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Investigation of Unified Power Quality Conditioner with Artificial Neural Network Based Control for Power Quality Enhancement

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Abstract **:** In this paper, an UPQC with Artificial Neural Network (ANN) controller is proposed to overcome certain power quality issues in the distribution network caused due to non-linear unbalanced loads and harmonics in supply voltage. The present mass penetration of digital and power electronic loads and source cause lot of harmonics. UPQC-a back to back connected shunt and series converters have been effectively mitigating these problems. Though UPQC is common these days in research, ANN controlled UPQC is presented in this work. ANN controller holds the benefit of eliminating mathematical calculations like a-b-c to d-q-0 transformation, its inverse transformation and requirement of complex and costly controllers like DSP/FPGA etc. TrainingANN controller to generate reference signals and to maintain constant dc link capacitor voltage is done using Levenberg-Marquardt back propagation (LMBP) algorithm. % THD of load voltage and source currents are compared for performance analysis of ANN with respect to SRF based control. The working of the proposed ANN controller under voltage sag/swell is also investigated. Simulations are done in Matlab/Simulink software and shows that ANN controller gave better performance in every area of consideration.

Keywords : Synchronous Reference Frame (SRF) based control, % Total Harmonic Distortion (%THD), Artificial Neural Network (ANN) controller, Levenberg-Marquardt back propagation (LMBP).

1. INTRODUCTION

In present competitive world with revolution in electronic applications, consumers expect a high quality electrical power supply, as load also became sensitive to quality of power input. Harmonics in source and non-linear unbalanced load cause overheating, poor efficiency, less life span and malfunctioning of equipment. Active power filters (APF's) were very effective to resolve the above issues in distribution network. UPQC having back to back connection of shunt and series converters witha dc link capacitor acting as an interface between them can resolve both voltage and current related power quality issues more effectively [1-3]. The performance of UPQC and its effectiveness in improving the quality of power delivered depends on the controller which operates these filters.

In controlling power electronic devices, reference signal generation is of great importance. PQ theory used earlier was helpful as each phase can be controlled individually in three phase system [4]. With supply voltage distortions, performance of PQ theory degraded. Though PQ theory is upgraded to resolve this problem, SRF based control proposed later gave quick and precise control with and without harmonics is supplied [5] - [7]. In

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the midst of all this, time taken to reach steady state with PI controller for capacitor voltage balancing is relatively high. It also involves high mathematical calculations. Some other intelligent control schemes like fuzzy [8-9] and ANN [10-12] can do the same in less time and eliminates mathematical calculations. Fuzzy logic controllers requires linguistic rules to define the behavior of the system where as ANN are trained from the data of previously run system information and take control decisions. This greatly reduces the need for mathematical calculations and transformation theories like *a-b-c* to *d-q*-0. Therefore simple microcontrollers are sufficient to perform control operation rather that DSP/FPGA controllers which are expensive and complex. Recently ANN controller is used to generate reference signals for DSTATCOM application [13-14].

This paper proposes a UPQC with ANN based controller supplied with source voltage harmonics and nonlinear unbalanced load. Voltage related issues like voltage sag and voltage swell are also considered to look into performance of UPQC with the proposed ANN controller. Using Levenberg-Marquardt back propagation (LMBP) training algorithm in ANN controller, reference signals are generated and dc link capacitor voltage is maintained constant. Its performance is compared with SRF based control under polluted supply voltage, voltage sag, voltage swell and unequal non-linear load conditions. The Matlab/Simulink software based simulations are performed to evaluate the effectiveness of the controllers. Mitigation of harmonics, voltage sag, voltage swell, capacitor voltage balancing and %THD are analyzed in this work. This paper is organized into five sections. Introduction is given in Section I, Section II describes working of UPQC, Section III explains the implementation of ANN based Controller, Simulation Results and Discussions are given in Section IV and Conclusion are given in Section V.

2. UPQC AND ITS WORKING

A UPQC is a set consisting back to back connected converters with a dc link capacitor as an interface between them. Across load, shunt converter is connected which act like a current source and near utility, series converter is connected which act like a voltage source. Series converter controls voltage related power quality problems and shunt converter controls current related power quality problems. UPQC can also provide reactive power balancing therefore improving power factor and performance of the electrical network. Figure 1 represents the basic configuration of a UPQC.

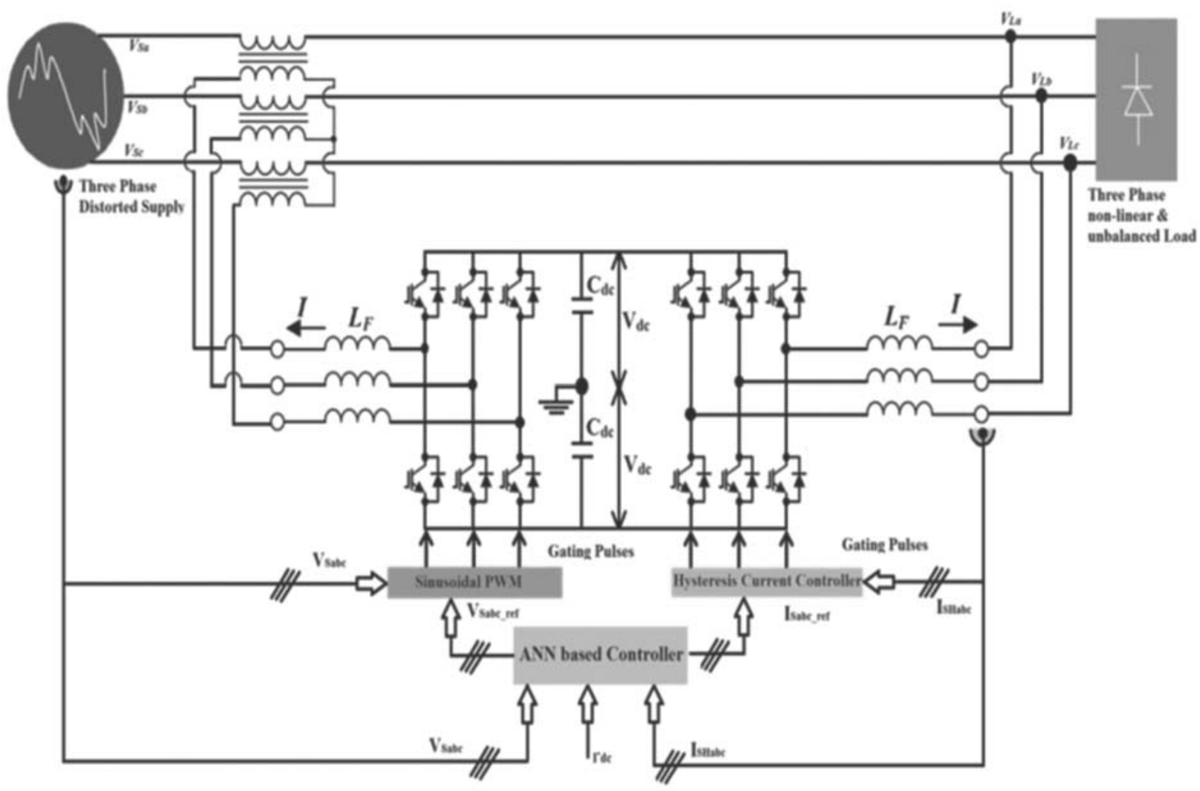


Fig. 1. Basic configuration of UPQC

Case 1: With UPQC still not connected to the network, source supplies both active and reactive power to the load. When UPQC is connected, shunt converter supplies required reactive power to the load as depicted in Figure 2. Hence burden on source reduces thereby improving power factor. As long as the shunt converter is connected to the network,it takes care of the reactive power demandedby load even when source has harmonics, voltage sag and voltage swell.

