Support Vector Machine (SVM) and Fuzzy Based Hybrid Feedback Technique for Harmonic Elimination of Multilevel Inverter

G.Nageswara Rao, Dr.P.Sangameswara Raju, Dr.K.Chandra Sekhar

Abstract—In the paper, support vector machine (SVM) and fuzzy based feedback harmonic elimination technique will be proposed. The proposed technique will overcome the drawbacks of control rule selection of fuzzy logic. Here, the feedback error voltage and change of error voltage of the load will be applied as the input of SVM classifier. SVM is one of the supervised learning models with associated learning algorithms that analyse data and recognize patterns, used for classification and regression analysis. The basic SVM takes a set of input data and predicts, for each given input, which of two possible classes forms the output, making it a non-probabilistic binary linear classifier. From the classified output of SVM, the decision making rule of fuzzy logic will be developed and the control pulse will be generated. The control pulse will be applied to multilevel inverter and the harmonics of the system will be eliminated. The proposed method will be implemented in MATLAB working platform and the harmonic elimination performance will be evaluated.

Index Terms—THD, Multilevel inverter, ANFIS, NFC, SVM, FLC, switching angle

I. INTRODUCTION

A multilevel inverters (MLI) have emerged as the solution for working with higher voltage levels diminishes the total harmonic distortion (THD) by getting the output voltage in steps and taking the output nearer to a sine wave [2]. Generating an estimated sinusoidal voltage from multiple stages of dc voltages, usually got from capacitor voltage sources is the general objective of multilevel inverters [1]. Using transformers, a multi-pulse inverter like 6-pulse or 12-pulse inverter accomplishes harmonic with reactive power (VAR) compensation through numerous voltage-source inverters interrelated in a crisscross manner [3]. A few power electronics applications are Flexible ac transmission systems, renewable energy sources, uninterruptible power supplies and active power filters; in which multilevel inverters are significant [4]. For power increase and harmonics reduction of AC waveform, Multi-level inverters (MLI) materialized have as a victorious and practical solution. Five level cascaded multilevel inverter as active power filter in power system for compensation of reactive power and harmonics [5]. By these harmonic currents, Voltage alteration is generated as they unite with the impedance features of the supply systems [6]. Extra heating losses, shorter insulation lifetime, increased temperature and insulation stress, decreased power factor, decreased output,
efficiency[7]. To diminish the problem of harmonics, different methods have been recognized. A few examples are: 1) Specific Harmonic Elimination (SHE) which is applied for abolition of discarded lower order harmonics and control of fundamental voltage in a square wave 2) Harmonic elimination pulse width modulation (HEPWM) technique that has a number of advantages compared to traditional sinusoidal PWM (SPWM) for Voltage Source Inverters (VSI) [8-9]. The harmonic contents present in the system are calculated by comparing the reference voltage with harmonic voltage for different time from the graph. The harmonic contents are eliminated by using frequency and switching angles [10]. Lately, Shunt Active power filter is commonly utilized for eliminating harmonics and for improving power factor to eradication of the negative and zero series elements. Intended for abolition of harmonics, an Active power filters are widely employed. The shunt compensator APF exterminates commotion in current, whereas the series compensator dynamic voltage Restorer (DVR) destroys turbulence in voltage.

By avoiding generation or consumption of reactive power, the load harmonic currents can be effectively reimbursed with fundamental frequency components by planning the active filter controller to take out and insert load harmonic currents and maintain up a steady dc capacitor voltage. Using pulse width modulation or by controlling the dc-link voltage, it has the prospective to change the amplitude of the synthesized ac voltage of the inverters. The plan of the power semiconductor device, modulation technique applied for controlling the switches and the plan of the coupling elements pressure the presentation of APF. Solitary technique applied to recognize active filter current indications is by linking Lf and Cf on the AC and DC sides correspondingly and standards can be met and power rating of the APF can be reduced by employing choosy harmonics compensation.

