Applications of Artificial Neural Networks in Power Electronics

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ABSTRACT

Power Electronics is defined as electronic circuits used for electrical conversion. The conversion includes rectification and inversion. For a UPS inverter the output voltage obtained for the linear load is sinusoidal whereas for the non linear loading conditions the output voltage waveform is highly distorted. Hence it is necessary to maintain a sinusoidal output voltage for all loading conditions with minimum total harmonic distortion (THD). In this paper a neural network controller for UPS inverter applications is presented. The proposed neural network controller is trained offline using the patterns obtained from a simulated controller, which had an idealized load current reference. A sinusoidal Pulse width modulation (PWM) based switching UPS inverter has been modeled. The error in the output voltage and current are traced especially under non-linear loads. Simulation results shows that the proposed neural network controller can achieve low total harmonic distortion under nonlinear loading condition and good dynamic response under transient loading condition.

1. INTRODUCTION

Uninterruptible power supplies (UPSs) are emergency power sources, which have widespread applications in critical equipments such as computers, automated process controllers, and hospital instruments.UPS play an important role in interfacing critical loads such as computers, communication systems, medical/life support systems, and industrial controls to the utility power grid. Among the various UPS topologies, on-line UPS provides the most protection to loads against any utility power problems. They are designed to provide clean and continuous power to the load under essentially any normal or abnormal utility power condition. With the rapid growth in the use of high-efficiency power converters, more and more electrical loads are nonlinear and generate harmonics. It is a big challenge for a UPS to maintain a high-quality sinusoidal output voltage under a nonlinear loading condition [1].For a UPS it is required to maintain a pure sinusoidal output voltage for non linear loads. A multiple-feedback-loop control scheme can be utilized to achieve good dynamic response and low total harmonic distortion (THD) [2], [3].

Such a scheme is essentially developed from linear system theory. When the loads are non linear, the performance degrades. Recently, a number of feedback control schemes have also been developed for PWM inverters [4], [5]. Although the performance of these schemes are good, the complicated algorithms and the heavy computational demands make the implementations difficult.

Neural networks (NNs) have been employed in many applications in recent years. An NN is an interconnection of a number of artificial neurons that simulates a biological brain system. It has the ability to approximate an arbitrary function mapping and can achieve a higher degree of fault tolerance [6]. NNs have been successfully

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introduced into power electronics circuits to generate the switching angles of a PWM inverter for a given modulation index.

2. Proposed Design

Fig. 1 shows the proposed design for the UPS inverter feeding a non linear load. ANN controller is used to achieve low THD under non linear loading conditions. Inverter is a dc to ac converter. At the output end of the full bridge inverter we get a squared wave output voltage waveform rather than getting a sinusoidal wave. Hence we use filter to get pure sinusoidal output voltage. This condition satisfies for linear loads like resistive, inductive and capacitive. But for non linear loads even by using filter this condition does not satisfy. This paper explains the ANN controller for non linear loads to get sinusoidal output voltage waveform. Here the inputs to the NN controller are output voltage, current and error signals. These patterns are obtained using simulations and trained using back propagation algorithm. The output of the controller is to provide the switching angles to the inverter switches [7].

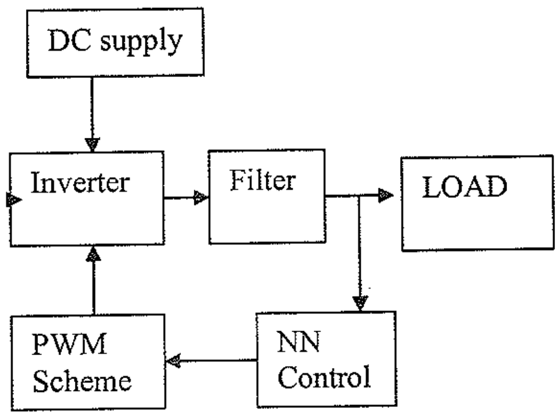


Figure 1 : Basic Block Diagram

The multiple feedback control scheme is used to sense the current in the capacitor of the load filter(inner feedback loop) and to ensure output voltage is sinusoidal and well regulated (outer feed back loop).This scheme is also helpful to produce nearly perfect sinusoidal load voltage waveform at moderate switching frequency and reasonable size of filter parameters.

3. Neural Network Controller

An Artificial Neural Network (ANN) is an information-processing paradigm that is inspired by the way biological nervous system, such as brain, process information. The key element of this paradigm is the novel structure of the information processing system. It is composed of large number of highly interconnected processing elements (neurons) working in unison to solve problems.

