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Research Paper

DSPACE Implementation of a Neural SVPWM Technique for a Two Level Voltage Source Inverter

Z. Boudjema*(C.A.), H. Benbouhenni**, A. Bouhani*, and F. Chabni*

Abstract: This article presents the implementation of an improved space vector pulse width modulation (SVPWM) technique based on neural network for a real two level voltage source inverter (VSI) realized in our Lab. The major goal of using this new technique is the amelioration of the voltage quality in the output of the VSI by decreasing the effect of the harmonics. The used technique has been simulated by MATLAB/Simulink and then implemented using a DSPACE card on a real two level VSI. The advantages of the used technique are shown by simulation and experiment results.

Keywords: Space Vector Pulse Width Modulation, Two Level Voltage Source Inverter, Neural Network, DSPACE Card.

1 Introduction

IN the last few decades, voltage source inverter (VSI) controlled by pulse width modulation (PWM) technique is the most widely used system to synthesize AC output voltage and frequency from a constant DC voltage [1]. In recent years, improvements in semiconductor technology have lead developments in power electronic systems. Therefore, many circuit designs namely PWM inverters have become popular and significant attention by researcher are given on them. Some of PWM schemes are employed to get variable voltage and frequency supply. The mainly used PWM scheme for VSIs is sinusoidal PWM [2].

A wide variety of techniques, differing in idea and performance, have been created in order to accomplish one of the following purposes: large linear modulation range, less switching losses, fewer total harmonic distortion (THD), simple realization and fewer calculation time [3-5].

With the important progress recorded in microprocessors technology, space vector pulse width modulation (SVPWM) has become one of the most used techniques for three-phase VSI [6]. In [7], the SVPWM reduced the harmonic distortion of current compared to traditional PWM technique. In order to find the duty cycle of the VSI switches, the SVPWM used the space vector notion. It is simply the digital implementation of PWM modulators. An aptitude for easy digital implementation and wide linear modulation range for line to line voltages are the noticeable features of space vector modulation.

Despite the improvements made by the SVPWM technique compared to the PWM, research into the development of other methods has not stopped. The main objective was to find efficient methods which give output voltages with low harmonic rate and fewer losses at the level of the switches. Among the methods that have been developed, we site for example: fuzzy SVPWM [8-10], neural SVPWM [11, 12], ANFIS-SVPWM [13] and ANFIS based multi- SVPWM [14].

Artificial neural networks (ANNs) are widely used in the control of AC machines and power electronic devices. This technique presents different advantages such as robust, simple algorithms and easy to implement compared to other algorithms. The ANN algorithm is becoming one of the most important intelligent algorithms. Many studies on power converters control techniques are oriented toward this type of algorithm [15-28]. The main objective of these works was the improvement of the output voltage quality by reducing the harmonic rate. In [29], the authors suggest an ANN-based SVPWM control approach for better

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* The authors are with the Electrical Engineering Departement, Faculty of Technology, Hassiba Benbouali University, Chlef, Algeria.
E-mails: boudjemaa1983@yahoo.fr, ha.ahmed@gmail.com, and f.chabni@gmail.com.
** The author is with the Labo. LAAS, National Polytechnic School Maurice Audin, Oran, Algeria.
E-mail: habib0264@gmail.com.
Corresponding Author: Z. Boudjema.
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performance of three-phase improved power quality converters for distorted and unbalanced AC Mains. The NN-based controller offers the advantages of very fast implementation of the SVPWM algorithm for disturbed supply. The proposed scheme employs a three-layer feed-forward NN which receives the command error voltage and line currents information at the input side to retransform the Clarke transformation for generating reference vector trajectory. The neural-network-based modulator retransforms the Clarke transformation to distribute the switching times for each device in each leg to have balanced line currents with nearly unity input power factor, low input current THD and reduced ripple factor of the regulated DC output voltage.

