Design of UPQC by Optimizing PI Controller using GA and PSO for Improvement of Power Quality

T.Gunasekar, Dr.R.Anita

***Abstract*— This paper presents a new control design of an Unified Power Quality Conditioner (UPQC). The DC link capacitor of UPQC is controlled by using PI controller. The conventional method of obtaining the coefficients of proportional plus integral (PI) controllers for the active power filter utilizes a linear model of the PWM inverter. This paper presents a new algorithm based genetic algorithm and Particle Swam Optimization to optimize the coefficients of the PI controller. Through the simulation results, it is observed that the dynamic response of the Particle Swarm Optimization algorithm PI (PSO–PI) controller is quite satisfactory. A simulation study of the proposed topology has been carried out using MATLAB/Simulink and the results are discussed.**

***Index Terms*—Coupling Transformer, Fuzzy Logic, Genetic algorithm, Hysteresis Controller, Phase Locked Loop, Particle Swam Optimization, Series Active Filter, Shunt active filter, Synchronous Reference Frame, Dc link capacitor**

I. Introduction

In modern electrical distribution system there has been a sudden increase of nonlinear loads, such as power supplies, rectifier equipment used in telecommunication networks, domestic appliances, adjustable speed drives, etc. These power electronic converters are from low power domestic applications to high power adjustable speed drives (ASDs). This power electronic converter generates harmonics which includes fundamental, third, fifth etc and other higher harmonics. These harmonic current may cause power quality degradation, transformer overheating, malfunctioning of medical facilities, destruction of electric power components, pollute the power system and rotary machine vibration etc. Many power quality standards are proposed, such as IEC1000-3-2 and IEEE519-1992 etc. To maintain the harmonic level and the harmonics can be suppressed by a passive or active power filter. However the passive filters are suffering from the disadvantages such as sensitive to the variation of frequency, system impedance, and possibility of series/parallel resonance and fixed filter frequency. Because of series/parallel resonance it may cause the damage to inductor and capacitor of passive power filters. Performance of passive power filter can be affected by the system impedance and APF's are used to resolve passive filters problems. APF'S are shunt active and series active power filter. The shunt active power filters (APFs) are used to eliminate current harmonics, load balancing, power factor correction of three-phase four wire distribution system and the series active filters are used to eliminate the voltage harmonics. DC Capacitors are used to give the supply for both filters. It is controlled by using PI controller. Some recently developed evolutionary algorithms, notably genetic algorithms (GAs), Partical Swarm Optimization, make optimal tuning of PI controllers. In this paper genetic algorithm and Particle Swarm Optimization is used for tuning of PI controller and the Comparison is made. The hysteresis band is implemented with fuzzy logic to improve the system performances. The effectiveness of the proposed controller is discussed below.

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II. Block Diagram Description

Fig 1 shows the block diagram of Unified Power Quality Conditioner. It consists of a three-phase source, which is connected to non-linear load. The UPQC is connected before the load to make the source and the load voltage free from any distortions. The UPQC, carried out by using two VSIs, is shown in Fig. 1.one VSI acts as the shunt APF and the other as the series APF. The shunt APF is realized using a three-phase, three-leg VSI, and the series APF is carried out using a three-phase, three-leg VSI. Both APFs share a common dc link between them.

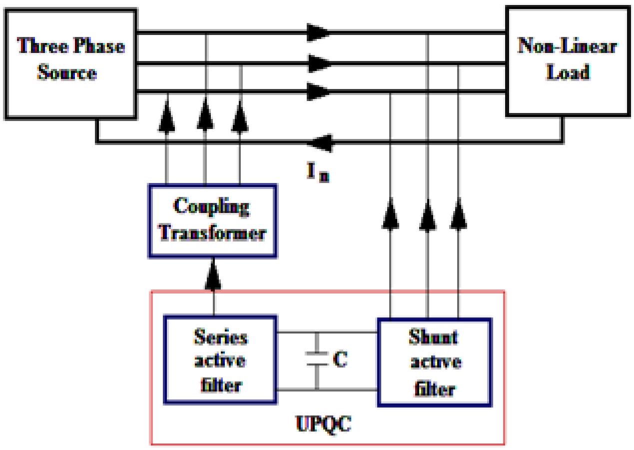

Fig 1. Block Diagram of UPQC

The Series Active Power Filter is coupled using coupling transformer and the shunt active filter is connected in parallel with the phases. The proposed control strategy aims to generate reference signals for both shunt and series APFs of the UPQC. The series active filter is controlled to eliminate voltage harmonics and the shunt active filter is controlled to alleviate current from harmonics and load balancing. The inverter can be implemented by IGBTs operating with the fuzzy hysteresis controller for the filtering function.

