Power quality enhancement using intelligent controllers for a Nine Switch Converter based UPQC

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Abstract- A unified power quality conditioner is a FACTS device which consists of both shunt and series converter with DC link capacitor. Each converter has six switches and these switches are controlled in order to mitigate power quality issues. A nine switch UPQC topology is proposed to reduce the switches in UPQC. But this topology has some limitations such as more switching stress, high value of DC link voltage etc. Hence in this work, intelligent control techniques are implemented in this nine switch UPQC to overcome the aforementioned issues. The proposed control techniques for UPQC are implemented in MATLAB/Simulink and the results are validated for various Nonlinear loads, sag and swell conditions.

1. Introduction

Nowadays, the emergent intricacy of the electric power transmission and distribution system has made the usage of modern Flexible AC Transmission System (FACTS) as inevitable. A FACTS device naturally consists of a power semiconductor device, hence affect the power quality of the system by injecting harmonics into the delivered power [1]. In addition the usage of power electronic converters has also affected the power quality. The power to be delivered to the consumer should be in required quantity and also its quality should be maintained. The consumers inject harmonics in the form of AC to DC converters and AC and DC drives, the utility inject harmonics in the form of FACTS devices [2]. The familiar FACTS devices are Static Synchronous Compensator (STATCOM), the Static Synchronous Series Compensator (SSSC), the Unified Power Flow Controller (UPFC) and the Dynamic Voltage Restorer (DVR).

The UPFC is a significant FACTS candidate in electric power transmission system. It consists of a STATCOM and SSSC with common DC link. The main function of UPFC is real and reactive power compensation, voltage sag/swell compensation, fault tolerant etc. The UPFC maintain the voltage profile of the system during the aforementioned issues. It guarantees the delivery of electric power at the desired voltage and frequency levels with improved power factor.

The UPQC consists of shunt and series converter and each converter has 6 switches [3]. Therefore it requires minimum 12 switches to achieve the desired power quality. In order to reducing the total cost of the system, minimization of number of switches is essential. But it is a challenging task for every researcher. The topology of UPQC can be modified into ten switch topology, nine switch topology, matrix converter based topology, and four legs VSI based UPQC etc. Matrix converter based topology suffers from increasing the number of switches and unidirectional power flow. The four leg inverter has the limitations, that at AC interface both converters have operated at same frequency. Ten switch and nine switch topology mitigate the power quality issues satisfactorily, but it increases the switch current rating to a considerable limit [4-6]. Therefore the size of the switches must be oversized and all the switches are remain operated irrespective of UPQC compensation. Hence its reliability is affected. It also suffers from high switching stress and phase shift. Hence in order to overcome the aforementioned issues, intelligent control techniques based nine switch UPQC are proposed in this work.

2. Topology of Nine switches Unified Power quality conditioner:

UPQC consists of both shunt and series converter in which dc link capacitor connects the converters back to back. shunt converter is a current source and series converter is a voltage source. Shunt converter injects current harmonics and series converter injects voltage harmonics for compensation. The traditional UPQC topology performs satisfactorily, it has limitations, that at lower modulation in the series converter leads to computational issues. Hence nine switch topology is proposed in [4]. The topology of nine switch UPQC is shown in Figure 1. It consists of three legs, and each leg consists of three switches. As depicted in Figure 1, the combination X acts as a series converter and combination Y serves as a shunt converter. For upper switches reference wave is generated by using load voltage error and for lower switches the reference wave is generated by source current error. For middle switches the gate pulse are generated by using gate pulses of both upper and lower switches as shown in Equation(1).

$$S_7 = \overline{S_1 \bullet S_4}\ , S_8 = \overline{S_2 \bullet S_5}\ , S_9 = \overline{S_3 \bullet S_6} \qquad (1)$$

Reference load voltages and source currents are generated using instantaneous reactive power theory.

