CONTROL OF OPTIMAL PWM VOLTAGE SOURCE INVERTER USING SIGMOID AND PICEWISE LINEAR ARTIFICIAL NEURAL NETWORKS

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ABSTRACT

A feed forward neural network is used to control a voltage source PWM inverter in a way that selected harmonics are removed from its output and the magnitude of fundamental is set at any desired level. Two cases are studied: neurons with the usual nonlinear (sigmoid) transfer function, and neurons with a piecewise linear characteristic. The latter shows good results and more easily lends itself to hardware implementation either by digital or analog networks.

INTRODUCTION

Voltage source inverters are widely used in motor drives, uninterruptable power supplies and bidirectional AC-DC converters. Many different types of voltage source inverters with different configurations and control schemes have been suggested. Among them the pulse width modulation (PWM) inverter is most popular. Although several different circuits are proposed to realize the PWM inverter, the main operating principle is the same in most cases. The inverter consists of switches which allow each line of AC load to be one or the other end of the DC source. By suitable selection of switching instants for all switches, the desired output characteristics can be achieved.There are two major approaches to find the best switching function: the time domain approach [1-3] and the frequency domain approach [4-5]. In the next sections we will concentrate on the frequency domain approach and will use a neural network for its implementation.

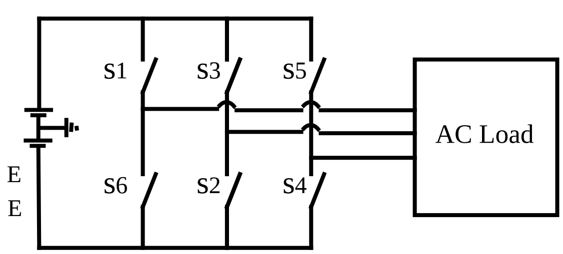

Fig. 1 Basic configuration of a three phase bridge two level VSI

HARMONIC ELIMINATION

Low harmonic content of the output voltage and current is always a major concern with voltage source inverters. For a two level inverter, where the output phase voltage is always either +E or -E (Fig. 2), the r.m.s. value of the voltage is always E^2. Since the mean squared of this voltage is equal to the sum of the mean squares of all harmonics, then for a given amplitude of fundamental harmonic, the total harmonic distortion is always the same, regardless of the selected switching method. But the switching instants can be adjusted such that the lower harmonics disappear (or decrease substantially) at the expense of increase in higher harmonics. Since loads are usually inductive, higher harmonics can be filtered more easily by the load without need of additional filters.

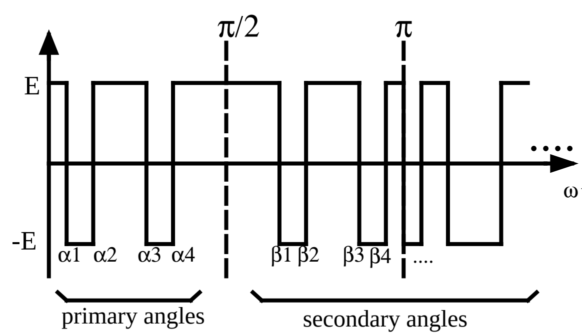

Fig.2 The output phase voltage waveform of a two level inverter

There are several methods to push the harmonics in a PWM waveform to the higher frequencies, but the harmonic elimination technique has the lowest number of switching actions.

The magnitude of harmonics for a PWM waveform with odd and half wave symmetries, and n switching actions per quarter cycle of fundamental, is obtained from the follow-

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ing equations:

$$h_1 = \left(8 \cdot \frac{E}{\pi}\right) \cdot \left[1 - 2\cos\alpha_1 + 2\cos\alpha_2 - 2\cos\alpha_3 \ldots 2\cos\alpha_n\right]$$

$$h_3 = \left(8 \cdot \frac{E}{3\pi}\right) \cdot \left[1 - 2\cos 3\alpha_1 + 2\cos 3\alpha_2 - 2\cos 3\alpha_3 \ldots 2\cos 3\alpha_n\right] \quad (1)$$

$$\vdots$$

$$h_k = \left(8 \cdot \frac{E}{k\pi}\right) \cdot \left[1 - 2\cos k\alpha_1 + 2\cos k\alpha_2 - 2\cos k\alpha_3 \ldots 2\cos k\alpha_n\right]$$

where E is half of the DC source voltage, h_i is the magnitude of the i^{th} harmonic and α_j is the j^{th} primary switching angle.