Fig.3 shows the controller model with idealized load current reference i_o^* for obtaining example patterns. When Neural Network is used in system control it can be trained either online or offline. In offline training weights and biases of the NN are adaptively modified during the control process. In real time control of the UPS inverter, there are no desired outputs to be presented to Neural Network since we have no prior knowledge about the loading conditions.

A Neural Network emulator can be employed to identify the inverter behavior in order to determine the output error of the Neural Network controller. The disadvantage is that Neural Network emulator also needs to be pretrained with data obtained from simulations or experiments. In this paper offline training is used since it requires a large number of example patterns. These patterns may be obtained through simulations. A selected feed forward Neural Network is trained to model this controller using back propagation algorithm. After training, the Neural Network controller is used to control the inverter on-line.

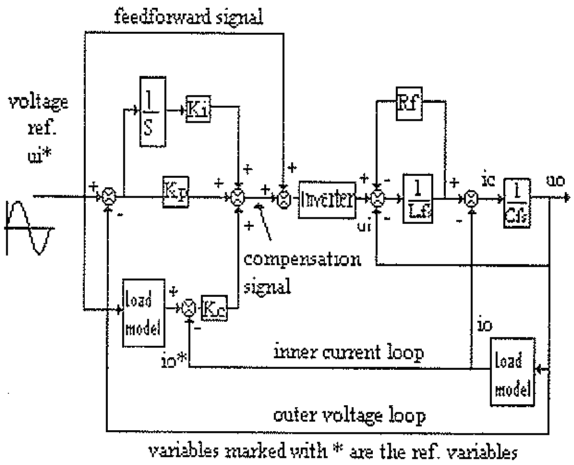


Figure 2 : Controller for obtaining example patterns

The PWM inverter is modeled as a proportional block with a gain K equal to V_{dc}/V_c where V_{dc} is the voltage of the dc power source and V_c is the peak voltage of the triangular carrier. Neural Network controller is to reduce the output voltage distortion under nonlinear loading condition. Offline training is adopted to ensure the inverter will have fast transient response and low cost.

In order to obtain good example patterns for NN off-line training, we need a simulation model (as shown in Fig.2) that can perform well not only under linear loading condition, but also under nonlinear loading condition. Hence the above model is designed using a derived transfer function based upon the inverter operation. The problem with the nonlinear load is that it draws nonsinusoidal current with rather high spike, so that the output voltage is distorted. If the load current can be predicted, we can design a controller to enable the output current to keep track of this predicted current. Starting with the multifeedback- loop control scheme changing the inner capacitor (or inductor) current loop to a load current loop, as shown in Fig. 3. A sinusoidal voltage reference is fed to the load model to generate an idealized load-current-reference. The error between this current reference, and actual load current is used as the input of the controller. An outer voltage loop is employed to achieve output voltage regulation. The load model specifies for both linear and non linear conditions. For non linear loading condition a full bridge rectifier serves as the load model. This model is easy to build and to simulate. Its performance is good not only under linear loading condition but also under nonlinear loading condition. We build such a controller with an idealized load- current reference using the software tool MATLAB [8].

The PWM inverter is described by the following equation in MATLAB:

$$Ui = \begin{Bmatrix} Vdc, um \geq ui \\ -Vdc, um < ui \end{Bmatrix} \tag{1}$$

where Vdc is the voltage of dc source um is the instantaneous voltage of the modulating signal, and ui is the instantaneous voltage of the triangular carrier wave in the PWM.

The load model in Fig. 2 can be of any type. Resistive, inductive, or capacitive load can be easily constructed in MATLAB. A nonlinear load, such as a full-wave diode bridge rectifier, can also be built in MATLAB. We can describe a diode using

$$id = \begin{Bmatrix} 0, ud < 0.7 \\ (ud - 0.7)/0.1, ud \geq 0.7 \end{Bmatrix} \tag{2}$$

It should be noted that a fixed set of controller parameters (Kp, Ki and Kc) is not good for every loading condition. Each loading condition has a set of optimal parameters, which can be determined from simulation that produces an output voltage with a low total harmonic distortion (THD) and a small enough steady state error.

The output voltage, load current, and capacitor current of the inverter are collected as the inputs to the NN. The compensation signal (as marked in the middle of Fig. 2), instead of the whole modulation signal, is collected as the desired output of the NN. By using this compensation signal as the desired output of the NN, more effective learning and better control performance can be achieved. In the case of UPS inverters, the database should include the input-output patterns under all possible loading conditions [9].A new example pattern is obtained each time the load model is changed. The pattern database contains hundreds of patterns, in which two-thirds are for linear loading condition, and the other one third is for nonlinear loading condition. In the selection of an NN for the inverter, we believe the NN should be as simple as possible (with fewer inputs and fewer hidden nodes) so as to speed up the control process and to reduce the controller cost. The training of the NN is automated by a computer program that presents a randomly selected example pattern from the pattern database to the NN a large number of times. During each time, the weights and biases of the NN are updated using the back propagation algorithm to make the mean square error between the desired output and the actual output of the NN less than a predefined value.