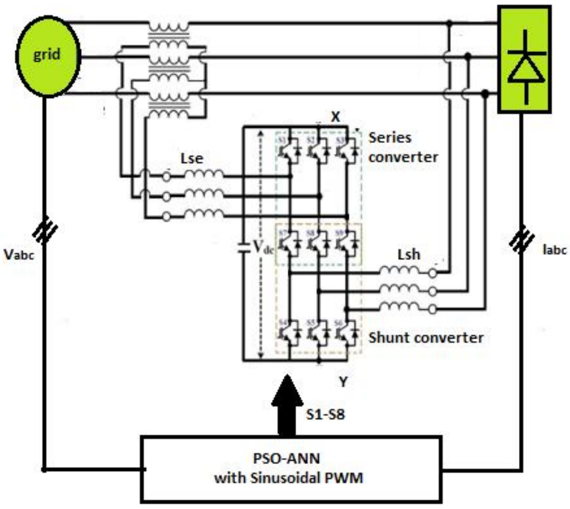

Figure 1. Block diagram of nine switch UPQC

3. Control techniques

3.1. Parks transformation

The parameters to be controlled in UPQC are source current and load voltage. Both these quantities are time varying sinusoidal three phase quantities. Hence in order to control real and reactive power independently and to satisfy bandwidth requirements, these time varying quantities are converted into DC like quantities. The transformation used for this conversion is parks transformation. The three phase voltage or current quantities are converted into d and q component as shown in Equation (2 & 3)

$$\begin{bmatrix} v_d \\ v_q \\ v_0 \end{bmatrix} = \begin{bmatrix} \sin\theta & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) \\ \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}$$

(2)

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} \sin\theta & \cos\theta & 1 \\ \sin\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta - \frac{2\pi}{3}\right) & 1 \\ \sin\left(\theta + \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) & 1 \end{bmatrix} \begin{bmatrix} v_d \\ v_q \\ v_0 \end{bmatrix}$$

(3)

3.2. Fuzzy logic control scheme

FLC is a knowledge based system. This technique is based on human experience and deals with linguistic variables. The conventional controller like PID controller needs an exact mathematical model of the system. But the FLC does not need a precise model. Hence it is used when there is non availability of mathematical model or the model has high complexity. FLC gives the convincing solution not accurate solutions.

The four FLC used in this work are of mamdani type with two inputs such as error and error rate and the output is a controllable parameter. The controllable parameter may be modulation index (MI), phase angle. From the MI and phase angle, a reference sine wave is created and compared with carrier to give the gate pulses. The control in FLC is done by linguistic rules. These rules are framed based on knowledge about the system. The three basic functions of FLC are fuzzification, interference and defuzzification [8-10]. The membership function used is triangular. The error and change in error is defined by the Equation (4).The rule base is shown in Table 1.

$$E(k) = \frac{X_{ph(k)} - X_{ph(k-1)}}{Y_{ph(k)} - V_{ph(k-1)}} \qquad (4)$$

$$CE(k) = E(k) - E(k-1) \qquad (5)$$

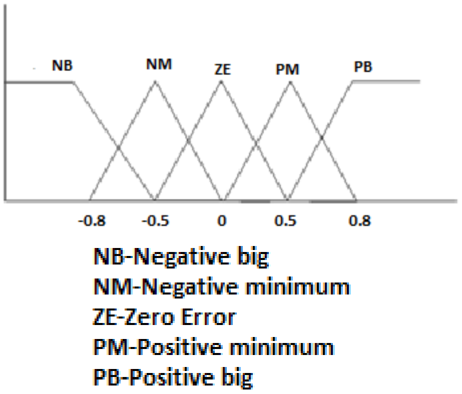

Figure 2. Universe of discourse

Table 1. Fuzzy rule base

Error Error rate	NB	NM	ZE	PM	PB
NB	NB	NB	NB	NM	ZE
NM	NB	NB	NM	ZE	PM
ZE	NB	NM	ZE	PM	PB
PM	NM	ZE	PM	PB	PB
PB	ZE	PM	PB	PB	PB

The FLC rules are derived from Equation (6).

$$u = -[\alpha E + (1-\alpha)C] \tag{6}$$

where, α is called the self-adjustable factor,
E is the error of the system,
C is the varying ratio error and
u is the control variable