In the paper, support vector machine (SVM) and fuzzy based feedback harmonic elimination technique will be proposed. The proposed technique is overcome the drawbacks of control rule selection of fuzzy logic. Here, the feedback error voltage and change of error voltage of the load is applied as the input of fuzzy logic. The Fuzzy Logic Controller (FLC) build the logical rules; it is depends on the input error voltage and change of error voltage. From the fuzzy rules, the basic SVM takes a set of input data and predicts optimum switching angle and frequency, for each given input. Then, the selected switching angle and frequency is applied to multilevel inverter and the harmonics of the system is eliminated. The remaining of the paper is sorted out as follows: Section 2 concisely assesses the associated works and section 3 explains the suggested technique with adequate mathematical models and pictures. Section 4 converses the accomplishment.

II. RELATED WORKS

A number of literary works associated to mitigation of harmonics in multilevel inverter is present in the literature. Some of the most new literature works in this subject are assessed in this part. The harmonic eradication problem in PWM inverter was treated as an optimization problem and worked out by means of particle swarm optimization (PSO) method has been proposed by Rup Narayan Raya et al. [11]. In the PSO algorithm, the obtained equation for computation of total harmonic distortion (THD) of the output voltage of PWM inverter was applied as the intent function. The objective function was reduced to supply the minimum THD in the voltage waveform and the consequent switching angles were calculated. The technique was used to examine the switching samples of both unipolar and bipolar case. By integrating the constraints in the PSO algorithm, the individual chosen harmonics like 5th, 7th, 11th and 13th could be managed inside the allowable limits while reducing the objective function.

A 7-level inverter for attaining reduction in the number of harmonics with number of switches has been proposed by Reddy et al. [12]. The whole harmonic distortion percentage for the 7-level inverter has been calculated. They have attained harmonic reduction by choosing appropriate switching angles. To end with, they have compared the harmonics in dissimilar levels of the multilevel inverter. The THD value is negligible for the 7-level inverter that has been proved by the comparison. The reproduction results have matched with the forecast and firmly counter parted with the experimental results.

The designs Fuzzy Logic Controller (FLC) that is law based for multilevel inverter has been proposed by Chitra et al. [13]. For regulating the multilevel inverter, The DC link voltage has been reserved steady and the modulation index of the inverter has been differed. Following to a wide-ranging assessment of the advantages of the nine-level cascaded H Bridge multilevel inverter topology, it has been extended as the test system for the plan of the fuzzy logic controller. Long-established control methods have been mostly restricted to the direct and indirect influence of the inverter. The suggested fuzzy logic controller has enhanced functionalities that were demonstrated by Simulative experimental studies. Succeeding to a complete research of the characteristics 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 obtained. Employed for harmonic reduction, Manokaran et al. [14] have offered multilevel VSI circuit supported simulation of STATCOM. For multilevel inverters based on cascaded converter, intermediate to high power reactive compensation function have been applied. Cascaded based multilevel STATCOM has the main disadvantage of been voltage unbalance. They have suggested an unsophisticated control approach for employ in STATCOM that is based on cascaded two-level inverter, for attaining voltage balance. Two long-established three-phase two-level inverters have been tumbled in their topology. By the two inverters operating at two split dc link voltages, four level operations at STATCOM output has been attained. By executing simulation studies, the concert of the suggested control approach has been forecasted. Voltage ripple caused harmonics have been reduced in STATCOM and have led to the decrease in the size of inductor and DC capacitor. Lesser number of tools has been the significant value of STATCOM. The reply of VSI to reactive power modify has been remarkably fast. Agarwal et al. [15] have suggested eliminating some great lower order harmonics, and along with, regulating too much magnitude of output voltage of a multilevel inverter by means of an optimization method for computing switching angles at basic frequency switching plan by working out choosy harmonic elimination equations which are non linear transcendental equations. Simple, multiple or even no solution may survive for a precise value of a modulation index, as these equations are nonlinear transcendental in life. The plan of the suggested method is executed in such way as to compose exact knowledge of initial guess needless for getting all feasible solutions. In addition, their technique has been suitable for higher level of multilevel inverters where computational load is too much making switching angles computation unfeasible by other obtainable methods. The solutions that produce least THD in the output voltage are chosen where multiple solutions survive for the values of modulation indices. For attaining an outstanding reduction in THD, multiple solution sets have been taken into report rather than captivating a single set of solution. By means of computational results illustrated graphically for improved comprehension, the efficiency of the technique has been proved. G. Durgasukumar et al. have proposed a Neuro-Fuzzy based Space Vector Modulation (SVM) technique for voltage source inverter and its performance was compared with the conventional based SVM and Neural Network based SVM methods. This scheme was five-layer network, receives the d-axis and q-axis voltages information at the input side and generates the duty ratios as an output for the inverter circuit. The training data for Neural Network and adaptive Neuro-Fuzzy was generated by simulating the conventional SVM. Neuro-Fuzzy uses the hybrid learning algorithm for training the network. Anup Kumar Panda et al. have investigated about a different cascade multilevel inverter (CMI) based topologies with reduced dc sources and finally the proposed CMI with single dc source by employing low frequency transformers was presented. Proposed topology significantly reduces size when compared with conventional topologies and increases the reliability. To verify the performance of proposed architecture, prototype experiments are carried out and adequate results were presented.

