POWER QUALITY IMPROVEMENT ANALYSIS BY USING DIFFERENT CONTROL TECHNIQUES

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ABSTRACT

Dynamic Voltage Restorer (DVR) is a series compensator which can compensate for powerquality problems such as voltage harmonics, voltage unbalance, voltage flickers, voltage sags and voltage swells. Distribution Static Compensator (D-STATCOM) is a shunt compensatorwhich can compensate for power quality problems such as current harmonics, current unbalanced reactive current, etc. Unified Power Quality Conditioner (UPQC) is a custom power device that consists of shunt and a series converter connected back to back and deals with load current andsupply voltage imperfections. Open UPQC consists of DVR and DSTATCOM without commonDC link. The chief objective of this thesis is to develop models of DVR, DSTATCOM and OPEN-UPQC for enhancement of power quality under various operating conditions. In thiswork, an open UPQC is used to compensate for high power load of 250 MVA consisting of Dynamic load and DTC motor drive. It is then simulated experimentally to mitigate voltagesag/swells and harmonic currents. Traditional dq-theory is applied with PI controller to investigate the performance of series, shunt, and combination of series-shunt compensators.

In this work, the off line drained data from conventional fuzzy logic controller. A novel control system with a Combined Neural Network (CNN) is used instead of the traditionally four fuzzy logic controllers. The performance of combined neural network controller compared with Proportional Integral (PI) controller and Fuzzy Logic Controller (FLC). The system performance is also verified experimentally.

1. INTRODUCTION

Power Quality is an important issue that is increasingly to electricity consumers because of sensitive equipment and non-linear loads are now more commonplace in both domestic environment and power sectors. We should have awareness of power quality is developing amongst electricity users. The electricity supplies that were once considered acceptable by electricity companies and users are now often considered a problem to the users of everyday equipment. The solution to power quality problems is available to the both the distribution network operator and the end users. Active Power Filters (APFs) are shunt, series and vice versa to compensate for current and voltage based distortions for better quality solutions. A Unified Power Quality Conditioners (UPQCs) have been introduced as a powerful and advanced compensating device to simultaneously deal with current and voltage related problems [1-3]. An UPQC, composed of shunt and series APFs, is capable of compensating voltage distortions at the supply side as well as current harmonics at the load side to make the load voltage and the supply current become pure sinusoidal. However, despite its effectiveness in power quality improvement, the application of the UPQC in practice is quite limited. Design of passive components for the proposed system is to achieve good performance. In this paper unified power quality conditioner (UPQC) is being used as a universal active power conditioning device to mitigate both current as well as voltage harmonics at a distribution end of power system network [4-7].

The performance of UPQC mainly depends upon how quickly and accurately compensation signals are derived. The unified power quality conditioner (UPQC) has been modeled for both active and reactive power compensation using fuzzy control strategy. The Fuzzy Logic controller is used to solve the non-linear problems efficiently. A block diagram of the proposed system is shown in figure1

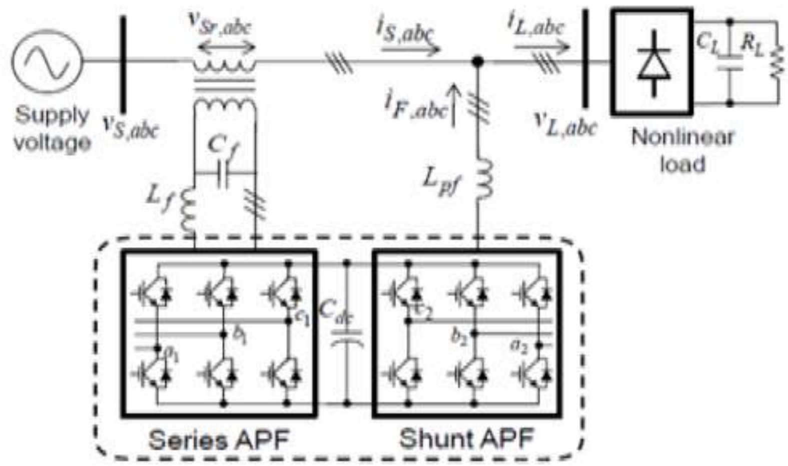

Fig. 1. Block Diagram of proposed system

The UPQC is one of the most researched entities in the world of power electronic control of power systems.Though volumes of papers stream into the literature domain every day, it is very hard to find the real UPQC inservice, even in the global electricity distribution scenario. This scenario can be attributed to the fact that theUPQC is hard to understand and it is still harder to handle the piece of equipment from the control system pointof view. Many researchers have contributed to the development of the controllers associated with the UPQC.Before proposing this idea, a summary of the existing ideas, as found in the literature, is hinted in this introduction. Ahmet Teke *et al.* proposed a novel reference signal generation method for the UPQC using the fuzzy logic scheme.In this paper an attempt is made to present a step-by-step development of a simple comprehensive controlscheme, at the same time, an effective control scheme for the management of the UPQC with a (CNN) controller, instead of the traditional four controller model. The objectives of this paper are as follows:

1) To maintain a steady voltage profile at the load end by injecting a series voltage in the appropriate phaseand magnitude at voltage sag and swell conditions.

