International Journal of Modern Engineering Research (IJMER)
www.ijmer.com Vol.3, Issue.4, Jul - Aug. 2013 pp-1910-1915 ISSN: 2249-6645

Neural Network Based Optimal Switching Pattern Generation for Multiple Pulse Width Modulated Inverter

K. Tamilarasi[1], C. Suganthini[2]
[1, 2] *Dept of CSE, Velammal Institute of Technology, Anna University, Chennai, India*

Abstract: *A novel concept of application of neural networks for generation of optimal switching patterns in voltage-controlled inverter is presented. In multiple pulse width modulated inverter (PWM) proper selection notch angles can eliminate the specific harmonics. In this work 8 notches per half cycle is assumed. This gives a choice of seven switching angles in a quarter cycle. It is proposed to eliminate all possible lower order harmonics by proper selection of switching angles for different modulation index. A neural network is trained to generate the switching angles and patterns for different modulation index. Simulation results confirm that neural network based switching pattern generation can eliminate all lower order harmonics up to the order 22nd. The switching patterns for different modulation index, training of neural network and the simulated performance of the inverter are presented.*

Key words: *Feed forward Neural Network, Inverter, Selective Harmonic Elimination Pulse Width modulation*.

I. INTRODUCTION

An inverter is an electronic circuit that converts DC to AC power by switching the DC input voltage (or current) in a pre-determined sequence to generate AC voltage (or current) output. The topology used here consists of three phase bridge inverter. The conversion from DC to AC using the power electronic device introduces harmonics in the output voltage. In conventional methods, large sized filters are used to filter the lower order harmonics (5^{th}, 7^{th} etc). These lower order harmonics cause serious voltage distortion. In the proposed method, selective harmonic elimination technique is used to eliminate the lower order harmonics.

The Optimal Switching Pattern (OSP) Pulse Width Modulation (PWM) strategies constitute the best choice for high power, three-phase voltage controlled inverter with low allowable level of switching frequency. The proposed project is presented in the following phases namely,

1. Elimination of lower order harmonics 2.Training of neural network 3.Gate pulse generation of inverter circuit.

Selective harmonic elimination pulse width modulation (SHE-PWM) techniques offer a tight control of the harmonic spectrum of a given voltage waveform generated by a power electronic converter along with a low number of switching transitions. These optimal switching transitions can be calculated through Fourier series theory, and quarter-wave and half-wave symmetries have been assumed when formulating the problem. In the selective harmonics elimination PWM, the undesirable lower order harmonics can be eliminated. And the fundamental voltage can be controlled by SHEPWM technique for the required value of modulation index, the necessary switching angles are calculated. This switching angles are used for generation of gating pulses for the inverter switches.

Neural network (NN) has 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. NN have been successfully introduced into power electronics circuits to generate the optimal switching angles of a PWM inverter for a given modulation index.

The PWM generator generates the switching signals to the full-bridge inverter. For linear load, the output voltage is pure Sinusoidal. The schematic block diagram representation as shown in figure1.

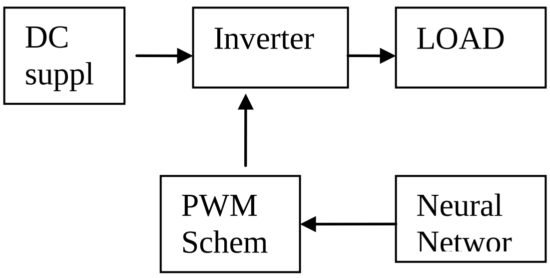


Fig.1 Basic Block diagrams.

II. HARMONICS ELIMINATION STRATEGY

By placing notch in the output waveform at proper locations, certain harmonics can be eliminated. This allows lower switching frequencies to be used. Normally, a look-up table is prepared in microcomputer memory and the angles, as functions of modulation index value, are retrieved for digital implementation. After training, as the commanded modulation index m* is impressed at the input, all the correct ‘α’ angles are retrieved at the output. The advantages of an ANN in this case, are avoiding the need of a large precision look-up table memory.

Harmonics elimination technique for single phase and three phases are presented below:

For Single-phase Inverter, with 7 values of α, the 3^{th}, 5^{th}, 7th, 9th, 11th and 13^{th} harmonics can be eliminated. Using MathCAD program, these transcendental equations can be solved numerically for the notch angles α_1, α_2, α_3, α_4, α_5, α_6 and

α_7 and for specified fundamental amplitude. For example, at m=0.9 the values are α1=7, α2= 17.263, α3=21.195, α4=34.879, α5=35.879, α6=50.908, α7=51.288.