In [30], the authors reports the neural network based space vector pulse width modulation for a five-level three-phase diode-clamped inverter. The ANN-based structure generates control signals for the five-level inverter. A multilevel three-phase inverter offers several advantages over conventional inverters such as lower-voltage stresses on power electronic switches, better electromagnetic compatibility and smaller ratings for the switches. SVPWM enhances the output features of this inverter by properly utilizing the DC link voltage. An ANN makes the implementation of SVPWM easier as now any non-linear function of an arbitrary degree can be approximated. The ANN for SVPWM was trained in Matlab Simulink and implemented with TMS320F2812 using Matlab embedded encoder. For comparisons, sinusoidal PWM-based control technique was also implemented. The results are presented that illustrate the merits of the ANN-based SVPWM for a five-level diode-clamped inverter.

In [31], the authors propose an ANN-SVPWM in order to research the influence of hidden layer neurons of ANN and switching frequency of power switches on the performance of permanent magnet synchronous motor (PMSM). The simulation and experiment of closed-loop PMSM control system are done. The results show that the PMSM generates less current harmonic distortion and pulsating torque by choosing the optimum hidden neurons of ANN and switching frequency of power switches, and the PMSM controlled by ANN-SVPWM works well.

In this paper, the SVPWM technique with the application of the ANN algorithm has been considered. The original contribution of this work is the application of the ANN algorithm in the SVPWM strategy with the two-level inverter and experimental investigation of this novel modulation strategy using DSPACE-DS1104. The practical design is modeled using the MATLAB/Simulink software package and experimentally implemented on the low-cost microchip PIC microcontroller 18F4431 platform.

2 Two Level VSI

The basic configuration circuit of a three phase two level VSI is shown by Fig. 1. It's composed by six switches (K_1-K_6). The main advantage of two-level inverter is simple structure, simple control and easy to implement compared to another topologies. The output for the three phase shifted sinusoidal signals are respectively represented by A, B and C. Depending on the control technique of the switches, the VSI will creating in its output the two-level signal ($+V_{dc}$ and $-V_{dc}$) [32].

The output phase voltage vector $v^T = [v_a \ v_b \ v_c]$ of a balanced star-connected AC load fed by the voltage source inverter is expressed by the equation below:

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix}\begin{bmatrix} S_a \\ S_b \\ S_c \end{bmatrix} . V_{dc} \tag{1}$$

where S_p are the upper switches states and ($p = a, b$, or c) are the phases of the inverter.

In the widely used PWM methods, the inverter output voltage approximates the reference value through high frequency switching for the six power semiconductor switches.

3 Conventional SVPWM

SVPWM is naturally a voltage control method that employs the reference voltage space vector to determine the optimum switching pattern for the three phase two level VSI to guarantee that the desired space vector voltage is obtained.

These calculations are performed in an (α, β) complex plane or "space-vector" plane based on the Clarke transformation of the reference three-phase voltage $V_r^T = [v_a \ v_b \ v_c]$ given by:

$$V_r = \begin{bmatrix} V_{r\alpha} \\ V_{r\beta} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 2 & -1 & -1 \\ 0 & \sqrt{3} & -\sqrt{3} \end{bmatrix}\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \tag{2}$$

According to (1) and (2), the eight possible switching states of the power switches will generate eight possible voltages (Vi, i = 0...7) as shown in Table 1.

The switching states are almost similar to the "Grey Codes". To change from one state to the other, only one

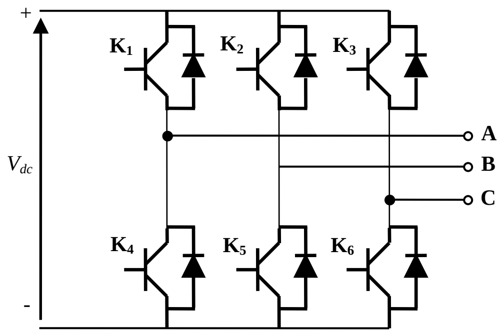


Fig. 1 Fundamental circuit of three phases two level VSI.