The Neural Network controller shown in Fig.3 has a 5-3-1 structure (five inputs, three nodes in a hidden layer and one output node). The nodes on the hidden layer have a sigmoid transfer function, and the output node has a linear transfer function. This NN structure is the result of many repeated trials. The structure is found to be simple but efficient. Its inputs are capacitor current, delayed capacitor current, load current, output voltage, and error voltage between the reference voltage and the output voltage.

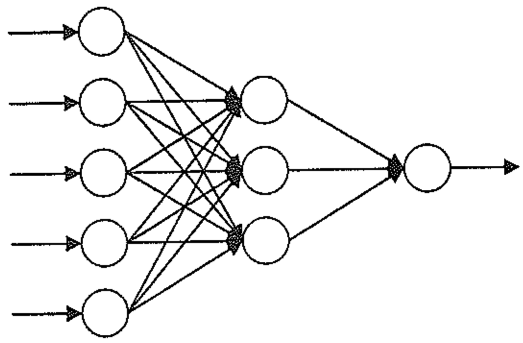


Figure 3 : Neural Network Controller

The delay time of the delayed capacitor current (i_{cd}) is one switching period. Such a time-delay is obtained from a simple R-C low-pass filter. The training of the NN is done using the Neural Network toolbox of MATLAB.

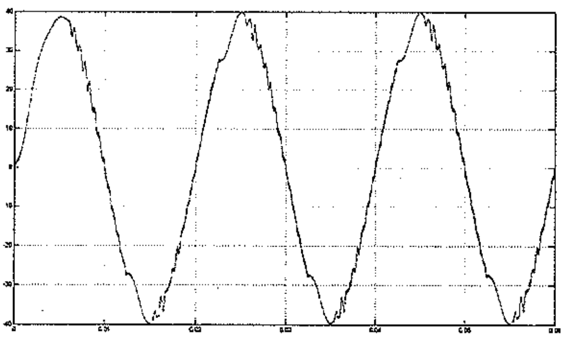
4. Design Specifications

The Inverter and filter are designed based upon the parameters listed in the table 1.The following steps are needed before the experimental setup. (1) To build the simulated controller with the idealized load current-reference for the inverter, as shown in Fig.3. (2) For each of the loading conditions, tune the parameters of the controller to the optimal values. Then collect the output voltage, load current, and capacitor current as the inputs of the Neural Network, and the compensation signal as the desired output of the Neural Network. These patterns form a pattern database for the training of the Neural Network. (3).Select a Neural Network structure that is simple and yet sufficient to model the simulated controller based on the pattern database. (4) Train the Neural Network using MATLAB with Neural Network Toolbox.

TABLE - I : INVERTER PARAMETERS

Parameter	Value	Unit
Switching frequency, f_s	20	kHz
DC source voltage, V_{dc}	48	V
Rated Output Voltage	25	V_{rms}
Rated Output Frequency	50	Hz
Rated Output Current	5	A_{rms}
Rated Output impedance	5	Ω
Filter Inductor, L_f		
Inductor Resistance, R_f	250	mH
Filter Capacitor, C_f	0.2	Ω
	30	μF

Fig.4 shows the linear model of inverter where the MATLAB function block includes the programs for triangular wave generation and inverter output generation. Its results so obtained are also shown. These programs are written in MATLAB M-file.Fig.5 shows the complete closed loop simulation of UPS inverter using NN controller. The output voltage waveform that obtained using NN controller is also shown in the figure.