III. FUNDAMENTAL COMPONENT EXTRACTION

There are different control strategies being used for the calculation of reference currents in active power filter namely Instantaneous Reactive Power Theory (p-q theory), Unity Power Factor method, One Cycle Control, Fast Fourier Technique etc. In this paper, SRF theory is used to extract the three-phase reference currents and voltages used by the active power filters. Fig.2 shows the block diagram of three-phase SRF-theory, used for harmonic component extraction. The synchronous reference frame theory is used to extract the fundamental component in the supply voltage or current. It is based on the transformation of the currents or voltages in synchronously rotating d-q frame. If θ is the transformation angle, then the current and voltage transformation from α-β to d-q is defined as in the Fig 2 In this method, the source currents and voltages are first detected and transformed into two-phase stationary frame (αβ-*0*) from the three-phase stationary frame (a-b-c), as per equation (1)

$$\begin{bmatrix} i_\alpha \\ i_\beta \\ i_o \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (1)$$

Now, the two phase current quantities iα and iβ of stationary αβ-axes are transformed into two-phase synchronous (or rotating) frame (d-q-axes) using equation (2), where cosθ and sinθ represents the synchronous unit vectors which can be generated using phase-locked loop system (PLL).

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (2)$$

The d-q currents thus obtained comprises of AC and DC parts. The fundamental component of current is represented by the fixed DC part and the AC part represents the harmonic component. This fundamental component can be easily extracted using a Low Pass Filter (LPF), as implemented in Figure 2. Now inverse transformation is performed to transform the currents from two –phase synchronous frame d-qinto two-phase stationary frame α-β as per equation(3)

Fig 2. SRF Method

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} i_{ca}^* \\ i_{cb}^* \\ i_{cc}^* \end{bmatrix} = \left[T_{abc} \right] \begin{bmatrix} i_\alpha \\ i_\beta \\ i_o \end{bmatrix} \quad (4)$$

Finally the current from two phase stationary frame αβ0 is transformed back into three-phase stationary frame abc as per equation (4) and the compensation reference currents ica*, icb* and icc* are obtained for the shunt active filter and as same voltage signals are obtained by giving the voltage signal as the input.

IV. FUZZY LOGIC CONTROLLER

Fuzzy set theory exhibits immense potential for effective solving of the uncertainty in the problem. It is an outstanding mathematical tool to handle the uncertainty arising due to vagueness. Fuzzy logic control is divided into Fuzzification, inference and defuzzification which is shown in Fig.3.

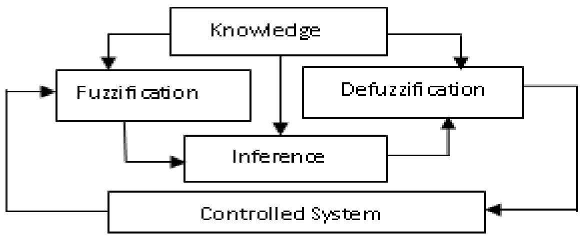

Fig 3. Fuzzy Inference System

The knowledge base is composed of a data base and rule base and is designed to obtain good dynamic response under uncertainty in process parameters and external disturbances.

The data base consisting of input and output membership functions, provides information for the appropriate fuzzification operations, the inference mechanism and defuzzification. The inference mechanism uses a collection of linguistic rules to convert the input conditions into a fuzzified Output. Finally, defuzzification is used to convert the fuzzy outputs into control signals. In designing of a fuzzy control system, the formulation of its rule set plays a key role in improvement of the system performance. The mamdani type fuzzy logic controller is used, the max-min inference method is applied in this study.

CHANGE IN ERROR /ERROR	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

Table 1: Fuzzy Rule Table

V. FUZZY HYSTERESIS CONTROLLER

The hysteresis band current control (HBCC) technique is used for pulse generation in VSIs shown in Fig.4.

