Online UPS Inverter Controlled Using Soft Computing Techniques Modeling and Simulation

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***Abstract*-A neural network controller for UPS inverter applications is presented. 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). This can be achieved using a neural network (NN) controller to control the on line UPS. 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 are that the proposed neural network controller can achieve low total harmonic distortion under nonlinear loading condition and good dynamic response under transient loading condition were verified and simulated.**

***Key words*- Neural networks, Pulse Width modulation, Inverters**

I. 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 [1].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.

Fig.1 shown is the block diagram of a typical UPS inverter. 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].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 [3], [4]. Although the performance of these schemes are good, the complicated algorithms and the heavy computational demands make the implementations difficult.

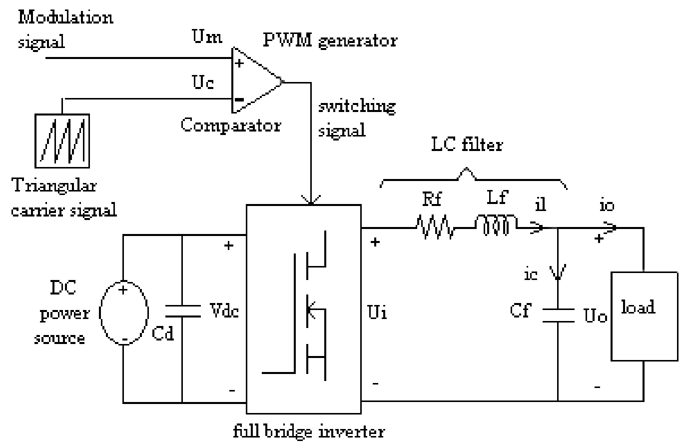


Fig. 1. Typical UPS inverter.

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 [5]. NNs have been successfully introduced into power electronics circuits to generate the switching angles of a PWM inverter for a given modulation index.

II. MATERIALS AND METHODS

Fig.2 shows the proposed design for the UPS inverter employing full bridge rectifier with a capacitor parallel to a resistance which acts as a nonlinear load. This paper presents an artificial neural network controller to achieve low THD under non linear loading conditions. The patterns for the neural network controller are obtained from the simulated controller. Inverter is a dc to ac converter. A serous disadvantage of the half bridge inverter is that it requires a three wire DC source. Hence full bridge inverters are widely used in UPS for computers, standby power power supplies etc. The fundamental component of the output voltage is twice than that of the half bridge. At the output end of the full bridge inverter we get a squared wave output voltage waveform rather than getting a sinusoidal wave. Hence it is necessary to include a filter to get a pure sinusoidal output voltage waveform. This sinusoidal AC voltage is used to give supply for the loads. For every loading conditions the voltage measured at the output of the inverter is to be pure sinusoidal. This condition is satisfied for linear loads like resistive, inductive and capacitive loads.

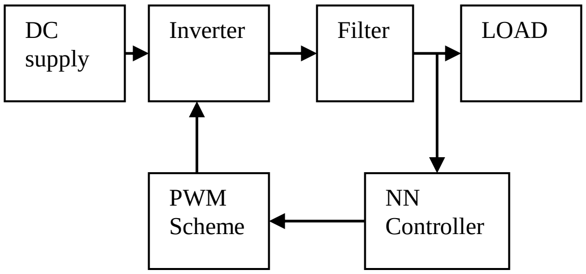


Fig. 2. Basic Block diagram of proposed system

But for the non linear loads the output voltage waveform is not sinusoidal which affects the performance. To make the output voltage of the non linear load to be sinusoidal a soft computation technique called neural networks is used. This NN controller is used to generate the switching angles to the inverter in order to maintain sinusoidal output voltage for the non linear loading condition also [7].

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.

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.

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 as shown in Fig.1.

