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Artificial Neural Network Controlled Shunt Active Power Filter for Minimization of Current Harmonics in Industrial Drives

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***Abstract:** In this paper development of three phase voltage controlled shunt active power filter is designed to compensate the harmonic current present in nonlinear load. The designed system overcomes the limitations of passive filter because of its resonance and bulky size. Voltage controlled shunt active power filter is the effective method for compensating harmonic elements caused by rectifier with RLE (nonlinear) load. In the proposed system classical PI controller is implemented and minimizes the ripple voltage of the DC capacitor voltage. The techniques used to control algorithm deals with the concept of instantaneous power of P-Q theory and a combination of neural network based intelligent technique to calculate three phase reference compensating current. The results ofPI based instantaneous power of P-Q theory and intelligent technique such as artificial neural network based back propagation algorithm is implemented and simulation are carried out in MATLAB/ Simulink environment.*

***Key Words:** PI controller, Voltage Controlled Shunt Active Power Filter (VCSAPF), Artificial Neural Network (ANN), Total Harmonic Distortion (THD)*

I. INTRODUCTION

During recent years the development of power electronic based systems creates a major issue in acting electrical system applications. The main source of the production and distribution of the electricity creates an issue and degrades the quality of the system. Because of the rapid increase in power electronic based loads such as thyristors, front end rectifier, uninterruptible power supply (UPS), fluorescent lamps and electric arc furnace draws a non-sinusoidal current that creates harmonics in power system [1-3]. Therefore these types of loads create a series problem mainly harmonic interference in industrial applications. The above problem is mitigated by passive filters and provides a distortion less current in the distribution network. But passive filters are used for low voltage systems and they are suitable to work at the low impedance path, in order to adjust the harmonic frequencies that are simple and inexpensive. In spite passive filter draws fixed compensation, resonance with the system impedance and lower bandwidth is a majorproblem. However in industrial applications voltage controlled active power filters are extensively used for harmonic compensation[4-5]. Moreover various types ofpower filters are feasible to overcome the above problem such as series active power filter and shunt active power filter. Series active power filter is expensive, complex and minimize the voltage harmonics.

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Because of its effective operation, VCSAPF is examined as viable solution to minimize the current harmonics produced by nonlinear load. To extract reference compensating current several control techniques such as synchronous reference frame D-Q theory, instantaneous power of P-Q theory, synchronous detection algorithm and wavelet transform are applicable in the present scenario. P-Q theory is one of the most simple andconvenienttechnique to implement. Due to the complexity of the conventional technique the proposed intelligent controller behaves for leading patterns to compensate the reference current [6-7].

II. INSTANTANEOUS P-Q THEORY BASED VOLTAGE CONTROLLED SHUNT ACTIVE POWER FILTER

The proposed system consist of three phase power supply, front end rectifier, PI controller, P-Q theory, and hysteresis band current controller and voltage source inverter. The principle of VCSAPFis mainly used to minimize the harmonics fed by rectifier with RLE load. The system is implemented in classical P-Q theory. The configuration scheme of voltage controlled shunt active power filter is shown in Fig. 1.

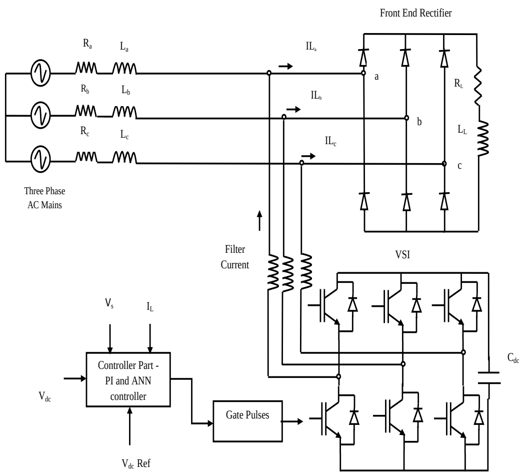

Fig. 1 Configuration scheme of voltage controlled shunt active power filter

Three phase AC source is fed to rectifier that converts ac to dc power and connected to RLE load. Source current harmonics is not minimized due to presence of non linear condition. The control circuit receives input from source voltage and load current and control circuit produces gate pulses by implementing P-Q theory.

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The corresponding pulses are given as input to the VCSAPF to generate compensating filter current andconnected at a point of common coupling.

P-Q theory explains about the transformation from three phase abcof current and voltage coordinates to two phase αβ voltage and current coordinate by Clarke's transformation and the corresponding αβ is transformed to active and reactive power component p-q.