The control method offers good stability, gives a very fast response, provides good accuracy and has got a simple operation. It consists of a hysteresis band surrounding the generated error signal. The error is obtained by subtracting the actual signal from the reference signal. The reference signal used here is obtained by the SRF method. The error signal is then fed to the fuzzy and then fed to relay with the desired hysteresis band to obtain the switching pulses for the inverter.

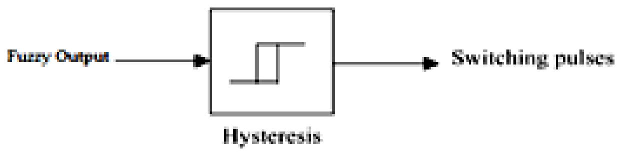

Fig 4. Hysteresis Controller

VI. DC LINK VOLTAGE

The dc side voltage of APF should be controlled and kept at a constant value to maintain the normal operation of the inverter. Because there is energy loss due to conduction and switching power losses associated with the diodes and IGBTs of the inverter in APF, which tend to reduce the value of V_{dc} across capacitor C_{dc}. A feedback voltage control circuit needs to be incorporated into the inverter for this reason. The difference between the reference value, V_{ref} and the feedback value (Vdc), an error function first passes a PI regulator and the output of the PI regulator is subtracted from the d axis value of the harmonic current components. The PI controller values are tuned using Genetic Algorithm and Particle Swam Optimization. The DC capacitor voltage can be found by using the equation.

$$V_{dc} = \frac{2\sqrt{2}V_{LL}}{\sqrt{3}} \qquad (5)$$

VII. GENETIC ALGORITHM

The basic principles of Genetic Algorithm (GA) were first proposed by Holland. It is inspired by the mechanism of natural selection where stronger individuals would likely be the winners in a competing environment.

In this Genetic Algorithm approach is used to determine the optimized value of PI controller parameters namely Kp and Ki. The genetic algorithm starts with no knowledge of the correct solution and depends entirely on responses from its environment and evolution operators (i.e. reproduction, crossover and mutation) to arrive at the best solution. By starting at several independent points and searching in parallel, the algorithm avoids local minima and converging to sub optimal solutions. In this way, GA has been shown to be capable of locating high performance areas in complex domains without experiencing the difficulties associated with high dimensionality, as may occur with gradient descend techniques or methods that rely on derivative information.

A genetic algorithm is typically initialized with a random population consisting of between 20-100 individuals.

This population (mating pool) is usually represented by a real valued number or a binary string called a chromosome. How well an individual performs a task is measured is assessed by the objective function.

The objective function assigns each individual a corresponding number called its fitness. The fitness of each chromosome is assessed and a survival of the fittest strategy is applied. The flowchart for GA is shown in Fig 5.

The objective function is given as,

$$1 + \left(kp + \frac{ki}{s}\right)\frac{3[vs - sLcIco - 2IcoRc]}{CdcVdco} = 0 \quad (6)$$

Where

C_{dc}, V_{dc} dc-side capacitor and its voltage
V_s, I_c ac-side voltage and current of PWM inverter
L_c,R_c Filter inductance and its resistance
I_{co},V_{dco} steady-state operating points of Ic and Vdc