To find the α's needed for elimination of specific harmonics, it is sufficient to set the corresponding h's in the above equations to zero and solve for the α's. The value of h_1 could be any desired value between zero and some limit lower than1.25E (depending on the harmonics to be eliminated). For three phase inverters, usually the low order nontriplen harmonics are eliminated. Triplen harmonics do not appear in line voltages and currents in a three wire system.

As the number of eliminated harmonics increases, the waveform of output current improves, but since the number of chops also increases proportionately, the switching losses will be higher. There are also restrictions on the maximum frequency of switching devices. As a compromise, we decided to eliminate all harmonics up to the 29^{th} in this study.

NEURAL NETWORK

During the operation of the inverter, the desired value of h_1 may change, so eq. (1) must be solved for new values of h_1. These equations are nonlinear and can be solved only by iterative methods. This process is time consuming, may diverge, and is therefore not suitable for on-line implementation. The conventional approach is to solve off-line for several values of modulation index M ($=h_1/E$), and store solutions in a look-up table. Our new approach is to use a feed-forward neural network which accepts modulation index as input, and outputs the primary switching angles (Fig. 3). The secondary switching angles(Fig.2) can easily be produced from the primary ones.

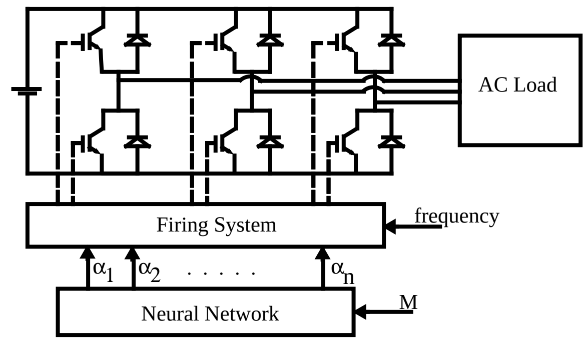

Fig. 3 The overall structure of the inverter

The neural network used has one input neuron and n output neurons (to produce n switching angles). Different numbers of hidden neurons were tested and it was found that about n/2 hidden neurons are usually sufficient. The neurons have sigmoid characteristics and bias. The training set for the network was produced by off-line solving of equations for more than one hundred values of M with 0.01 steps. The Newton-Raphson method was used to solve the equations. To avoid jumping between different possible solutions and to make sure of convergence, the values of α_i obtained for each M were used as the initial guess for the next value of M. Using this method, the off-line solution of eq.(1) is easy and there is no need to use complicated techniques like the Walsh function method, as suggested by some authors [6].

For values of M greater than 1.16 we could not find any solution for eq. (1), but this is not of practical importance, because, for these values of M, the inverter must produce such a narrow pulse that it is beyond the capabilities of most switching devices. The whole system including the neural network, the firing system, inverter and load was simulated using PSCAD-EMTDC electromagnetic transient simulation software. Figures 4 and 5 show the voltage and current waveforms and spectra for two arbitrary values of M. The load has a power factor of 0.8 lagging. As can be seen, the selected nontriplen harmonics are completely eliminated and the fundamental harmonic is at the ordered level.

PIECEWISE-LINEAR NEURAL NETWORK

Hardware implementation of the neural network is not an easy task. The commercially available neural network chips and boards are expensive. Sequential processors can