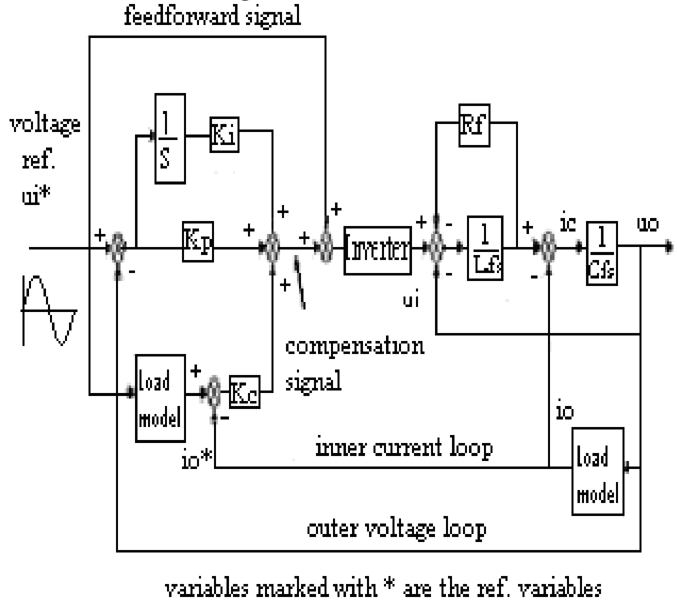


Fig. 3. Controller for obtaining example patterns

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.3) 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:

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

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 (as shown in Fig. 1).

The load model in Fig. 3 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

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

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. 3), 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. 4 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. 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.

PULSE WIDTH MODULATION SCHEME

Since the DC bus voltage is always constant, the inverter has to be controlled to vary the magnitude and frequency of AC output voltage .This is normally accomplished by PWM that control the inverter.Fig.5 shows the generation of PWM pulses [10].

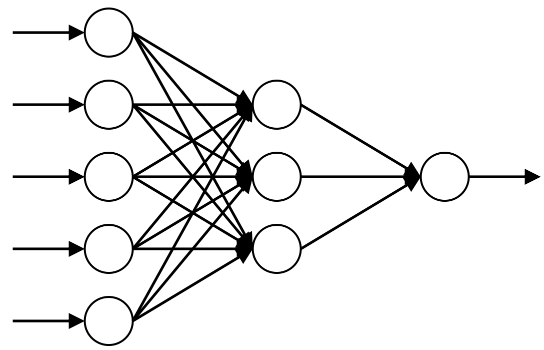


Fig. 4. Neural Network Controller

The sinusoidal pulse width modulation technique is popular in industrial applications. SPWM is a particular type of multiple pulses. Sinusoidal Pulse Width Modulation (SPWM), which includes different schemes for shaping the output voltage and controlling its frequency. There are two major concerns for generating SPWM. The first is to minimize the creation of low order harmonics in the output voltage. The second is the mitigation of switching frequency harmonics. Often, the inverters used in these UPS systems have a half or full bridge topology. Those based on a half bridge configuration require a smaller number of components, but can only be operated in bipolar mode, with the associated larger filtering requirements. Therefore full bridge inverters such as that shown in Fig.1 is often chosen for medium to high power single-phase voltage source inverter applications.

The general principle of SPWM is the comparison of two voltage waveforms:(1) a sinusoidal voltage of the same frequency as the inverter, which is called as the reference voltage ,and (2) a high frequency voltage, which has a triangular waveform, which is called as the carrier voltage. The triangular carrier waveform has fixed amplitude. The amplitude of the reference sine wave is usually made adjustable.

The inverter output frequency is the same as the reference sine wave, the inverter output frequency is adjustable by adjustment of the reference wave frequency. In each half period, the pulse width is maximum in the middle. From the center, the pulse widths decrease as cosine function towards either side. In an SPWM waveform the total harmonic content is still very significant .The order of harmonics in the SPWM waveform depends on the number of pulses per half cycle employed. If SPWM is implemented in an inverter with a large number of pulses per half cycle, the harmonic frequencies will be so large that for many applications, such as motor speed control, no separate filter may be needed on the output side. SPWM offers greater functionality in terms of the minimization of the total harmonic distortion, reductions in size and price, and in additional inverter functional capabilities such as active filtering and reactive power support. A Fourier analysis for sine pulse width modulation is made. This analysis involves the determination of harmonics and the modulation index. The modulation index is defined as the ratio of the carrier and modulated wave amplitudes. Here in this paper carrier wave is triangular signal.