Case 2: Voltage Sag ($k < 0$, $V_{Sabc} < V_{Labc}$) : During this period, series converter supplies required active power to the load. This can be done with the help of shunt converter. To preserve power balance of the system, shunt converter draws more current from source and supplies to series converter via dc link capacitor. It also helps to maintains dc-link voltage constant. Active Power flows from source (P_{Sabc}) to shunt converter (PS_{Habc}) and series converter (P_{SEabc}) through dc-link capacitor and to the load as shown in Figure 3.

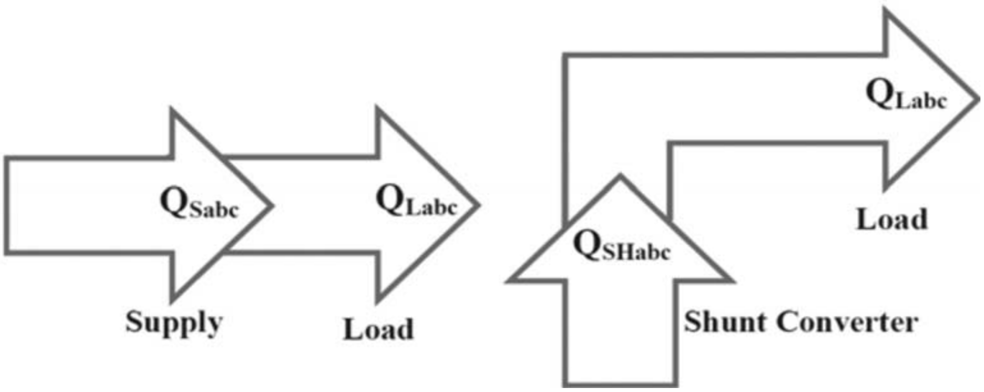


Fig 2. Reactive power flow (*a*) without UPQC (*b*) with Shunt Converter.

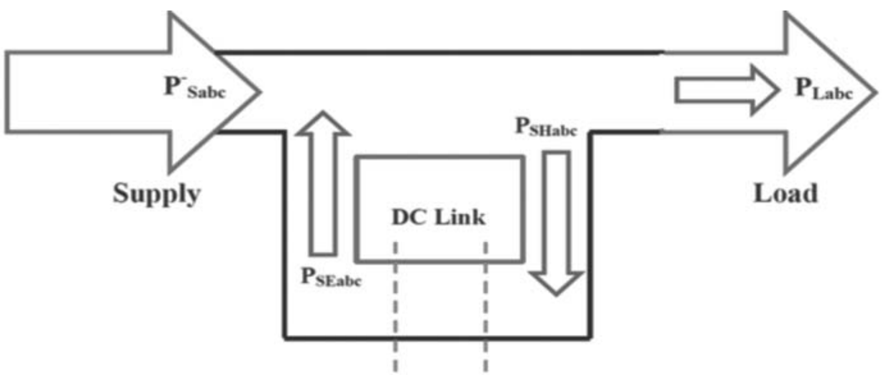


Fig. 3. Active power flow during voltage sag conditions.

Case 3 : Voltage Swell ($k > 0$, $V_{Sabc} > V_{Labc}$): During this period, series converter will absorb real power from source and fed to the line through dc-link capacitor and shunt converter. This cause dc-link voltage to rise, therefore shunt converter reduces the current drawn from the supply to balance and maintain the dc-link voltage constant. Active power flow is shown in Figure 4. Power drawn by series converter from the line is same as power given by shunt converter to the line.

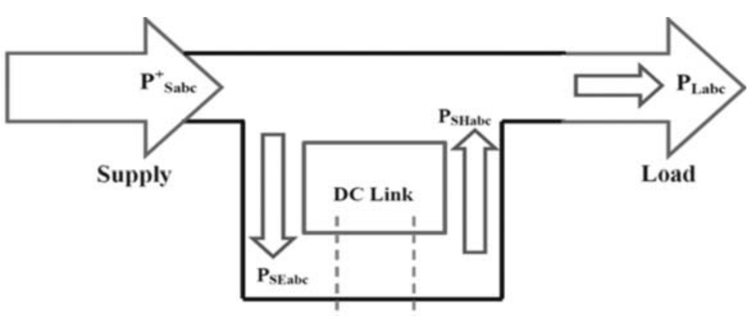


Fig. 4. Active power flow during voltage swell conditions.

3. ARTIFICIAL NEURAL NETWORK BASED CONTROL

Artificial Neural Network (ANN) is based on biological Neural Network. How brain process information and takes decision regarding various situations is simulated and that control network is called ANN. Different types of architectures and training methods are available to develop an ANN controller. A feed forward error back propagation type of architecture is being used in this paper, where input data is feed-forwarded for information processing to give an output. If output is different from desired target, error is generated and the error correction is propagated in backward direction. To train this network Levenberg-Marquardt back propagation (LMBP) [15-16] is used which with mean square error performance function gives faster convergence. Maintaining capacitor voltage at desired level and generating reference current and voltage signals using ANN controller with LMBP algorithm is explained as follows.

3.1. ANN based shunt controller

ANN controller is trained for generating reference signal and also for dc-link capacitor voltage balancing. Error generated from comparing reference voltage of 700 V with actual dc link voltage (V_{dc}) is considered as input data and the estimated output from the ANN *i.e*. loss component of current (I^*_{dc}) is taken as the target to the network. Considering 100 hidden layers and using Levenberg-Marquardt back propagation (LMBP) algorithm, network is trained. Matlab/Simulink model of capacitor voltage balancing with ANN controller is depicted in Figure 5.

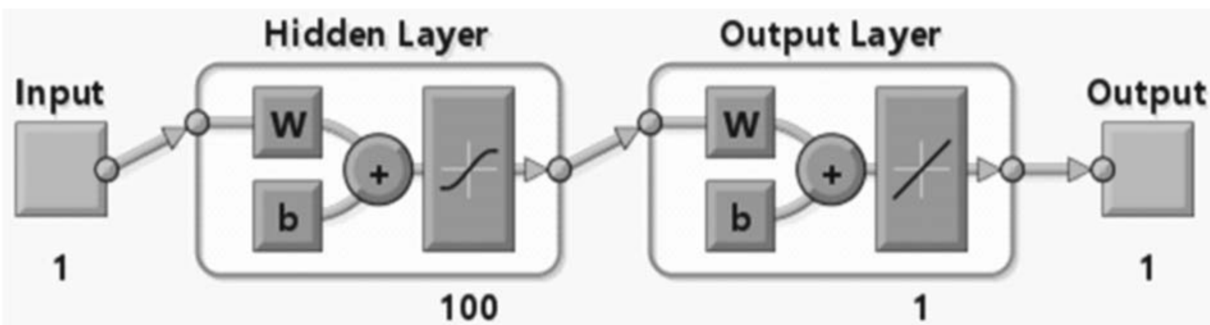


Fig. 5. ANN structure for Capacitor Voltage balancing

For reference current generation, I_{La}, I_{Lb}, and I_{Lc} *i.e*. load currents of three phases and loss component of current (I^*_{dc}) are considered as inputs and estimated reference currents are given as target data. 200 hidden layers are taken and Levenberg-Marquardt back propagation (LMBP) training algorithm is used to train ANN controller. Reference current generation using ANN in Matlab/Simulink is given in Figure 6.

