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Shunt Active Filter based on three–level (NPC) Inverter using Current and DC Voltage Artificial Neural Network Controllers

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Abstract— **This paper presents a shunt active filter based on three-phase three-level (NPC) inverter using two artificial neural network controllers. Shunt active filter is the best solution to eliminate harmonics drawn from nonlinear load especially for low power system, the most inverter used is the two-level voltage source inverter. Multilevel inverters are being investigated and recently used for active filter topologies. Today Three-level inverter becomes a good alternative for most inverter applications, such as machine drives and power factor compensators. The advantages of multilevel inverters is that they can reduce the harmonic content generated by the active filter and can reduce the voltage or current ratings of the semiconductors. Two ANN's are proposed in this paper, the first one is used to replace the PWM logic controller while the second regulate the dc voltage link of the shunt active filter. The results simulations of global system control and power circuits are obtained using Matlab-Simulink and SimPowerSystem Toolbox.**

Index Terms— **ANN controllers, Harmonic compensation, Shunt active filter, Three-level (NPC) inverter.**

I. INTRODUCTION

A large part of total electrical energy, produced in the world, supplies different types of non-linear loads. The loads such as variable frequency drives and electronic ballasts draw current, which does not resemble the grid sinusoidal voltage. This load is said to be non-linear and typically is composed of odd order currents, which are expressed as multiples of the fundamental frequency. The harmonic current cannot contribute to active power and need to be eliminated to enhance the power quality [1]. Active Power Filter (APF) is the popular solution used to eliminate the undesired current components by injection of compensation currents in opposition to them [2].The most power converter used in APF is the two-level voltage source inverter [3]-[4]-[5], due to power handling capabilities of power semiconductors, these inverter are limited for low power applications. Three-level inverters have been successfully employed. The advantages of the three-level voltage source inverter have been applied typically in medium and high power applications in the last years [6]-[7].

The controller is the main part of the active power filter operation and has been a subject of many researches in recent years [8]-[9]. Multilevel pulse-width modulated (PWM) techniques have been proposed for high power or medium-voltage applications such as reactive power compensation and AC motor drives. The advantages of multilevel techniques are low voltage stress of power semiconductors, lower current or voltage harmonics, and less electromagnetic interference. To ameliorate the APF

Performances there's a great tendency to use intelligent control techniques, particularly neural network controllers. The first studies have shown that ANNs are reliable in improvement of power electronic systems control [10]-[11]. Some research work are elaborated using ANNs based a two-level VSI in the last years.

In this paper we present, the application of neural network to control shunt active filter based on three-level neutral point clamped (NPC) inverter associated with a second ANN to regulate the DC voltage link. The performances of the complete structure including control and power circuit are evaluated through computer simulations for steady-state conditions using Matlab-Simulink program.

II. SHUNT ACTIVE FILTER

The basic compensation principle of a shunt active power filter is shown in Fig.1. It is controlled to draw/supply a compensating current from/to the utility. So that it cancels current harmonics on AC side, and makes the source current in phase with the different waveforms. The current drawn from the power system at the coupling point of the shunt APF will result sinusoidal [12]-[13].

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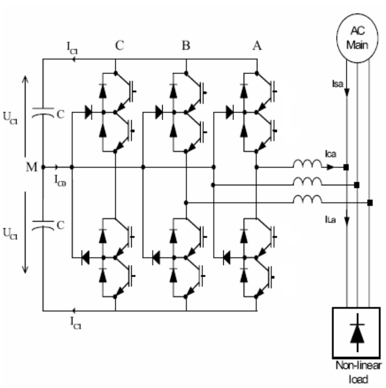


Fig.1 Three-level (NPC) shunt active filter

II.1 THREE-LEVEL INVERTER

Multilevel inverters are being investigated and recently used for active filter topologies. Three-level inverters are becoming very popular today for most inverter applications, such as machine drives and power factor compensators. The advantage of multilevel converters is that they can reduce the harmonic content generated by the active filter because they can produce more levels of voltage than conventional converters (more than two levels). Another advantage is that they can reduce the voltage or current ratings of the semiconductors and the switching frequency requirements [14].