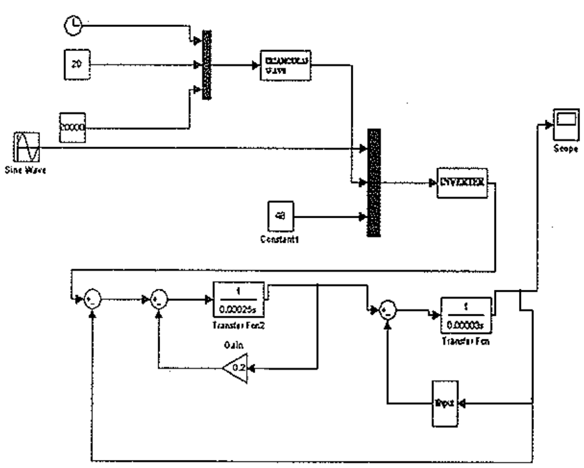
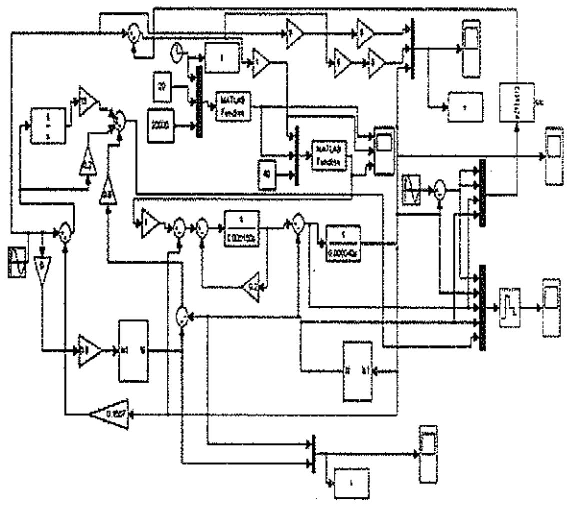


Figure 4 : Linear model of inverter with its output voltage waveform



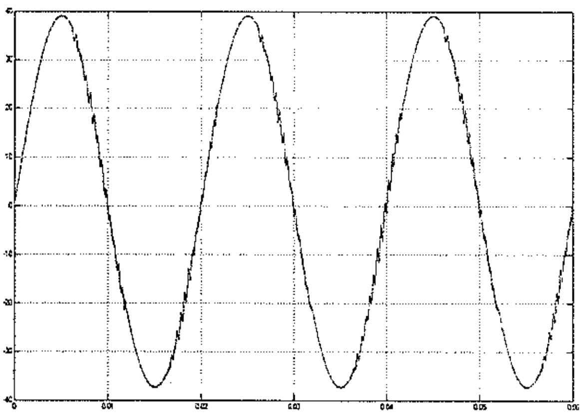


Figure 5 : Simulation of UPS inverter with NN controller with its output voltage waveform

5. Implementation

The experimental set up is made by making a dead time of 2.5μs for inverter MOSFET (Metal oxide semiconductor field effect transistor) on the same inverter leg. Initially full bridge inverter is constructed where its input DC voltage is obtained from single phase fully controlled bridge rectifier. For non linear loads voltage sags slightly when the load current rises sharply. The difference between experimental and a simulation result is the effect of filters used in practical system to suppress high frequency noise in the measured signals. The current and the voltage feedback signals are obtained from the filter components are fed to the microcontroller. The Neural Network program written in the controller accepts these parameters and compares with the trained patterns and drives the switching signals for the inverter.Either the Neural Network controller directly controls the inverter switches or it controls the PWM generator to control the inverter switches. The waveforms thus obtained by using the above setup gives sinusoidal waveform as shown in Fig.13.The performance of results using NN controller holds good than any conventional controllers.

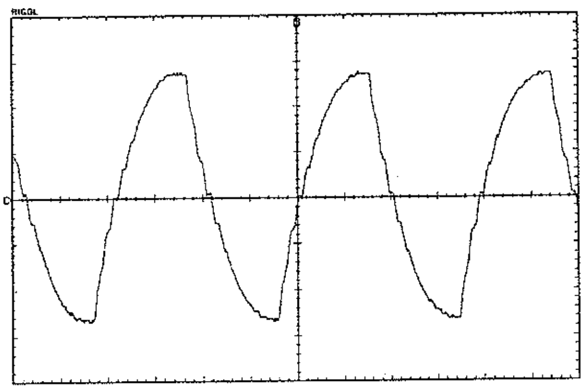


Figure 6. Resulting Waveform

6. Conclusion

An NN controller for UPS inverter applications has been proposed in the paper. Training patterns for the NN controller are obtained from a simulated controller with idealized load-current reference. After training, the NN can be used to control the UPS inverter on-line. The proposed neural network controller is particularly suitable for non linear load that introduces periodic distortions. After the simulation training, the NN can be used to control the UPS inverter on-line. The proposed neural network controller is particularly suitable for non linear load that introduces periodic distortions. The simulation results of other methods does not show the desired requirement, hence the usage of Neural Network controller is unavoidable. The disadvantages of analogue implementation such as temperature drift, electro magnetic interference are completely absent in this technique. The digital technique involves the complicated algorithms and the heavy computational demands make the implementations difficult. Hence the control of UPS inverter by Neural Networks is highly applicable.

7. References

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