For the three-phase inverter with 7 values of α, the 5^{th},7^{th},11^{th},13^{th},17^{th} and 19^{th} harmonics and the 3rd order harmonics can be eliminated. Thus n=7 and the equations can be written as:

To reduce harmonics, we have to solve the following equations

Cosα1-Cosα2+Cosα3-Cosα4+Cosα5-Cosα6+Cosα7 =m+0.5

Cos5α1- Cos5α2+ Cos5α3- Cos5α4 +Cos5α5-Cos5α6+Cos5α7 =0.5

Cos7α1-Cos7α2+Cos7α3-Cos7α4+Cos7α5-Cos7α6+Cos7α7 =0.5

Cos11α1-Cos11α2 + Cos11α3- Cos11α4+Cos11α5-Cos11α6+Cos11α7 =0.5

Cos13α1- Cos13α2+ Cos13α3- Cos13α4 +Cos13α5-Cos13α6+Cos13α7=0.5

Cos17α1- Cos17α2+Cos17α3-Cos17α4+Cos17α5-Cos17α6+Cos17α7 =0.5

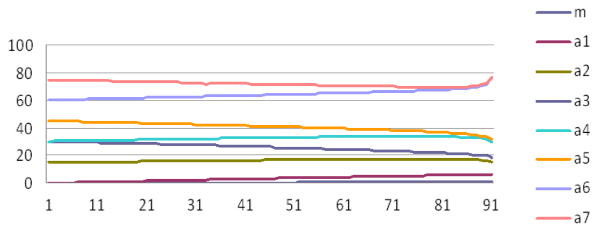
Cos19α1-Cos19α2+ Cos19α3- Cos19α4 +Cos19α5-Cos19α6+Cos19α7 =0.5

α1< α2 <α3 <α4 <α5<α6<α7< 90

M varies from 0.01 to 0.99

Using MathCAD program, these transcendental equations can be solved numerically for the notch angles α_1, α_2, α_3,α_4 , α_5 , α_6 and α_7 for specified fundamental amplitude.

For example, At m=0.9 the alpha values are a1=6.313, α2=16.41, α3=19.921, α4=31.586, α5=33.347,α6=71.833, α7=72.335.



For obtaining the above values of a1 to a7, an analytical Approach of MathCAD software is employed.Various objective functions can be used in the optimal control of an inverter. In the method, notches are created on the square wave at predetermined angles, as shown in fig.2, positive half – cycle output is show with quarter-wave symmetry. It can be shown that the seven notch angles α1, α*2*, α*3*, α*4*, α*5*, α*6*, *and* α*7* can be controlled to eliminate significant harmonic components. The full-cycle switching pattern must possess the half-wave and quarter-wave symmetry in order to eliminate even harmonics; hence, the resultant optimal switching pattern yields a fundamental voltage that corresponds to a given value of the modulation index, where as (n – 1) low-order, odd harmonics are absent in the output voltage.

At even significant deviations from the optimal switching pattern, barely affect the magnitude of the output voltage. This is an advantageous feature, because as seen in Fig. 1 α1, α*2*, α*3*, α*4*, α*5* and α*6*, as well as α*7*, tend to converge at M > 0.95. Therefore, the neural network converter should be made to accurately reproduce the optimal switching angles only within the 0 to 0.95 range of the modulation index.

III. OPTIMAL SWITCHING ANGLES GENERATION USING NEURAL NETWORK.

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.

Neural network deals with Mathematical information about processing of a system with input and output. A neural network used for generation of optimal switching angles has a single input for the reference value of the modulation index and N outputs that provide the values of the switching angles. The neurons are trained using the Neural Network toolbox of MATLAB.

3.1 Feed-forward Neural Network:

Individual processing units are organized in three types of layer namely input, hidden and output layer. All neurons within the same layer operate simultaneously.

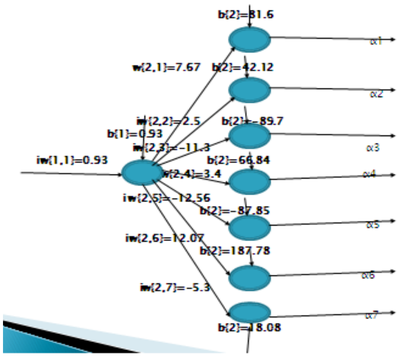


Fig.3 Train neural network representation diagram.

3.1 TRAINING OF FEED-FORWARD NEURAL NETWORK:

- Input encoding
- Output encoding
- Number of hidden units
- Learning rate
- Momentum

Feed-Forward back propagation algorithm is used to train the neural network and input data are given for modulation index m from 0.01 to 0.95, and the training function TRAINLM is employed.