Table 1 The switching states and inverter output voltages.

Sect	$S_a\ S_b\ S_c$	$[v_a\ v_b\ v_c]$	$[v_{i\alpha}\ v_{i\beta}]$	v_i
0	-1 -1 -1	$\begin{bmatrix}0 & 0 & 0\end{bmatrix}\cdot V_{dc}$	$\begin{bmatrix}0 & 0\end{bmatrix}\cdot V_{dc}$	v_0
4	1 -1 -1	$\begin{bmatrix}\frac{2}{3} & \frac{-1}{3} & \frac{-1}{3}\end{bmatrix}\cdot V_{dc}$	$\begin{bmatrix}\frac{2}{3} & 0\end{bmatrix}\cdot V_{dc}$	v_1
6	1 1 -1	$\begin{bmatrix}\frac{1}{3} & \frac{1}{3} & \frac{-2}{3}\end{bmatrix}\cdot V_{dc}$	$\begin{bmatrix}\frac{1}{3} & \frac{1}{\sqrt{3}}\end{bmatrix}\cdot V_{dc}$	v_2
2	-1 1 -1	$\begin{bmatrix}\frac{-1}{3} & \frac{2}{3} & \frac{-1}{3}\end{bmatrix}\cdot V_{dc}$	$\begin{bmatrix}\frac{-1}{3} & \frac{1}{\sqrt{3}}\end{bmatrix}\cdot V_{dc}$	v_3
3	-1 1 1	$\begin{bmatrix}\frac{-2}{3} & \frac{1}{3} & \frac{1}{3}\end{bmatrix}\cdot V_{dc}$	$\begin{bmatrix}\frac{-2}{3} & 0\end{bmatrix}\cdot V_{dc}$	v_4
1	-1 -1 1	$\begin{bmatrix}\frac{-1}{3} & \frac{-1}{3} & \frac{2}{3}\end{bmatrix}\cdot V_{dc}$	$\begin{bmatrix}\frac{-1}{3} & \frac{-1}{\sqrt{3}}\end{bmatrix}\cdot V_{dc}$	v_5
5	1 -1 1	$\begin{bmatrix}\frac{1}{3} & \frac{-2}{3} & \frac{1}{3}\end{bmatrix}\cdot V_{dc}$	$\begin{bmatrix}\frac{1}{3} & \frac{-1}{\sqrt{3}}\end{bmatrix}\cdot V_{dc}$	v_6
7	1 1 1	$\begin{bmatrix}0 & 0 & 0\end{bmatrix}\cdot V_{dc}$	$\begin{bmatrix}0 & 0\end{bmatrix}\cdot V_{dc}$	v_7

phase-arm changes the state. When the Clarke transformation is performed on eight inverter switching states, it translates into six voltage vectors. e.g $|V_1|^2 = |V_2|^2 = |V_i|^2 = ⅔V_{dc}$, i=1..6 but with different angles, as well as two zero vectors V_0 and V_7 of the zero length. These space vectors are graphically shown in Fig. 2. It can be seen that the adjacent switching state transform to adjacent space vectors in a transformed two-phase (α, β) plane.

The SVPWM can best be explained based on a two-phase representation of Fig. 2.

Reference voltage V_r is to be generated by the inverter. First, it is located on one sector i (i=1,..,6) defined by two adjacent active vectors V_i and V_{i+1}. Then it can be approximated based on a timely switching among (V_i,V_{i+1}) and one or two zero vectors. In this case, vector V_2 should be applied for a longer time than V_1 since V_r is nearer to V_2; and the time of the zero vectors should also be applied to reduce the magnitude.

The objective of using the space-vector PWM technique is to approximate reference voltage vector V_r using the eight switching patterns. One simple method of approximation is to generate the average output of the inverter in a small period, T_s, to be the same as that of V_r in the same period.