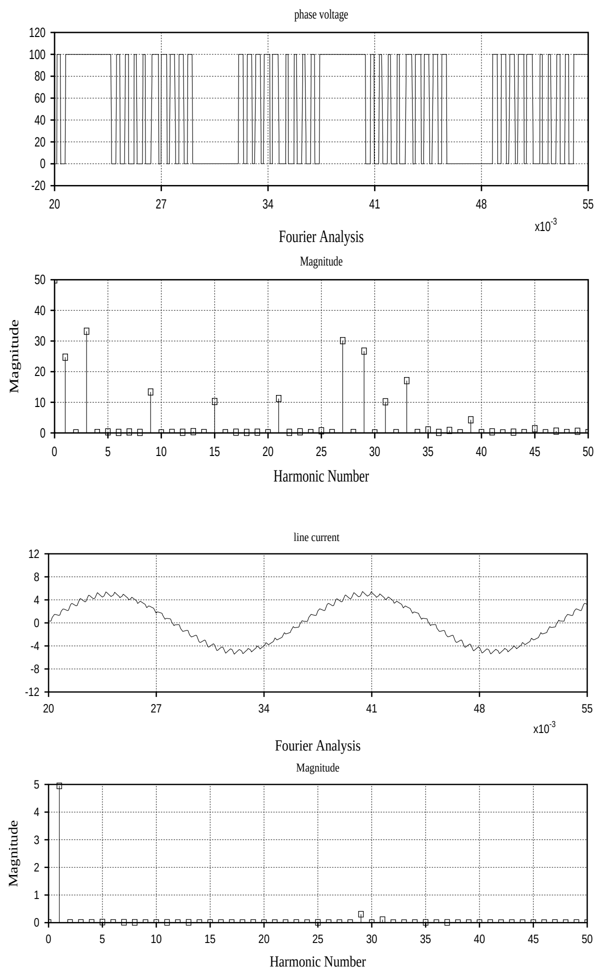

Fig.4 Voltage and current waveforms and spectra for M=0.5

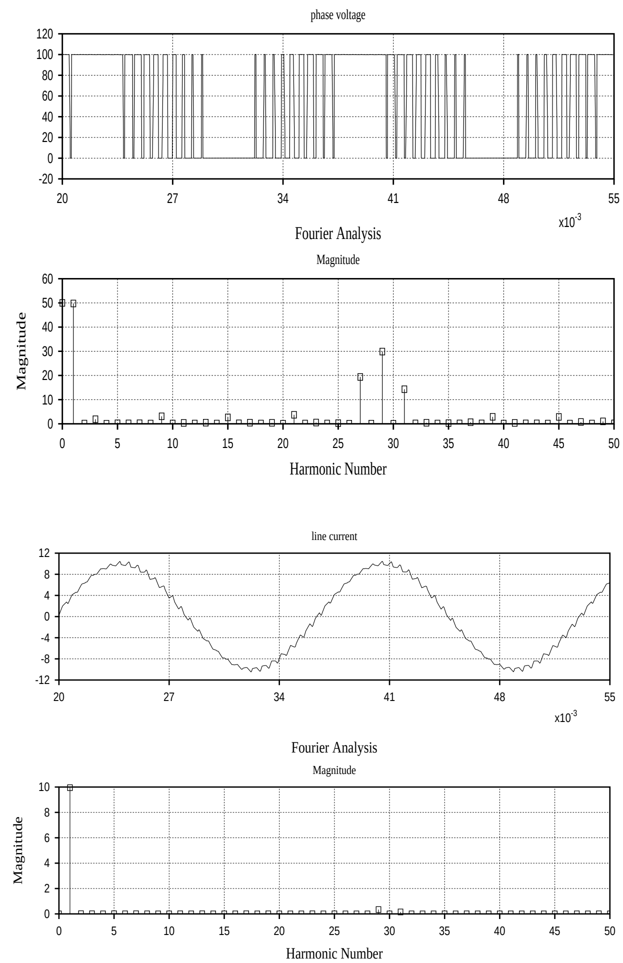

Fig.5 Voltage and current waveforms and spectra for M=1

be used to emulate the neural network, but since calculation of exponential function and division takes a lot of time for each neuron, they are not fast enough. To solve this problem, we replaced the sigmoid transfer function of neurons with a piecewise-linear transfer function (Fig. 6). When we use this characteristic for the neurons with the same weights for the links as before, we obtain α's not far from the previous ones. But since the magnitude of harmonics in the output voltage is very sensitive to changes in α's, we have unacceptably large harmonics in the output. Fig. 7 shows a typical output voltage waveform and spectrum for this case. To solve this problem, we chose to train the network containing the piecewise-linear characteristic for neurons. Although in this case the objective function is not differentiable at all points, it is still continuous and therefore it is possible to find a global minimum. We used the weights of the previous network (with nonlinear neurons) as the starting point and chose back propagation as the optimization technique. Since for modulation index M greater than 1 the variations of α's with M is highly nonlinear, we limited M to 1. This way we could reduce the

