# Application of ANN to the Control by Elimination Harmonics of a Seven Level Voltage Inverter

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*Abstract* – This study, deals with the artificial neural networks (ANN) implementation problem of the PWM harmonics elimination strategy applied to the control of a seven levels voltage inverter.

The implementation of this method requires initially, calculating the switching angles related to power components. Their determination is carried out in order to cancel the harmonics 5, 7 and 11 and to control the fundamental voltage output. The computation of the switching angles is carried out for a large range of the variations of the modulation index. In order to avoid dealing with the tabulation method which requires an important size of storage memory for the computed values, it is proposed to generate these angles using an ANN.

Thus, after the training phase, the elaborate ANN is able to reproduce the switching angles related to the modulation index for the control of a seven levels voltage inverter. So, for a real time control, it is sufficient to implement this network embedding the obtained synaptic weights.

Keywords- multilevel, inverter, PWM strategy, Harmonic elimination, ANN, THD.

# **1** Introduction

The sinusoidal fed source voltage plays an important role in the industrial field. For electric actuators, it is necessary to vary the amplitude of fed voltage and sometimes even its frequency [1] [2] [3]. This is generally carried out by voltage inverters. Nevertheless, for high power and high voltage applications using the two levels voltage inverters and the connecting series/ parallel of power semiconductor switches, this can give rise to serious problems. This is due to dispersion of the static and dynamic characteristics related to the power electronic components. А possible solution to this problem is to use a voltage inverter with multilevel structure[[4][5]. In addition, the recourse to such a structure can be justified by the need of a good quality voltage.

It should be noted that the quality of the voltage provided by this kind of inverter also depends on the used control strategy. It is necessary then to select the adequate strategy among the whole of existing PWM strategies. Indeed, in high voltage and high power applications, requiring high level performances, it is essential to produce voltage exhibiting a minimum total harmonic distortion (THD). This can be done by cancelling low order harmonics which form the fundamental cause of alteration related to the output signal generated by multilevel converters. This goal can be carried out by applying the elimination harmonics method adapted to the case of the multilevel inverters.

However, the real time control of these converters by the suggested strategy passes first by the determination of all the turn on and turn off instants (switching angles) of power components and second by the storage of resulting values.

Indeed, the implementation operation can especially need an important storage memory in the case of wide variation of the modulation index with a weak increment. Therefore, it is suggested to exploit other techniques easier to implement, such as the ANN. This later is largely applied in classification, memorization, filtering and approximation problems. The problem raised, by the application of neural networks, concerns the determination of the network structure. Up to now, there is not effective method to fix the number of layers of an ANN and the number of neurons per layer. The second difficulty, related to the exploitation of the ANN, is in the choice of a suitable training algorithm in order to confer the desired performances to the ANN.

The interest in the use of the multi-layer ANN lies in the fact that it can be used as a universal approximator and has the generalization capacities. By an adequate training, it is thus possible to make the network able to reproduce the stored values of the switching angles needed for the inverter control.

Consequently, we present here the seven levels voltage inverter with NPC structure. Then, the switching angles necessary to control, this inverter on the base of harmonics cancellation strategy, are determined. In order to control this inverter in real time, multi-layer ANN is elaborated. This network ANN must generate the switching angles according to the modulation index. The results obtained by simulation validate the network performances.

## 2 NPC Structure of Seven Levels Inverter

The NPC structure of three-phase seven levels inverter is illustrated on figure 1. It consists of three symmetrical arms with 8 commutation cells. Each cell is fed by a continuous voltage Ucassumed constant and it is related to the input voltage Us by:

$$U_c = \frac{U_s}{6} \tag{1}$$



Fig.1. Three-phase seven levels inverter with NPC structure

The topological analysis, carried out for this inverter, reveals that there are seven, possible and controllable, configurations. Table 1 gives switches logical states of an arm k (k=1, 2, 3) according to the  $V_{km}$  arm voltage.

TABLE I LOGICAL STATES OF THE SWITCHES FOR SEVEN LEVELS INVERTER.