Usually, the switching times are derived using complex trigonometric calculations which makes the SVPWM implementation inefficient and takes more resources from the digital hardware.

The SVPWM controller is designed to drive the inverter to generate desired voltage V_r by projecting the instantaneous transformed voltage in a sector (x) defined by two adjacent vectors (V_x, V_y) expressed during modulation period T_s as:

$$T_s = V_x T_x + V_y T_y + V_z T_z \tag{3}$$

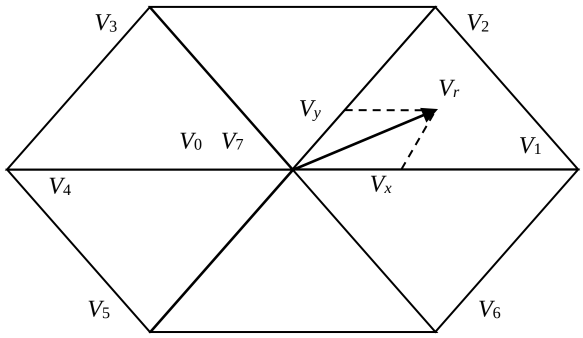


Fig. 2 Principle drawing SVM for a three-phase two level VSI.

where T_x and T_y are the on-times of adjacent non-zero vectors V_x, V_y. They are calculated based on projections of two adjacent vectors of an appropriate sector among the six sectors using equations below [33]:

$$\begin{bmatrix}V_{r\alpha}\\ V_{r\beta}\end{bmatrix} T_s = \begin{bmatrix}V_{x\alpha} & V_{y\alpha}\\ V_{x\beta} & V_{y\beta}\end{bmatrix}\begin{bmatrix}T_i\\ T_{i+1}\end{bmatrix} \tag{4}$$

$$\begin{bmatrix}T_i\\ T_{i+1}\end{bmatrix} = \begin{bmatrix}V_{x\alpha} & V_{y\alpha}\\ V_{x\beta} & V_{y\beta}\end{bmatrix}^{-1}\begin{bmatrix}V_{r\alpha}\\ V_{r\beta}\end{bmatrix} T_s \tag{5}$$

And $T_z = T_s - (T_x + T_y)$ is the on-time of appropriate zero vector V_z.

Equation (5) is usually used for a digital implementation of SVPWM in most papers in the literature either for the microcontroller, FPGA or DSPACE card, but it is not optimal and uses more recourses and makes the algorithm more complex compared to the simpler Sine PWM. In this paper, a more intelligent implementation of SVPWM is achieved by an intelligent manipulation of (5).

4 Neural SVPWM Technique

The proposed method is a technique which consists of using the ANN algorithm to learn the principle of the conventional SVPWM technique and then to use the resulting program to generate the control signal of the switches of the two-level VSI. In [34], a new SVPWM technique is based on ANN controllers to control the two-level inverter. Benbouhenni *et al.* [35], have designed a four-level neural SVPWM strategy to control the four-level inverter of the DFIG and also, the proposed SVPWM technique has compared to the traditional technique by using MATLAB software. The simulation results have shown the superiority of the proposed SVPWM technique. Five-level SVPWM and ANN controllers are combined to reduce the reactive and active power ripples [36].

In neural networks, there are many types of neural networks. More existing types widely used a radial basis function neural network (RBFNN), feedforward neural network (FNN), modular neural network (MNN), recurrent neural network (RNN), Kohonen

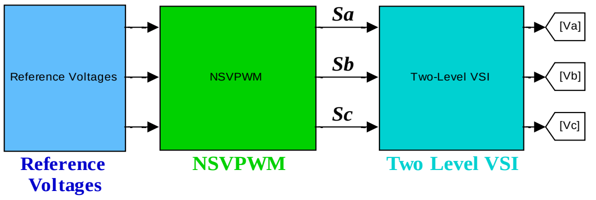


Fig. 3 Block diagram of the neural SVPWM a three-phase two level VSI.