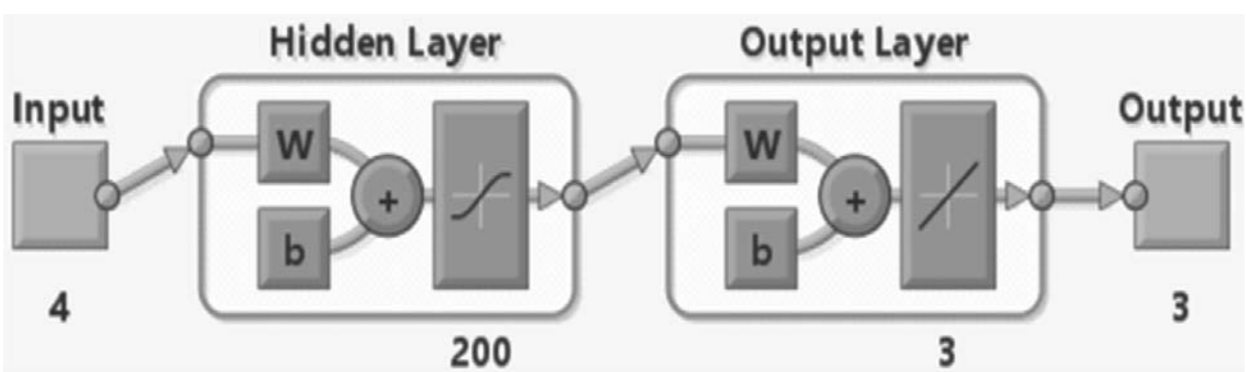


Fig. 6. ANN based control for reference current generation

The reference currents generated using ANN control scheme are compared with actual source currents in a fixed hysteresis band of ± 0.5A to generate proper switching for shunt converter.

3.2. ANN based series controller

ANN controller is used to generate reference voltage signals for controlling series converter. Supply voltages (V_{Sa}, V_{Sb} and V_{Sc}) are considered as input data and estimated reference currents as target data. 200 hidden layers, LMBP training algorithm is used to train ANN controller. The ANN architecture in Matlab/Simulink model isgiven in Figure 7. These generated reference voltages are compared with supply voltages and the error signal is used to develop gating pulses for series converter using SPWM.

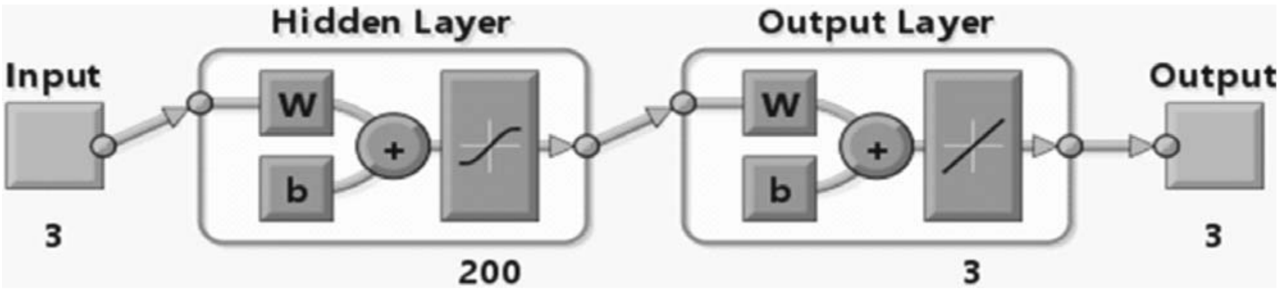


Fig. 7. ANN based control for reference current generation

4. SIMULATION RESULTS

The Matlab/Simulink model of the proposed ANN controller based UPQC is depicted in Figure 8. Simulation results are observed to evaluate the effectiveness of the system during transient and steady state of different operating conditions and dc link capacitor voltage balancing.To evaluate the effectiveness of UPQC using the proposed ANN controller, supply voltages polluted with 5^{th} and 7^{th} order harmonics are considered along with nonlinear unbalanced load. With these supply voltage harmonics shown in Figure 9(*a*), load voltages are also polluted. In addition to that an unbalanced non-linear load, injects harmonics into the load currents which will transfer towards supply and infect other consumers connected to same supply. Since UPQC is connected after 0.2 sec, the compensation of load voltage and source current will start from 0.2 sec.