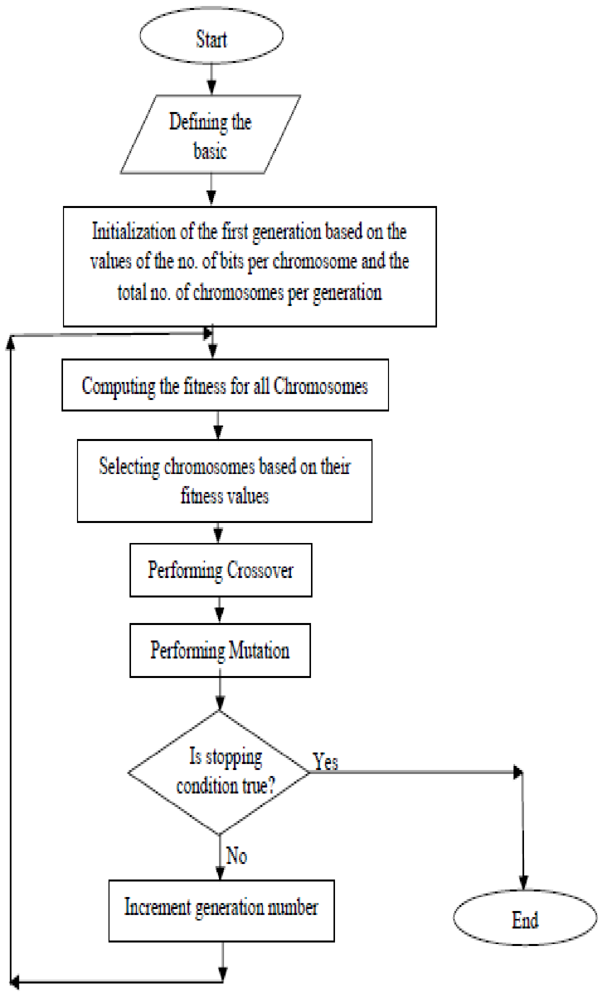

Fig 5. Flow chart for Genetic Algorithm

VIII. PARTICLE SWAM OPTIMIZATION

In order to improve the power quality further by reducing the THD to great extent, Particle Swam Optimization technique is used to tuning the parameters of the PI controller. PSO is a population based stochastic optimization technique inspired by social behavior of bird flocking or fish schooling. PSO learns from the scenario and uses it to solve the optimization problems.

In PSO, each single solution is a bird in the search space which is called as particle. All particles have fitness values which are evaluated by the fitness function to be optimized, and have velocities which direct the flying of the particles. The particles fly through the problem space by following the current optimum particles. PSO is initialized with a group of random particles (solutions) and then searches for optima by updating generations. In each iteration, every 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 that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the population. This best value is a global best and called gbest. PSO has the good sharp of finding the optimal fitness function and also has proved it effectiveness in finding the optimal K_P and K_i parameters. The flow chart for particle swam optimization is shown in Fig.6.

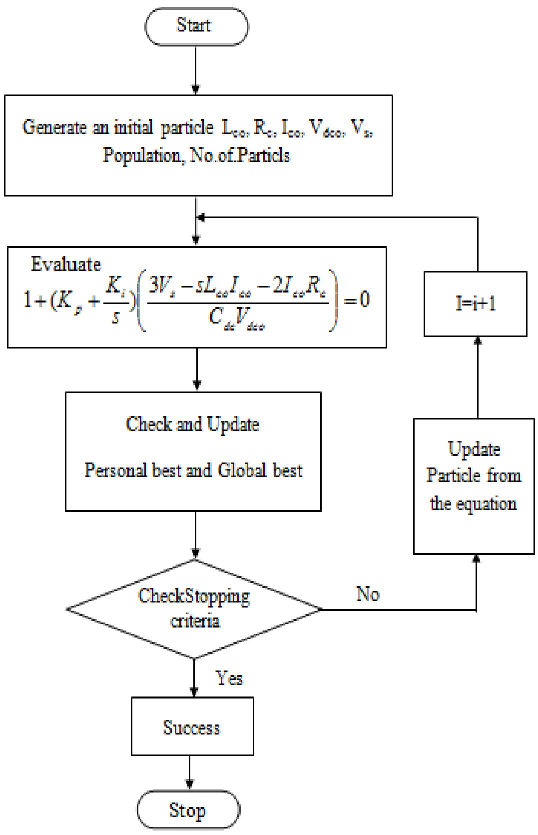

Fig 6. Flow chart for Particle Swam Optimization

IX. RESULT AND DISCUSSION

The simulation results without filter shown in figure 5 it shows that the voltage contains harmonics and the load current contains harmonics and it is unbalanced. Due to the unbalanced nature the neutral current flow is high. MATLAB SIMULINK model for the proposed system is shown in Fig 7.The installation of UPQC compensates the harmonics and unbalance and the neutral current magnitude gets reduced effectively. The DC link Capacitor value is maintained constant using the GA and PSO. Fig.8 shows the waveform with GA tuning and Fig.9 shows the waveform with PSO tuned PI controller. The THD values without UPQC, GA tuned and PSO tuned PI controller is shown in Table.2.