Fig. 2, shown the circuit topology of a diode-clamped three-level inverter based on the six main switches (T11, T21, T31, T14, T24, T34) of the traditional two-level inverter, adding two auxiliary switches (T12, T13, T22, T23, T32, T33) and two neutral clamped diodes on each bridge arm respectively, the diodes are used to make the connection with the point of reference 0 to obtain Midpoint voltages. Such structure allows the switches to endure larger dc voltage input on the premise of not raising the level of their withstand voltage. Moreover, take phase-A as example, three kinds of voltage level $Vd/2$, 0 and $-Vd/2$ can be output corresponding to three kinds of switching states A, 0, B, listed in Table I. As a result, there exist 27 kinds of switching output from the three-phase three-level inverter [15]-[16].

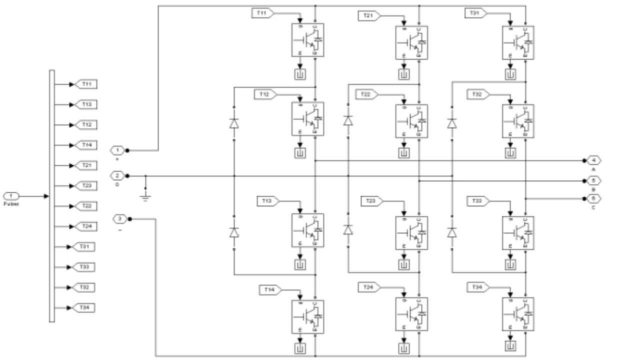


Fig.2 Three-level NPC inverter

Switching States	Voltage output	T11	T12	T13	T14
A	$Vd/2$	ON	ON	OFF	OFF
0	0	OFF	ON	ON	OFF
B	$-Vd/2$	OFF	OFF	ON	ON

Table 1 Switching states of three-level inverter

II.2 PWM THREE-LEVEL INVERTER CONTROL

The PWM controller calculates the difference between the injected current and the reference current that determine the modulation wave of the reference voltage. This voltage is compared with two carrying triangular identical waves shifted one from other by a half period of chopping and generate switching pulses [17].

The control of inverter is summarized in the two following stages:

Determination of the intermediate signals V_{i1} and V_{i2} :

- If error Ec $\geq$ carrying 1 Then $V_{i1}=1$
- If error Ec $<$ carrying 1 Then $V_{i1}=0$
- If error Ec $\geq$ carrying 2 Then $V_{i2}=0$
- If error Ec $<$ carrying 2 Then $V_{i2}=-1$

Determination of control signals of the switches T_{ij} and V_{i2} $(i=1,2,3\ ;\ j=1,2,3,4)$:

- If $(V_{i1}+V_{i2})=1$ Then $T_{i1}=1$, $T_{i2}=1$, $T_{i3}=0$, $T_{i4}=0$,
- If $(V_{i1}+V_{i2})=0$ Then $T_{i1}=0$, $T_{i2}=1$, $T_{i3}=1$, $T_{i4}=0$,
- If $(V_{i1}+V_{i2})=-1$ Then $T_{i1}=0$, $T_{i2}=0$, $T_{i3}=1$, $T_{i4}=1$,

The three level inverter logic control as shown in Fig.3.

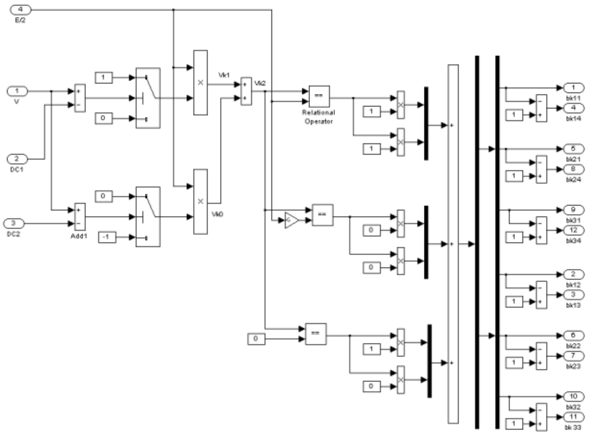


Fig.3. Three level inverter logic control

III. CONTROL STRATEGY

The strategy control used in this work is the synchronous current detection method is concise and requires less computational efforts than many others method control [18]-[19]. It is formed by a DC voltage regulator and reference current calculation. The compensating currents of active filter are calculated by sensing the load currents, DC capacitor voltage, peak voltage of AC source (Vsm) and zero crossing point of source voltage. The last two parameters are used for calculation of instantaneous voltages of AC source as below:

$$v_{sa}(t)=V_{sm}\cdot\sin(\omega t)$$

$$v_{sb}(t) = V_{sm} \cdot \sin(\omega t - \frac{2\pi}{3}) \qquad (1)$$
$$v_{sa}(t) = V_{sm} \cdot \sin(\omega t - \frac{4\pi}{3})$$

