Dual Phase Analysis Based Harmonic Elimination in Multilevel Inverters

V.J. Vijayalakshmi, 2P. Ravikumar, 3R. Uthirasamy and 4J. Karpagam
1,2Department of EEE, KPR Institute of Engineering and Technology
3Department of EEE, KPR Institute of Engineering and Technology
4Department of EEE, KPR Institute of Engineering and Technology

Abstract - In this paper Dual Phase Analysis based harmonic elimination technique is proposed for eliminating selected harmonics present in the multilevel inverters. Elimination of harmonics is done by considering equal DC sources. The switching angles are calculated using Artificial Neural Network. As an example, nine level inverters are considered and simulated using the switching angles obtained from the optimization technique for non linear loads. The simulation results validate the effectiveness of the method in eliminating selected harmonics present in the inverter circuit.

Keywords - Dual Phase Analysis (DPA), Selected Harmonic Elimination (SHE), Artificial Neural Network (ANN), Multilevel inverters, Total Harmonic Distortion (THD).

1. Introduction

For any non-conventional sources, it is intended to exchange a DC to AC which is employed by the use of inverter. Harmonics are unsolicited vibrations which weakens the output intensity of the inverters. Many optimization techniques are introduced to minimize the THD present in the system. [1] Presented a comparison of various pulse width modulation (PWM) techniques to reduce the THD present in voltage and current. [2] Explored several control techniques applied to the multi level cascaded inverter in order to ensure an efficient voltage consumption and better harmonic spectrum. [3] discussed the reduction of THD in the output voltage of cascaded Multilevel Inverter (MLI) using sinusoidal PWM technique under the condition of identical DC sources. [4] conferred a methodology to enumerate the angles in a MLI and to conceive the essential fundamental profile so as to diminish the harmonics in a Multilevel Converter by means of the presumption of symmetric polynomials and corollary while at the same time terminate specified elevated order of harmonics. The clarification of optimized switching angles is also obtained with asymmetrical DC sources [5]. The higher order harmonics [6] is eliminated using multilevel converters. [7] gave the solution for harmonic elimination using Ant Colony Optimization Algorithm (ACO).

The predicament of discriminatory harmonic eradication, collectively with output voltage regulation, is reorganized as an optimization problem, and the elucidation is attained through the unique concept. Initial guesses were made in choosing the parameters for switching angle generation. [8] Discussed the solutions for harmonic elimination in high power inverters. The switching angles were calculated using equal area criteria method. In all the techniques discussed above only low order harmonics are considered. In this paper the higher order harmonics is predetermined by using DPA [9]. Composing the level of elevated order harmonics is also an essential factor to condense the harmonics spectrum. A novel method of ANN is used to determine the optimized switching angle. This paper urges a design applicable for non linear loads appropriate for all levels.

2. Problem Formulation

In the above equation $V_i$, $V_3$, $V_5$, and $V_7$ correlate the odd harmonics in the system. In a three-phase system, the triplen harmonics abolishes obviously. The occurrence of the harmonics and its eradication is mathematically demonstrated as follows. Consider the third harmonics and its corresponding equation is

$$V_{a_3}(t) = \frac{4V_{dc}}{\pi} (\cos(3\theta_1) + \cos(3\theta_2) + \cos(3\theta_3)) \sin(3\omega t)$$

$$V_{b_3} \text{ and } V_{c_3} \text{ corresponds to the voltages in other two phases}$$

$$V_{b_3}(t) = \frac{4V_{dc}}{\pi} (\cos(3\theta_1 + 120) \cos(3\theta_2 + 120) + \cos(3\theta_3 + 120)) \sin(3\omega t)$$

$$= \frac{4V_{dc}}{\pi} (\cos(3\theta_1) + \cos(3\theta_2) + \cos(3\theta_3)) \sin(3\omega t)$$

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$$V_{c3}(t) = \frac{4V_{dc}}{\pi} \left( \cos(3\theta_1 + 240) + \cos(3\theta_2 + 240) + \cos(3\theta_3 + 240) \right) \sin(3\omega t)$$

Hence,

$$V_{a3}(t) = V_{b3}(t) = V_{c3}(t)$$

In a three-phase system,

$$V_{ab3}(t) = V_{a3}(t) - V_{b3}(t) = 0$$

Similarly,

$$V_{bc3}(t) = V_{ca3}(t) = 0$$

Similarly, the odd multiples of third harmonics eliminate each other and in three-phase system the other odd number harmonics are to be dealt. The even harmonics are not present or negligible due to the quarter wave symmetry of the waveform. This deals with the waveform being a mirror image about the quarter wave point. This is applicable to both positive and negative half cycles.