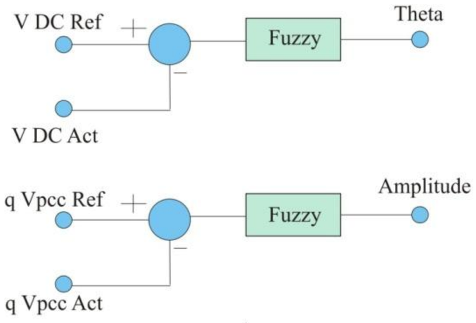

Figure 3. FLC for shunt converter

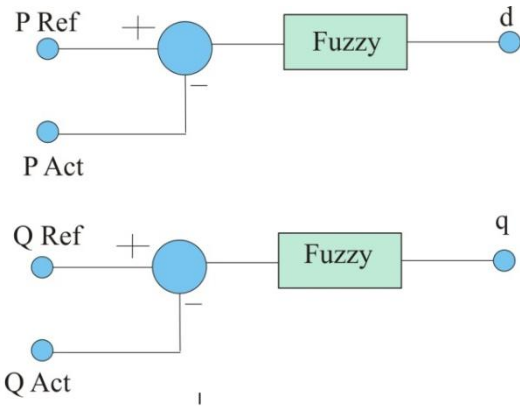

Figure 4. FLC for series converter

3.3. ANN CONTROLLER

ANN mimics the human brain. In this work feed forward neural network structure is used. The typical feedforward ANN has three layers, input, output and hidden layer. The neurons are the functional element in ANN and it performs the functions called activation function [11]. The neurons in one layer is connected to other layer through synapse and the weight is called synaptic weight. At learning phase, the synaptic weights vary with each iteration. The typical neuron structure is shown in Figure. It consists of two inputs and two outputs. The data set of 1000 samples for ANN system are taken from PI controller. Of which 75% is used for training and 25% is used for testing. The inputs are error of dc link voltage and error in load voltage and the outputs are modulation index and phase angle.

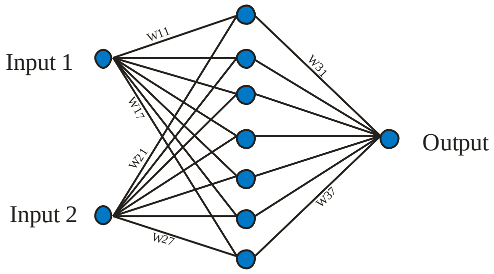

Figure 5. Typical ANN network

3.4. PSO-ANN

The PSO is a Meta heuristic search technique famed for its efficient computation and easy implementation [12]. The PSO is used along with ANN in this work. In ANN, the weight updating is a crucial part to get the feasible and accurate results. The weight updation in learning phase needs high computation. Hence PSO is used for updating synaptic weights in the learning phase. In back propagation algorithm, the systematic weight updation results in local optima. PSO avoids the local optima by include the randomness in particle initialization. The flow chart for the proposed technique is shown in Figure 6.

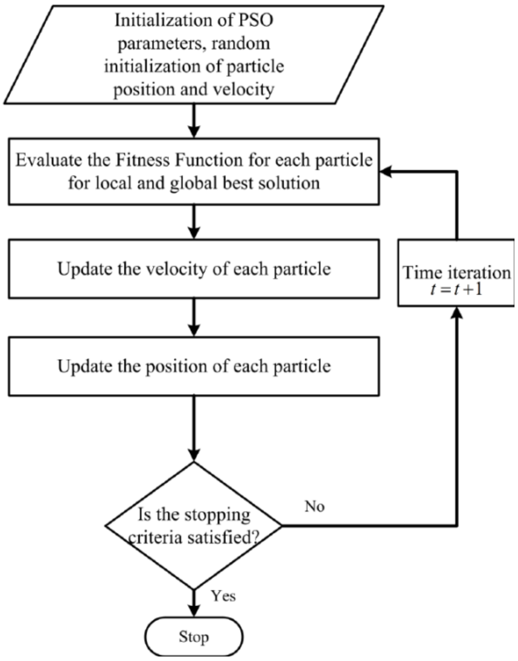

Figure 6. Flow chart for PSO

4. Results and discussion

The FLC, ANN and PSO-ANN for the nine switch UPQC was designed and implemented in MATLAB SIMIULINK.