The corresponding power components are converted to two phase αβ current by low pass filter. Then the αβ current is converted to abc reference compensating current by using inverse Clarke transform and the output of control circuit produces gate pulses. The load current produced by rectifier with RLE load and filter current produced by P-Q theory have equal magnitude but opposite phase to that of load current cancel each other and produce distortion less current in supply side. Block diagram of PI controller based instantaneous power of P-Q theory is shown in Fig. 2.

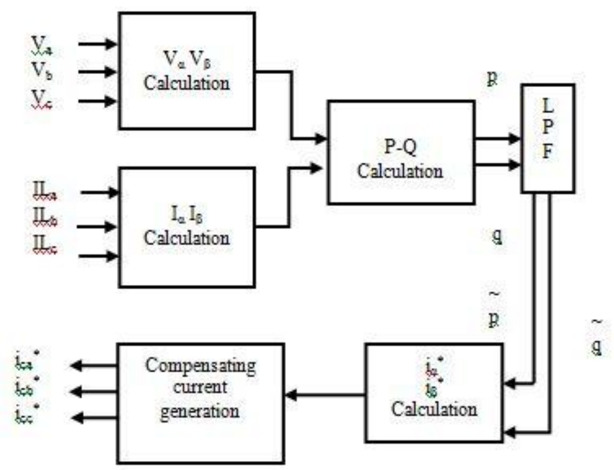

Fig. 2.Block diagram of P-Q theory

III. INTELLIGENT CONTROLLER - ANN

In recent years artificial neural network plays a vital role that has the capacity to learn by specimen that makes them more extensible and robust. While implementing neural network, it does not require any internal structure to perform that task. The most primary element of the human brain is the special type of cell is neuron and it provides the abilities to realize and executes the previous existence to every action[8-10]. A_1 and A_2 are the input neuron that imparts the signals and B is the output neuron that receives the signals. The input neurons namely A_1 and A_2 are associated with the output neuron B over interdependent weights (W_1 and W_2). The simple neural network architecture is shown in Fig. 3.

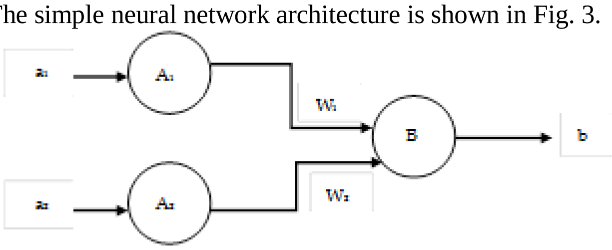

Fig. 3.Neural network architecture

The net input is calculated in the following equation given below:

$$b_{in}= a_1w_1 + a_2\, w_2$$

Whereas a1 and a2 are the activations of the input neurons A1 and A2 that is fed to the output of input signals. The output b of output neuron B can be obtained by using the activations over the net input.

$b= \ f\,(b_{in})$

Output neuron = function (calculated net input)

Topology of ANN consists of tan sigmoid function is depicted in Fig. 4.

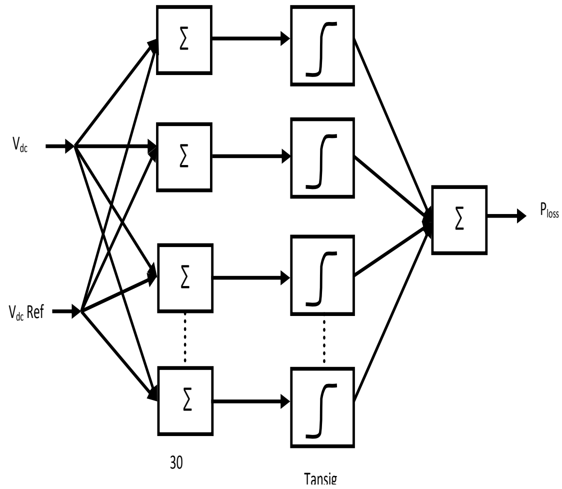

Fig. 4.Topology of ANN

Through many interconnection and number of neurons are involved, the power of the human mind appears across it. In order to improve the characteristic performance of voltage controlled shunt active power filter, multilayer neural network is chosen[11-12]. The design parameters consist of input layer, hidden layer with 30 neurons and output layer with a neuron. The values are chosen from conventional proportional integral controller and these data's are used to train the network by selecting back propagation algorithm depending on users need. The activation function is selected as tan sigmoid for the input layer and positive linear activation function for target layer.For training the algorithm, Marquardt Levenberg Back Propagation (MLBP) is used. Each training session requires 265 values with 10 iterations and the error occurrence is calculated. Back propagation algorithm is mainly used for artificial neural network to estimate the error improvement of every neuron. The network is based on first iterative optimization algorithm to vary the weight of the neuron. Because of the estimated error at the output and delivered back to the network it is termed as backward propagation of errors. For better internal representation of the network, back propagation algorithm is the best one.