2) To eliminate the harmonic content in distribution system during unbalanced and nonlinear load condition.

3) To develop control techniques for overcoming the problems related to dc link voltage deviations duringtransient conditions.

4) To compensate harmonics currents, unbalanced nonlinear load currents.

OVERVIEW

One of the main responsibilities of a utility system is to supply electric power in the form of sinusoidal and currents with appropriate magnitudes and frequency for the customers at the points of common coupling (PCC). Although the generated voltage of synchronous machines in power plants are almost sinusoidal, some unsighted conditions such as lightning and short circuit faults and non linear loads cause steady state error or transient voltages and current disturbances. For instance, electric arc furnaces cause voltage fluctuations, power electronic converters generate current harmonics and distort voltage waveforms, and short circuits faults result in voltage sags and swells [1-4]. On the other hand most customer loads such as computers, microcontrollers and hospital equipment are sensitive and unprotected to power quality disturbances and their proper operation depends on the quality of the voltage that is supplied to them.

This is possible only by ensuring an uninterrupted flow of power at proper voltage and frequency levels. As a result of this, FACTS devices and Custom power devices are introduced to electrical system to improve the power quality of the electrical power. With the help of these devices we are capable to reduce the problems related to power quality. There are many types of Custom Power devices. Some of these devices include Active Power Filters (APF), Surge Arresters (SA). Battery Energy Storage Systems (BESS), Super conducting Magnetic Energy Systems (SMES), Static Electronic Tap Changers (SETC), Solid State Fault Current Limiter (SSFCL), Solid-State Transfer Switches (SSTS), Static VAR Compensator (SVC), Distribution Series Capacitors (DSC), Dynamic Voltage Restorer (DVR), Distribution Static synchronous Compensators (DSTATCOM) and Uninterruptible Power Supplies (UPS) , Unified power quality conditioner (UPQC). But in this work, the main focus is kept only on DSTATCOM, DVR and OPEN UPQC.

A DVR is based on power electronic converter, placed in series with sensitive load to protect critical loads from all supply side disturbances. The DVR is a promising and effective device for power quality enhancement due to its quick response and high reliability. A DSTATCOM is a shunt compensator, based on power electronic converter. It is connected in shunt at PCC to protect critical loads from all load side disturbances.The open unified power quality conditioner (UPQC), composed of a power-electronic series main unit installed in the medium-voltage/low-voltage (LV) substation, along with several power-electronic shunt units connected close to the end users.

UPQC is an effective CPD for the enhancement of power quality due to its quick response, high reliability and nominal cost. It can be used to mitigate the current and voltage-related PQ problems simultaneously in power distribution systems. UPQC employs two inverters that are connected to a common DC link with an energy storage capacitor. The main components of UPQC are shunt and series inverters, DC capacitors, low pass & high pass filters and series transformer [1]. Series inverter is used to compensate voltage related disturbance by injecting opposite voltage in the line where shunt inverter is used to compensate current related disturbance by providing opposite current that cancel the disturbance. Low and high pass filter help in the reduction of harmonics in the system voltages and currents [4]. DC capacitor supports the both inverters for effective and quick operation during disturbances. But, it has the disadvantage of high discharging time due to which it needs the aid of a proper controller for regulating its voltage. A NF controller is a control system based on the neural networks (NN) and fuzzy inference systems (FIS). NN is the artificial model of human brain and doesn’t need any mathematical model for its structural network. FIS is empirical rules based model is operated based on fuzzy rules and NN is operated based on training dataset. The neural network training dataset are generated from the fuzzy rules. NN is applicable in real life applications like regression analysis, classification, data processing, robotics etc. Fuzzy logic is applicable in real applications like industrial control, human decision making, image processing etc. ABC optimization algorithm is a relatively new member of swarm intelligence. ABC tries to model natural behavior of real honey bees in food foraging. Originally the ABC algorithm was developed for continuous function optimization problems, but it can also be successfully applied to various other optimization problems [2]. It is applicable in real world applications like power systems, management, image classification etc.

2. LITERATURE REVIEW

Numerous research works already exist in the literature that compensate power quality problem in power operating system. Some of them are reviewed here. Sobha Rani Injeti et al. have presented a new compensation strategy implemented using an UPQC type compensator. Their proposed compensation scheme enhances the system power quality, exploiting fully DC–bus energy storage and active power sharing between UPQC converters, features not present in DVR and D–STATCOM compensators. The internal control strategy is based on the management of active and reactive power in the series and shunt converters of the UPQC and the exchange of power between converters through UPQC DC–Link. They have proved that their proposed algorithm was efficient and stability accurate, and robust in comparing with the commonly used backward/forward sweep method for weakly meshed networks.