$V_{km}$	$B_{k1}$	$B_{k2}$	$B_{k3}$	$B_{k4}$	$B_{k5}$	$B_{k6}$	$B_{k7}$	$B_{k8}$
3U <sub>c</sub>	1	1	1	1	0	0	0	0
2U <sub>c</sub>	1	1	1	0	0	0	0	0
Uc	1	1	0	0	0	0	0	0
0	1	0	0		0	0	0	0
-Uc	0	0	0	0	1	1	0	0
-2U <sub>c</sub>	0	0	0	0	1	1	1	0
-3Uc	0	0	0	0	1	1	1	1

To ensure continuous operation of inverter, the switches states must obey to a complementary control definite by the following relations:

$$B_{k1} = B_{k6}$$

$$B_{k2} = \overline{B_{k5}}$$

$$B_{k3} = \overline{B_{k7}}$$

$$B_{k4} = \overline{B_{k8}}$$

$$B_{k9} = B_{k1}B_{k2}B_{k3}\overline{B_{k4}}$$

$$B_{k10} = B_{k1}B_{k2}B_{k3}B_{k4}$$

$$B_{k11} = B_{k5}B_{k6}\overline{B_{k7}B_{k8}}$$

$$B_{k12} = B_{k5}B_{k6}B_{k7}\overline{B_{k8}}$$
(3)

Where Bks is the base signal of the transistors Tks and k indicates the number of the arm (1, 2 or 3).

## **3 Harmonics Elimination Strategy**

Various PWM strategies were developed for the control of the multilevel inverters; in order to obtain an output voltage close to the sinusoidal form with a weak THD. Our study concerns the generation of PWM signal based on elimination harmonics method. This later was proposed, for the first time by Turnbull and then was developed by Patel and Hoft for the case of two levels inverters [6].

This strategy has the advantage, to ensure the elimination of undesired harmonics related to the inverter output signal and, to impose the fundamental one on the desired value. However, the extension of this method to the case of multilevel inverters led, for the determination of switching angles, to non-linear algebraic equations more complex than those obtained in the case of two levels inverter [7][8][9].

The goal of this technique is the determination of the commutation instants (switching angles) related to the power semiconductor switches of the converter[10]. Indeed, the strategy implementation consists first in establishing the general expression of harmonics amplitude according to switching angles  $\alpha_i$ . This can be

carried out by Fourier series expansion related to the arm voltage delivered by the inverter. Then, by equating the fundamental value to the desired value and, by eliminating some harmonics, we obtain a system of nonlinear algebraic equations [8].

In this study, the target is to cancel the harmonics 5, 7 and 11 and to control the fundamental voltage.



Fig.2. Imposed profile of the arm voltage of the seven levels inverter

First of all, it is necessary to choose a waveform profile for arm voltage of the seven levels inverter (fig.2).

It is clear that, the signal of figure 2 exhibits a quarter period and middle period symmetry. Therefore, even harmonics are null and the Fourier series expansion of this signal is given by:

$$A_n = \frac{4U_c}{\pi n} \left[ \ell_1 \cos(\alpha_1) + \ell_2 \cos(\alpha_2) + \dots + \ell_c \cos(\alpha_c) \right]$$
(4)

Where n represents the harmonic row, c the considered number of angles necessary to eliminate (c-1) harmonics and  $\ell_i$  are unitary coefficients related to imposed form of the arm voltage (fig.2). In case of figure 2, these parameters are as:

n= 5, 7 and 11, c=4,  $\ell_1 = 1, \ell_2 = 1, \ell_3 = 1, \ell_4 = -1.$ 

While introducing modulation index r and replacing these coefficients values in relation (4), we are led to the following system of algebraic equations:

$$\cos(\alpha_{1}) + \cos(\alpha_{2}) + \cos(\alpha_{3}) - \cos(\alpha_{4}) = \frac{3r\pi}{4}$$

$$\cos(5\alpha_{1}) + \cos(5\alpha_{2}) + \cos(5\alpha_{3}) - \cos(5\alpha_{4}) = 0$$

$$\cos(7\alpha_{1}) + \cos(7\alpha_{2}) + \cos(7\alpha_{3}) - \cos(7\alpha_{4}) = 0$$

$$\cos(1\alpha_{1}) + \cos(1\alpha_{2}) + \cos(1\alpha_{3}) - \cos(1\alpha_{4}) = 0$$
(5)

With:

$$r = \frac{2V_{\text{max}}}{U_c} \tag{6}$$

It is clear that, the equations system (5) corresponds to the elimination of harmonics 5, 7 and 11 and that the fundamental value is imposed to the desired value represented by r. The system (5) has four nonlinear equations and four unknowns. Its resolution is carried using the Newton-Raphson iteration method. Noting that the difficulty encountered during application of this method lies in the choice of the initial values. The latter must be close to the solution in order to ensure convergence.



