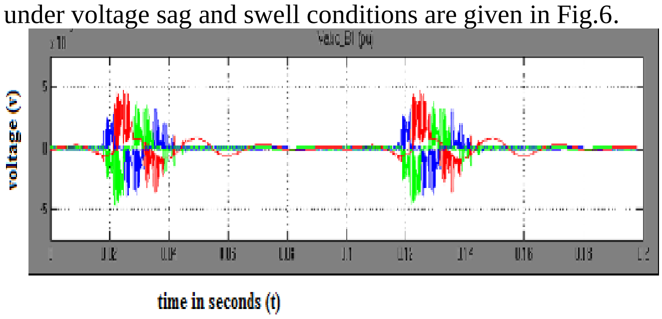

Figure. 6(a) Load voltage under sag condition

The proposed concept is implemented on IEEE 14 bus system. Here figure (a) shows the three phase wave form of load voltage under sag conditions. The load voltage magnitudes are decrees from .1 to .9 of the nominal value of voltage under this condition.

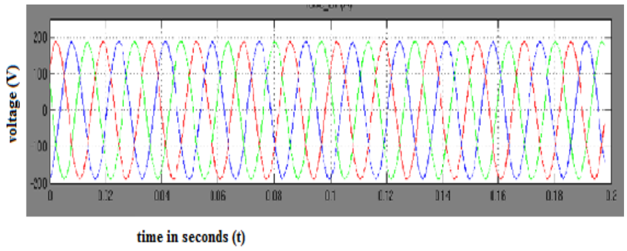

Figure. 6(b) Regulated load voltage using UPQC

Figure (b) shows the regulated load voltage wave form using the UPQC device. After the compensation load voltage wave forms become sinusoidal and the magnitudes is approximately equal to 1.

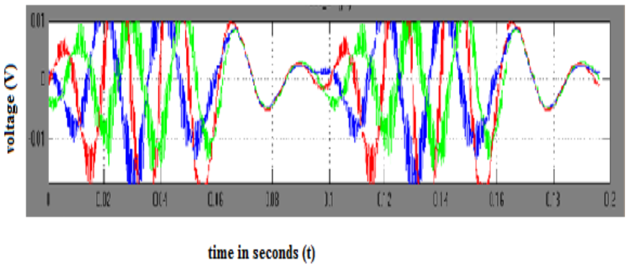

Figure. 6(c) Load voltage under swell condition

Figure (c) represents the three phase load voltage under the swell condition. The load voltage magnitudes are increases from 1.1 to 1.8 of the nominal voltage value. The compensation is done using the UPQC device and after this the load voltage is purely sinusoidal and nearly equal to 1.

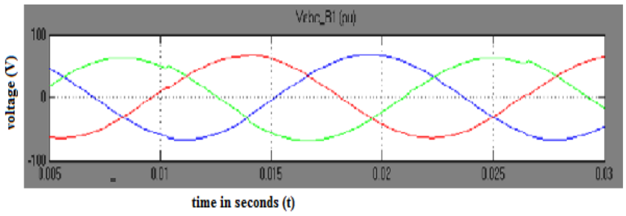

Figure. 6(d) Series injected voltage

The series injected voltage is represented by the figure (d). The series injected voltage is used to compensate the voltage related problems on the system.

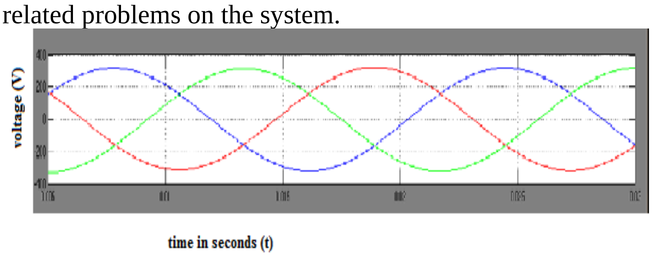

Figure. 6(e) Shunt injected current

Figure (e) shows the shunt injected current by the device. The shunt injected current is used to mitigate the current related problems on the system.

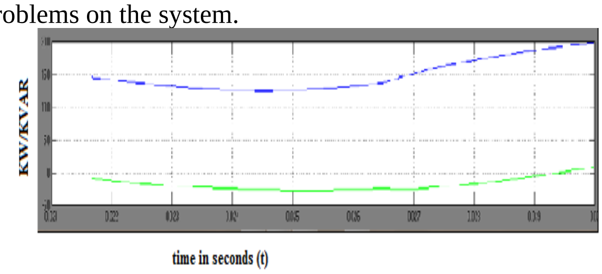

Figure. 6(f) Series inverter active and reactive power

From figure 5 (f) shows the series inverter active and reactive power and (g) shows the shunt inverter active and reactive power. the reactive power supplied by the series inverter during the voltage sag condition increases due to the increased source current.

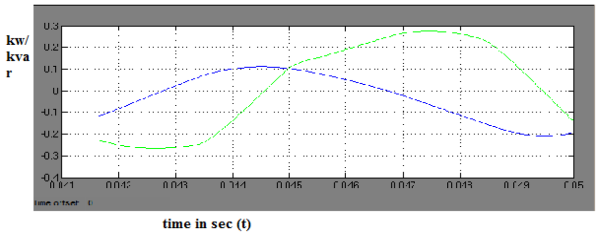

Figure. 6(g) Shunt inverter active and reactive power

As load reactive power demand is constant, the reactive power supplied by the shunt inverter reduces accordingly. On the other hand, during the voltage swell condition, the reactive power shared by the series inverter reduces and the shunt inverter increases.

VII. CONCLUSION

In distribution system power Quality problem is a major issue. Out of the custom power devices UPQC is the most effective device for mitigating these issues. In this paper a new concept for the optimal utilization of UPQC is introduced. Using the UPQC device the voltage sag and swell can be mitigated successfully. The complex power (simultaneous active and reactive powers) controlling through series inverter of UPQC is proposed and named as UPQC-S. Here the controlling of series inverter of UPQC is done using the PSO based fuzzy logic controller. 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.

The membership function of the fuzzy controller is optimized using the PSO algorithm. Also the use of Particle Swarm Optimization algorithm improves the output results. That is the effectiveness of voltage sag /swell mitigation is increased. In future both inverters can be controlled. The series inverter can be controlled using ANFIS controller with different evolutionary algorithms such as GA, Ant Colony algorithm etc. ANFIS controller is the combination of neural and fuzzy controller.

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