Yash Pal et al. have proposed a control strategy for a three-phase four-wire UPQC for an enhancement of different PQ problems. The UPQC is accomplished by the integration of series and shunt active power filters (APFs) and both APFs share a common DC bus capacitor. The shunt APF is realized by means of a three-phase, four leg voltage source inverter (VSI) and the series APF is realized by means of a three-phase, three legs VSI. A unit vector template technique (UTT) based control method has been used to obtain the reference signals for series APF, whereas the ICosΦ theory has been used for the control of Shunt APF. The performance of the implemented control algorithm has been evaluated in terms of power-factor correction, load balancing, source neutral current mitigation, voltage and current harmonics mitigation, mitigation of voltage sag and swell, and voltage dips in a three-phase four-wire distribution system under a diverse combination of linear and non-linear loads. In the control system, the current/voltage control has been applied on the fundamental supply currents/voltages rather than fast changing APFs currents/voltages, and thus the computational delay and the required sensors have been reduced. The simulation results have been obtained using the MATLAB/Simulink and it proves that the proposed control system could maintain the functionality of the UPQC.

M Siahi et al. have proposed a design of combined operation of UPQC and PV array. Their proposed system is composed of series and shunt inverters, PV array and DC/DC converter which have capable for compensating the voltage sag, swell, interruption, harmonics and reactive power in both islanding and interconnected modes. The benefits of their proposed system are 1) it reduces the expense of PV interface inverter connected to grid by applying UPQC shunt inverter and 2) it has the ability of compensating the voltage interruption using UPQC because of connecting PV to DC link. In the proposed system, P&O technique has been used to reach the maximum power point of PV array. PSCAD/EMTDC software has been used for analyzing operation of the proposed system and the simulation results have proved that their proposed system operates correctly. K S Ravi Kumar et al. have proposed FL controller and ANN controller for UPQC to enhance the power quality of power distribution network. The proposed FLC and ANN were capable of providing good static and dynamic performances compared to PID controller. UPQC performance mainly depends upon how accurately and quickly reference signals were derived. By using conventional Akagi‟s principle reference signals was derived. Using conventional compensator data, a FLC was tuned with large number of data points. Then conventional compensator was replaced with fuzzy logic controller and simulated using Matlab/Simulink for R-L load using uncontrolled rectifier. They showed that the UPQC performed better with FLC proposed scheme and eliminates both voltage as well as current harmonics effectively. The ANN controller also performs in a similarly with slightly better voltage compensation It was also observed that the response time for derivation of compensation signals reduced significantly with improved accuracy. They also showed that it had considerable response time for yielding effective compensation in the network.

K. Manimala et al. have described the automatic classification of power quality events using Wavelet Packet Transform (WPT) and Support Vector Machines (SVM). The features of the disturbance signals were extracted using WPT and given to the SVM for effective classification. The two optimization techniques were used to their proposed classification system, such as, genetic algorithm and simulated annealing. Their proposed system was detected the best discriminative features and estimated the best SVM kernel parameters in a fully automatic way. The effectiveness of their proposed detection method was compared with the conventional parameter optimization methods like grid search method, neural classifiers like Probabilistic Neural Network (PNN), fuzzy k-nearest neighbor classifier (FkNN). They have proved that their proposed method was reliable and produces consistently better results.

3. PROBLEM FORMULATION PROPOSED APPROACH

Nowadays, PQ related issues are of most concerned because of their importance in power operating devices. Nonlinear loads such as adjustable speed drives (ASD), programmable logic controllers (PLC), energy efficient lighting and rectifiers, led to PQ problems. Common PQ problems are voltage sag, voltage spike, voltage swell, harmonic distortion, voltage fluctuations, voltage unbalance and interruptions. If the system maintains the PQ, it will provide stable operation or else it provides unstable operation. So maintaining of PQ is an essential one in power operating device. From the related research works, it shows that intelligent techniques are adopted in various electrical and electronics applications. In the previous papers intelligent techniques are being used for improving the PQ problem compensating performance of UPQC. This technique improves the performance of UPQC in PQ problem compensation by optimizing the output of the NN which provides the PQ disturbance in terms of voltage to the bias voltage generator. Bias voltage generator is the replacement for DC link capacitor which acts as a DC voltage source for two active power filters of UPQC. DC link capacitor has the disadvantage of long discharging time due to which full compensation of the voltage disturbances is not possible and getting delayed. To avoid these issues, bias voltage generator is used in the place of DC capacitor. Bias voltage generator regulates the DC link voltage fast and effectively for better compensation of PQ problem. Bias voltage generator has two inputs: reference voltage and calculated voltage from NF controller. In this paper, ABC optimization algorithm based NF controller is proposed, which is an improvement over the existing NF controller and ANFIS controller for improving the compensating performance of the UPQC.