Table 2. Parameters of the FNN algorithm

Parameters of the FNN	Values
Training	LMB algorithm (trainlm)
TrainParam.Lr	0.05
TrainParam.goal	0
Coeff of acceleration of convergence (mc)	0.9
Performances	Mean Square Error (MSE)
TrainParam.mu	0.8
TrainParam.show	50
TrainParam.eposh	2000
Derivative	Default (default deriv)
Number of hidden layer	1
Number of neurons in hidden layer	70
Number of layer 1	1
Number of neurons in layer 1	3
Number of layer 2	1
Number of neurons in layer 2	3
Functions of activation	Tensing, Purling, trainlm

self-organizing neural network (KSONN), and conventional neural network (CNN). In this work, we use the FNN algorithm because is a robust and simple algorithm. The FNN algorithm was the first type of neural network algorithm. This algorithm is similar to the CNN algorithm, where the neurons have learnable weights and biases. In this algorithm, the mathematical model of the system is not necessary. This algorithm is based on experimentation and observation. On the other hand, there are several algorithms to training FNN algorithm, the most famous of which are recalled: Gradient descent with adaptive lr backpropagation (GDALRB), Gradient descent w/momentum & adaptive lr backpropagation (GDMALB), Levenberg-Marquardt backpropagation (LMB), and Gradient descent with momentum. The simulation block diagram of the neural SVPWM (NSVPWM) technique is given in the Fig. 3.

To make the FNN algorithm, we used the LMB algorithm. This algorithm is simple and easy to use. In MATLAB/Simulink, trainlm is the word we use to accomplish this algorithm. The structure of an FNN controller is shown in Fig. 4. The FNN controller consists of one input layer, one hidden layer, and an output layer. The input layer comprises three neurons and the output layer three neurons. The hidden layer has five neurons. The parameters of the FNN algorithm for the SVPWM technique are shown in Table 2. Fig. 5 shows the FNN training performance of the two-level SVPWM method. The best training performance is 0.92085 at epoch 1989. On the other hand, the block diagram of layer 1 and layer 2 is shown in Figs. 6 and 7, respectively.

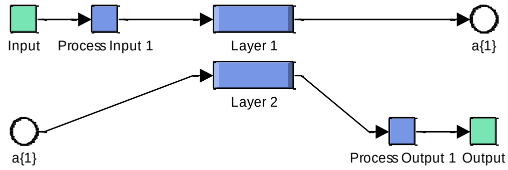


Fig. 4 FNN structure of SVPWM technique.

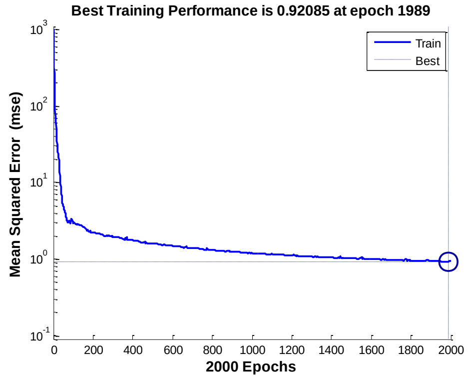


Fig. 5 Training performance.

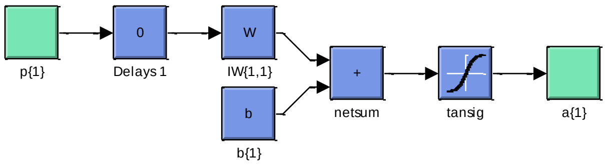


Fig. 6 Layer 1.

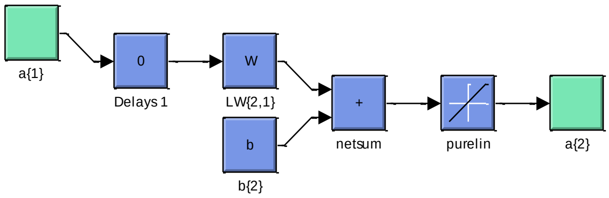


Fig. 7 Layer 2.

