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Harmonic elimination of cascaded H-bridge multilevel inverter based active power filter controlled by intelligent techniques

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ABSTRACT

In this paper, an Adaptive Neuro Fuzzy Interference System (ANFIS) is proposed for eliminating voltage harmonics present in the multilevel inverter. It is achieved by reducing the THD present in the multilevel inverter output voltage. Here, the voltage variation of the multilevel inverter is determined from the actual load voltage and the reference voltage. The voltage variation at different time interval has been applied to the ANFIS. According to the voltage variations, the switching angles can be generated from the interference system. These switching angles can make the multilevel inverter output voltage with reduced THD. The proposed technique is implemented in the MATLAB/simulink working platform. The effectiveness of the proposed method is evaluated by the multilevel inverter output voltage without controller and with Neuro Fuzzy Controller (NFC).

1. Introduction

The power conversion strategy called multilevel inversion decreases the total harmonic distortion (THD) by obtaining the output voltage in steps and bringing the output closer to a sine wave [2]. Producing an approximate sinusoidal voltage from multiple levels of dc voltages, normally obtained from capacitor voltage sources is the common objective of multilevel inverters [1]. A multi-pulse inverter like 6-pulse or 12-pulse inverter achieves harmonic as well as reactive power (VAR) compensation through numerous voltage-source inverters interconnected in a zigzag manner by means of transformers [3]. Flexible ac transmission systems, renewable energy sources, uninterruptible power supplies and active power filters are some power electronics applications in which multilevel inverters are important [4].

Multi-level inverters (MLI) have emerged as a successful and realistic solution for power increase and harmonics reduction of AC waveform [19]. Non-linear loads like adjustable speed drives; electronically ballasted lighting and the power supplies of the electrical equipment used in modern offices cause current harmonics in modern electrical distribution systems [5]. Voltage distortion is produced by these harmonic currents as they combine with the impedance characteristics of the supply systems [6].

Extra heating losses, shorter insulation lifetime, increased temperature and insulation stress, decreased power factor, decreased output, efficiency, ability and deficiency of plant system performance occur as a result of an increase in the harmonic distortion constituent of the transformer [7].

Diverse techniques have been identified to decrease the problem of harmonics. Some examples are: (1) Specific Harmonic Elimination (SHE} [18] which is used for eradication of unwanted lower order harmonics and control of fundamental voltage in a square wave (2) Harmonic elimination pulse width modulation (HEPWM) method that has a number of benefits compared to traditional sinusoidal PWM (SPWM) for Voltage Source Inverters (VSI) [8,9]. Elimination of harmonics in nonlinear system is also achieved by employing an artificial neural Network [10]. Recently, Shunt Active power filter is generally employed for eradicating harmonics as well as for enhancing power factor to elimination of the negative and zero sequence elements [11].

An Active power filters are extensively utilized for eradication of harmonics. The shunt compensator APF eradicates turbulence in current, while the series compensator dynamic voltage restorer (DVR) eradicates turbulence in voltage [12]. The load harmonic currents can be successfully compensated by preventing generation or consumption of reactive power with fundamental frequency components by designing the active filter controller to extract and inject load harmonic currents and keep up a constant dc capacitor voltage [13]. It has the potential to alter the amplitude of the synthesized ac voltage of the inverters by means of pulse

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width modulation or by controlling the dc-link voltage [14,15]. The design of the power semiconductor device, modulation method utilized for regulating the switches and the design of the coupling elements influence the performance of APF. One method used to identify active filter current references is by connecting Lf and Cf on the AC and DC sides respectively and standards can be met and power rating of the APF can be decreased by using selective harmonics compensation.[16,17].

In this paper, an Adaptive Neuro Fuzzy Interference System (ANFIS) is proposed for eliminating voltage harmonics present in the multilevel inverter. It is achieved by reducing the THD present in the multilevel inverter output voltage. Here, the voltage variation of the multilevel inverter is determined from the actual load voltage and the reference voltage. The voltage variation at different time interval has been applied to the ANFIS. According to the voltage variations, the switching angles can be determined from the interference system. Then the THD of the proposed method is determined. The effectiveness of the proposed method is evaluated by the multilevel inverter output voltage without controller and with Neuro Fuzzy Controller (NFC). The rest of the paper is organized as follows: Section 2 briefly reviews the related works and Section 3 describes the proposed technique with sufficient mathematical models and illustrations. Section 4 discusses the implementation results and Section 5 concludes the paper.