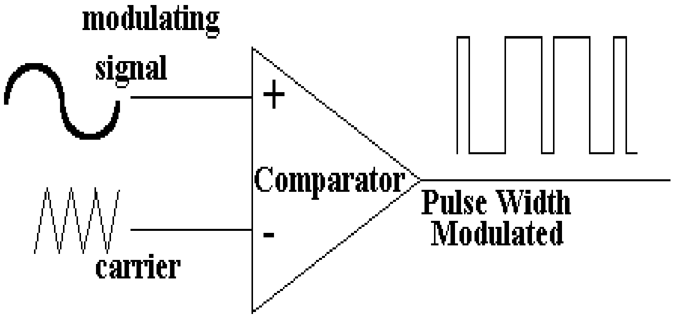


Fig. 5. Generation of PWM pulses

A Fourier analysis of the Sine PWM wave is

v (t) = $m_a V_S$ sin (ωst + φ) + Bessel function harmonic terms.

m_a is the modulation index,

ωs is the fundamental frequency,

φ is the phase shift of the output depending on the position of the modulating wave.

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.

III. SIMUALTION RESULTS AND DISCUSSIONS

Fig.6 shows the PWM circuit to generate the gating signals to the inverter switches and its resulting waveform. These simulations are done in MATLAB-Simulink package. Fig.6 is the subsystem in which the input marked 1 is the carrier triangular wave which is compared to the reference sinusoidal wave to generate gate pulses. Block marked P1 is used to trigger the switches in the positive half cycle and similarly P2 is used to trigger the inverter in the negative half cycle. Fig.7 shown is the output voltage waveform obtained for the linear

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	250	mH
Inductor Resistance,R_f	0.2	Ω
Filter Capacitor,C_f	30	µF

loads. Here the resistive load of 120Ω is used. The result shows that for linear loads the output voltage waveform is found to be pure sinusoidal. The subsystem shown for PWM generation is incorporated in Gate signal generation block.

For the non linear loads it is required to maintain low distortion in the output voltage.Fig.8 shows the circuit simulation and its resulting current and voltage waveform for non linear load (full bridge rectifier with 3200µF capacitor and 10Ω resistor) without using any controller .It is found that the output voltage waveform is highly distorted. It is the open loop simulation of UPS inverter. Fig. 9 shows the non linear load model that depicts the full bridge rectifier, which includes the diodes and other transfer functions.

Neural Network controller can achieve low distortion in output voltage by the following methodology. Input-output mapping is stored in pattern database which includes many cases of non linear loads. Neural Network learns control law from this database. Neural Network takes care of charactristics of those rectifier type loads.Neural networks is suitable for applications where load introduces perodic distortions [11].