5 Simulation Results

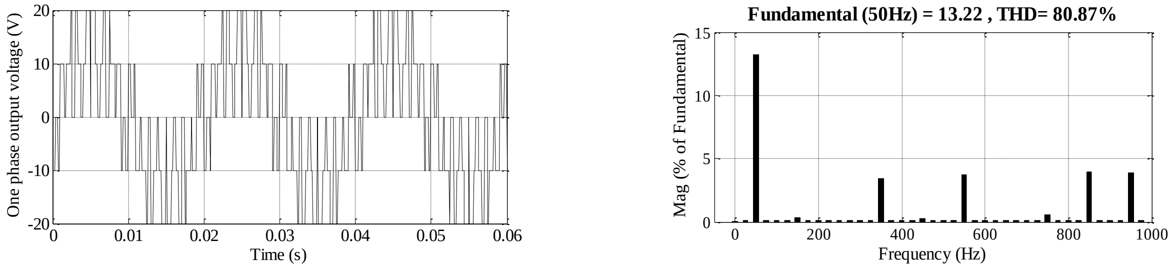
In order to validate the three control techniques used (PWM, SVPWM and NSVPWM) and see the effectiveness of the proposed method, a numerical simulation by MATLAB/Simulink software was performed in this session.

In the simulation tests, we used reduced voltages (V_{max} = 20 V) to allow afterwards, a comparison of the results with those of the experimental. The obtained simulation results are shown by Figs. 8-10. From these figures, it can be noted that the output voltage of the inverter for the three control techniques used has an alternative form and close to the sinusoid, with a maximum value V_{max} = 20 V. The difference between the three techniques is clearly appear in the THD output voltages, as noted that the latter is reduced (42.90%) for the NSVPWM technique compared to two other techniques: 80.87% for the PWM technique and 61.38% for the SVPWM one.

6 Experimental Results

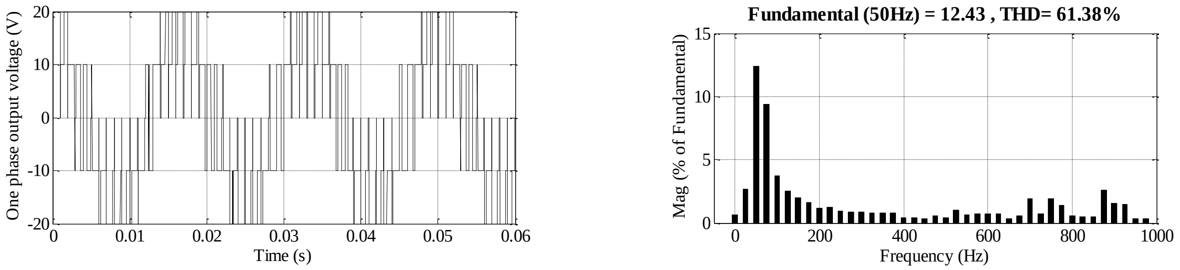
In order to confirm the obtained simulation results and validate the performances provided by the proposed technique (NSVPWM), a practical implementation was carried out in our laboratory and by our own resources. The hardware used for the implementation is shown in Fig. 11. The material presented in this figure, numbered from (1) to (5) is defined as follows:
(1): A computer, (2): DSPACE card 1104, (3): Oscilloscope, (4): Two level VSI, (5): DC voltage source, (6): resistive load, (7): AC volatge source.

The obtained results are shown by Fig. 12. As this figure shows, we note that for the three control techniques used, the voltage has an alternative form close to the sine wave, with amplitude equal to 20 V and a frequency equal to 50 Hz. This result confirms that obtained in the previous session (simulation tests). The essential advantage provided by the NSVPWM technique is shown by the voltage spectra (green curves) such that it is noted that the low order harmonics present in the PWM technique have been eliminated. For high harmonics, it is easy to remove them using a conventional high pass filter.