2. Related works

Several literary works related to mitigation of harmonics in multilevel inverter exist in the literature. A few is most recent literature works in this topic are reviewed in this section. Rup Narayan Raya et al. [26] have proposed the harmonic elimination problem in PWM inverter was treated as an optimization problem and solved using particle swarm optimization (PSO) technique. The derived equation for computation of total harmonic distortion (THD) of the output voltage of PWM inverter was used as the objective function in the PSO algorithm. The objective function was minimized to contribute the minimum THD in the voltage waveform and the corresponding switching angles were computed. The method was applied to investigate the switching patterns of both unipolar and bipolar case. While minimizing the objective function, the individual selected harmonics like 5th, 7th, 11th and 13th could be controlled within the allowable limits by incorporating the constraints in the PSO algorithm. Salam z et al. [20] has proposed a HEPWM scheme for voltage source inverters (VSI) based on the curve fittings of certain polynomial functions for controlling modulation index of VSC. Raya Rup Narayana et al. [21] proposed a PSO based optimal switching technique for voltage harmonic reduction of multilevel inverter.

Reddy et al. [22] have proposed a 7-level inverter for achieving reduction in the number of harmonics as well as number of switches. The total harmonic distortion percentage for the 7-level inverter has been computed. By selecting proper switching angles, they have achieved harmonic reduction. As a final point, they have compared the harmonics in different levels of the multilevel inverter. The comparison has proved that the THD value is minimal for the 7-level inverter. The simulation results have coincided with the prediction and strictly matched with the experimental results.

Chitra et al. [23] have proposed the design s Fuzzy Logic Controller (FLC) that is rule based for multilevel inverter. The DC link voltage has been kept constant and the modulation index of the inverter has been varied for controlling the multilevel inverter. Subsequent to a comprehensive evaluation of the benefits of the nine-level cascaded H Bridge multilevel inverter topology, it has been developed as the test system for the design of the fuzzy logic controller. Traditional control techniques have been mostly limited to the direct and indirect influence of the inverter. Simulative experimental studies have shown that the proposed fuzzy logic controller has improved functionalities. Subsequent to a comprehensive research of the features and comparison of traditional controller for harmonic disturbance, voltage profile and other system parameters with the conventional controller the Fuzzy Associative Memory (FAM) table has been derived.

Manokaran et al. [24] have presented multilevel VSI circuit assisted simulation of STATCOM utilized for harmonic reduction. Medium to high power reactive compensation application have been utilized for multilevel inverters based on cascaded converter. Cascaded based multilevel STATCOM has the major drawback of been voltage unbalance. They have proposed an uncomplicated control strategy for use in STATCOM that is based on cascaded two-level inverter, for achieving voltage balance. Two traditional three-phase two-level inverters have been cascaded in their topology. Four level operation at STATCOM out-put has been obtained by the two inverters functioning at two separate dc link voltages. The performance of the proposed control strategy has been predicted by performing simulation studies. Voltage ripple caused harmonics have been decreased in STATCOM. This has led to the reduction in the size of inductor and DC capacitor. Smaller number of devices has been the important merit of STATCOM. The response of VSI to reactive power change has been exceedingly rapid.

Agarwal et al. [25] have proposed to eradicate some outstanding lower order harmonics, and concurrently, control excessive magnitude of output voltage of a multilevel inverter by using an optimization technique for calculating switching angles at fundamental frequency switching scheme by solving selective harmonic elimination equations which are nonlinear transcendental equations. Uncomplicated, multiple or even no solution may exist for a specific value of a modulation index, since these equations are nonlinear transcendental in nature. The design of the proposed method is performed in such way as to make correct knowledge of initial guess unnecessary for obtaining all possible solutions. Further, their method has been appropriate for higher level of multilevel inverters where computational load is excessive making switching angles calculation impossible by other available methods. The solutions that generate smallest THD in the output voltage are selected where multiple solutions exist for the values of modulation indices. Instead of taking a single set of solution, multiple solution sets have been taken into account for obtaining a remarkable reduction in THD. The effectiveness of the method has been confirmed by means of computational results depicted graphically for better comprehension.

Rup Narayan Raya et al. [26] have presented the selected lower order harmonics of multilevel inverter were eliminated while the overall voltage THD was optimized by computing the switching angles using particle swarm optimization (PSO) technique. The discontinuity in the solution of selected harmonic elimination (SHE) problem at certain modulation indices was avoided by optimizing the individual harmonics to allowable limits. While choosing the set of solution leading to minimum THD, the abrupt changes in the switching angles were discarded by limiting the voltage THD within allowable limits. Also the selected higher order harmonics were eliminated by additional switching along with the lower order harmonics. In order to reduce the computational burden for online application, the switching angles computed by the proposed PSO technique for optimum THD at varying modulation indices were stored as a look-up table in the DSP memory.

Fathi et al. [27] have proposed the application of selective harmonic elimination pulse width modulation (SHEPWM), for the elimination of low order harmonics in multilevel inverters. Obviously, feasible solution does not exist for the associated equations for certain operating points related to the modulation index (M). Consequently detrimental harmonics like the 5th harmonic has