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Design of ANN Controller for Selective Harmonic Elimination

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Abstract **In this paper, a continuous Feed Forward back propagation Network is designed for low order odd Harmonic minimization in a single phase inverter output voltage. Results show considerable improvement in voltage spectrum if trigger pulses are generated at the ANN positions as harmonic contents are reduced with significant improvement in fundamental voltage resulting in reduction in device ratings. The traditional method SPWM and SHE-NR do not yield accurate pulse position as non-linearity is involved in computation. Neural Network designed for Harmonic minimization and result shows comparative difference between SHE-NR and SHE-ANN. The quantitative analysis is given in list relative to fundamental. This shows flexibility of design of a ANN controller better than the SHE-NR.**

Keywords-* *ANN,SHE-ANN,SHE-NR,VSI,SPWM.

I. INTRODUCTION

The selective harmonic elimination using SHE-NR method by solving algebraic equations and it is found that it gives better solution. The SHE-NR has the skill to eliminate the low order harmonics, up to the specified order and to control the magnitude of fundamental RMS voltage at the output of voltage source inverter. The execution of SHE-NR needs solving a set of nonlinear equations, contain trigonometric terms and are transcendental in nature. Consequently multiple solutions are possible. These equations should be solved by numerical methods, first by applying Newton Raphson's method to obtain a linearized set of equations and the solution of these equations is achieved by Gauss elimination method [6]. The numerical methods have inherent difficulties such as divergence of response, convergence to wrong results, consuming time and requiring large memory size. The convergence problems are highly arising especially when the numbers of equations are increased. Artificial Neural networks can be used to solve these problems in on/off line applications.

The application of artificial neural networks (ANN) is recently growing in power electronics and drives area. A feed forward neural network with back propagation training algorithm is used to generate the computed PWM signals. A feed forward ANN basically implements nonlinear input-output mapping [8]. The computational delay of this mapping becomes negligible if parallel architecture of the network is implemented. For any chosen objective function, the optimal switching pattern depends on the desired modulation index. In the existing practice, the switching patterns are pre-computed for all the required values of this index, and stored in look-up tables of a microprocessor-based modulator. This requires a large memory and computation of the switching angles in real time is, as yet, impossible. To overcome this, an ANN is trained in off-line to obtain the notching angles required to generate an output voltage without using the real time solution of nonlinear harmonic elimination equation. The complete set of solutions to the non linear equations is found using the back propagation of the errors between the desired harmonic elimination and the nonlinear equation systems using the switching angle given by the ANN. The ANN offers the following advantages over the conventional techniques. In this technique, it is not necessary to establish specific input- output relationships but they are formulated through a learning process. Complex iterations involved in solving the nonlinear equations using any of the numerical methods are eliminated. Though training takes a long time it is not a disadvantage since the training is carried offline. The conventional lookup table method involves larger memory which is not required in case of neural net. After the weights of the neural net are determined the net can be implemented online. Parallel neuron units enable parallel processing reducing the computation time significantly in real time [10]. In this paper the computed PWM signals for various values of N and modulation index are generated using ANN and it is applied to single phase voltage source inverter to eliminate low order harmonics for simulation result.

II. SHE-NR CONVENTIONAL TECHNIQUE

Mathematical analyses play a vital role in most of the process implementations. In power electronic circuits, one of the main problems is the formulation of the pulse for switching of the power electronic devices. When the gate pulse is a pulse of constant duty cycle, the problem becomes simpler. But in the case of a PWM waveform, there is a great deal of calculations and they vary according to the PWM generation method used. Mathematical analysis is to solve the non-linear simultaneous harmonic equations [1]. The non-linear equations are the transcendental equations of the switching instants of the PWM waveform. These transcendental equations have to

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be solved either as such or by suitable transforms in order to obtain the final refined angles to be used in the generation of PWM pulses for the elimination of desired harmonics. Some non-linear iterative methods are used to generate the angles by finding the solutions of the given set of equations [7]. The whole procedure is finally implement in MATLAB programs.