The power quality upholds is one of the significant missions a tool which operating based on power electronics device. Due to non linearity loads linked in the system, Power quality problem happens. These non linear loads cause diverse kinds of power quality problem in the system such as harmonics sags and etc. By reducing the power quality of the system, the power quality of the system is sustained. Different kinds of power quality improvement methods are applied for reducing the power quality problem. Along with these techniques, the soft computing methods such as fuzzy logic, neural network, neuro-fuzzy etc, are generally applied method for power quality development. For reimbursing power quality problem, Fuzzy logic is applied. However it is one of the top methods for the linear controlling problem it is not appropriate for non linear cases.

III. MULTILEVEL INVERTER

Maintaining the power quality is one of the important tasks a device which is operating based on power electronics device. Power quality problem occurs due to non linearity loads connected in the system. These non linear loads cause different types of power quality problem in the system such as harmonics sags and etc. To reduce the harmonic contents present in the multilevel inverter output voltage is used to maintain the power quality.
Multilevel inverter model used in this method is shown in figure 1. $S$ level multilevel inverter is used in this method. The proposed method is described with the multilevel inverter, i.e., seven level inverter; the output of the multilevel inverter is connected to the nonlinear load. In the multilevel inverter each bridge contains Insulated Gate Bipolar Transistors (IGBT). Each bridge contains its own identical dc supply $V_{dc}$. The output of the multilevel inverter is given to the nonlinear RLC load. Here, the system output voltage $V_{out}$ is compared to the reference voltage $V_{ref}$. The difference between output voltage and the reference voltage is known by the error voltage $V_{err}$. Then the error voltage and change in error voltage is the input of the proposed hybrid technique, which generates the gate pulses to mitigate the harmonics. The output voltage of the present multilevel inverter is of fundamental sinusoidal staircase waveform, which contains seven levels. The multilevel inverter output harmonic voltage can be described in the following equation (1).

$$V_{out}(\omega t) = \sum_{n=1}^{\infty} V_h \sin(n\omega t)$$  \hspace{1cm} (1)

Where, $\omega = 2\pi f$, $f$ is the frequency in Hz, $t$ is the continuous time signal; $0 \leq t \leq T$, $V_h$ is the amplitude of harmonics. The THD present in the voltage can be identified from the following equation (2).

$$THD = \sqrt{\sum_{k=2}^{\infty} \left( \frac{V_{out}(kT)}{V_1} \right)^2}$$  \hspace{1cm} (2)
Where, $V_{\text{out}}(k)$ is the multilevel inverter output voltage of the $k^{\text{th}}$ order, the reduced THD has been achieved by the gate pulses generated from the fuzzy logic and SVM based hybrid technique.