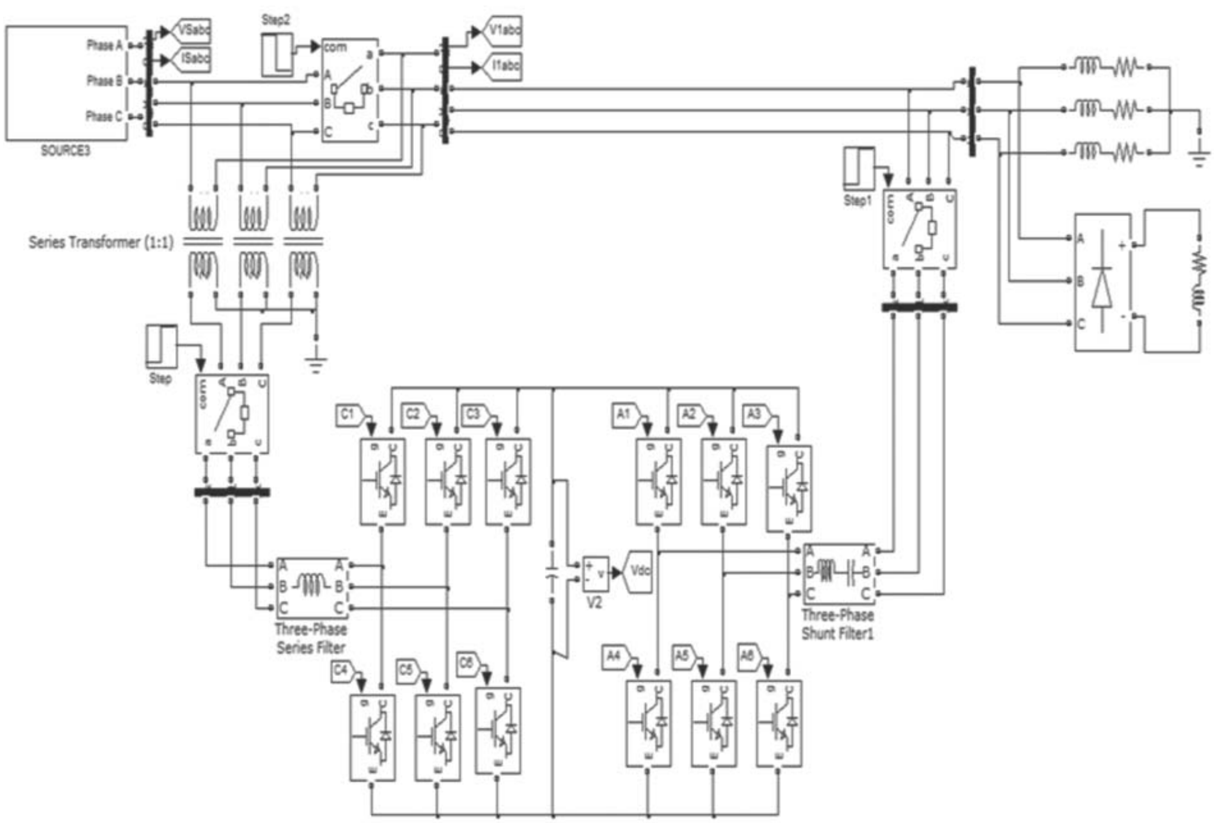
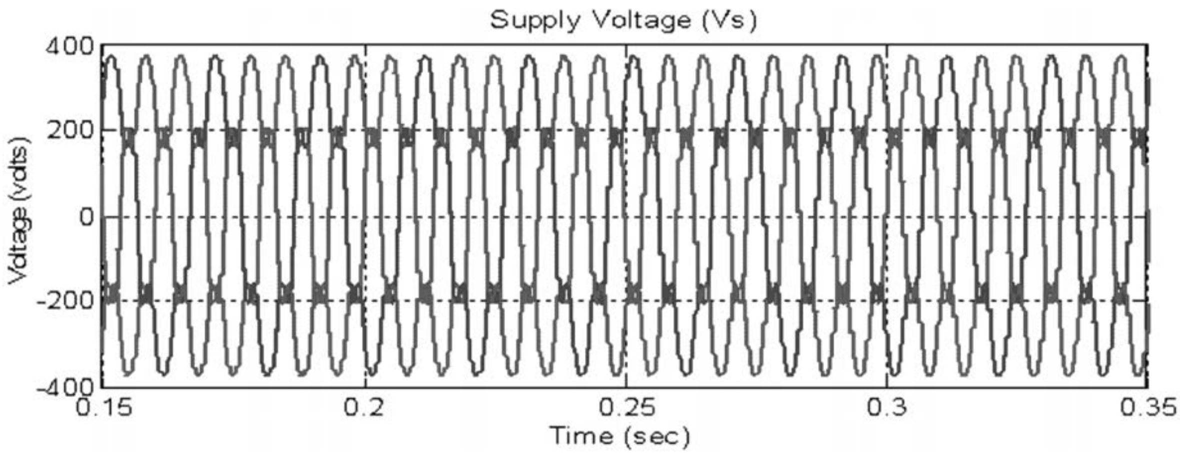
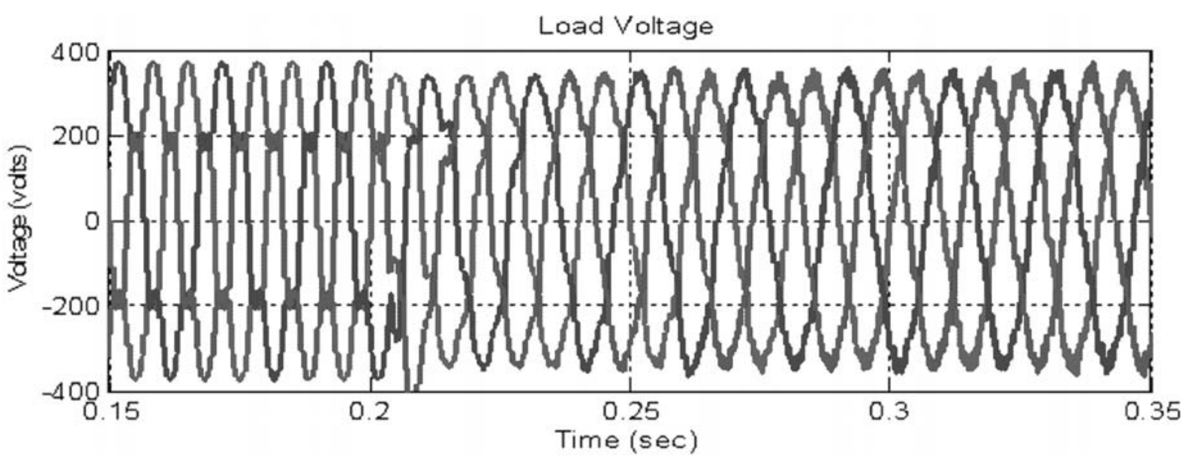


Fig. 8. UPQC Matlab/Simulink model of Three Phase Four Wire System

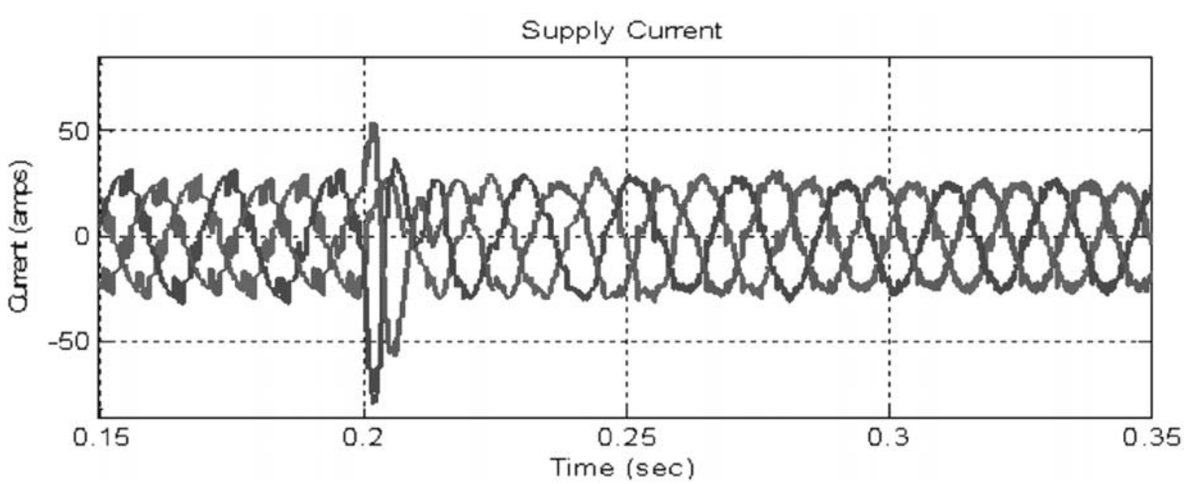
In UPQC with the proposed ANN controller, series converter injects deviated voltage component from fundamental into the system thereby compensating the voltage harmonics at from 0.2 sec load as depicted in Figure 9(*b*). On the other hand shunt converter injects deviated current component from fundamental in to the system thereby compensating supply current harmonics from 0.2 sec as depicted in Figure 9(*c*). Along with this it is also observed that reactive power is supplied to the load as demanded by it and therefore maintains supply currents in phase with supply voltages. In other words it maintains unity power factor. Eliminating supply current harmonics will not eliminate current harmonics at load, but with eliminating load voltage harmonics will reduces the effect of harmonics in load currents. The same can be observed from Figure 9(*d*) from 0.2 sec.