A. simulation model

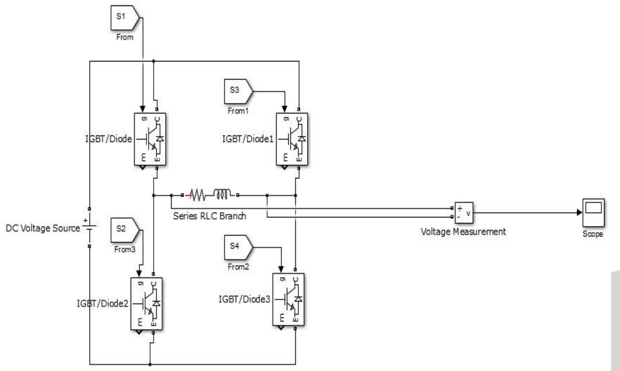

Fig 1: Simulink model of a single phase voltage source inverter

*B.Table 1: **simulation parameter***

Input voltage	100V
Resistive load	100 ohm
Inductive load	1Mh
Simulation time	0.5 sec

C. simulation output SHE-NR

```
Sampling time        = 1e-06 s
Samples per cycle    = 20000
DC component         = 0
Fundamental          = 0.8999 peak (0.6363 rms)
THD                  = 49.45%

   0 Hz   (DC):         0.00%     0.0°
  50 Hz  (Fnd):       100.00%    -0.0°
 100 Hz   (h2):         0.00%     0.0°
 150 Hz   (h3):         0.05%    19.9°
 200 Hz   (h4):         0.00%     0.0°
 250 Hz   (h5):         0.02%    39.7°
 300 Hz   (h6):         0.00%     0.0°
 350 Hz   (h7):         0.04%   205.0°
 400 Hz   (h8):         0.00%     0.0°
 450 Hz   (h9):         0.02%   -44.0°
 500 Hz  (h10):         0.00%     0.0°
 550 Hz  (h11):        39.12%   180.0°
 600 Hz  (h12):         0.00%     0.0°
 650 Hz  (h13):         2.91%   179.7°
 700 Hz  (h14):         0.00%     0.0°
 750 Hz  (h15):        26.74%    -0.0°
 800 Hz  (h16):         0.00%     0.0°
 850 Hz  (h17):        10.69%    -0.1°
```

Fig 2: FFT Analysis of SHE-NR [MI=0.9]

III. SHE-ANN PROPOSED TECHNIQUE

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 [4]. NNs have been successfully introduced into power electronics circuits. For the harmonic elimination of PWM inverters, NN replaced a large and memory-demanding look-up table to generate the switching angles of a PWM inverter for a given modulation index. When an NN is used in system control, the NN can be trained either on-line or off-line. In on-line training, since the weights and biases of the NN are adaptively modified during the control process, it has better adaptability to a nonlinear operating condition [2]. The most popular training algorithm for a feed forward NN is back propagation. It is attractive because it is stable, robust, and efficient. However, the back propagation algorithm involves a great deal of multiplication and derivation. If implemented in software, it needs a very fast digital processor.

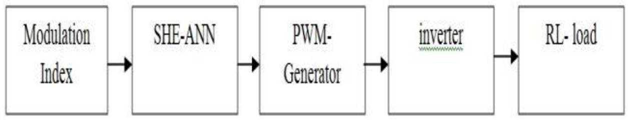

Fig 3: Block diagram of proposed technique

IV. FEED FORWARD NETWORK

This neural network has one input, some hidden and N output neurons respectively to eliminate N-1 harmonics. The input accepts an input data and distributes it to all neurons in the middle layer. The input layer is passive and does not alter the input data. The neurons in the middle layer act as feature detectors. They encode in their weights a representation of the features present in the input patterns. The output layer accepts a stimulus pattern from the middle layer and passes a result to a transfer function block which usually applies a nonlinear function and constructs the output response pattern of the network [3]. The number of hidden layers and the number of neurons in each hidden layer depend upon the network design consideration and there is no general rule for optimum number of hidden layers

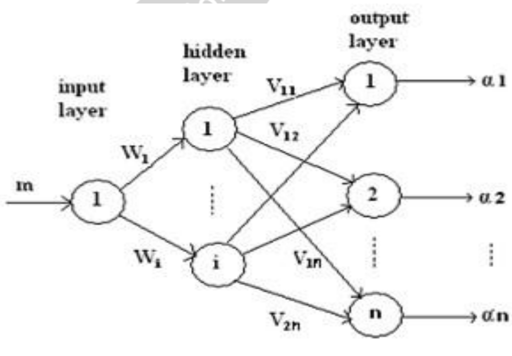

Fig. 4: Basic Structure of Feed Forward Neural Network

V. DIRECT SUPERVISED TRAINING FOR SHE

In the direct supervised training, the targets, which are to find the notching angles, corresponding to different modulation indexes are obtained from the Cauchy's relation. Thus, with the available targets, the net can be