In order to compensating the current harmonics, the average active power of AC source must be equal with P_{Lav}, with considering the unity power factor of AC source side currents the average active power of AC source can be calculated as bellow :

$$P_s = \frac{3}{2} V_{sm} . I^*_{smp} = P_{Lav} \qquad (2)$$

From this equation, the first component of AC side current can be calculated as bellow:

$$I^*_{smp} = \frac{2}{3} \frac{P_{Lav}}{V_{sm}} \qquad (3)$$

The second component of AC source current (I^*_{smd}) is obtained from DC capacitor voltage regulator. The desired peak current of AC source can be calculated as bellow:

$$I^*_{sm} = I^*_{smp} + I^*_{smd} \qquad (4)$$

The AC source currents must be sinusoidal and in phase with source voltages, theses currents can be calculated with multiplying peak source current to a unity sinusoidal signal, these unity signals can be obtained from equation (5):

$$i_{ua}(t) = v_{sa} / V_{sm}$$
$$i_{ub}(t) = v_{sb} / V_{sm} \qquad (5)$$
$$i_{uc}(t) = v_{sc} / V_{sm}$$

The desired source side currents can be obtained from equation (6):

$$i^*_{sa}(t) = I^*_{sm} . i_{ua}$$
$$i^*_{sb}(t) = I^*_{sm} . i_{ub} \qquad (6)$$
$$i^*_{sc}(t) = I^*_{sm} . i_{uc}$$

Finally, the reference currents of AF can be obtained from (7):

$$i^*_{ca} = i^*_{sa} - i_{La}$$
$$i^*_{cb} = i^*_{sb} - i_{Lb} \qquad (7)$$
$$i^*_{cc} = i^*_{sc} - i_{Lc}$$

The control strategy principle for the shunt active filter based on three-level inverter is given by Fig.4.

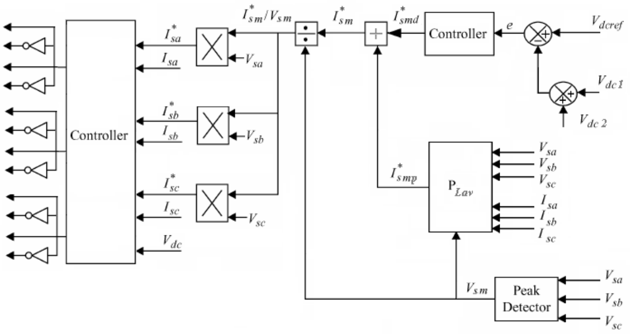


Fig.4 Control strategy principle

IV. DC VOLTAGE REGULATOR

To compensate the inverter losses and maintain the constant dc-link voltage U_{dc}, a proportional integral controller is used to obtain the current I^*_{smd}. The regulation loop consists of the comparison of the measured voltage $U_{dc1} + U_{dc2}$ with the reference voltage U^*_{dc} [20],[21]:

$$I^*_{smd} = K_p . \Delta U_{dc} + K_i \int \Delta U_{dc} . dt \qquad (8)$$

V. ARTIFICIAL NEURAL NETWORK CONTROLLERS

V.1 ANN CURRENT CONTROLLER

Artificial Neural Networks have provided an alternative modeling approach for power system applications. The MLPN is one of the most popular topologies in use today. This network consists of a set of input neurons, output neurons and one or more hidden layers of intermediate neurons. Data flows into the network through the input layer, passes through the hidden layers and finally flows out of the network through the output layer. The network thus has a simple interpretation as a form of input-output model, with network weights as free parameters. The use and training of MLPNs is well understood.

The objective of the training is to modify weight matrices W and V such that the ANN function approximates the plant function and the error *e* between the desired function output *y* and the ANN output ˆ*y* is minimal. The training cycle has two distinct paths:

- Forward propagation: It is the passing of inputs through the neural network structure to its output.
- Error back-propagation: It is the passing of the output error to the input in order to estimate the individual contribution of each weight in the network to the final output error. The weights are then modified so as to reduce the output error [22].