Hidden layer activation function (tangent sigmoid transfer function) TANSIG (N)

Output layer activation function (tangent sigmoid transfer function) TANSIG (N)

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 that can perform well in the inverter.

The following codes show the neural network equations used for generation of firing pulse to the inverter circuit.

```
v01=u*1.007-0.45;
α1=v01*7.05+3.3;
α2=v01*2.3+16.5;
α3=v01*(-10.4) +25.8;
α4=v01*3.13+32.1;
α5=v01*(-11.6) +40.5;
α6=v01*11.11+64.3;
α7=v01*(-4.9) +72.2;
```

As shown, this information is sufficient for generation of the full-cycle switching pattern for all the three phases of the inverter.

IV. NEURAL NETWORK PULSE WIDTH MODULATOR

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 technique.

The general principle of SHEPWM is the comparison of two voltage waveforms:(1) a variable voltage of the same frequency as the inverter, which is called as the reference voltage ,and 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 constant value is adjustable.

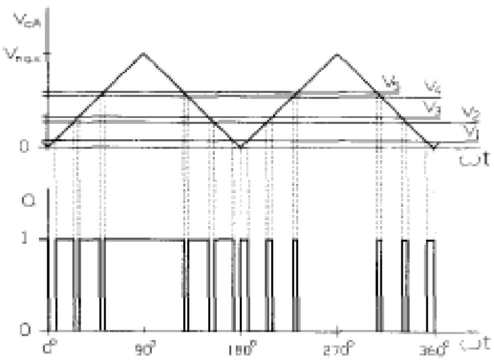


Fig.4 Pictorial representation of selective harmonics elimination technique.

The inverter output frequency is the same as the reference square wave; the inverter output frequency is adjustable by adjustment of the reference wave frequency. In an SHEPWM wave form the total harmonic content is still very significant. The order of harmonics in the SHEPWM waveform depends on the number of pulses per half cycle employed. 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.

V. DESIGN SPECIFICATIONS

The Inverter based PWM technique is designed based upon the following steps are needed before the experimental setup. (1) To perform the simulation and the gating signal are generated and given to an inverter circuit. (2).Select a Neural Network structure that is simple and yet sufficient to model the simulated and based on the pattern database. (3) Train the Neural Network using MATLAB with Neural Network Toolbox. (4) The gating pulse generated by using the coding written in the c language and in- turn embedded in the microcontroller.

TABLE 1

SINGLE PHASE INVERTER PARAMETERS

PARAMETER	VALUE	UNIT
Switching frequency, f_s	750	Hz
DC source voltage, V_{dc}	100	V
Rated Output Voltage	83	V_{rms}
Rated Output Frequency	50	Hz
Resistive load	10	Ω

TABLE 2

THREE PHASE INVERTER PARAMETERS

PARAMETER	VALUE	UNIT
Switching frequency, f_s	750	Hz
DC source voltage, V_{dc}	220	V
Rated Output Voltage	173	V_{rms}
Rated Output Frequency	50	Hz
Resistive load	10	Ω

VI. SIMULATION RESULTS

Fig 4.Shows the PWM signal to generate the gating signals to the inverter switches and its resulting waveform. The simulation results are obtained using MATLAB - Simulink package. Fig 4 is the subsystem in which the input marked is the carrier triangular wave, which is compare to the reference constant value to generate gate pulses. P1 is use to trigger the switches in the positive half cycle and P2 is used to trigger the inverter switches in the negative half cycle Fig5.2. Show is the output voltage waveform obtained for the linear loads. Here resistive load of 10**Ω** is used. The result shows that for linear load the output voltage waveform is found to be square wave.

Total harmonic Distortion (THD) is define as

$$THD = \frac{\sqrt{{V_3}^2 + {V_5}^2 + V_7^2 + \ldots\ldots.. V_{21}^2}}{V_1}$$

Where, terms 2...N is the power levels of the harmonics and term 1 is the power level of the fundamental (the pure tone).

The MATLAB function block includes the programs for triangular wave generation. The results so obtained are shown fig 6.5. The program was written in MATLAB M-file. Fig 6.1 & Fig 6.5. shows the complete simulation of single phase and three-phase inverter using Neural Network.

The simulated results are shown in Fig 5 for single-phase inverter and in Fig 6.for three-phase inverter. For single phase inverter the lower order harmonics are removed by adjusting the switching angles (i.e.) 3^{rd},5^{th},7^{th},9^{th},11^{th} and 13^{th} order harmonics are completely eliminated.