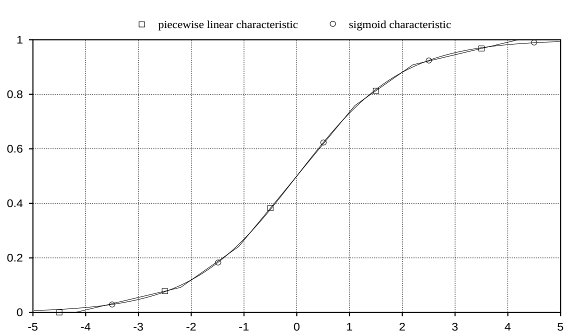

Fig.6 Piecewise linear characteristic

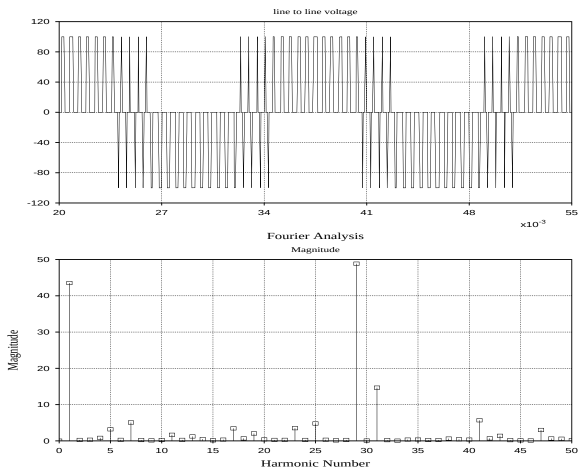

Fig.7 Results for piecewise-linear network with the weights of sigmoid-neuron network

number of hidden units to 3 and get quite satisfactory results. Fig. 8 illustrates the voltage and current waveforms and spectra for two different values of M. All harmonics up to the 29th are cancelled and the load current has very little ripple

CONCLUSIONS

A neural network can be successfully used to control a voltage source inverter such that the fundamental component of output voltage has the desired magnitude and selected harmonics are eliminated. The fact that this control is independent of frequency control, makes this inverter a suitable tool for motor speed control and other variable speed-variable frequency applications. The inverter has low loss due to the low number of switching actions compared to other techniques. Using piecewise-linear characteristic for neurons makes it much easier to implement the network in hardware. We are now implementing the network using a digital signal processing board.

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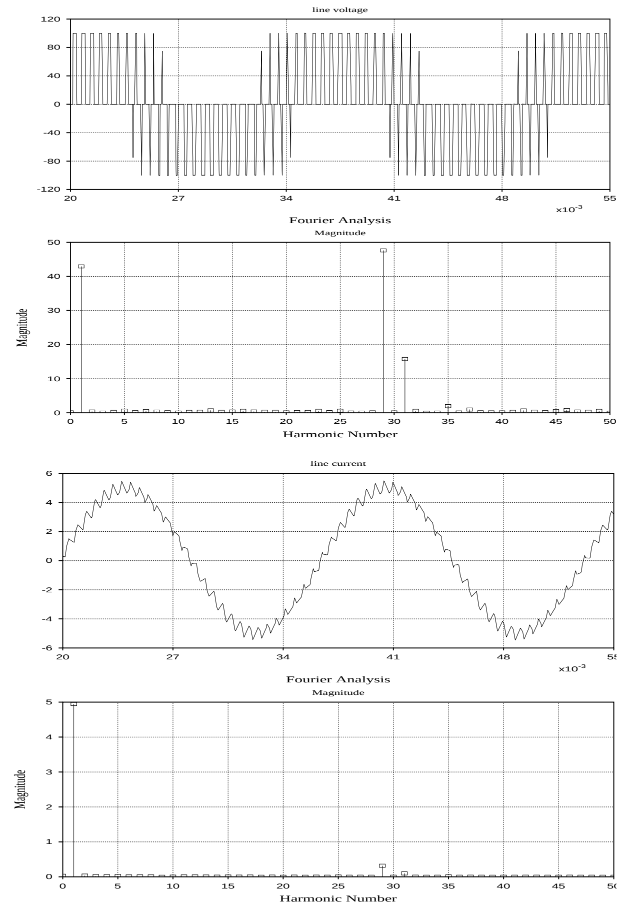

Fig.8 Voltage and current waveforms and spectra for piecewise-linear network

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