A. Switching Angles and Frequency using Neuro Fuzzy System

The neuro fuzzy is used for calculating switching angle and frequency. Neuro fuzzy system is a combination of fuzzy logic and neural network. The steps for training neuro fuzzy system are as follows. First fuzzy rules are generated based on the number of input and output variables. After generating rules the training data is trained using neural network based on the fuzzy rules. First about the operation of fuzzy logic.

B. Generating $V - \theta$ Fuzzy Rules

Generally, there are three different steps for the operation of fuzzy logic i.e. fuzzification, generating fuzzy rules and defuzzification. In fuzzification process, the given data is converted into system data. The next step after fuzzification is generating fuzzy rules. The fuzzy rules are generated based on the number of input and output parameters.

In this method, there are $n$ input variables and $s+1$ output variables. The input variables considered for generating fuzzy rules are different voltage values and the output variables are switching angles and frequency. The input variables are fuzzified into three sets namely small, medium and large, and output variables also fuzzified into three sets namely small, medium and large. Triangular membership function is used for generating fuzzy rules. After generating fuzzy rules, next step is to train neural network based on the rules generated using fuzzy.

C. Feeding Voltage and Angle to Neural Network

Neural network consists of two different processes, namely training and testing. In the training process, network is trained using the training dataset with above generated fuzzy rules. In the testing stage if input is given to the network, it gives corresponding output. Neural network consists of three layers, namely input layer, hidden layer and output variable. It consists of $n$ input variables, $r$ hidden variables and $s+1$ output variables. Output obtained from the neural network is switching angles and frequency. The structure of neural network used in this method is shown in figure.2.

The steps for training the neural network are

**Step 1**: Initialize the input weight of each neuron.

**Step 2**: Apply a training dataset to the network. Here $Y_1, Y_2, \ldots, Y_n$ are the input to the network and $Z_1, Z_2, \ldots Z_{s+1}$ are the output of the network.

\[
Z_1 = \sum_{r=1}^{n} W_{2r1} Z_1 (r)
\]  
(4)

\[
Z_2 = \sum_{r=1}^{n} W_{2r2} Z_2 (r)
\]  
(5)

\[
Z_{s+1} = \sum_{r=1}^{n} W_{2r(s+1)} Z_{s+1} (r)
\]  
(6)

where, \[
Z(r) = \frac{1}{1 + \exp(-w_{1c} \cdot \sum_{k=1}^{n} Y(k))}
\]  
(7)
Eqn 4, 5, 6 & 7 represents the activation function performed in the output and input layer respectively.

Step 3: Adjust the weights of all neurons.

Step 4: For each set of voltage values, select the switching angle and frequency.

Step 5: Select the best switching angle and frequency.

After completion of training, neuro fuzzy is used for practical application.

D. Elimination of Harmonic Contents in the System

After completion of training neuro fuzzy system the next step is to eliminate the harmonic contents in the system. First voltage error values are calculated using the equation 3. By giving voltage error values as input to the neuro fuzzy system, it gives corresponding frequency and switching angles as output. By applying this frequency and switching angle values to the system the harmonic contents present in the system are eliminated. The frequency and switching angle are substituted in the equation given below.

\[ V(t) = V_h \sin(h.2\pi f_j t) \]  

(8)

where, \( f_j \) is the frequency obtained from neuro fuzzy system.

\[ V_h = \frac{4V_{dc}}{h\pi} \sum_{j=1}^{S} \cos(h\theta_j) \]  

(9)

where, \( \theta_j \) is the switching angles obtained from neuro fuzzy system and \( h \) is the harmonic order.

By substituting equation 5 in 1 we get the output dc voltage. The harmonics content eliminated or not is calculated using the below condition.

\[ H_{eli} = \begin{cases} \frac{V_{ref}(t) = V(t)}{\text{harmonics eliminated}} \\ \frac{V_{ref}(t) \neq V(t)}{\text{harmonics present}} \end{cases} \]  

(10)

By using the equation the harmonic content present in the system are identified. If there is no harmonics the proposed method stop its process. If the harmonics content are present in the system then the process is repeated until the harmonic contents are eliminated.
IV. PROPOSED HYBRID TECHNIQUE

The harmonic elimination on the multilevel inverter using SVM and fuzzy based technique has been proposed. The proposed method structure is given in the figure 4.