TABLE 3

COMPARISON OF THD for SINGLE PHASE INVERTER

Order of harmonics	3^{rd}	5^{th}	7^{th}	9^{th}	11^{th}	13^{th}
Sine PWM THD	8.14	6.92	6.56	6.15	5.91	5.21
Proposed THD	6.55	6.12	5.81	5.63	5.21	4.97

COMPARISON OF THD for THREE PHASE INVERTER

Order of harmonics	3^{rd}	5^{th}	7^{th}	9^{th}	11^{th}	13^{th}
Sine PWM THD	14.32	13.7	13.2	12.91	12.5	11.5
Proposed THD	7.14	6.91	6.52	6.3	6.51	5.22

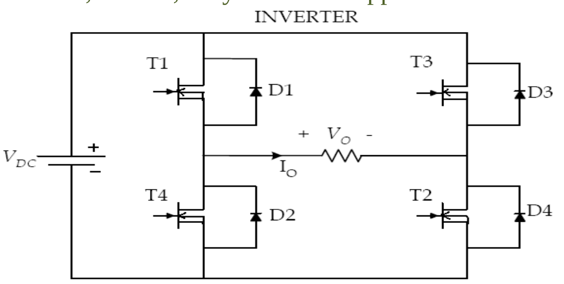


Fig6.1 for single-phase inverter

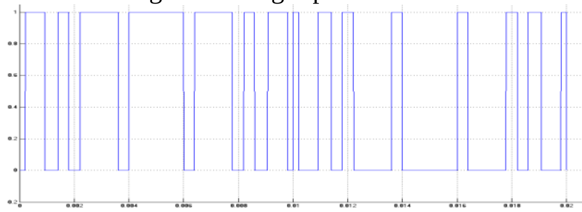


Fig.6.2 for single-phase inverter gating pulse

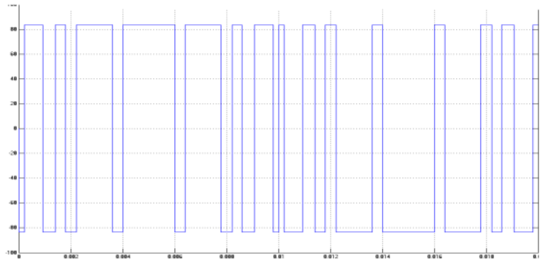


Fig.6.3 for single-phase inverter output voltage waveform result.

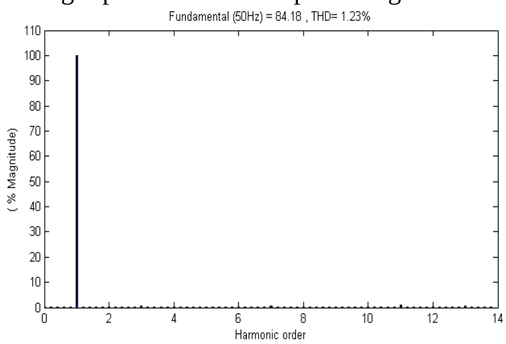


Fig.6.4 simulated harmonic spectrum for single-phase inverter.

And for three phase inverter the lower order harmonics are removed by adjusting the switching angles (i.e.) 5^{rd},7^{th},11^{th},13^{th},17^{th} and 19^{th} order harmonics are completely Eliminated.

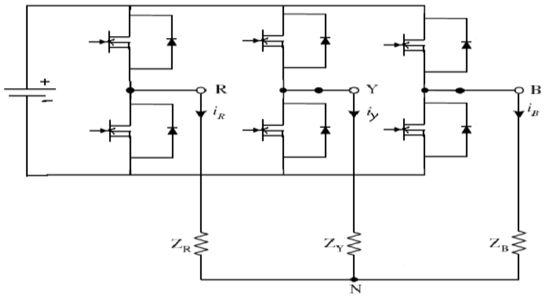


Fig.6.5 three-phase inverter

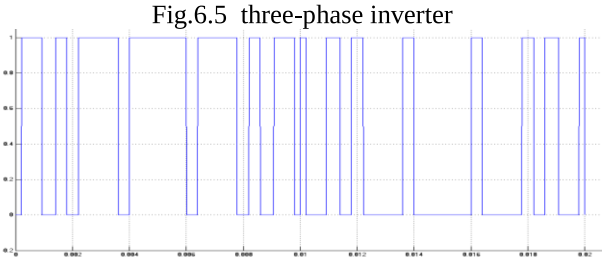


Fig.6.6 for three-phase inverter gating pulse

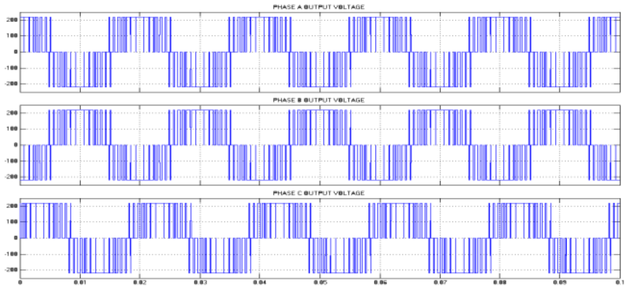


Fig.6.7 for three phase inverter output voltage waveform result.