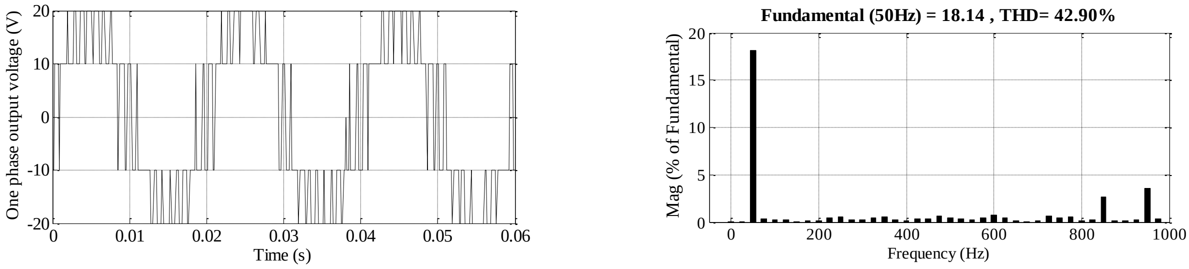
(a) (b)

Fig. 8 One phase output voltage and THD (PWM method).



(a) (b)

Fig. 9 One phase output voltage and THD (SVPWM).



(a) (b)

Fig. 10 One phase output voltage and THD (neural SVPWM).

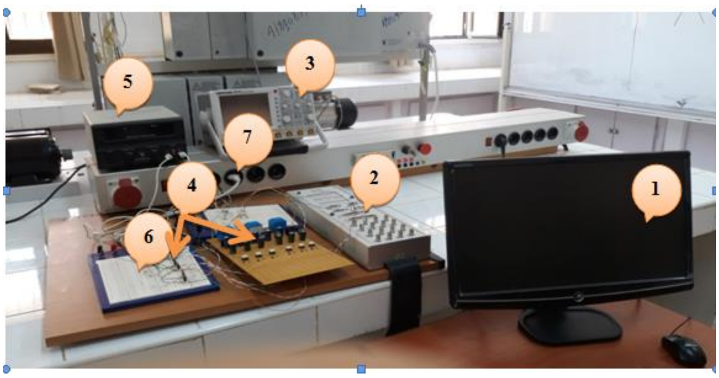


Fig. 11 Real image of the equipment used for experimental tests.

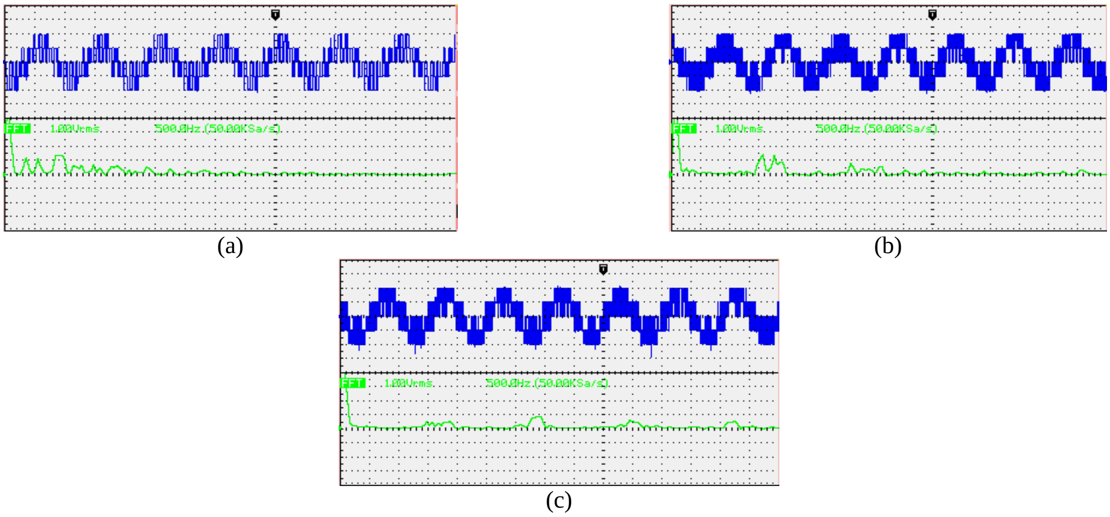


Fig. 12 Experimental results: output voltages and their spectra; a) PWM, b) SVPWM, and c) NSVPWM.