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The internal representation of the network is mainly used to get accurate results. Because of its efficiency in the network, back propagation algorithm is more significant to estimate the delta rule.The back propagation algorithm is the improvement of least mean square algorithm in which it changes the network weights to minimize the mean squared error between the actual and desired outputs of the network.

IV. IMPLEMENTATION OF P-Q THEORY BASED ANN CONTROLLER

The neural network based instantaneous power P-Q theory modeling is shown in Fig.5.

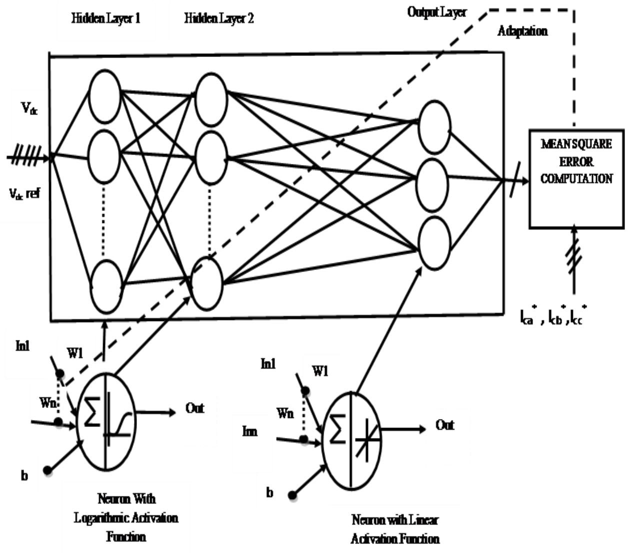

Fig. 5. Neural Network of P-Q theory modeling

V_{dc} and V_{dc} reference are the inputs fed to hidden layer and compensating current is the output that is observed from the P-Q theory. In neural network adaption of the weights (w) and bias (b) arebased on the computation of mean square error between its outputs. The process for the calculation of two phase αβ coordinate is given below.

$$I_\alpha = 2/3\, I_a - 1/3(I_b+I_c) \quad (3)$$

$$I_\beta = 1/\sqrt{3}\,(I_b+I_c) \quad (4)$$

Therefore the compensating current obtained from two phase αβ coordinate to three phase abc frameis given by,

$$IC_a = (\sqrt{2/3}) * IC_1 \quad (5)$$

$$IC_b = (\sqrt{2/3}) * ((-0.5 * IC_1) + \sqrt{3}/2 * IC_2) \quad (6)$$

$$IC_c = (\sqrt{2/3}) * ((-0.5 * IC_1) - \sqrt{3}/2 * IC_2) \quad (7)$$

From the above equations compensating currents are calculated from α-β to abc frame. To calculate the derivative function for the least square error with respect to the weights and bias of the network, first order iterative optimizationalgorithm is used. The squared error function is defined by the following equation:

$$E = ½\,(T-C)^2$$

E is the squared error, T is the Target output for a given sample and C is the actual output of the neuron. The constant ½ is included while differentiating the constant is cancelled. Training steps for back propagation algorithm is given below:

Step 1: Start the process and initialize weights of the network and level the input/output data.

Step 2: The network of the structure is chosen and correspondingly the hidden layers for each neuron is selected.

Step 3: The activation function is selected and these activation functions can be uniform and may be vary for different layers.

Step 4: Training pair for each training set is determined. To determine the output of the network, it is based on input vector set andinitial weights.

Step 5: The network output is determined by taking the error output and the corresponding error is propagated back that varies the weights in such a way it minimizes the error. Itagain start from the output layer and fed backward to input layer.

Step 6: Repeat steps from 4 to 6 and for each vector the training set is analyzed unless the error for the given vector set is lower than the required minimum error.

Neural network model and best validation performance is shown in Fig. 6 and Fig. 7.