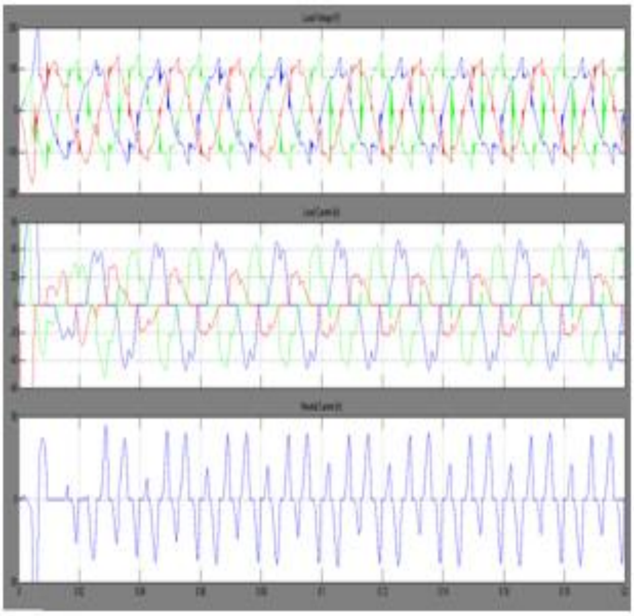

Fig 7. Load Voltage, Load Current and Neutral current waveform without UPQC

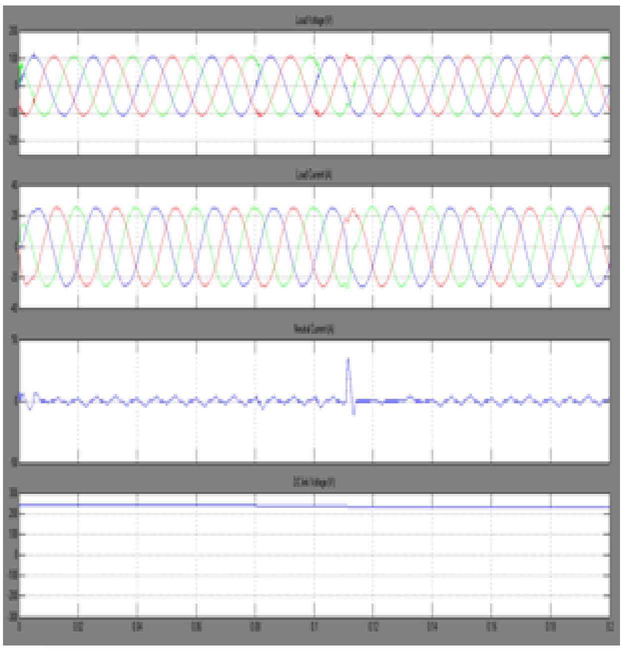

Fig 8. Load Voltage, Load Current and Neutral current waveform with GA UPQC

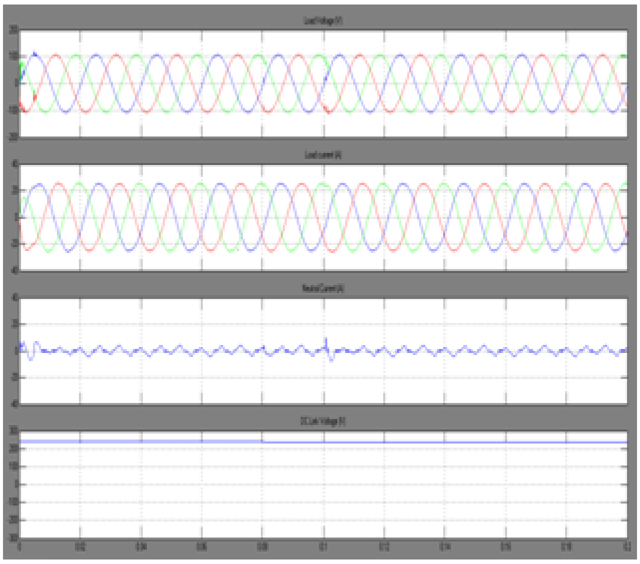

Fig 8. Load Voltage, Load Current and Neutral current waveform with PSOs UPQC

Table.2. Comparison of THD GA Vs PSO

Controller	Load Currents						Load Voltages		
	Magnitude (Amps)			THD (%)			THD (%)		
	I_{La}	I_{Lb}	I_{Lc}	I_{La}	I_{Lb}	I_{Lc}	V_{La}	V_{Lb}	V_{Lc}
Without UPQC	35.82	32.93	18.61	34.3	38.4	34.0	20.2	22.6	13.3
GA based PI Controller	25.60	25.82	25.63	2.20	2.48	1.59	1.11	1.29	1.07
PSO based PI Controller	25.64	25.68	25.65	2.14	2.05	1.52	0.96	1.08	0.93