The harmonic voltages of fifth and seventh order are eradicated. The number of levels in the output voltage of the MLC is the key parameter that plays the major role in the elimination of number of harmonics in the system. For instance, a five-level inverter can be used to eliminate third order harmonics. Therefore, two harmonics can be eliminated from our proposed configuration of four level converter. The equations are written as follows

$$\cos(5\theta_1) + \cos(5\theta_2) + \cos(5\theta_3) = 0$$

(2)

$$\cos(7\theta_1) + \cos(7\theta_2) + \cos(7\theta_3) = 0$$

The odd harmonic voltage levels of three and five are eliminated. Higher the number of levels in the system the higher the elimination of harmonics in the system. By solving the Equation (2) we will be able to eliminate third order and fifth order harmonics. The proposed theoretical concepts need to be verified in the following simulated results.

3. Proposed Methodology

The first order optimization is done by gradient descent which is been most effective tool for fixing the parameters of the network. The huge data set is filtered using linear regression technique to find the best group of possible switching angles that can be used to train the artificial neural networks. The classical solutions of harmonic elimination problem are used for obtaining the training data.

Algorithm

1. Start the process.
2. Get the modulation index and the inverter level as user input.
3. Carry out DPA for the given level of inverter.
4. Train the linear regression based on DPA results.
5. Predict switching angle range for required modulation index using voltage profile input.
6. Calculate error between switching angles. (required and predicted output)
7. Train ANN DPA based on error generated.
8. Final switching angle is given to the inverter.
9. The voltage level of the inverter is analyzed.
10. End the process.

4. Results and Discussion

The results of switching angles obtained for various modulation index is shown in Table 1. It is observed from the table the THD is minimum for the 0.9 modulation index.

| Modulation Index | $\theta_1$ | $\theta_2$ | $\theta_3$ | $\theta_4$ | %THD |
|------------------|-----------|-----------|-----------|-----------|------|
| 0.84             | 2.34      | 9.54      | 21.74     | 38.76     | 10.57|
| 0.85             | 2.89      | 11.22     | 24.39     | 40.60     | 10.33|
| 0.86             | 3.78      | 12.55     | 28.87     | 45.52     | 9.76 |
| 0.87             | 4.34      | 15.67     | 30.98     | 50.56     | 9.06 |
| 0.88             | 6.89      | 18.33     | 31.34     | 53.45     | 8.98 |
| 0.89             | 7.0082    | 19.001    | 33.660    | 57.33     | 8.6  |
| **0.9**          | **7.0123**| **20.954**| **34.876**| **59.142**| **8.38**|
| 0.91             | 10        | 28.186    | 35.56     | 61.534    | 8.43 |
| 0.92             | 11.34     | 30.45     | 37.87     | 63.86     | 8.78 |
In the proposed algorithm the modulation index and the number of levels is changed according to the level of the inverter. The modulation index for 0.9 with switching angles θ₁=7.0123, θ₂=20.954, θ₃=34.876 and θ₄=59.142 gives the minimum harmonics present in the system compared to any other modulation index. The THD of the scheme obtained through the proposed gradient descent ANN gives 8.38% of harmonics compared to any other optimization techniques.

The switching angles obtained from ANN with θ₁, θ₂, θ₃ and θ₄ are simulated using H-bridge inverters using SIMULINK. It consists of four full-bridge inverters that are connected in a series form. Figure 1 shows the nine-level inverter circuit. The input supply of the nine-bridge inverter is fed from a constant DC source. In this module the input of the four levels is same.

Figure 2 shows the harmonic spectrum of nine level inverter. The total harmonic distortion present in the system is conceded out using Simulink software and the results are being tabulated and shown in Figure 2.
5. Conclusion
The results obtained from neural network have better response than the open loop simulation without neural network. The estimation of optimum switching angle for MLI is validated using feed forward neural network trained by DPA. This proposed model eliminates the selective set of harmonics and controls the voltage levels of the fundamental.

The resulting neural network implementation of the harmonic elimination strategy uses very few computational costs, high performance and technical advantages of the harmonic elimination strategy for the control of cascaded multilevel inverter. This method reduces the harmonic content more predominantly than any other techniques. The use of filters can be eliminated by using dual phase analysis method so that the overall cost of the system is also reduced.

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