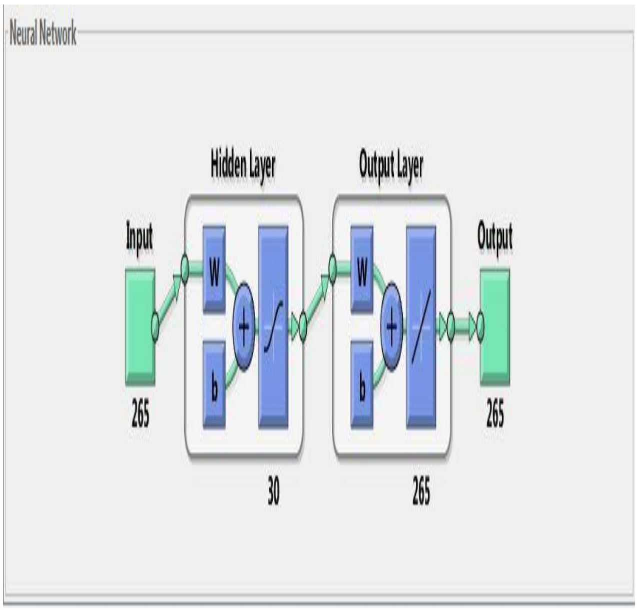

Fig. 6. Neural network model

In the back propagation network, testing of data's are implemented only in the feed forward path and during implementation of the network, even though network has the ability to operate in more hidden layers, it is more sufficient to operate under one hidden layer. During training process it requires more time to train the network but it produces an output in a clear manner when compare to other networks.

The best validation performance is obtained by training and testing the network by selecting number of neurons and epochs in a clear manner.

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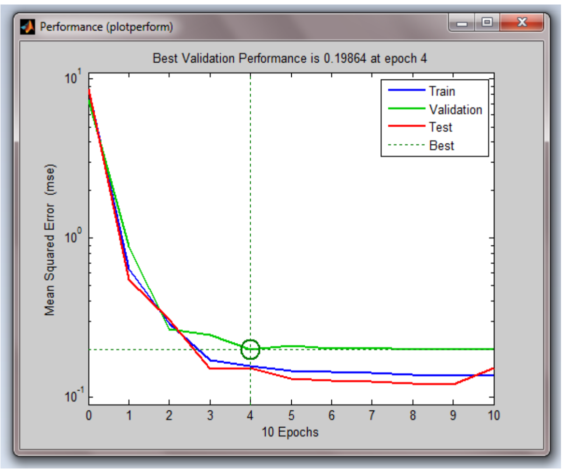

Fig. 7. Best validation performance

The algorithm consists of input and output layer to vary the weights in a network to analyze the arrangements of input in a correct manner.

Back propagation algorithm is different from other techniques because during learning period itself the weights are calculated. The error signals are determined by obtaining the difference between the calculated and targeted output that measures in the output layer. Training set for neural network provides a good performance while taking proportional and integral control in the range of 1.25 and6.5.The configuration parameter for the voltage controlled shunt active power filter is given in Table I:

Configuration Parameters	
Source voltage	440 V, 50 Hz, Three phase
Source inductance	0.5mH
Load resistance	300Ω
Load inductance	1mH
Filter inductance	0.1017H
Filter capacitance	100µF
Proportional gain(K_p)	1.25
Integral gain(K_i)	6.5
V_{dc}	620V
C_{dc}	3600µF

Table I. Configuration Parameter

V. RESULTS AND DISCUSSIONS

The proposed voltage controlled shunt active power filter is designed and rectifier with RLE load is a nonlinear. It is viewed that rectifier with RLE load results in harmonic current is not minimized to IEEE standard due to presence of nonlinearity. With the addition of VCSAPF the current harmonics is minimized by instantaneous power of P-Q theory and ANN tuned proportional integral controller. To train the network, values obtained from PI controller is chosen to train the neurons in order to get a distortion less current in supply side when compared to proportional integral controller. The results are described for rectifier with RLE load, PI controller and ANN tuned back propagation algorithm.The parameters aided in the proposed system are supply voltage = 440V, R=300Ω, L=1mH, E=1V. The output of source voltage THD without filter is 2.24%.