(*a*)



(*b*)



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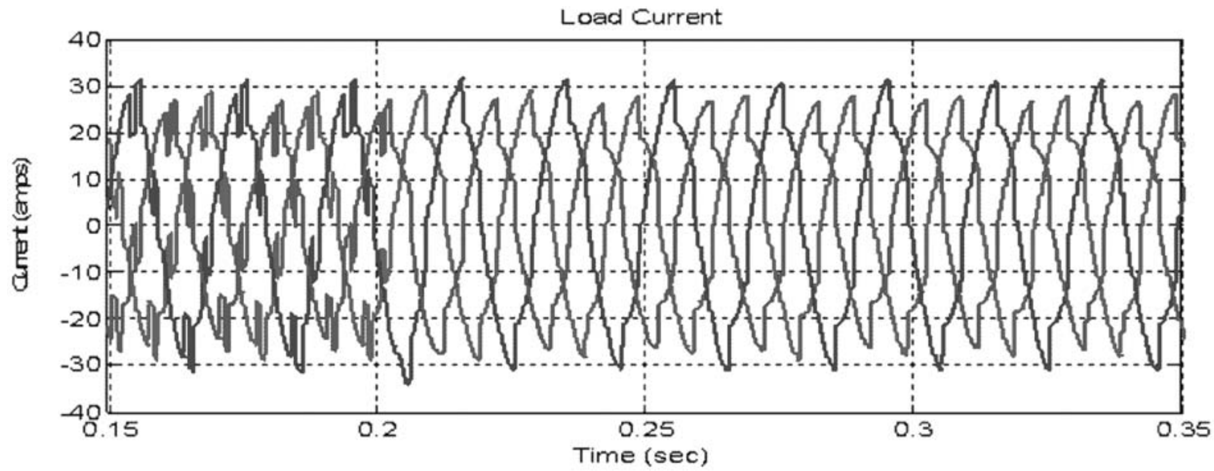
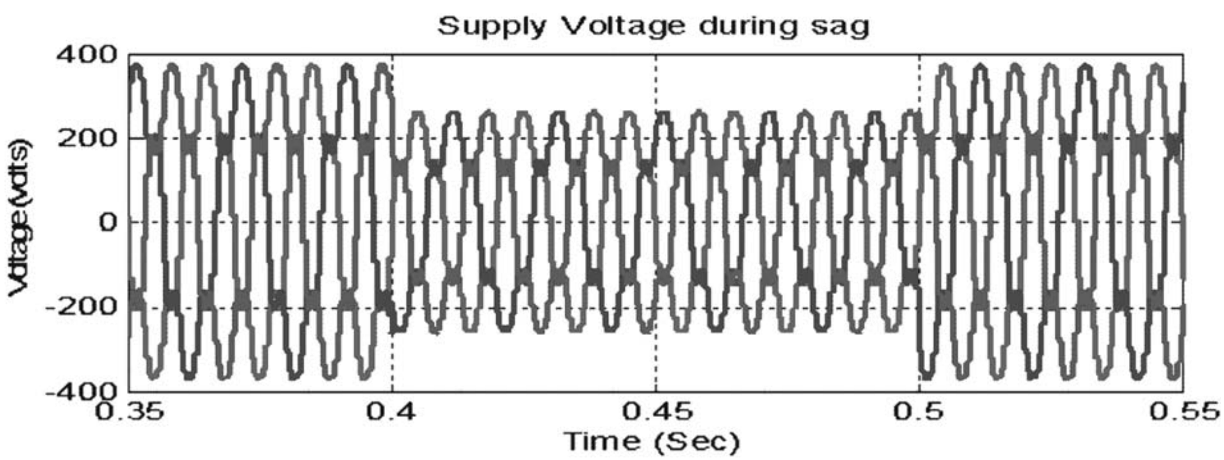


(*d*)

Fig. 9.(*a*) Supply Voltage (*b*) Load Voltage (*c*) Supply Current and (*d*) Load Current before and after compensation

If the supply voltages suffer a dip *i.e*. voltage sag as shown in Figure 10(*a*), it will affect the load voltage and equipments will underperform. Series converter in UPQC with the proposed ANN controller will supply the sagged voltage and maintains the load voltage magnitude constant during this period as depicted in Figure 10(*b*). To provide sufficient active power to series converter which is to be injected during voltage sag period, shunt converter draws some active power and supply to series converter via dc link capacitor. This makes the supply currents to increase slightly as shown in Figure 10(*c*). Since the load voltages are harmonic free with constant magnitude during voltage sag the load currents are same as in the case of normal operating conditions after compensation.



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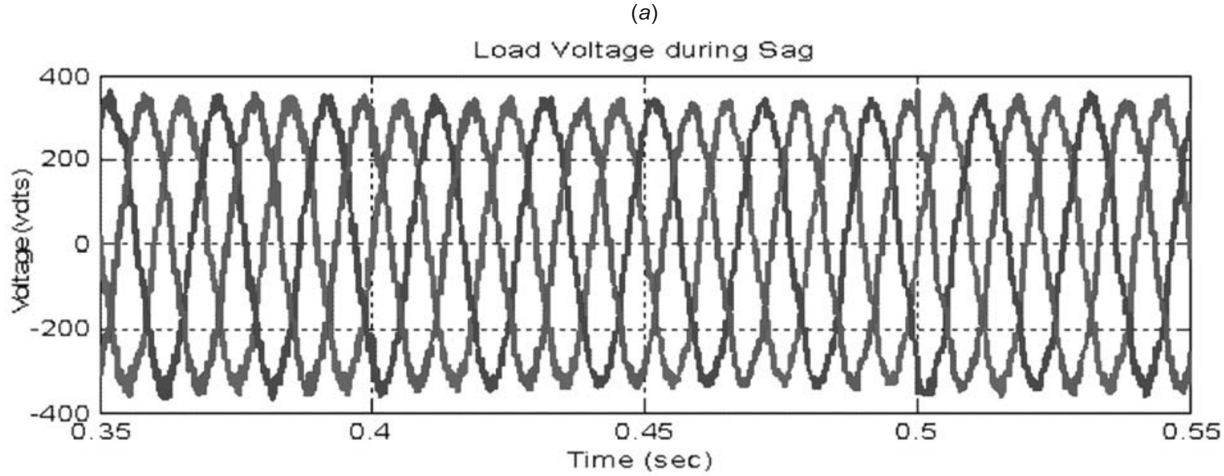