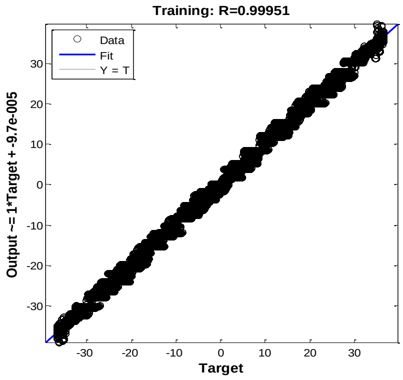


Fig. 13 Target of FNN algorithm.

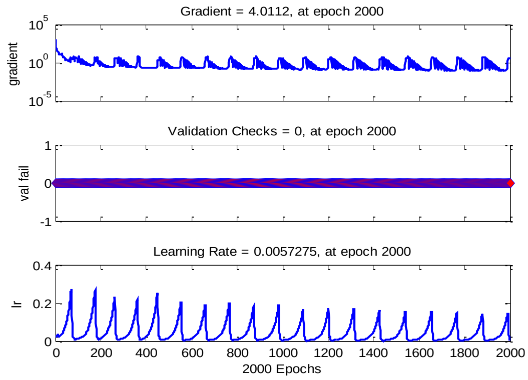


Fig. 14 FNN characteristics.

7 Conclusion

In this article, an interesting control method based on SVPWM technique and neural networks was presented. This new method, symbolized by the abbreviation (NSVPWM), was applied for the control of a two-level VSI and compared to conventional PWM and SVPWM techniques. The comparison between the three techniques was carried out by numerical simulation and through the experimental. The results obtained (simulation and experimental) have clearly shown the effectiveness of the NSVPWM technique compared to other techniques (PWM and SVPWM), especially in reducing the harmonic rate. This reduction plays a very important role in reducing losses and increasing the lifespan of installations (especially AC machines) supplied by inverters controlled by this type of technique.

Appendix

A.1 The Target of FNN Algorithm

Fig. 13 shows the target of the FNN algorithm for two-level SVPWM strategy.

A.2 The FNN Algorithm Characteristics

Fig. 14 shows the FNN algorithm characteristics of the SVPWM method, where the gradient is 4.0112 at 2000 epoch, validation checks (Val fail) are 0, and the learning rate (Lr) is 0.0057275 at 2000 epoch.

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Z. Boudjema was born in Algeria in 1983. He is Teacher in University of Chlef, Algeria. He received a M.Sc. degree in Electrical Engineering from ENP of Oran, Algeria in 2010. He received a Ph.D. in Electrical Engineering from University of Sidi Belabes, Algeria in 2015. His research activities include the study and application of robust control in the wind-solar power systems.

H. Benbouhenni was born in chlef, Algeria. He is a Ph.D. Student in the Departement of Electrical Engineering at the ENPO-MA, Oran, Algeria. He received a M.A. degree in Automatic and Informatique Industrial in 2017. His research activities include the application of robust control in the wind turbine power systems.

A. Bouhani was born in chlef, Algeria. He received a M.Sc. degree in Electrical Engineering from University of Chlef, Algeria. His research activities include the application of robust control in the wind turbine power systems.

F. Chabni was born in Algeria, Algeria. He received a Ph.D. in Electrical Engineering from University of Chlef, Algeria 2019. His research activities include the study and application of multilevel inverter in the AC machines.