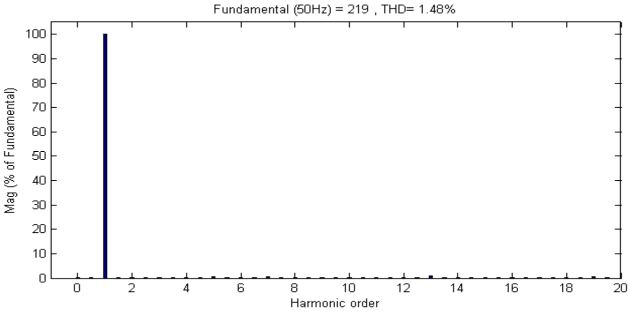


Fig.6.8 simulated harmonic spectrum for three-phase inverter.

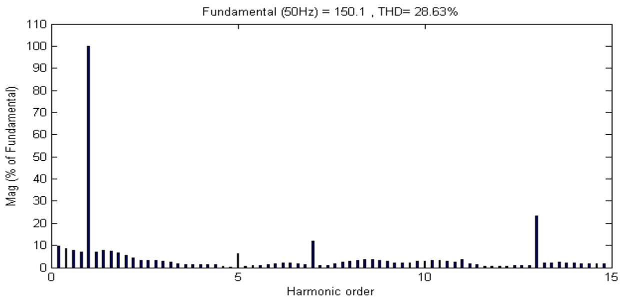


Fig.6.9 simulated harmonic spectrum for three-phase inverter by sinusoidal pulse width modulation.

VII. CONCLUSION

The optimal switching pattern-pulse width modulation strategy constitutes the best choice for high power voltage controlled inverters with low allowable level of switching frequency. The neural network used for elimination of lower order harmonics can be used as optimal technique for non-linear loads. The proposed multiple PWM technique improves the fundamental voltage. In future power factor correction can also been implemented.

REFERENCES

[1]. José R. Espinoza, Géza Joós, Johan I. Guzmán, Luis A. Moran, and Rolando P. Burgos" Selective Harmonic Elimination and Current/Voltage control in Current/Voltage- Source Topologies: A Unified Approach" IEEE transactions On industrial electronics, vol. 48, no. 1, February 2001.

[2]. Li Li, Dariusz Czarkowski, Yaguang Liu, and Pragasen Pillay, *Senior Member, IEEE "*Multilevel Selective Harmonic Elimination PWM Technique in Series-Connected Voltage Inverter", IEEE transactions on industry Applications, vol. 36, no. 1, January/February 2000.

[3]. Vassilios G. Agelidis, Anastasios Balouktsis, Ioannis Balouktsis, and Calum Cossar, "Multiple Sets of Solutions for Harmonic Elimination PWM Bipolar Waveforms: Analysis and Experimental Verification", IEEE transactions on power electronics, vol. 21, no. 2, march 2006.

[4] O.Bouhali,M.Berkouk,B.Francois,Saudemont,S.Labiod, "Solving Harmonics Elimination Problem in Three-Phase Voltage controlled Inverter Using Artificial Neural Networks". J. Electrical Systems 1-1 (2005): 39-51

[5]. S. sirisukprasert, J. S. Lai and T. H. Liu, "Optimum Harmonic Reduction with a Wide Range of Modulation indexes for Multilevel Converters", *IEEE Transactions on Industrial Electronics,*Vol.49,No.4,Aug2002, pp.875-881.

[6]. K.W.E.Cheng, H.Y.Wang and D.Sutanto, "Adaptive directive neural network control for three phase AC/DC PWM converter" *IEE Proc-Electr. Power Appl. Vol. 148, No. 5, September 2001.*

[7]. John N.Chiasson, Leon M. olbert, Keith J.McKenzie, and Zhong Du, "A Unified Approach to Solving the Harmonic Elimination Equations in Multilevel Converters", *IEEE* Transactions on power electronics,vol.19,no.2,march- 2004