Artificial Neural Network based Harmonics Estimator for a Power Electronics Converter

A. Venkadesan¹*, K. Sedhu Raman², K. Chandrasekaran¹ and C. S. Boopathi³

¹Department of EEE, NIT Puducherry, Karaikal - 609609, Puducherry, India; avenkyeee@gmail.com, chansekaran23@gmail.com
²Department of EEE, MVIT, Kalitheerthalkuppam - 605107, Puducherry, India; sedhur@gmail.com
³Department of EEE, SRM University, Chennai - 603203, Tamil Nadu, India; cs.bhoopathy@gmail.com

Abstract

Objectives: This paper presents harmonics estimation using Artificial Neural Network (ANN) for a 2 pulse Uncontrolled power electronics converter. Methods/Analysis: Feed-forward architecture is chosen to model ANN-based Harmonics Estimator. The Feedforward architecture trained with various Learning algorithms is investigated. The suitable ANN model is identified. The performance of ANN based harmonics estimator is compared with conventional Fourier series method. Findings: The feed-forward architecture trained with LM algorithm is identified to be suitable for harmonics estimation in 2-pulse uncontrolled rectifier. Novelty/Improvement: The suitability of feed-forward architecture with different learning algorithms is investigated which is novel in this paper.

Keywords: Artificial Neural Networks, Estimator, Feed-Forward Neural Architectures, Harmonics, Learning Algorithms, Power Electronics Converters, 2-Pulse Controlled Rectifier

1. Introduction

An electrical supply should be a perfect sinusoidal voltage/current at every consumer point. But, due to many reasons, utilities find difficult to maintain such wanted conditions. The deviation of voltage and current waveform from sinusoidal is known as harmonic distortion. Recently, power electronics find many applications in many areas. The use of power electronics converters inject harmonics and pollute the electrical utilities. Many papers on power quality are reported. Harmonics cause harmonics losses and reduce the efficiency of the system.

The harmonics filters are used to filter the harmonics. Now-a-days, active harmonics filter are gaining lot of momentum. The filter requires the knowledge of harmonics levels and monitoring of the harmonics levels becomes an active area of research.

Several techniques and algorithms have been developed since 1989 to estimate harmonics for non-sinusoidal periodic waveforms. The popular Conventional Method of Harmonic Estimation is the Fourier series method. However, this method is computationally rigorous and takes more time for computation. It may not be suitable for real time applications. The artificial neural network provides an alternate solution for harmonics estimation. The capability of ANN to map non-linear data is well proven in the literature. Radial Basis function neural network is proposed for harmonics estimation. Comparison of Adaline Neural Network and Fast Fourier Transform for Selective Harmonic Extraction for Power Electronic Converters is proposed. The harmonics detection method based on Neural Network for Harmonics Compensation is proposed. Adaptive Wavelet Neural Network is used for lower order dominant harmonics estimation. FPGA based neural harmonics estimator is proposed. Neural network based harmonics identification and its application in single phase active power filter is proposed. Through the
In this paper, harmonic estimator using neural network is proposed to estimate harmonics in the input current of a 2-pulse un-controlled power electronics converter. The neural architectures namely Feed-Forward architecture (FF) trained with different neural learning algorithms is investigated. The results obtained are presented.

2. Two Pulse UN-Controlled Rectifier

The 2 pulse uncontrolled rectifier \(^1\) considered in this paper is shown in the Figure 1. The rectifier are used widely in many applications namely TV sets, computers, and battery chargers. The main drawback of these rectifiers is that they generate harmonics. In some cases, the total harmonic current distortion can be as high as 100%. The harmonics can have an adverse impact on the power systems. It is therefore essential to predict these harmonics accurately. This circuit injects harmonics in the input current. For a \(p\)-pulse rectifier, the input current contains harmonics of the order \(n = kp\pm1\) where \(k\) is any integer. The dominant harmonics in 2 pulse converter are \(3^{\text{rd}}, 5^{\text{th}}, 7^{\text{th}}, 11^{\text{th}}\). In this paper, Feed-Forward neural network is proposed for harmonics estimation.