The proposed ANN current controller for the three-level inverter shunt active filter is shown in Fig.5. The input pattern of the current controller network is the error values

(E_{ca}, E_{cb}, E_{cc}) between the measured filter currents (i_{fa}, i_{fb}, i_{fc}) and the compensating reference currents $(i^*_{fa}, i^*_{fb}, i^*_{fc})$ whereas the outputs values are the switching states $T_{i1}, T_{i2}, T_{i3}, T_{i4}$ for every phase. The hidden layer contains 50 neurons with a sigmoid activation function, whereas the output layer contains six neurons with a linear activation function. The network is trained using Levenberg-Marquardt back propagation algorithm, about 10000 training examples obtained by simulation.

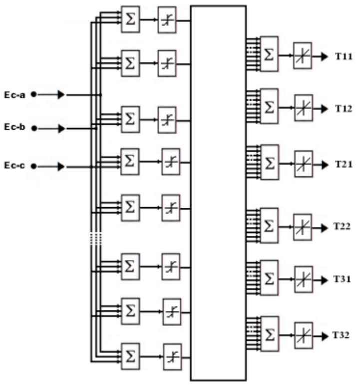
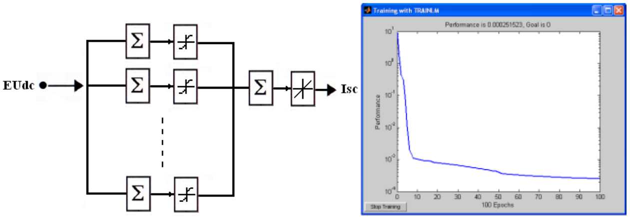


Fig.5 ANN current controller

V.2 ANN DC VOLTAGE CONTROLLER

The dc voltage neural network controller used is presented in Fig.6 (a). Its role is to maintain constant voltage around a desired value Udc-ref = 800V. The input pattern of the network is the error values EUdc between the measured dc voltage Udc-mes and its reference value Udc-ref. The architecture adopted for this network is three layer perceptron; the hidden layer contains eight neuron with tansig activation function, whereas the output layer contains one neuron with linear activation function.

The network is trained with back propagation Levenberg-Marquardt algorithm using 30,000 examples of learning (off-line) obtained by simulation-based on PI control loop, Fig.6 (b). The training criterion considered is the mean square error of ANN outputs. The performance is 0.000251523 after 100 epochs.



(a) (b)

Figure.6 ANN dc voltage controller

VI. SIMULATION MODEL

The Matlab-Simulink simulation block diagram of the proposed ANN controllers for the three-phase three-level shunt active filter under ideal voltages conditions is shown in Fig.7. The parameters of the proposed shunt active filter are L_f=3mH, C_1=C_2=300uF, V_s=220V/50Hz, U_{dc}=800V.

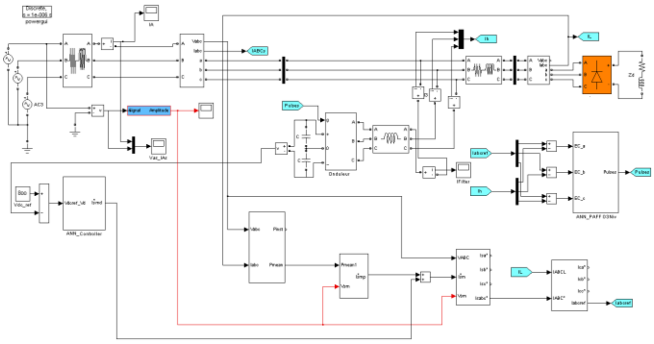
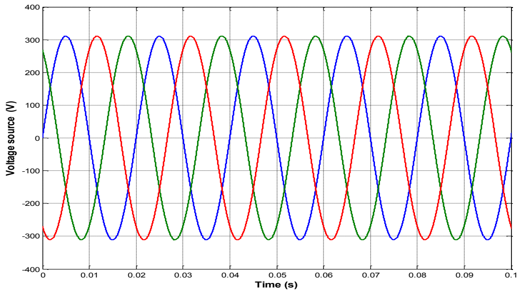
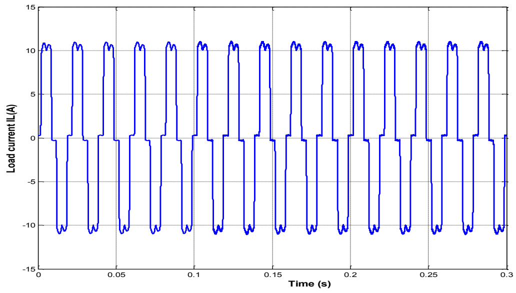