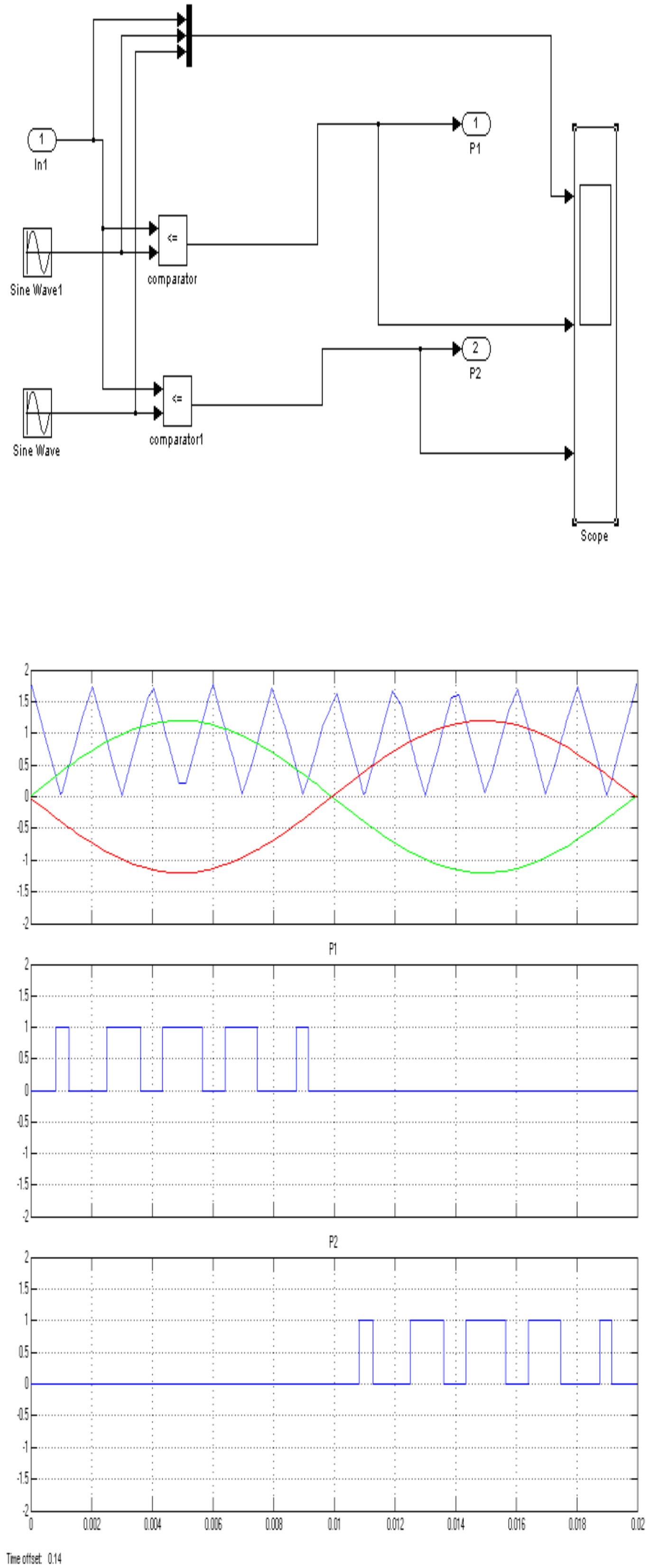


Fig. 6. PWM simulation circuit and its result

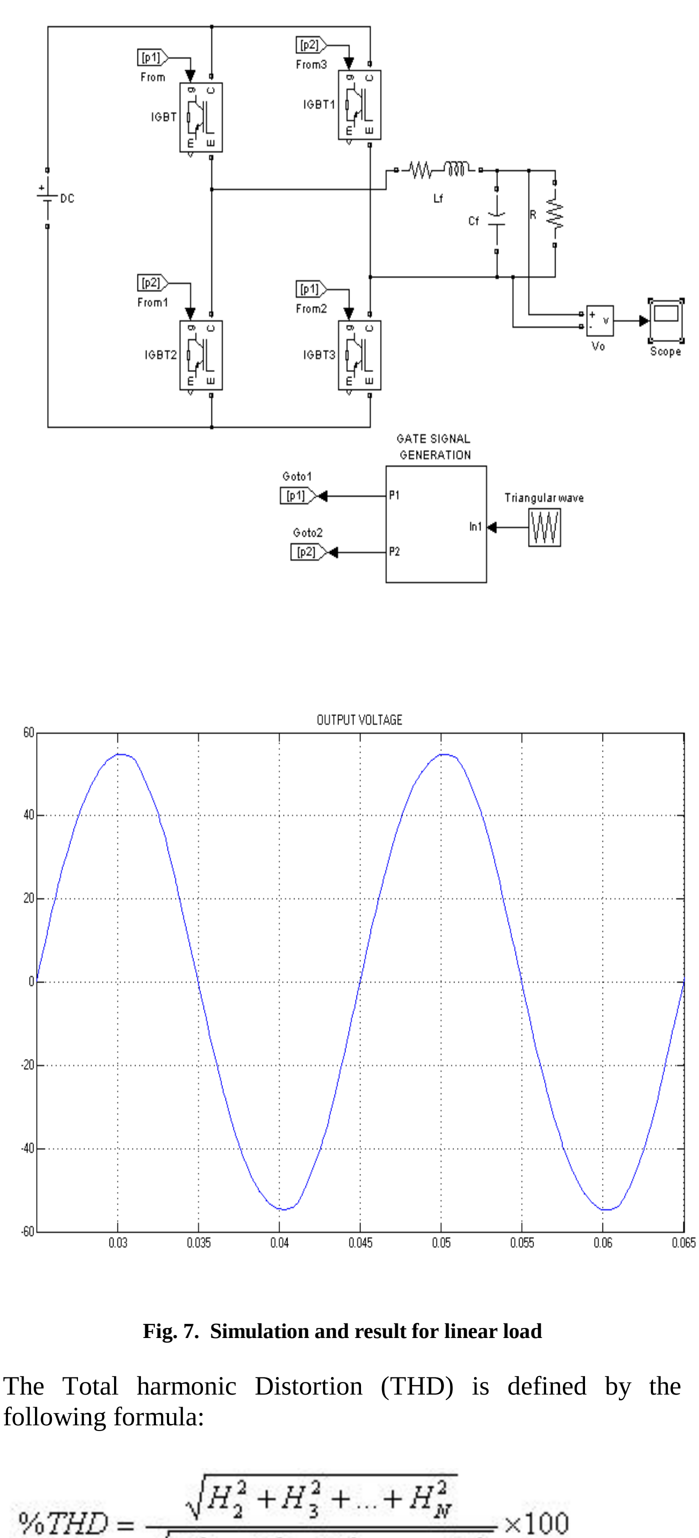


Fig. 7. Simulation and result for linear load

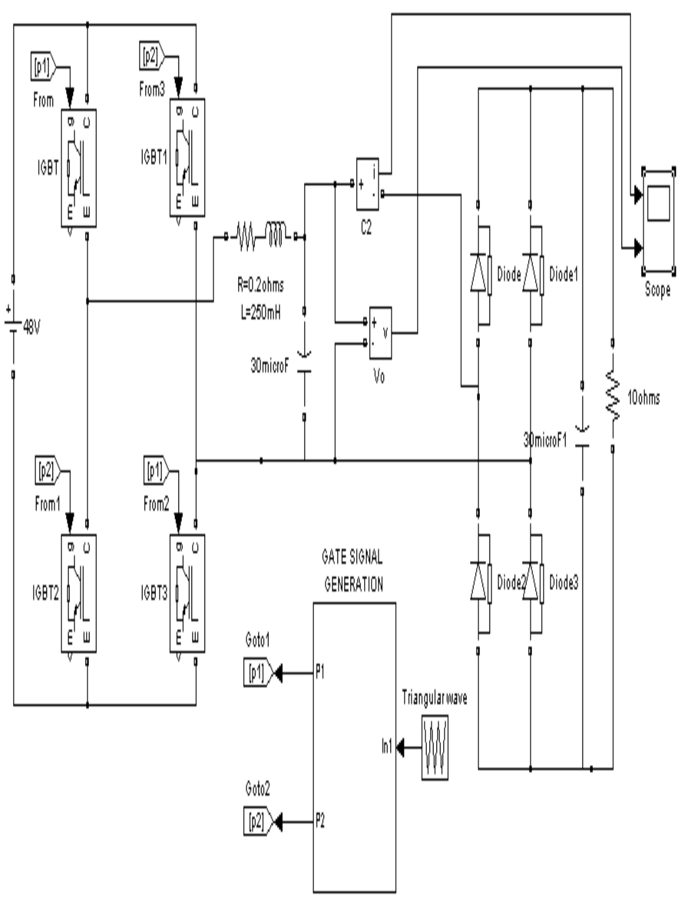
The Total harmonic Distortion (THD) is defined by the following formula:

$$\%THD = \frac{\sqrt{H_2^2 + H_3^2 + \ldots + H_N^2}}{\sqrt{H_1^2 + H_2^2 + H_3^2 + \ldots + H_N^2}} \times 100$$

where terms 2...N are the power levels of the harmonics and term 1 is the power level of the fundamental (the pure tone). Fig.10 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. The MATLAB functions included in the circuit depicts the triangular wave generation and inverter output generation programs. These programs are written in MATLAB M-file. The performance of results using NN controller holds good than any conventional controllers.