As of now, various research works have been tried in the section of PQ maintenance and enhancement. Some devices such as DVR, UPS and many others are used for maintaining the quality power supply. But, these devices are capable of maintaining only the symmetrical or unsymmetrical power supplies, so the PQ is not maintained at all time. To avoid these problems, an enhanced NF controller has been proposed. But, the system developed by had drawbacks like they can only be applied to small networks. Hence, to overcome the issue involved in previous methods, we have proposed an ABC optimization algorithm based NF controller. Output of the NN is given to ABC algorithm and then the output DC link voltage of the bias voltage generator is optimized so that compensation performance of the PQ problem is achieved effectively. ABC algorithm is an optimization algorithm inspired by intelligent food foraging behavior of honey bee swarm and is invented by Karaboga in 2005. It can be used in unconstrained or constrained optimization problem. It is effectively applied in NN training, cluster analysis, face pose estimation etc.

4. MODELING OF UPQC

The UPQC basically has two power electronic converters linked by a common DC link. These two convertersengaged in the operation of the constrained power transaction process make use of four controllers that help inmeeting out the constraints of power transaction. Shunt converter is a three-leg three-phase Graetz bridge converter with a DC side and a three phase AC side. The three phase AC side is connected across the three phaseAC bus bar at the point of common coupling through a voltage transformer and a series reactor as shown in Figure 2. A pulse width modulation (PWM) generator generating synchronized switching pulses, switch the sixswitches of the three leg shunt converter. The objectives of the shunt convertor can be achieved by appropriatelysupplying the switching pulses. The generation of the switching pulses is governed by the three phase referencesignal that is produced by the contribution of two controllers. The control objectives of the two controllers influencethe generation of the reference signal and this leads to the operation of the convertor meeting out its requirements. There are two controllers associated with the shunt converter.

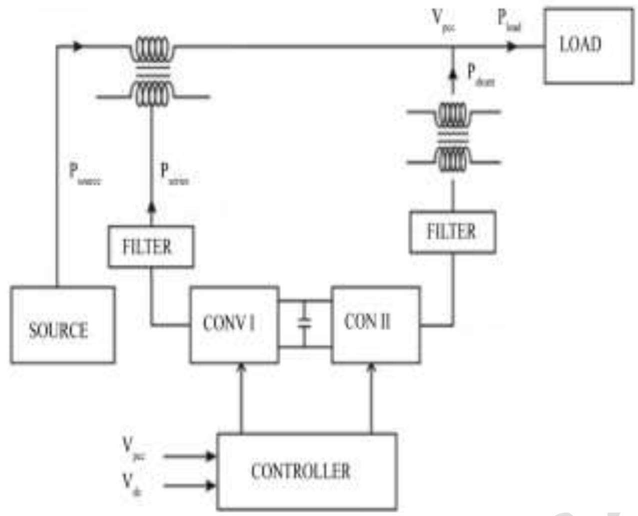

Fig. 2. Structure of unified power quality conditioner

5. COMBINED NEURAL NETWORKS

In this work four FLC are designed, two FLCs, each respectively for the series converter and shunt converter.These four FLCs are tuned appropriately for the expected performance. Then these four controllers are replacedby four individual ANN based controllers. Then, the four controllers with two inputs and one output are replacedby a single ANN unit with eight inputs and four outputs. However, if a single ANN is replaced by four ANNs, which results in increasing the speed of operation and better dynamic performance of the system under consideration.

The input and output data required to train the ANNs are the error, error rate and the corresponding output ofthe FLC, when the FLC controlled model is running environment. The same procedure is simultaneouslyadopted for collecting the input/output data pertaining to other FLCs. Using the neural network, Four ANNs areformed and each one was trained with the input/output data corresponding to each of the four FLCs.The UPQC model is then rearranged with the ANNs in the place of the FLCs. The performance of the overallUPQC system, being controlled by the four ANNs, is observed under different loading conditions which couldpotentially cause disturbances to the power quality. After it is observed that the four ANNs based controlscheme worked satisfactorily, they are replaced by a single ANN.After removing the four ANNs, the UPQC model is now rearranged with the CNN. The inputs and outputsassociated with the four ANNs are now routed through the CNN. The performance of the overall UPQC system, being controlled by the CNN is observed under different loading conditions which could potentially cause disturbancesto the power quality.