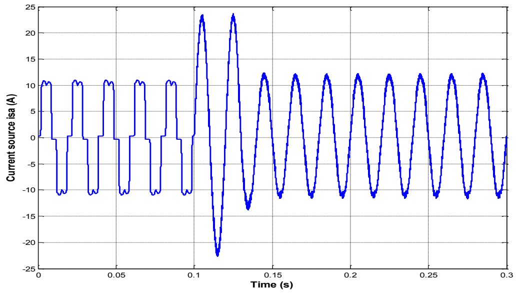
Fig.7 block diagram of the three-phase three-level shunt active filter using ANN controllers

VII. SIMULATION RESULTS

The computer simulation results are provided to verify the effectiveness of the proposed control scheme. Figure 8 shows the simulated results of line voltage, line current, load current and compensated current after shunt active filter operation. After active filter operation the AC-source current only supplies the active fundamental current to the load. The harmonic currents of a nonlinear load are compensated by the inverter.







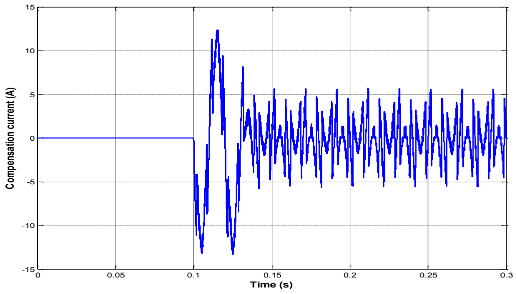
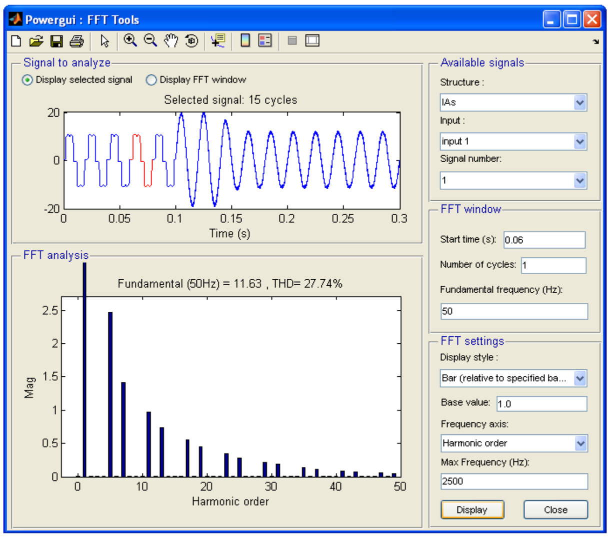


Fig. 8 Waveforms of mains voltage, load current, line current and compensation current before and after active filter operation

Figure 9 show the harmonic spectrum of the source current without APF.



○ Display selected signal ○ Display FFT window

Selected signal: 15 cycles

Fundamental (50Hz) = 11.63 , THD= 27.74%

Structure : IAs

Input : input 1

Signal number: 1

Start time (s): 0.06

Number of cycles: 1

Fundamental frequency (Hz): 50

Display style : Bar (relative to specified ba...

Base value: 1.0

Frequency axis: Harmonic order

Max Frequency (Hz): 2500

Fig.9 Harmonic spectrum without APF (THD=27.74%)

Figures 10 and 11, shows the output line voltage UAB and output phase voltage UAN when the three-level inverter is connect with the nonlinear load.