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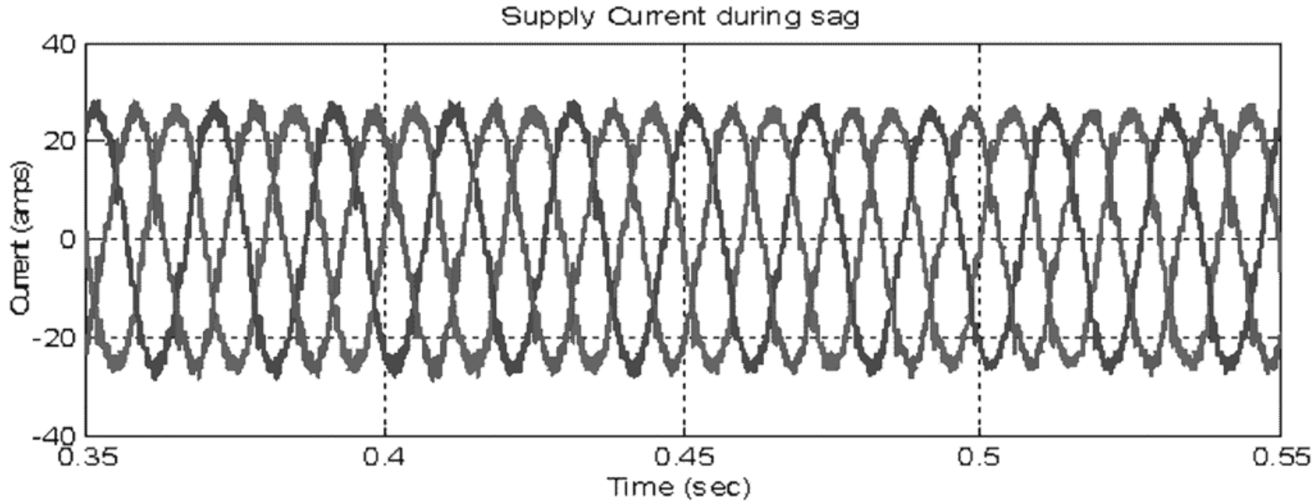
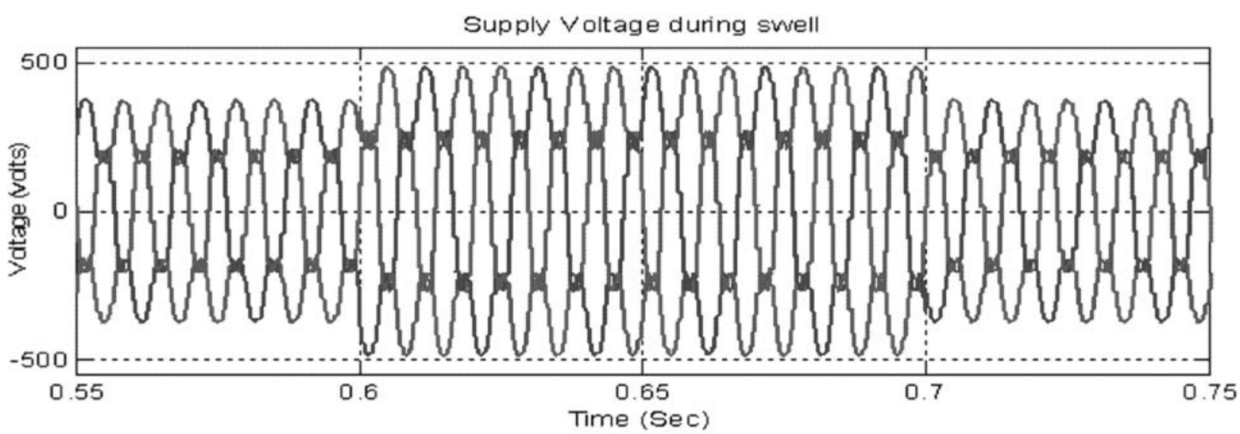


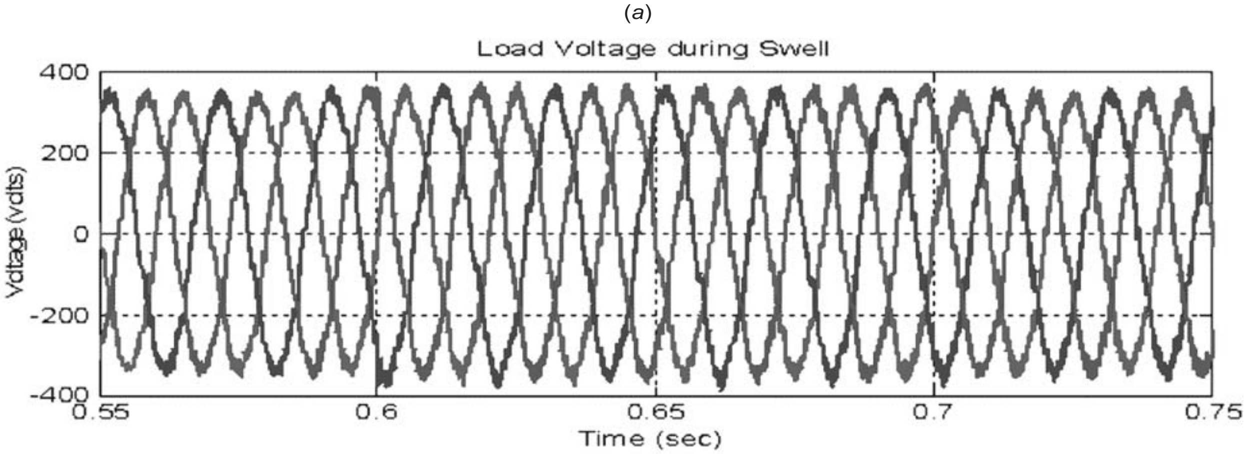
(*c*)

Fig. 10. (*a*) Supply Voltage (*b*) Load Voltage and (c) Supply Current during voltage sag period

If the supply voltages suffer rise in magnitude *i.e*. voltage swell as shown in Figure11(*a*), it will affect the load voltage and equipments connected to it will damage. Series converter in UPQC with the proposed ANN controller will consume the excess voltage and maintains the load voltage magnitude constant as depicted in Figure11(*b*). This consumed voltage is fed back to line via dc link capacitor and shunt converter. So series converter supplies some active power to shunt converter which is used to compensate current harmonics. This causes the shunt currents to draw less current from the line and the same is depicted in Figure11(*c*). Since the load voltages are harmonic free and with constant magnitude during voltage swell the load currents are same as in the case of normal operating conditions after compensation.



(*a*)



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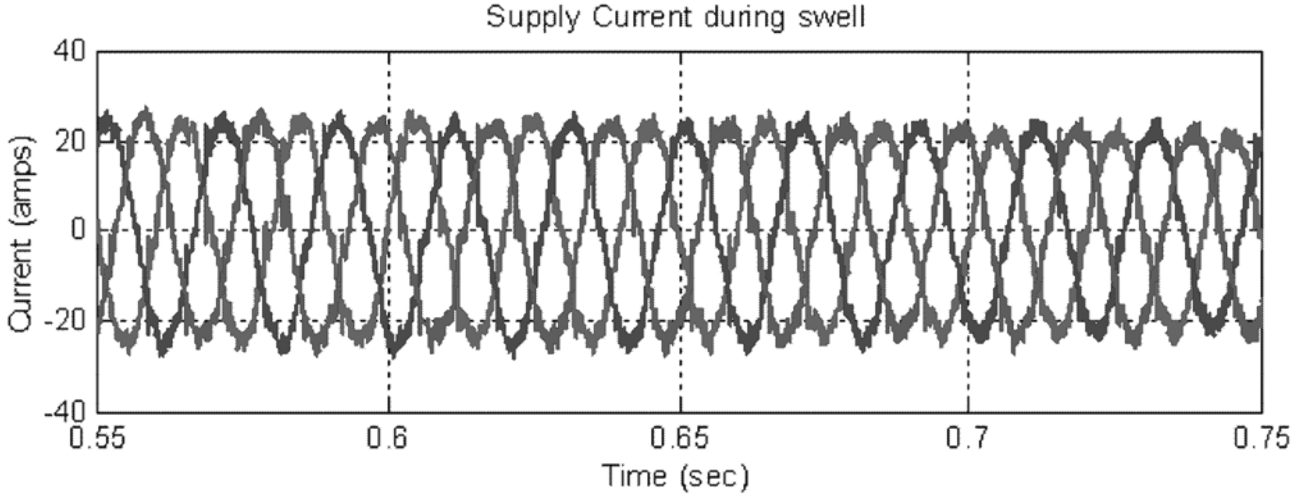


(*c*)

Fig. 11. (*a*) Supply Voltage (*b*) Load Voltage and (*c*) Supply Current during voltage swell period

During working condition of UPQC, both converters consume active power for compensating voltage and current harmonics. Sometimes depending on the situation, series converter will supply active power to shunt converter or vice-versa via dc link capacitor. Whatever the case it may be, it is necessary to maintain dc link voltage constant all the time. This can be achieved with various controllers like PI, Fuzzy logic or ANN etc. Comparison of dc link voltage with SRF based control using PI, Fuzzy logic and ANN controllers and ANN based control with ANN controller is plotted in Figure 12. It is observed from Figure 12 that, almost all controllers used in this paper has same dc link voltage response, but it is a bit faster with fuzzy logic controller. Further ANN based control used for capacitor voltage balancing and reference signal generation has superior performance in load voltage and supply currents over SRF based control.