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trained offline. Once when the net is trained to the desired level such that the error obtained is minimum, the weights are updated. Using these updated weights, the required notching angles can be found. Back propagation training algorithm is most commonly used in feed forward ANN. When a set of input values are presented to the ANN, step by step calculations are made in the forward direction to drive the output pattern [5]. Squared difference between the net output and the desired net output for the set of input patterns is generated and this is minimized by gradient descent method altering the weights one at a time starting from the output layer. This is used as the training data and the net is directly trained.

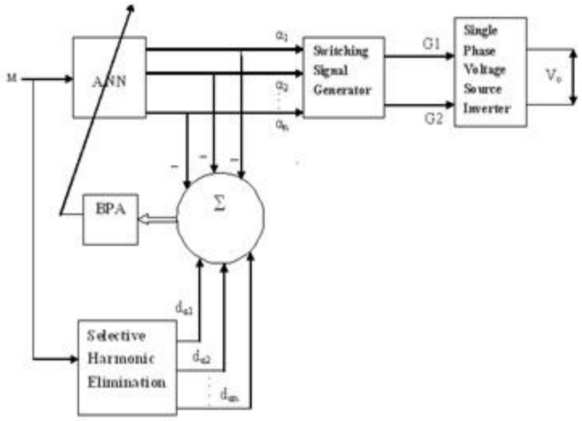

Fig 5: Direct Supervised Training of ANN for SHE

VI. Training Process of the NN

1) Firstly, the training pattern is decided. Here, various values of modulation indices from 0.1 to 1 in steps of 0.01 are taken as the training pattern.
2) For the various modulation indices taken as training pattern, the notching angles are obtained as targets, by solving the nonlinear equations.
3) Then the initial weights for both input and hidden layers including the bias are assumed.
4) With the available training pattern, targets and the initial weights, the network is trained by the back propagation algorithm.
5) Once when the error is less than the tolerance value, training is stopped.
6) Thus using the updated weights, the notching angles are obtained for any value of modulation index.

Simulation of SHE-ANN

A. Training of ANN to generate switching angles

In training process take a various sample of the modulation indices and various nothing angle are obtain for the neural network training process.

MI	0.1	0.3	0.5	0.7	0.9	1
α1	29.23	27.62	25.90	24.08	22.03	20.35
α2	30.73	32.06	33.13	33.74	33.32	31.13
α3	58.68	55.93	52.96	49.63	45.45	41.51
α4	61.41	63.74	66.03	67.93	68.11	61.52
α5	88.50	85.46	82.27	78.68	73.34	64.42

A. Table 2: **Training Parameter**

Network Type	Feed Forward backprop
Training Function	TRAINLM
Adaptive Learning Function	LEARNGD
Performance Function	MSE
Number of Layers	1
Number of neurons	20
Transfer Function	TANSIG

In this paper single layer feed-forward network, and the system used are the back propagation network. Parameter of the training process is following

1) Input data : mi, provide the specific input of the neural network .
2) Target dada: angles, select the target data related to the output of the neural network.
3) Training function: TRAINLM, trainlm is a network training function that updates weight and bias values according to Levenberg-Marquardt optimization.
4) Number of layer: one, single layer network used in the training process.
5) Number of Neurons: 20

6) Performance function : MSE, the mean squared error or mean squared deviation of an estimator measures the average of the squares of the errors or deviations that is, the difference between the estimator and what is estimated. MSE is a risk function, corresponding to the expected value of the squared error loss or quadratic loss. The difference occurs because of randomness or because the estimator doesn't account for information that could produce a more accurate estimate. The MSE is a measure of the quality of an estimator it is always non-negative, and values closer to zero are better.