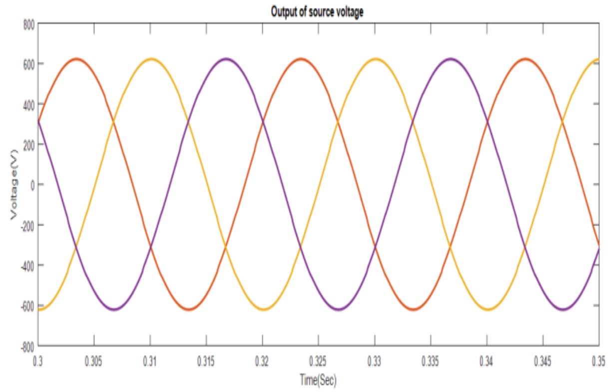

Fig. 8.Source voltagewaveform -Rectifier with RLE load

Sourcecurrent total harmonic distortion - rectifier with RLE load (non linear) is 12.33%.

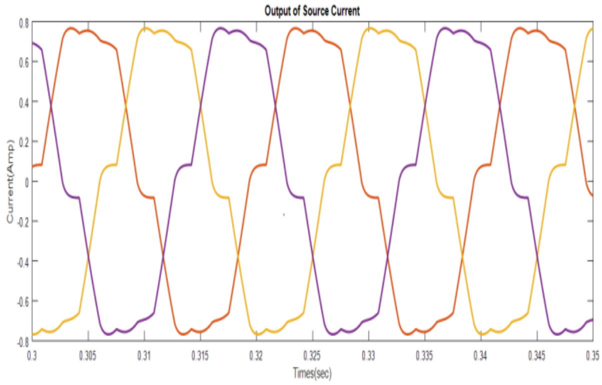

Fig. 9. Source current waveform –Rectifier with RLE load

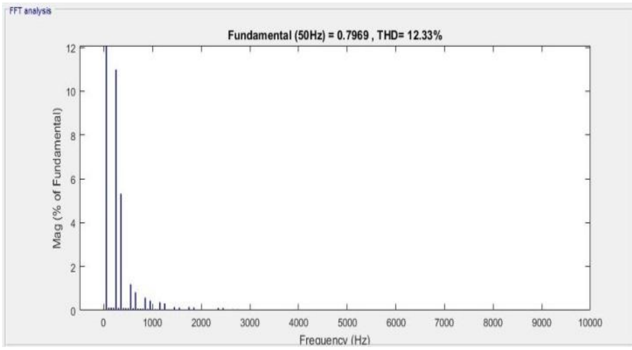

Fig. 10.Source current THDof rectifier with RLE load- FFT analysis

It is observed from the simulation result the waveform of source current is non sinusoidal nature due to the occurrence of nonlinear load and the above result isrectified by implementing conventional PI controller.

The source voltagetotal harmonic distortion with IRP theory based on PI controller is 0.55%.

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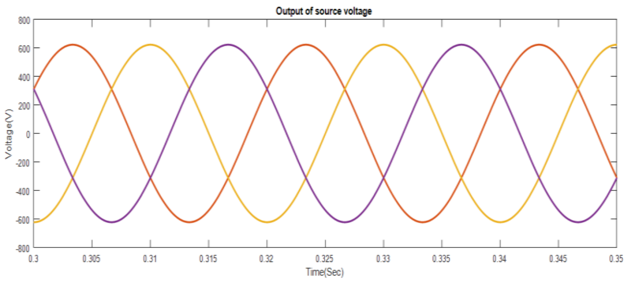

Fig. 11. Source voltage waveform –IRP theory based on PI controller

Source current total harmonic distortionwith IRP theory based on PI Controller is 4.62%.

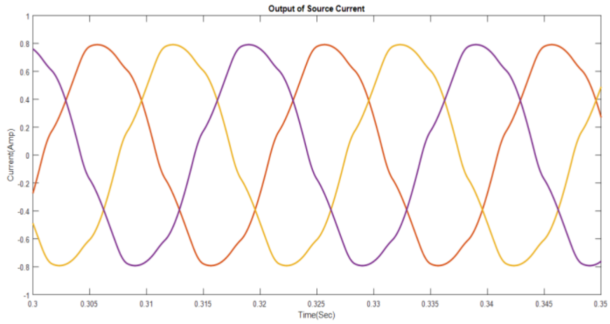

Fig. 12.Source current waveform- IRP theory based on PI controller

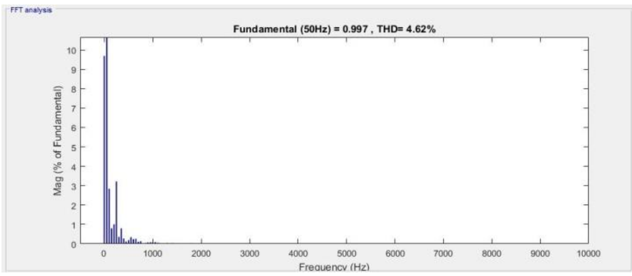

Fig. 13.Source Current THD ofPI controller – FFT analysis

Itis observed from the simulation result with the addition of VCSAPF generate the compensating filter current which is equal to the harmonic current. Thus it minimizes the source current harmonics and produce distortion less current in the mainsupply.