3. Feed-Forward Neural Architecture

Feed-forward architecture has the input layer, one or more hidden layers and output layer. Feed-forward architecture \(^2\) with \(R\) inputs and \(M\) layers (\(M\)) is shown in Figure 2. The detailed description is given in \(^2\). The total number of parameters (\(\text{XMLFF}\)) in the multilayer feed-forward architecture can be obtained from Equation (1).

\[
\text{XMLFF} = \sum_{m=1}^{M} \sum_{s=1}^{S} w_{m,s} + \sum_{m=1}^{M} \sum_{s=1}^{S} b_{m,s} \quad (1)
\]

where,

- \(w_{m,s}\) - Interconnection weight of neuron ‘\(i\)’ of layer ‘\(m\)’ for input from neuron ‘\(j\)’ of layer (‘\(m-1\)’).
- The structure of the FF-NN architecture is denoted as \(S^0- S^1- \ldots - S^M\).

4. Harmonics Estimation using ANN for TWO-Pulse UNcontrolled Rectifier

The Feed-forward Neural architecture is chosen for study. The training data required to train the ANN is obtained through simulation using the conventional Fourier Series Method. The inputs to the ANN based estimator is chosen as the input current and the outputs are chosen as magnitude of the harmonics \((3^{\text{rd}}, 5^{\text{th}}, 7^{\text{th}}, \text{and } 11^{\text{th}})\). The design methodology is detailed as given below,

- Two-Pulse Un-controlled Rectifier shown in Figure 1 is simulated using MATLAB Simulink.
- The input/output data for training neural network are collected using popular Fourier series method.
- The activation function for hidden layer neurons is chosen as tan-sigmoid and pure-linear function is chosen for output layer neurons.
- Choose the hidden layers/hidden neurons between the input and output layer.
- Feed-forward neural architecture is trained using the Chosen learning algorithm.
- Neural network is trained for the desired target accuracy.
• The hidden layers/neurons are adjusted till the target accuracy is achieved.
• Once the target accuracy is achieved, the trained neural network is tested for harmonics estimation.
• The initial weights and biases are initialized using Nguyen Window Algorithm.

Figure 3. Input current waveform of a 2-pulse un-controlled rectifier.

Figure 4. MSE convergence graph. (a) GDM. (b) VLR. (c) LM.

Figure 5. MATLAB simulink model of LM trained feed-forward architecture for Harmonics Estimation.

Table 1. Performance comparison of neural network based estimator for feed forward neural architecture with different learning algorithms trained with same accuracy

| Learning Algorithm | Structure | Epochs |
|--------------------|-----------|--------|
| GDM                | [1-4]     | 8974   |
| VLR                | [1-4]     | 137    |
| LM                 | [1-4]     | 1      |
Artificial Neural Network based Harmonics Estimator for a Power Electronics Converter

For training the ANN, around 400 input/output data sets sampled at 100 μs are collected using Fourier series method through simulation. The input is chosen as input current. The outputs are chosen as harmonics 3rd, 5th, 7th and 11th. The input current data used for training is shown in the Figure 3. The ANN is trained using the above explained design methodology. The three learning algorithms namely Gradient Descent with Momentum algorithm (GDM), Variable Learning Algorithm (VLR) and Levenberg Marquardt (LM) Algorithm are considered for investigation. The structure of the ANN based harmonics estimator obtained as 1-4 for all the three algorithms. It takes only output neurons and does not take any hidden neurons to meet the desired Mean Square Error (MSE) of $1 \times 10^{-7}$. The MSE convergence Graph is shown in Figure 4. The performance comparison of ANN trained using three algorithms are also shown in Table 1. The ANN trained with three algorithms met the desired MSE. The ANN models trained with three algorithms are tested for harmonics estimation. The results obtained are compared with the Fourier series method. The steady state percentage error is computed and tabulated in Table 2. From the results obtained, it is observed that all the three models performs well and found to estimate harmonics with the maximum steady state error of -0.09556%. But LM algorithm meet the desired accuracy with lesser number of epochs during training because it is derived based on second order approach. Hence LM trained ANN model is found to be suitable for harmonics estimation. The MATLAB Simulink Model for Harmonics Estimation is shown in Figure 5. The sample result for 3rd harmonics estimated using LM trained ANN model and Fourier series method is shown in the Figure 6. It is found that Fourier series method takes around 3 cycles to estimate the harmonics. But off-line trained ANN found to estimate harmonics in no time.