X. CONCLUSION

This paper describes GA and PSO tuned PI and Fuzzy based control strategy used in the UPQC, which mainly compensates the reactive power along with voltage and current harmonics under unbalanced load-current conditions. For proposed system the simulation results with PSO techniques prove to be more effective than with GAs. In GAs, the limits defined by the number of parameters gives the search region while in PSO, the search region is independent of the number of parameters, given by the distance between the randomly selected initial position and the position corresponding to optimal fitness value. The speed of computation is determined by the velocity initializing the PSO algorithm with which it reaches to the best solution. It is also observed that the speed of computation in PSO is very less in comparison to GAs.

APPENDIX

Supply voltage: 110V, 50Hz.
Load Used:
Three Single phase loads
Load 1: R=15Ω; C = 1000µf
Load 2: R=25Ω ; C = 1000µf
Load 3: R=50Ω; C = 1000µf
Single Three phase load:
R=10Ω ; C = 1000µf
DC link voltage: 240V.
DC link capacitance value: 2500µf
Ripple filter parameters: L_f=1.8mH, R_f=0.25Ω.
Dc link voltage PI controller parameters:
K_p = 0.0125, K_i=9.99.(Tuned using GA)
K_p = 0.0315,k_i=10.0 (Tuned using PSO)

REFERENCES

[1] A. Arabali, M. Ghofrani, M. Etezadi-Amoli, M. S. Fadali, and Y. Baghzouz, "Genetic-Algorithm-Based Optimization Approach for Energy Management" IEEE Transactions On Power Delivery, Vol. 28, No. 1, January 2013

[2] Bhim Singh , Venkateswarlu.P, "A Simplified Control Algorithm for Three-Phase Four-Wire Unified Power Quality Conditioner"2010

[3] Dr.S.Murugan, M.Tech., Ph.D and M.L.Ashly Beby,"Improvement of Unified Power Quality Conditioner based on GA Optimized NN Controller" International Journal of Electrical Engineering.ISSN 0974-2158 Volume 7, Number 1 (2014), pp. 25-34

[4] Fatiha Mekri , Mohamed Machmoum , Nadia Ait Ahmed , Benyounes Mazari, "A Fuzzy hysteresis voltage and current control of An Unified Power Quality Conditioner"2008

[5] Giuseppe Di Fatta, Frank Hoffmann, Giuseppe Lo Re, and Alfonso Urso, "A Genetic Algorithm for the Design of a Fuzzy Controller for Active Queue Management" IEEE Transactions On Systems, Man, And Cybernetics—Part C: Applications And Reviews, Vol. 33, No. 3, August 2003

[6] Hany M. Hasanien,, and S. M. Muyeen, " Design Optimization of Controller Parameters Used in Variable Speed Wind Energy Conversion System by Genetic Algorithms" IEEE Transactions On Sustainable Energy, Vol. 3, No. 2, April 2012

[7] Hurng-Liahng Jou, Jinn-Chang Wu, Yao-Jen Chang, and Ya-Tsung Feng,"A Novel Active Power Filter for Harmonic Suppression" 2005

[8] Jayalaxmi.A Bangarraju.J, and Rajagopal.V, "Shunt Active power filter for power quality enhancement using reduced sensor switching control strategy", Fifth International Conference on Power and Energy Systems, Kathmandu, Nepal 28 - 30 October, 2013

[9] Mukhtiar Singh, Vinod Khadkikar, Ambrish Chandra, and Rajiv K. Varma, "Grid Interconnection of Renewable Energy Sources at the Distribution Level With Power-Quality Improvement Features" IEEE Transactions On Power Delivery, Vol. 26, No. 1, Jan 2011

[10] Metin Kesler and Engin Ozdemir, "Synchronous-Reference-Frame-Based Control Method for UPQC Under Unbalanced and Distorted Load Conditions" IEEE Transactions On Industrial Electronics, Vol. 58, No. 9, September 2011.