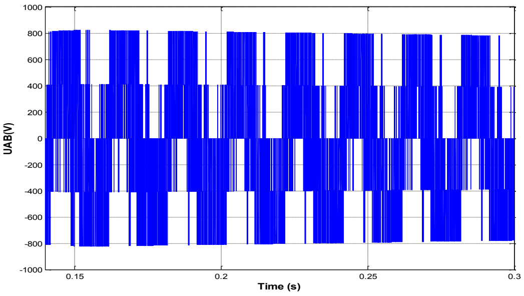


Fig.10 Output line voltage UAB(V)

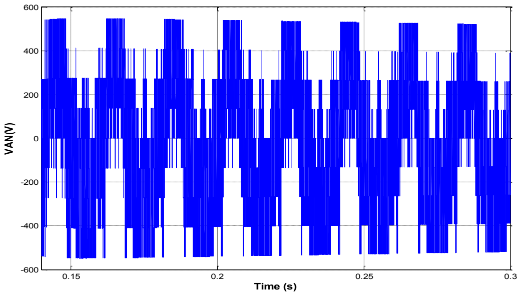


Fig.11 Output phase voltage UAN (V)

Figures 12 show that the source current is sinusoidal with acceptable low harmonic distortion and in the phase with the line voltage.

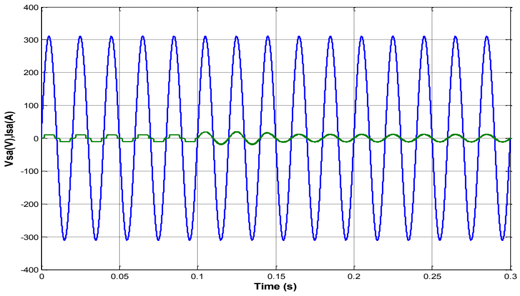
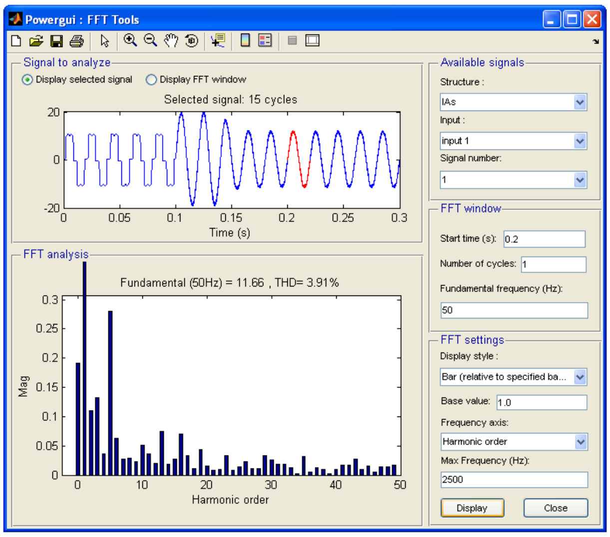


Fig.12 Current and voltage source

Figure 13 shows the harmonic spectrum of the current source after compensation with THD=3.91%.



○ Display selected signal ○ Display FFT window

Selected signal: 15 cycles

Fundamental (50Hz) = 11.66 , THD= 3.91%

Structure : IAs

Input : input 1

Signal number: 1

Start time (s): 0.2

Number of cycles: 1

Fundamental frequency (Hz): 50

Display style : Bar (relative to specified ba...

Base value: 1.0

Frequency axis: Harmonic order

Max Frequency (Hz): 2500

Fig.13 Harmonic spectrum with APF (THD=3.91%)

Fig.14 shows the DC voltage capacitor with Udc-ref=800V.

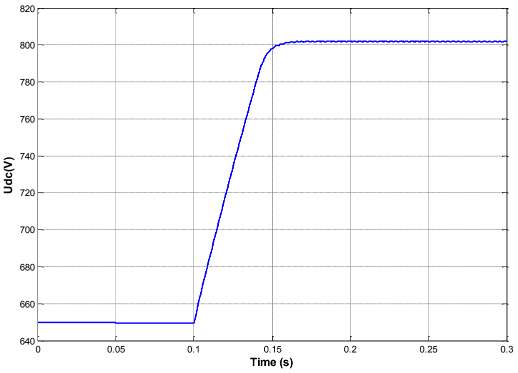


Fig.14 DC voltage capacitor using ANN controller

VIII. CONCLUSION

A three-phase three-level shunt active filter with neutral-point diode clamped topology is adopted to suppress current harmonics using ANN controllers. The first ANN is used to replace the three-level PWM logic controller, the second one to compensate the power loss of the active filter and to regulate the dc-link voltage. The current after compensation is balanced and sinusoidal in phase with line voltage source. The harmonic spectrum shows that the THD is very acceptable and respect IEEE Norms.

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