The harmonic present in the system is identified by comparing the system output voltage and reference voltage for different time. The fuzzy logic controller build the logical rules; it depends on the input error voltage and change in error voltage. From the rules, the optimum switching angle and the frequency has been predicted by the SVM technique. Then, the selected switching angle and frequency eliminate the harmonic content present in the system. In the SVM technique training process is much needed for the voltage and switching angle dataset. The proposed technique training dataset can be described in the following.

\[
D_{trn} = \begin{bmatrix}
V_{11}^T & V_{12}^T & \cdots & V_{1n}^T \\
V_{21}^T & V_{22}^T & \cdots & V_{2n}^T \\
\vdots & \vdots & \ddots & \vdots \\
V_{r1}^T & V_{r2}^T & \cdots & V_{rn}^T
\end{bmatrix}
\begin{bmatrix}
\theta_{11}^T & \theta_{12}^T & \cdots & \theta_{1n}^T \\
\theta_{21}^T & \theta_{22}^T & \cdots & \theta_{2n}^T \\
\vdots & \vdots & \ddots & \vdots \\
\theta_{r1}^T & \theta_{r2}^T & \cdots & \theta_{rn}^T
\end{bmatrix}
\]

(11)

Here, \( n \) stands for number of voltage values taken for generating dataset, \( r \) is the total number of dataset generated, \( \theta \) is the switching angle, \( V \) is the voltage and \( \theta \) stands for number of switching angles.

A. Generating Switching Angle and Frequency Fuzzy Rules

Fuzzy logic is the form of probabilistic logic rules, which deals with reasoning that is approximate rather than fixed and exact. Generally, there are three different process for the fuzzy logic i.e., fuzzification, decision making and defuzzification. In fuzzification process, the given input data is converted into fuzzy values. The next step after fuzzification is generating fuzzy rules. The fuzzy rules are produced based on the number of input and output parameters. Finally the fuzzy values are converted into the output. The general structure of the fuzzy logic controller is given in the following figure.

In this method, there are \( n \) input variables and \( s + 1 \) output variables. The input variables are different voltage values, i.e., error voltage and change in error voltage, which are considered for generating fuzzy rules. Here, the error voltage is the difference between the system output voltage \( V_{out}(t) \) and reference voltage \( V_{ref}(t) \). The input variables are fuzzified into small medium and large. Then the fuzzy rules are generated using the triangular membership function. The fuzzy logic output variables are switching angles and frequency. The output variables are used to train the SVM, which is briefly described in the following section.

B. SVM Based Prediction

The SVM technique is supervised learning or statistical learning technique, which analyze data and recognize pattern used for classification and regression analysis. The SVM learning theory is used to plot the data from the input point to the high dimensional point. From the problem categories based, the SVM can be classified into two types, i.e., binary classifier based SVM and multiclass classifier based SVM [28]. The separation of the SVM classifier is made by the optimal characteristics point of the hyper plane. The number of classes is exceeding more than two, and then the binary classifier is not applicable for classification. Because the binary classification based SVM is only applicable for two classes. In that condition the multiclass classifier based SVM is used for the classification. Here, the multiclass classifier based SVM is used to predict the switching angles and frequency of the multilevel inverter.

Multiclass classifier based Switching Angle and Frequency prediction: - The multiclass classifier is the one of the SVM technique, which classifies the multilevel inverter switching angles and frequency in pair wise. It has two different process likely training and testing. Here the multiclass classifier is trained using the training dataset with above generated fuzzy rules. Then, the testing process of the input is given to the multiclass classifier and obtains the corresponding output. In the proposed method multilevel inverter harmonic elimination, the \( N \) training data points \( (x_i, y_i) \) are choose, i.e., \( y_i \) is the class label and \( x_i \) is the input vector, the value of \( i \) is in-between the range from 0 to \( N \). The training process of the multiclass classifier requires data set. The experimental steps to predict the switching angle and frequency is given in the following.
Procedure

Step 1: Initialize all the parameters of the multilevel inverter, i.e., the voltage \( (V) \), switching angle \( (\theta) \) and frequency. Here, the voltage \((V)\) and switching angle \((\theta)\) are the two classes, which are selected from the separated target class.