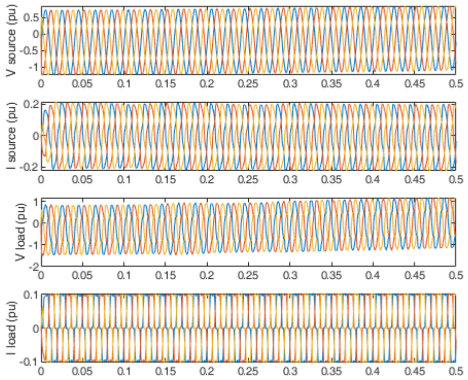

Figure 7. Source voltage, Source current, Load voltage and Load current for nonlinear load without nine switch UPQC

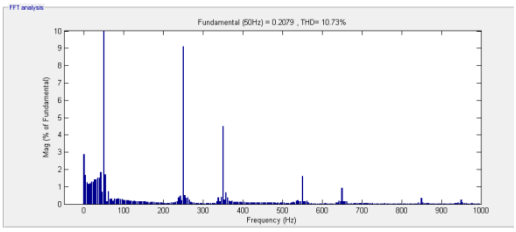

Figure 8. THD for non linear load without nine switch UPQC

The Figure 7 shows the source voltage, source current, load voltage and load current. The non linear load makes the source current distorted and the THD is increased without the nine switch UPQC. The THD pertaining to the non linear load is 10.73% and it is shown in Figure 8.

Figure 9 shows the source voltage, source current, load voltage and load current for the non linear load with nine switch UPQC using PSO-ANN. The UPQC is controlled by FLC, ANN and PSO-ANN. The THD corresponding to FLC, ANN and PSO-ANN is shown in Figures 10-12. From the figures 10-12, it is reveal that PSO-ANN improves the power quality of the system by reducing THD to 0.53%. Hence the PSO-ANN outperforms compared to FLC and ANN.

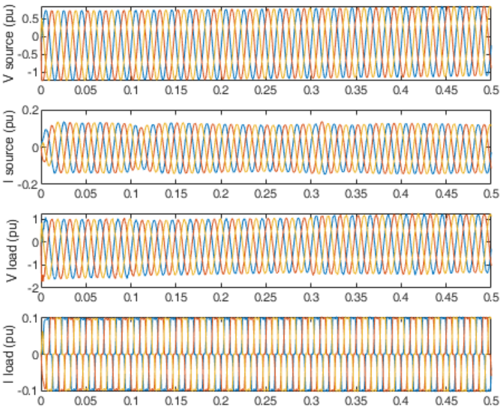

Figure 9. Source voltage, Source current, Load voltage and Load current for nonlinear load with nine switch UPQC using PSO-ANN

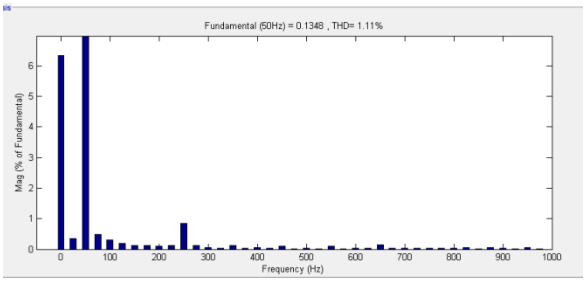

Figure 10. THD for non linear load with nine switch UPQC using FLC

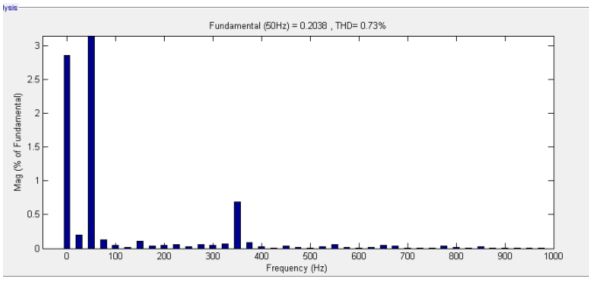

Figure 11. THD for non linear load with nine switch UPQC using ANN

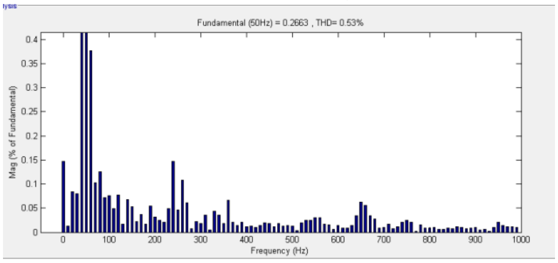

Figure 12. THD for non linear load with nine switch UPQC using PSO-ANN

A 10% sag condition is introduced during the period between 0.1 and 0.3 second. The source voltage reduced abruptly which will affect the load side voltage if UPQC is not present. The PSO-ANN based nine switch UPQC maintain the load voltage at the rated level. Figure 13 shows the source voltage, source current, load voltage and load current for the sag condition with nine switch UPQC using PSO-ANN. The real and reactive power compensation for both source and load side is shown in Figure 14. The power factor on the source side is maintained within 0.95-0.99 for reactive load with the help of nine switch UPQC as shown in Figure 15.