Fig.3. switching angles of a seven level multilevel



Fig.4. THD from a seven level multilevel inverter.

Figure (3) represents the switching angles, solutions of system equations (5), according to r variation, and figure (4) gives the THD of voltage signal delivered by the seven levels inverter controlled by impulses generated from these switching angles. It appears that a double solution exists for r in the interval [0.63, 0.83] and so a selection of the adequate angles must be involved. This selection is done on the basis of the best THD obtained by the two varying angles in this interval. The figures (5) and (6) show respectively the selected angles and their correspondent THD.



Fig.5. Variation of the selected switching angles



Fig.6. Variation of the THD

In view to confirm the validity of obtained results using the harmonics elimination technique, a test is carried out for r=0.8. The phase voltage delivered by inverter and its harmonics spectrum are illustrated on figure 7.

From analysis of the obtained results, by the strategy of harmonics elimination applied to the seven levels inverter, it results that:

- For certain values of modulation index r, the equations system can admit double solutions or it can not admit some;
- This PWM strategy allows eliminating the undesirable harmonics with a good control of the fundamental one.

# 4 Application of the Artificial Neurons Networks

In real time, the control, by the strategy of harmonics elimination of the seven levels inverter, requires first the knowledge of the switching angles, which has been the subject of the first section and second the storage of all the obtained values. Indeed, this operation leads imperatively to a very large size of memory, since the solutions are computed with step size of  $10^{-3}$  related to the modulation index.

To overcome this problem, is proposed instead to exploit an ANN, since they have proven their ability to approximate with an arbitrary precision, any continuous function defined in a compact set [11][12]. Also, in this section, an ANN is elaborated in view to replicate the four curves of the figure (5).

The static multi-layer network, with back propagation training is adequate for the approximation problem of nonlinear continuous functions [12]. Since, the goal is to reproduce the control characteristic already determined by the Newton – Raphson algorithm. Indeed, the tentative network receive, at its input, the value of modulation index r and, must produce, at its output, the four switching angles  $\alpha_i$  (*i*=1,...4). So, the network has only one neuron in its input layer and, four neurons in its output layer. There is one hidden layer with some number of neurons to be determined (Fig.8).



Fig.7. Output phase voltage of a 7-level inverter and his frequency spectrum.



Fig.8. Architecture of elaborated network

The network training is done, on the basis of the backpropagation algorithm with gradient descent, in order to get the desired input-output behaviour. During the training phase, the value r(k) is presented at the network input and, then propagated through the network to obtain the output signal  $\hat{\alpha}(k)$ . The training error e(k), on the kith example, is determined by:

#### $e(k) = \alpha(k) - \hat{\alpha}(k)$

This process is repeated for all examples. Thereafter, the total quadratic error on all the examples is exploited by the back propagation algorithm in order to adapt the network parameters (synaptic weights). In the same way, several iterations are carried out on all the examples until the network convergence is obtained.

At the end of the training, all the parameters are adapted, such that the network receives a current value r(k), it gives automatically the switching angles  $\alpha(k)$  corresponding to this input. Figure 9 gives the switching angles, according to r, given by the elaborated network.



Fig.9. switching angles given by ANN ( o) and by Newton-Raphson (-).

These results are obtained with a network having 14 neurons in its hidden layer. The training network was obtained, after 1000 adaptation cycles which have reduced the quadratic error to  $10^{-3}$  on all the examples.

It is clear that the characteristic provided by the proposed network is similar to that determined by the Newton-Raphson numerical method.

# **5** Conclusion

The aim of this work is to ensure, in real time, the PWM control of a seven levels inverter based on the harmonics elimination strategy. Also, the turn on and turn off instants, related to power semi conductor switches, are first computed in order to control the fundamental of output voltage and to eliminate harmonics 5, 7 and 11. Usually, this PWM is implemented by tabulation method which requires, in this case, an important size for memories. Also, a multi-layer static ANN is used in place; it receives modulation index value and delivers automatically at its output the corresponding switching angles. The obtained results show that the characteristic obtained by the use of an ANN and those obtained by the Newton-Raphson method are practically similar. Indeed, by good network training, generalization property is obtained which is the fundamental advantage of the ANN and confers to the elaborated network, the ability to provide the switching angles, even for values of the modulation index not included in tabulation method.

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