### 5. Conclusion

This paper presented harmonics estimation using Artificial Neural Network (ANN) for an Uncontrolled 2 pulse converter. Feed-forward architecture is chosen to model ANN-based Harmonics Estimator. The architecture with different learning algorithms is investigated. The Feed-forward architecture trained with LM algorithm

| Learning Algorithm | Harmonics Order | Steady State Magnitude of Harmonics (Fourier Series Method) | Steady State Magnitude of Harmonics (Neural Network) | %Error |
|--------------------|----------------|-------------------------------------------------------------|------------------------------------------------------|--------|
| GDM                | 3              | 43.454                                                      | 43.457                                               | -0.0069                      |
|                    | 5              | 25.955                                                      | 25.961                                               | -0.02312                     |
|                    | 7              | 11.410                                                      | 11.418                                               | -0.07011                      |
|                    | 11             | 7.325                                                       | 7.331                                                | -0.08191                      |
| VLR                | 3              | 43.454                                                      | 43.460                                               | -0.01381                      |
|                    | 5              | 25.955                                                      | 25.967                                               | -0.04623                      |
|                    | 7              | 11.410                                                      | 11.419                                               | -0.07888                      |
|                    | 11             | 7.325                                                       | 7.332                                                | -0.09556                      |
| LM                 | 3              | 43.454                                                      | 43.457                                               | -0.0069                      |
|                    | 5              | 25.955                                                      | 25.961                                               | -0.02312                      |
|                    | 7              | 11.410                                                      | 11.418                                               | -0.07011                      |
|                    | 11             | 7.325                                                       | 7.331                                                | -0.08191                      |
is found to be suitable for harmonics estimation for a 2-pulse un-controlled rectifier. The performance of ANN based estimator is compared with Fourier Series Method. The ANN based estimator is found to be as accurate as Fourier Series Method but results in faster estimation of harmonics. The Fourier Series Method takes around 3 cycles for harmonics estimation. The ANN based estimator is found to be suitable for Harmonics Estimation for a 2-pulse Un-controlled Converter.

5. References

1. Venkatesh C, Kumar DS, Sarma DVSSS, Sydulu M. Modelling of nonlinear loads and estimation of harmonics in industrial distribution system. Fifteenth National Power Systems Conference (NPSC); IIT Bombay. 2008. p. 592–7.
2. Rrezvani F, Mozafari B, Faghahi F. Power quality analysis for photovoltaic system considering unbalanced voltage. Indian Journal of Science and Technology. 2015 Jul; 8(14). DOI: 10.17485/ijst/2015/v8i14/60194
3. Ravi M. Comparison of PV supported DVR and DSTATCOM with multiple feeders in standalone WECS by mitigating power quality problems. Indian Journal of Science and Technology. 2015 Jul; 8(15). DOI: 10.17485/ijst/2015/v8i15/54089.
4. Srinivasarao B, Sreenivasan G, Sharma S. Comparison of facts controller for power quality problems in power system. Indian Journal of Science and Technology. 2015 Nov; 8(31). DOI: 10.17485/ijst/2015/v8i17/76302.
5. Sahinya KS, Sneha R, Srilakshmi M. Neural network based harmonic estimation of non-linear loads in power system applications [BTech thesis]. SRM University; 2012.
6. Almaita E, Asumadu JA. On-line harmonic estimation in power system based on sequential training radial basis function neural network. IEEE International Conference on Industrial Technology (ICIT); 2011. p. 139–44.
7. Sekaran EC, Anbalagan P. Comparison of neural network and fast fourier transform based selective harmonic extraction and total harmonic reduction for power electronic converters. Asian Power Electronics Journal. 2008; 2(1):1–9.
8. Dehini R, Bassou A, Ferdi B. The harmonics detection method based on neural network applied to harmonics compensation. Asian Power Electronics Journal. 2010; 2(5):258–67.
9. Jain SK, Singh SN. Low-order dominant harmonic estimation using adaptive wavelet neural network. IEEE Transaction on Industrial Electronics. 61(4); 2014:428–35.
10. Valtierra-Rodriguez M, Osornio-Rios RA, Garcia-Perez A, de Jesus Romero-Troncoso R. FPGA-based neural network harmonic estimation for continuous monitoring of the power line in industrial applications. Elsevier Journal on Electric Power Systems Research. 2013; 98:51–7.
11. do Nascimento CF, de Oliveira AA, Goedtel A, da Silva IN. Neural network-based approach for identification of the harmonic content of a nonlinear load in a single-phase system. IEEE Latin America Transactions. 2010; 8(1):65–73.
12. Venkadesan A, Himavathi S, Muthuramalingam A. Performance comparison of neural architectures for on-line flux estimation in sensor-less vector controlled IM Drives. Springer Journal on Neural Computing and Applications. 2013; 22(7-8):1735–44.