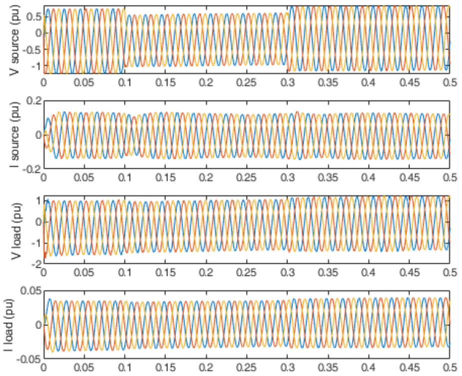

Figure 13. Source voltage, Source current, Load voltage and Load current for sag condition with nine switch UPQC using PSO-ANN

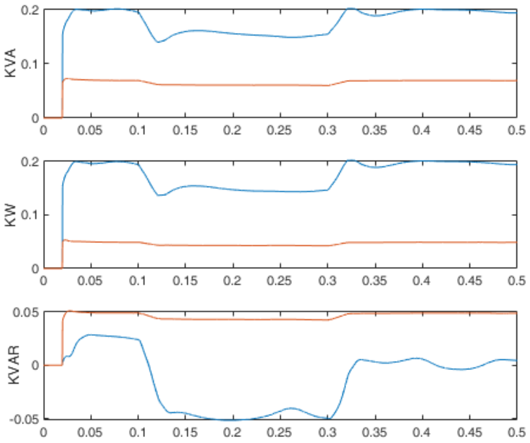

Figure 14. Reactive power, Real power and apparent power for sag condition

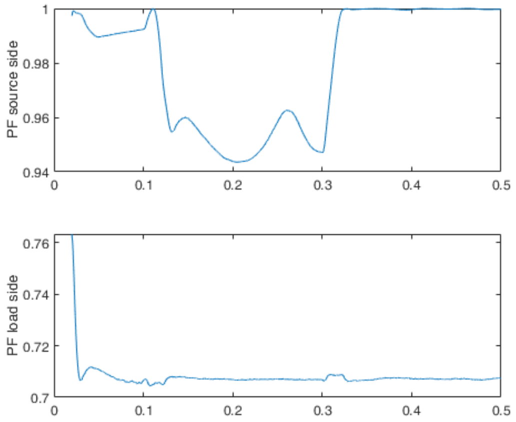

Figure 15. Power factor for source and load side

A 10% swell condition is introduced during the period between 0.1 and 0.3 second. The source voltage increased abruptly which will affect the load side voltage if UPQC is not present. The PSO-ANN based nine switch UPQC maintain the load voltage at the rated level. Figure 16 shows the source voltage, source current, load voltage and load current for the swell condition with nine switch UPQC using PSO-ANN. The real and reactive power compensation for both source and load side is shown in Figure 17. The power factor on the source side is maintained within 0.95-0.99 for reactive load with the help of nine switch UPQC as shown in Figure 18.

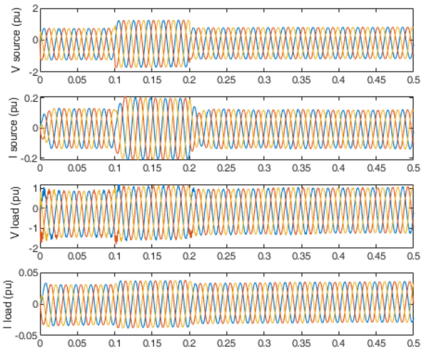

Figure 16. Source voltage, Source current, Load voltage and Load current for swell condition with nine switch UPQC using PSO-ANN