The synaptic weights are randomly initialized at the first time formation of an ANN but during the trainingphase, the synaptic weights undergo changes according to the learning rule. Finally, as the training is over, eachsynaptic weight reaches its final value. During the test phase or during the period, the ANN is put under service tomimic a function. Even as the inputs are applied, the synaptic weights do not change; they just work together withthe neurons to give the output. A CNN is feed forwards back propagation type and its basic form has an input layer, a hidden layer and an output layer. There may be more number of hidden layers than one. Let us consider the case of CNNs having only one hidden layer. The style adopted in the CNN model as shown in Figure 3. Actually, as aresult of combination of the ANNs, the resultant ANN has now more number of inputs and outputs. However, thenumber of neurons in the hidden layer remains the same. Thus, all the neural networks combined to form the ANN, have to share the common hidden layer neurons. As an example of demonstrate as how the ANNs are combined inthis work, the following example may be considered. Going by an example, consider the following two nonlinearequations in "time".

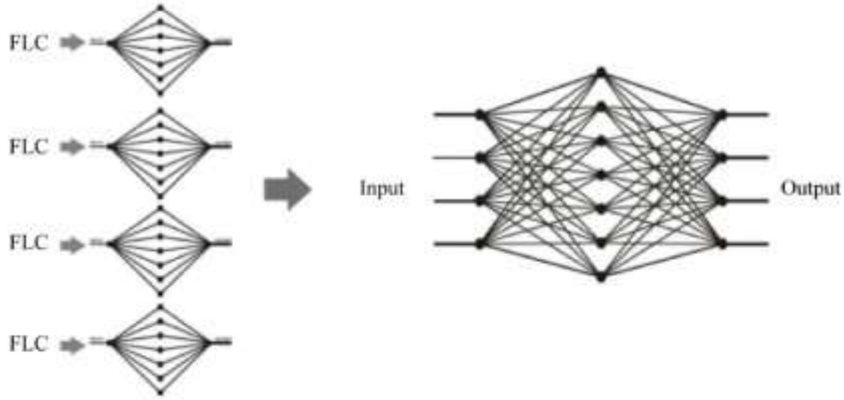

Fig. 3. CNN model

6. SIMULATION RESULTS

In this article, to demonstrate the proposed control strategy of CNN model described in Figure 4. The performance of the novel CNN based controller for the UPQC can be appreciated by comparing the results of the multiple controllers. Under unbalanced condition Figure 5(a) shows the source voltage distorted in sag and swell condition. The compensation of voltage sag and swell condition using PI controller, Fuzzy logic controller, ANN controller and CNN controller depicted in Figure 5(b). From Figure 5(b) after compensation of voltage swell condition the per unit values PI, FLC and ANN controllers are 1.083, 1.038, 1.102 respectively. But in CNN controller after compensation of voltage swell condition the per unit value is 0.983 (nearest to unity), similarly after compensation of voltage sag condition the per unit value of CNN controller nearest to unity (0.994). The load voltage is maintained at the constant value, irrespective of the voltage sag and swells in the source voltage magnitude. In this case, the voltage sag and swell can be analyzed by creating unbalanced load on the network system. The time duration of the voltage sag is 0.5 sec - 0.1 sec and voltage swell from its duration between 0.15 - 0.2 sec.

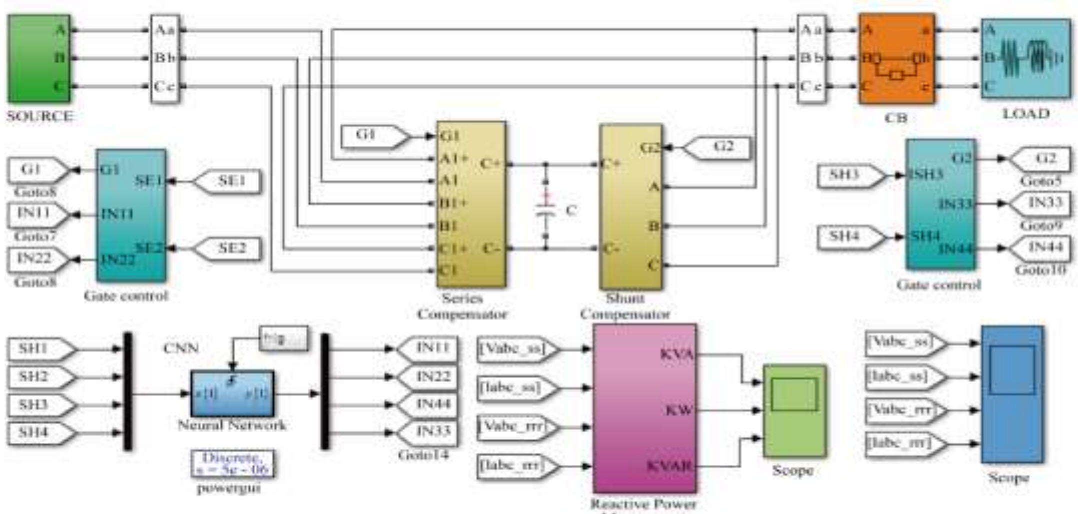

Fig. 4. Simulink model of proposed CNN system

The supply voltages are unbalanced sinusoidal with the magnitudes below the 1 per unit. The series compensator injecting the voltage, the load side maintains balanced sinusoidal voltage. The load voltage maintains the nominal value of 1 per unit. The UPQC can compensate voltage of sag and swell conditions under PI controller, Fuzzy logic controller, ANN controller and CNN controller depicted in Figure 5(b). Performance analysis of PI, FLC and CNN controller are shown in Table 1. From the results, CNN controller.