Step 2: To identify the decision function of the separated target class, which is given by the following equation (12).

\[
f_{V,\theta}(x) = w_{V,\theta} \cdot K(x, y) + b_{V,\theta} \tag{12}
\]

where, \( w \) is the normal to the hyper plane between class \( m \) and \( n \), \( b_{V,\theta} \) is the offset value of class \( m \) and \( n \), \( w_{V,\theta} \cdot x \) is the scalar product between \( w_{V,\theta} \) and \( x \), \( K(x, y) \) is the kernel function and \( \alpha_i \) is the non-negative Lagrange multipliers.

Step 3: Apply kernel function; here the \( K(x, y) \) value is changed based on the function. The kernel functions are linear, Gaussian, polynomial and tangent hyperbolic. And the resultant function is applied into the equation (12). The equations for kernel functions are described as follow,

Linear kernel function,

\[
K(x, y) = (x, y) \tag{13}
\]

Gaussian kernel function,

\[
K(x, y) = \exp \left( -\frac{||x - x_i||^2}{2\sigma^2} \right) \tag{14}
\]

Polynomial kernel function,

\[
K(x, y) = (x, y)^p \tag{15}
\]

Tangent Hyperbolic kernel function,

\[
K(x, y) = \tanh(x, y - \theta) \tag{16}
\]

Where, \( \sigma \) is the standard deviation and \( p \) is the polynomial.

Step 4: To classify the data based on the signum function of the decision function, which is used for setting the threshold decision. The signum function is described as follow,

\[
sign(f_{V,\theta}(x)) = \begin{cases} 1 & f_{V,\theta}(x) > 0 \\ -1 & f_{V,\theta}(x) \leq 0 \end{cases} \tag{17}
\]

Then, the pair wise function is summed to determine the class decision function. The class decision function of \( f_V(x) \) is determined as follow,

\[
f_V(x) = \sum_{V,m \neq n=1}^{C} sign(f_{V,\theta}(x)) \tag{18}
\]

Where, \( C \) is the class classification. Similarly, the class decision function of \( f_{\theta}(x) \) is determined. Finally, the \( \max_v f_v = (k - 1) \) condition is checked.

Step 5: To evaluate the training and testing error by using the following equation.

\[
R_{emp}(\alpha) = \frac{1}{m} \sum_{i=1}^{m} L(f(x_i, \alpha), y_i) \tag{19}
\]

\[
R(\alpha) = \int L[f(x, \alpha), y] dP(x, y) \tag{20}
\]
Where, equation (19) is the training error and (20) is the testing error. The process is continued until the training and the testing error gets minimized.

Once the process is finished, the system is ready to give the optimum switching angle and frequency. The multiclassifier structure can be described in the following figure. After training process has been finished, the next step is the harmonic elimination, which can be described in the following section.

C. Harmonic Elimination of the Multilevel Inverter

The harmonic contents present in the system output voltage is eliminated after the SVM training process. In the proposed technique the optimum switching angle and frequency has been predicted from the multiclassifier based SVM. Here, error voltage and change in error voltage is used for the generation of fuzzy rules. From the fuzzy rules, the SVM has identified the switching angle and frequency. The SVM training is possible by the training dataset, which is given in the equation (3). The system output voltage is given in the following equation (13).

\[ V_{\text{out}}(t) = V_{ih} \sin(h2\pi f_{sf} t) \]  

Where, \( V_{ih} = \frac{4V_{dc}}{h\pi} \sum_{h=1}^{N} \cos(h\theta_k) \), \( f_{sf} \) is the frequency obtained from the SVM and fuzzy technique.