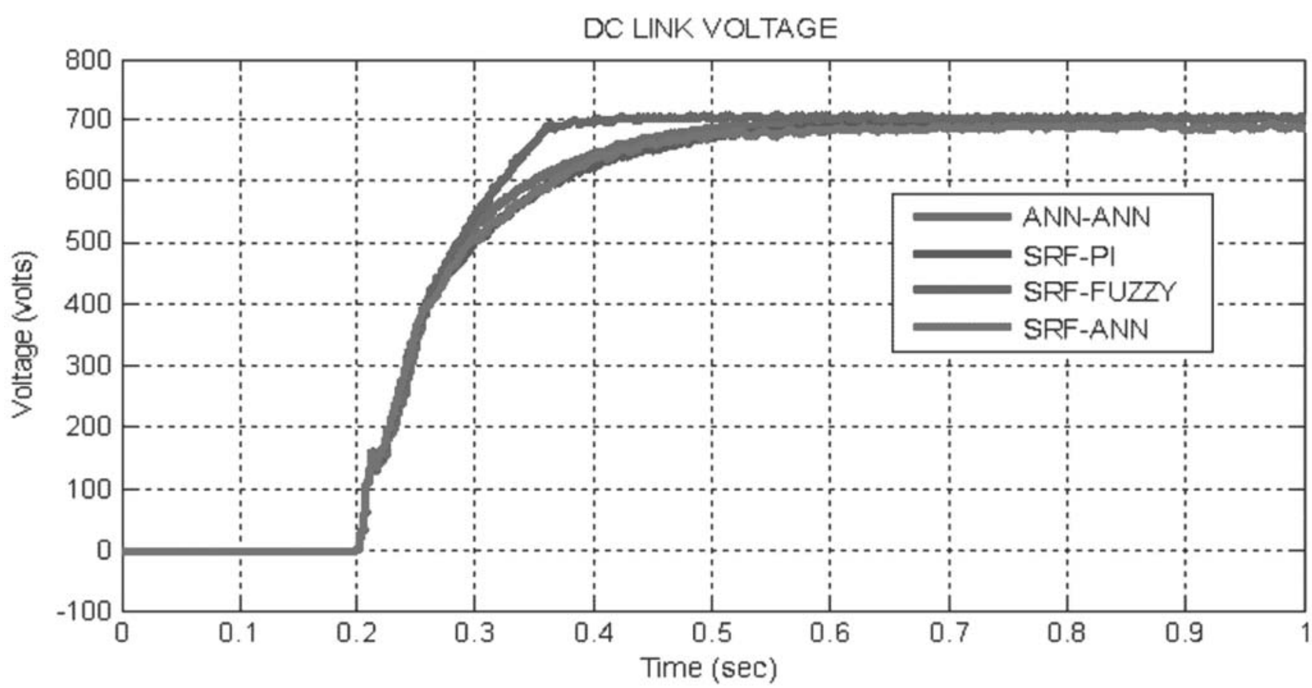


Fig. 12. Comparison of Capacitor voltage with various control schemes

%THD in load voltage with and without compensation is depicted in Figure 13. Observing %THD, without compensation what was 22.36% is minimized to 4.07%, 3.87% and 4.01% in phase A, phase B and phase C of load voltage and are depicted in Figure 13(*a*) to Figure 13(*d*). Similarly % THD of supply currents in each phase before and after compensation is depicted in Figure 14. It is observed that % THD of supply currents in phase A, phase B and phase C before compensation is 23.50%, 21.17% and 25.59%. After compensation these harmonics are reduced to 5.81%, 5.68% and 5.35% respectively and are depicted in Figure 14(*a*) - Figure 14(*c*). % THD of load voltage and supply currents with SRF based control and ANN based control are tabulated in Table 1.