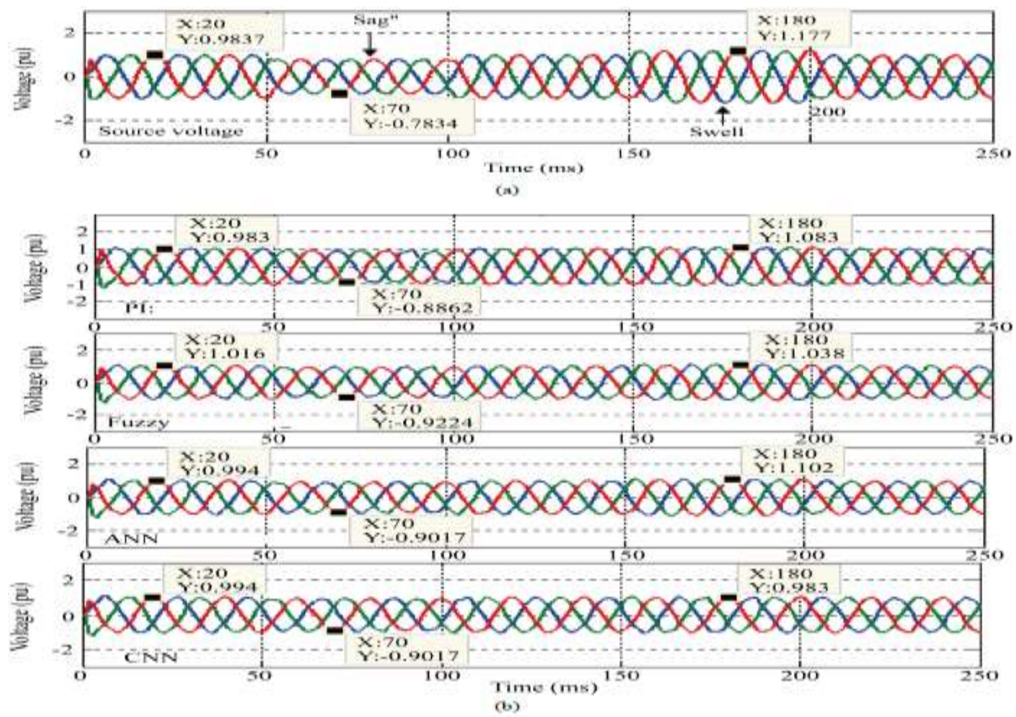

Fig. 5. (a) Source voltage; (b) Compensation of voltage sag and swell

Table 1. Performance analysis of PI, FLC and CNN controller

Quantity/R phase	PI controller		FLC		CNN Controller	
	THD%	Magnitude	THD%	Magnitude	THD%	Magnitude
Source voltage	3.82	0.983	3.12	0.983	2.66	0.983
Load voltage	2.52	0.983	2.23	1.01	1.90	0.994
Source current	3.81	0.965	2.86	0.949	2.46	0.956
Load current	2.53	0.968	1.92	0.965	1.21	0.943

THDs are maintained within permissible limits. The source voltage under distorted condition from 0.5 sec - 0.1 sec undergoes sag condition. The source voltage with sag/swell before compensation has THDs of 2.66% in R phase. The load voltage with sag/swell after compensation has THDs 1.90% in R phase respectively. An unbalanced created in load condition, the shunt compensator forces the load current to be sinusoidal in nature. The source current before compensation have THDs of 2.46%. The source current after compensation have THDs of 1.21%. Hence in different controllers operation, from **Table 1**, it is clear that CNN controller gives better performance in terms of reduced THDs in voltage and current after compensation. The THD within the limit specified in the IEEE 519-1922. From **Figure 6(a)** and **Figure 6(b)**, shows the load voltage is maintained constant irrespective of voltage sag and swell condition. The **Figure 6(a)** shows the source side active power and reactive power during sag and swell condition with a load. The **Figure 6(b)** shows the load side compensated output results of active power and reactive power at the simulation time of 0.15 to 0.20 sec.

It is observed from the **Table 2**, that the THD of the source current is 2.68% for single ANN controller while it is 2.46% for CNN. Similarly, the THD for load current is 1.69% for single ANN controller while it is 1.21% for CNN controller. The THDs of source voltage, load voltage, source current and load current with CNN controller is shown in **Figure 7**.