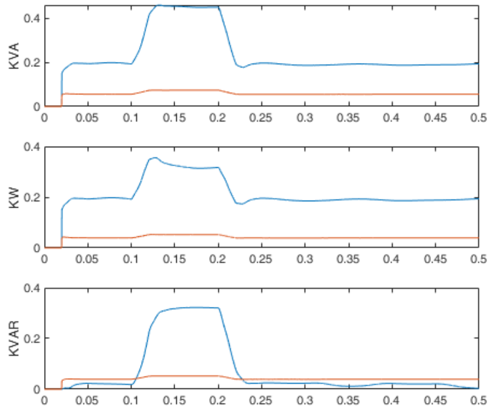

Figure 17. Reactive power, Real power and apparent power for swell condition

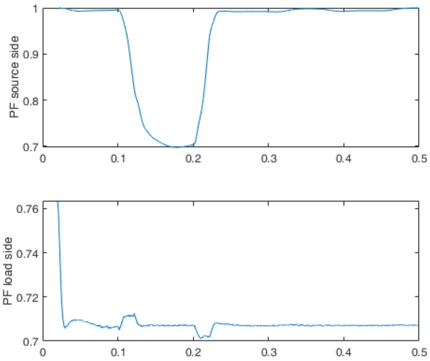

Figure 18. Power factor for source and load side for swell condition

Table 2. Comparison of controllers

Parameters	FLC	ANN	PSO-ANN
THD of source current	1.11%	0.73%	0.53%
Reactive power compensation	91%	92%	95%

5. Conclusion

A nine switch UPQC topology is proposed to reduce the switches in UPQC. Intelligent control techniques such as FLC,ANN and PSO-ANN are implemented in this nine switch UPQC. The proposed control techniques for UPQC are implemented in MATLAB/Simulink and the results are validated for nonlinear loads, sag and swell conditions. From the results, it is concluded that PSO-ANN algorithm gives encouraging results compared to FLC and ANN controller.

Reference

[1] A., G., and F., L. G., “Power quality enhancement using custom power devices”. Kluwer academic publishers, 2002.

[2] N.G. Hingorani and L. Gyugyi, “Understanding FACTS: Flexible AC Transmission Systems”, A book, IEEE press, USA, 2000.

[3] 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.

[4] Sudheer Vinnakoti and Venkata Reddy Kota, “SRF and Real Power Theory based Control of a Nine Switch Converter based UPQC”, 5th International Electrical Engineering congress, Pattaya, Thailand, 2017.

[5] S. Vijayasamundiswary, J. Baskaran, “Performance analysis of nine switch unified power quality conditioner using linear and non linear loads”, International conference on computation of power, energy information and commuincation (ICCPEIC), 2018.

[6] Lei zhang, Poh, Chiang Loh “An integrated nine switch power conditioner for power quality enhancement and voltage sag mitigation”, IEEE Transactions on power electronics, vol 27. no.3, March 2012.

[7] Abdul Mannan Rauf, Amit Vilas Sant Vinod Khadkikar “ A Novel ten switch Topology for Unified Power Quality Conditioner”, IEEE Transactions on power electronics October 2015.

[8] Y, L., and B, L. J., “A fuzzy-expert system for classifying power quality disturbances”, International journal of electrical power & energy systems , pp.199-205.

[9] Mohamad Milood Almelian, Izzeldin I Mohd, Mohamed Asghaiyer Omran and Usman Ullah Sheikh, “Performance of unified power quality conditioner (UPQC) based on fuzzy controller for attenuating of voltage and current harmonics”, IOP Conference Series: Materials Science and Engineering, vol.32, 2012.

[10] S, M., & K, P. A, “Real-time implementation of PI and fuzzy logic controllers based shunt active filter control strategies for power quality improvement”, International Journal of Electrical Power & Energy Systems , vol.43, no.1, pp.1114-1126,2012.

[11] K.S.R, K., & S.V.A.R., S., “Application of PI, fuzzy logic and ANN in improvement of power quality using UPQC”, International Conference on Sustainable Energy and Intelligent Systems, pp. 316 – 319,2012.

[12] H. Shayeghi, H.A. Shayanfar, S. Jalilzadeh, A. Safari , “A PSO based Unified Power Flow Controller for damping of Power system Oscillations”, Energy Conversion and Management,vol.50, no. 10, pp. 2583-2592, October 2009.