IMPLEMENTATION

Fig.11 shows the circuit for implementation with the Proposed Neural network controller. 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



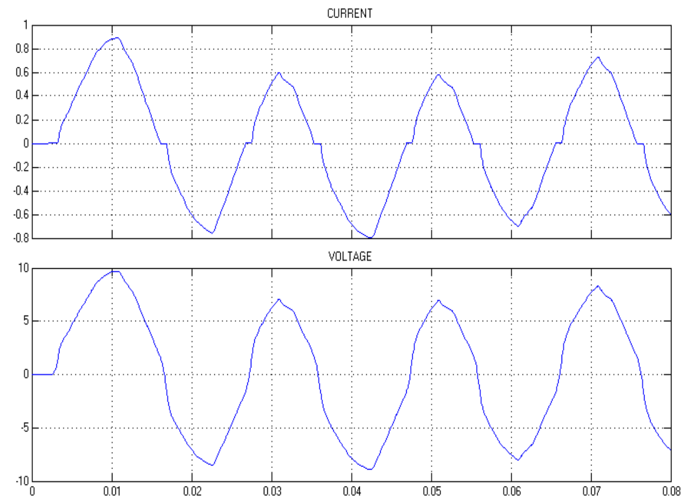


Fig. 8. Simulation and result for non linear load

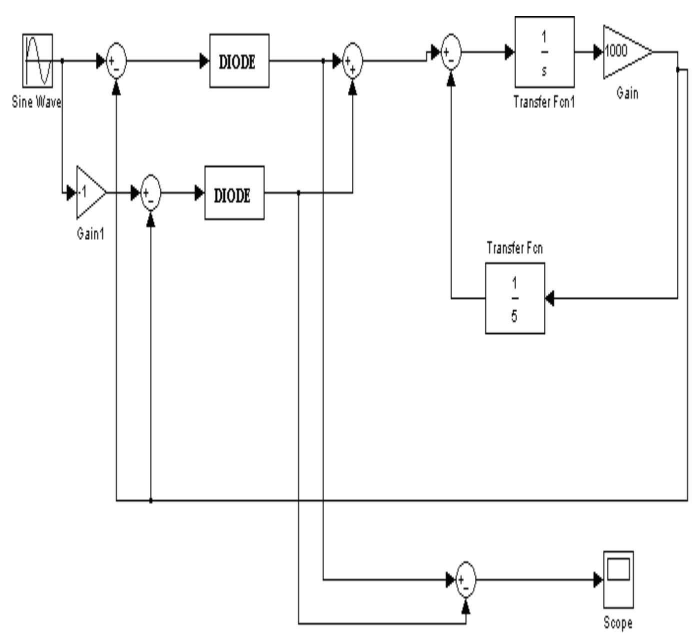


Fig. 9. Nonlinear load model

slightly when the load current rises sharply. The difference between experimental and a simulation result is the effect of controlled bridge rectifier. For non linear loads voltage sags slightly when the 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 analog signals obtained from the filter components is sampled to the necessary digital signal using DAC.After this conversion the