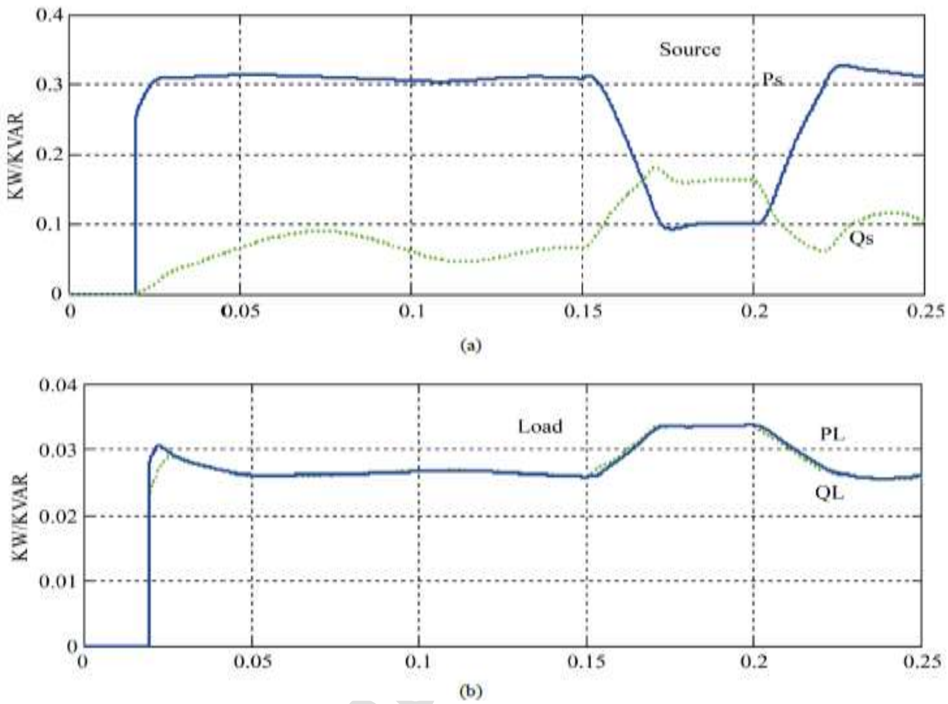

Fig. 6. Real and reactive power on source and load side. (a) Source side (Ps: Source side active power, Qs: Source side reactive power); (b) Load side (PL: Load side active power, QL: Load side reactive power).

Table 2. Performance analysis of ANN and CNN controller

Quantity/R phase	ANN Controller		CNN Controller	
	THD%	Magnitude	THD%	Magnitude
Source voltage/sag	2.96	0.983	2.66	0.994
Load voltage	2.16	0.994	1.90	0.994
Source voltage/swell	2.96	1.177	2.66	1.17
Load voltage	2.16	0.994	1.90	0.983
Source current	2.68	0.968	2.46	0.956
Load current	1.69	0.976	1.21	0.943