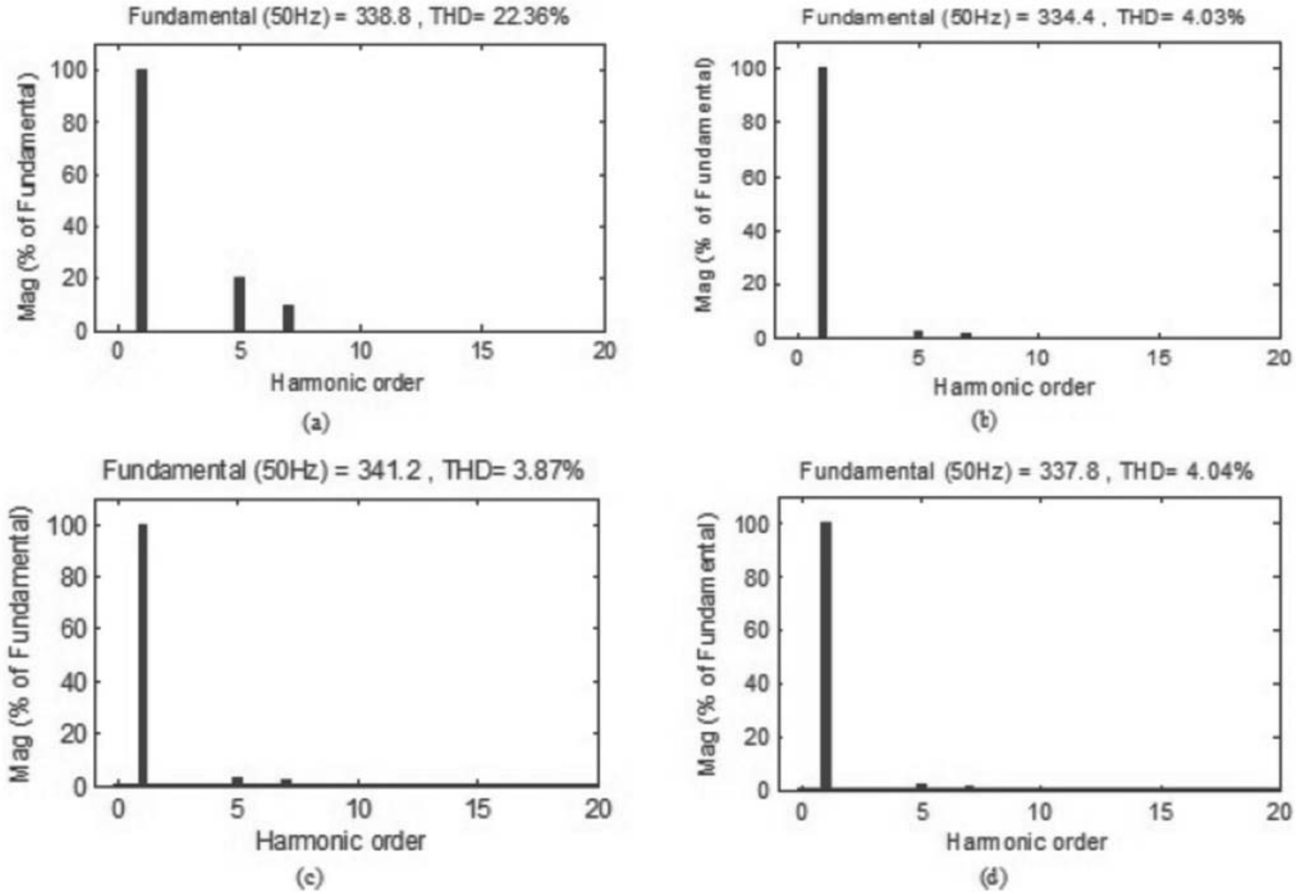
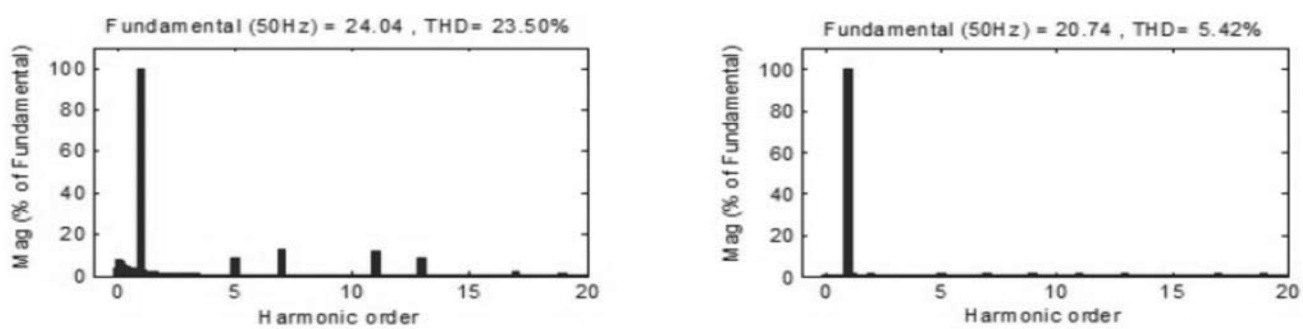
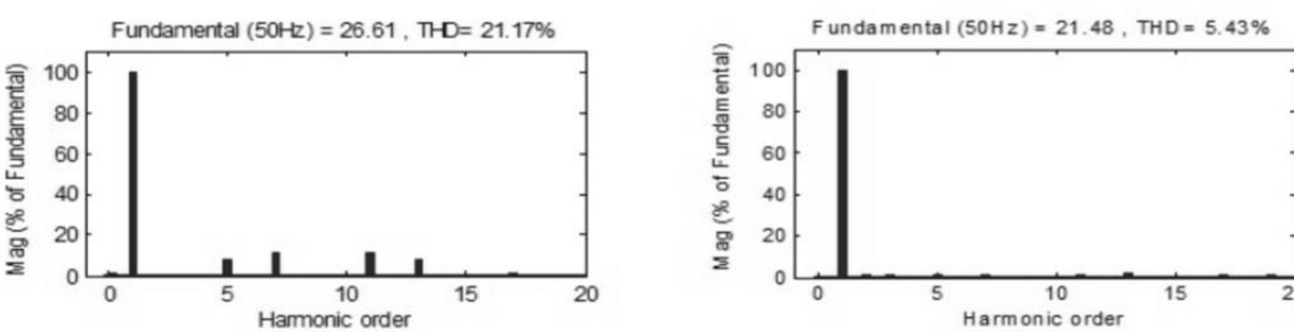


Fig. 13. %THD of (*a*) Supply Voltage and Load Voltage (*b*) phase A (*c*) phase B and (*d*) phase C



Before Compensation **(a)** **After Compensation**



Before Compensation **(b)** **After Compensation**

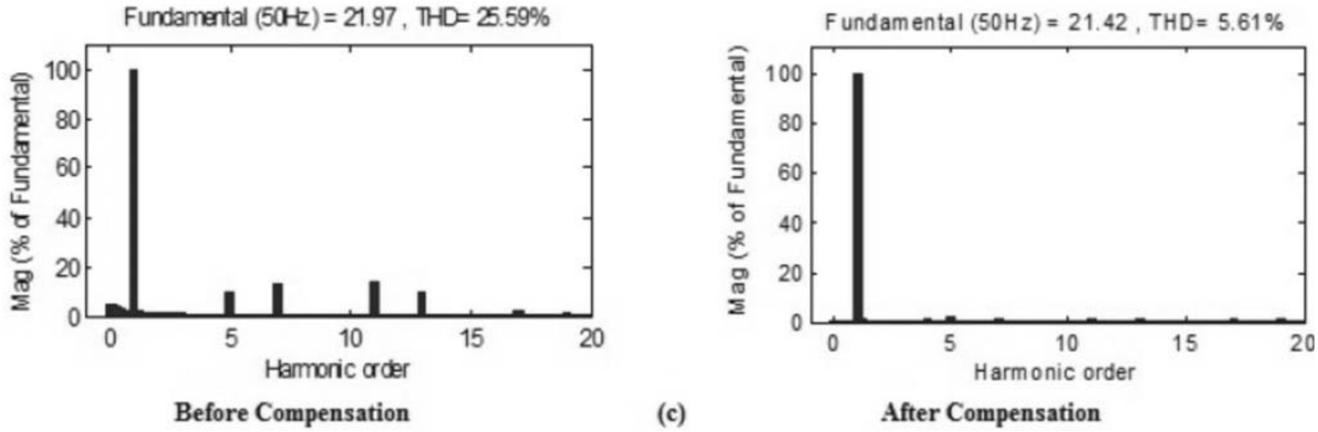


Fig. 14. %THD of Supply current in (*a*) Phase A (*b*) Phase B and (*c*) Phase C.

Table 1. Comparison of % THD with SRF and ANN based controllers

Nonlinear Unbalanced Load with 0.72 P.F.		*% THD*				
		Without Compensation	*SRF based control*			*Proposed ANN controller*
			PI	*FUZZY*	*ANN*	
Load Voltage	$\mathbf{V}_{La}$	22.36%	4.51%	4.41%	4.46%	**4.03%**
	$\mathbf{V}_{Lb}$	22.36%	4.61%	4.63%	4.67%	**3.87%**
	$\mathbf{V}_{Lc}$	22.36%	4.81%	4.73%	4.85%	**4.04%**
Supply Current	$\mathbf{I}_{Sa}$	23.50%	5.53%	5.54%	5.22%	**5.42%**
	$\mathbf{I}_{Sb}$	21.17%	6.13%	6.04%	5.63%	**5.43%**
	$\mathbf{I}_{Sc}$	25.59%	6.31%	6.14%	5.92%	**5.61%**

5. CONCLUSION

The UPQC with the proposed ANN controller is tested supplying non-linear unbalanced load with source consisting of harmonics in voltage being supplied. It is observed on analyzing the simulation results that proposed ANN controller nullified the impact of harmonics in supply voltage and prevented harmonics in load voltage and supply currents. The impact of voltage sag/swell was also compensated well. ANN controller further reduced the % THD in load voltage and supply currents in comparison to SRF based control. The adaptation of ANN controller for UPQC operation would not only improve the quality and performance of electrical system and also reduces thecomplexity and cost of the system. Hysteresis Current Controller and SPWM perform well in reducing %THD. So in this paper it is claimed that, ANN controller gave superior performance over SRF based control.

6. REFERENCES

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