The source voltagetotal harmonic distortion with ANN based back propagation algorithm is 0.21%.

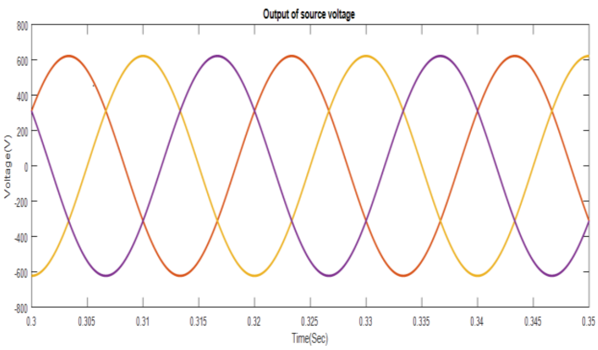

Fig. 14.Source voltage waveform – ANN tuned back propagation algorithm

The source currenttotal harmonic distortion with ANN based back propagation algorithm is 2.73 %.

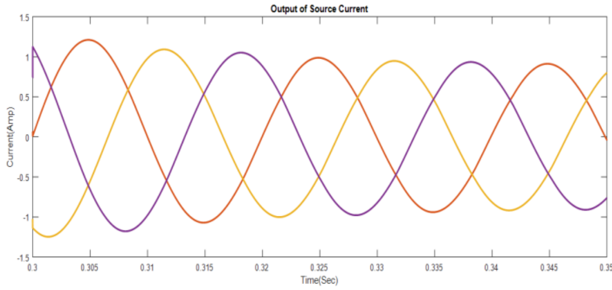

Fig. 15. Source current waveform– ANN tuned back propagation algorithm

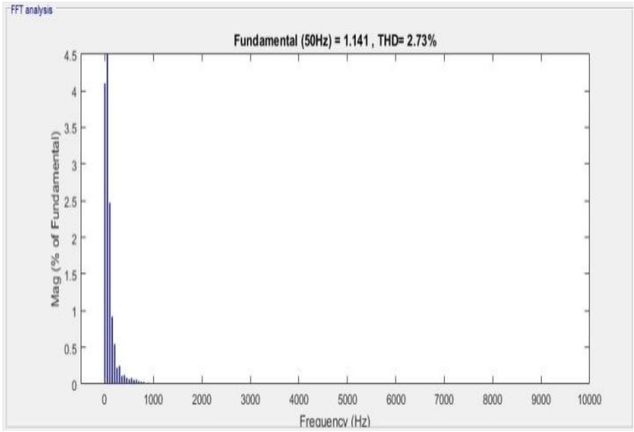

Fig. 16.Source Current THD of ANN controller –FFT analysis

The system is designed and the performance is verified for the proposed system with RLE load. By implementing PI controller based IRP theory source current harmonics is minimized in which filter current gets injected that are equal in magnitude and opposite in phaseopposite to that of load current cancel each other and produce distortion less current in supply side as per IEEE standard. In a similar manner, by implementing intelligent technique it minimize the current harmonics to an acceptable limit and obtains better performance. Source current THD is described for different controller is shown in Table II:

Controller	**Source current – THD**	**Source voltage- THD**
Rectifier with RLE load	12.33%	2.24%
With PI	4.62%	0.55%
With PI - ANN	2.73%	0.21%

Table II.Comparison Table

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VI. CONCLUSION

Voltage controlled shunt active power filter with ANN controller has been implemented for minimization of source current harmonics. The present system is designed to mitigate the harmonics produced by nonlinear load. Compared to conventional controller, neural network minimizes the source current harmonics that has higher attenuation against higher order harmonics and improves the power quality of the system. Conventional controller regulates average level of the DC capacitor voltage,whereas neural network avoids mathematical operation and simplifies the control configurations. Compensation is employed for power quality improvement by minimizing the current harmonics in various fields such as variable speed drives, electric arc furnace and UPS application.

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