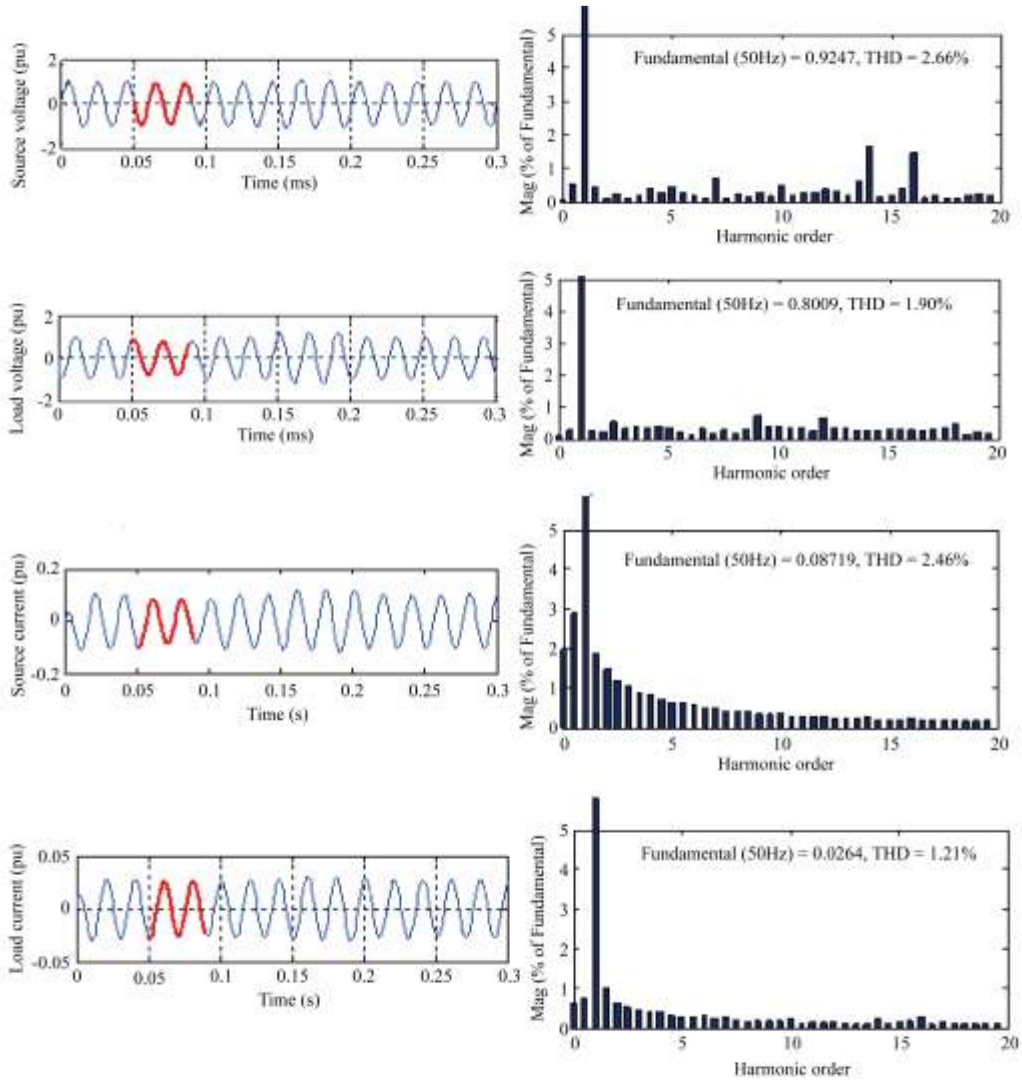

Fig. 7. THD level of "R" phase for CNN controller

5. EXPERIMENTAL RESULTS

The performance of proposed concept is validated through experimental results. The hardware laboratory setup is shown in **Figure 8**. The source voltage, load voltage, source current and load current for single phase can be seen in hardware results. The structure of the CNN, realized in simulation, can be easily implemented in KEIL C and can be embedded in the microcontroller. The sigmoidal functions, used by the CNN can be implemented by the programming segment shown below. The segment of the program containing the sigmoidal function can be kept as a C function and can be called repeatedly by the CNN main program. The synaptic weights of the MATLAB simulated CNN units are constants and in the keil implementation the synaptic weights are implemented as floating point constants. The trained CNN controller is simulated using microcontroller unit. To the sudden variation in load creates the sag and swell conditions.

Figure 9 shows the experimental results during voltage sag condition. **Figure 9(a)** shows the unbalanced source voltage and corresponding THDs which are found to be 2.79%. **Figure 9(b)** shows the compensated load voltage and corresponding THDs which are found to be 1.98%. The load voltage maintains constant value.

Fig. 8. Hardware setup

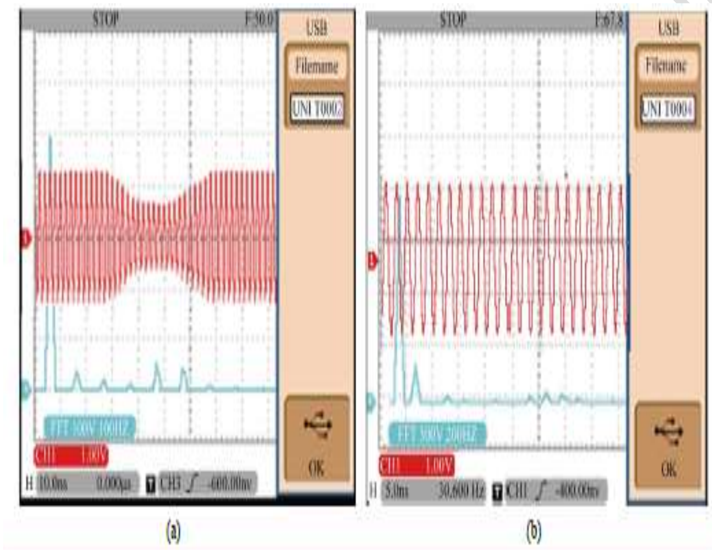

Fig. 9. Voltage sag and harmonics

CONCLUSION

A new methodology is proposed to compensate voltage sag, voltage swell and reactive power compensation. The artificial intelligence based CNN controller has been developed. The proposed system can improve the power quality at the distribution systems. The simulation model and hardware prototype model delineate in this paper. It can be implemented for higher power rating circuits. The acceptable results for the proposed system summarized as follows. Moreover, proposed control scheme is in steady state and transient response. A detailed comparison is also verified between conventional controllers. The proposed controller provides better performance with conventional controllers. The current unbalance, current harmonics, and load reactive power of nonlinear loads are compensated. The simulation results are validated experimentally.

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