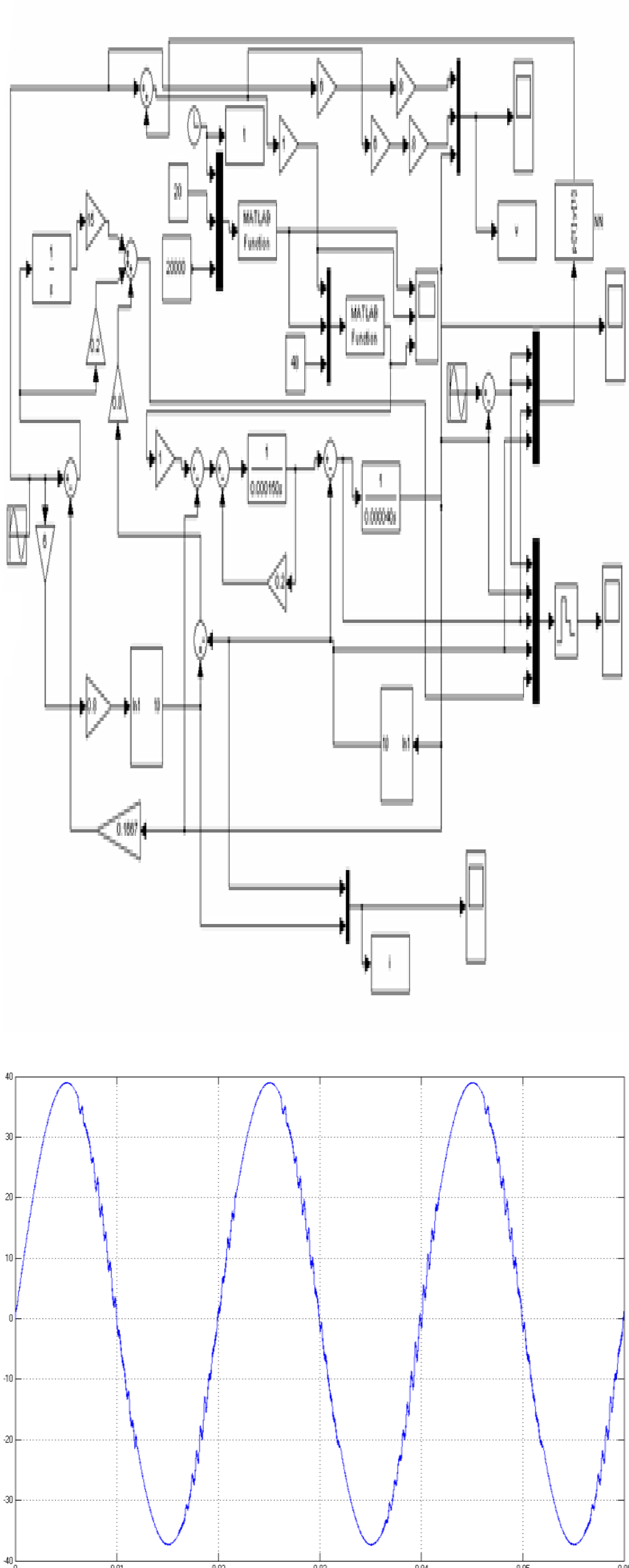


Fig. 10. Simulation of UPS inverter with NN controller with its output voltage waveform

digital input is fed to the computer system through the bidirectional serial port. The Neural Network program written digital input is fed to the computer system through the bidirectional serial port. The Neural Network program written in the computer system accepts these parameters and compares with the trained patters 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.

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. 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

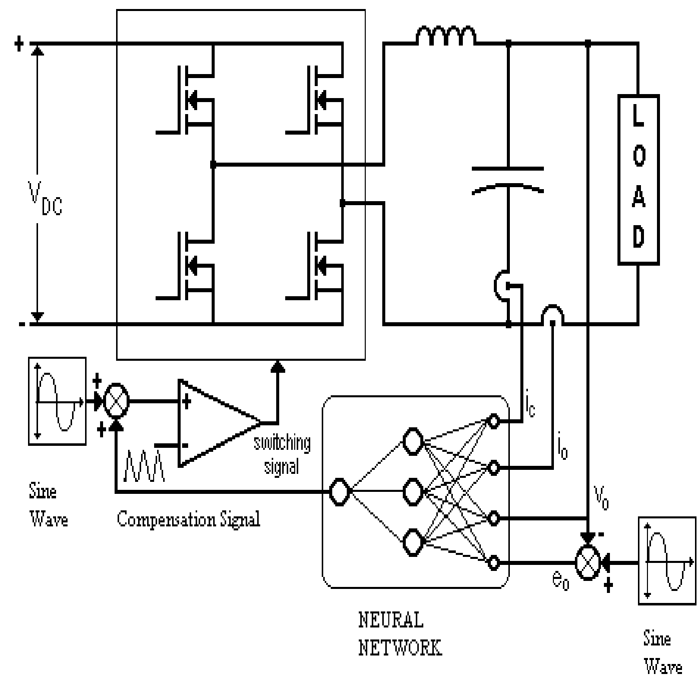


Fig. 11. Implementation circuit

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.

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