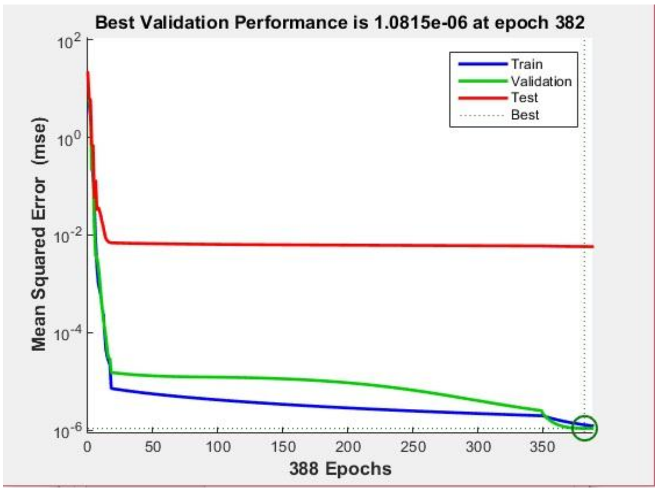

Fig. 6: Neural network performance plot

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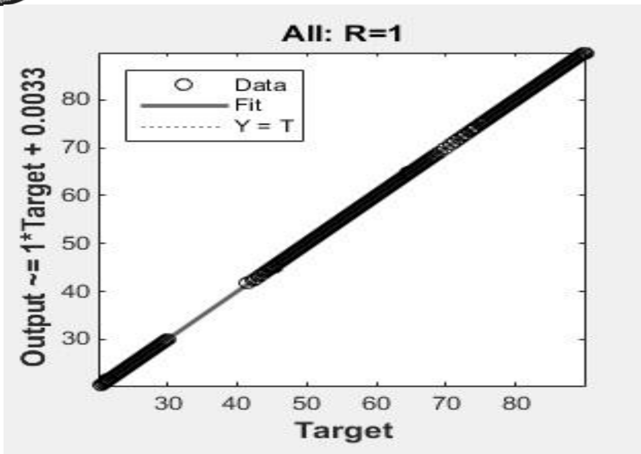

Fig. 7: Regression plot of neural network

The design of the Artificial Neural Network Control technique is working platform of MATLAB. The technique is satisfy in such a way `that it can eliminate the odd order harmonics and so it can minimize the total harmonic distortion.

Sampling time = 5e-05 s
Samples per cycle = 400
DC component = 1.102e-07
Fundamental = 107.3 peak (75.86 rms)
THD = 34.98%

0 Hz	(DC):	0.00%	90.0°
50 Hz	(Fnd):	100.00%	-0.8°
100 Hz	(h2):	0.00%	268.5°
150 Hz	(h3):	1.40%	-1.8°
200 Hz	(h4):	0.00%	267.2°
250 Hz	(h5):	4.09%	175.8°
300 Hz	(h6):	0.00%	267.6°
350 Hz	(h7):	4.01%	-5.9°
400 Hz	(h8):	0.00%	263.9°
450 Hz	(h9):	3.96%	172.9°
500 Hz	(h10):	0.00%	262.2°
550 Hz	(h11):	18.76%	171.1°
600 Hz	(h12):	0.00%	79.5°
650 Hz	(h13):	15.37%	169.5°
700 Hz	(h14):	0.00%	78.5°
750 Hz	(h15):	6.32%	-12.4°
800 Hz	(h16):	0.00%	77.1°
850 Hz	(h17):	20.35%	-13.9°

Fig. 8: FFT Analysis result[MI 0.9]

C. Comparison between SHE-NR and SHE-ANN

Comparison of SHE-NR method with SHE-ANN illustrate the effectiveness of SHE technique. Result showed that SHE-ANN effectively eliminate dominant odd harmonic along with component and even harmonic comparison between two techniques shows that THD is reduced from 49.45%to 34.98%.

VII. Conclusion

In this paper design of Artificial Neural Network is developed for reducing the lower order odd of harmonics. The harmonics are reduced to the extent of elimination with simultaneous increase in fundamental voltage component. Increase in output voltage results in reduction in ratings of the devices consequently reducing the cost. It is observed that the trigger pulse-positions given by SHE-ANN controller produces better quality of voltage at the Inverter output as is seen from MATLAB simulation as compared to that obtained by the conventional numerical technique of Newton-Raphson method. The SHE-ANN controller can handle the complex non-linear equation set in a better manner producing the optimum trigger pulse-positions. This Result showed that SHE-ANN effectively eliminate dominant odd harmonic along with component and even harmonic comparison between two techniques.

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