The harmonic content elimination can be identified using the following conditions:
- If the system output voltage \( V_{\text{out}}(t) \) is equal to the reference voltage \( V_{\text{ref}} \), the harmonic contents has been eliminated.
- If the system output voltage is not equal to the reference voltage, the harmonic contents are present in the system output voltage.

By using above conditions, the harmonic content present in the system are identified. If there is no harmonics the proposed method stop its process or else the process is repeated until the harmonic contents are eliminated. The proposed method is implemented in the MATLAB platform and effectiveness is analyzed, which is given in the following section 4.

V. RESULTS AND DISCUSSIONS

The fuzzy and SVM based hybrid technique is implemented in the MATLAB 7.10.0 (2012a). The input dc supply is 230V, the bridge IGBT resistance is 0.1 \( \Omega \), IGBT diode resistance (\( R_d \)) is 0.01 \( \Omega \), the load \( R=10 \), \( L=1\text{mH} \), \( C=1\text{\mu F} \) respectively and the reference voltage is 230V, 50Hz. The effectiveness of the proposed method is demonstrated with the various techniques like NFC and ANFIS. The proposed method implemented MATLAB model is shown in the figure 5 and the corresponding results are described in below.

A neuro fuzzy feedback controller for eliminating harmonic contents in the system. Here neuro fuzzy feedback controller is used for eliminating the harmonic contents in the system. The amount of harmonic contents present in the system is calculated using the feedback controller. The feedback controller compares the system with harmonics and reference system. The output of feedback controller is given as input to neuro fuzzy, Switching angles and frequency value used to eliminate the harmonic contents in the system are calculated using neuro fuzzy. The overall process take place in this method is shown in figure 3.
place in neuro fuzzy system is explained briefly. The input variables to neuro fuzzy system are different voltage values and obtained outputs from fuzzy logic are switching angles and frequency. By using these switching angles and frequency the harmonics that are present in the system are eliminated.

This technique was implemented in the working platform of MATLAB and tested for different harmonic order. Maximum time used in our method, \( T = 0.5 \) sec. First the voltage waveform is generated and that voltage values are taken as reference voltage value with respect to various time intervals.

Fig. 4. Structure of neural network

Fig. 5. Structure of the fuzzy logic controller
Fig. 6. MATLAB model of the proposed technique

Fig. 7. Seven level inverter output voltage without controller

Fig. 8. Reference voltage waveform
Fig. 9. Difference between normal output and reference voltage

Fig. 10. Change in error voltage waveform

Fig. 11. Multilevel inverter output voltage with NFC
Fig. 12. Multilevel inverter output voltage with ANFIS

Fig. 13. Multilevel inverter output voltage with proposed technique

(a)

Fig. 14. THD analysis of output voltage with NFC (a) Selected 5 cycles of voltage (b) THD
In this section the numerical results of the proposed method are presented and discussed. Comparisons between the proposed system and the NFC, ANFIS are also presented. Here, the maximum time interval used in the proposed technique is $T=0.1\text{sec}$. Initially the multilevel inverter produced the output which is sinusoidal staircase waveform. The output voltage of the multilevel inverter is given to the non linear RLC load ($R=10\Omega, L=1\text{mH}, C=1\mu F$).
The presence of the nonlinear load generates the harmonic contents in the output voltage. It is slightly different from the standard waveform and it has distortions. To find the distortion of the output voltage from the comparison of standard voltage and the multilevel inverter output voltage. The standard voltage is considered as the reference voltage, which is illustrated in the figure 6. The reference voltage contains 230V amplitude and 50Hz frequency. By using the output of the voltage of the multilevel inverter and the reference voltage, the error voltage has been determined. Then apply the delay to the error voltage at various time intervals and the change in error voltage is attained, which is explained in the figure 7.

The harmonic contents present in the output voltage are eliminated using the NFC, ANFIS and proposed hybrid technique. For using these methods, the obtained results are illustrated in the figures 8, 9 and 10 respectively. Then the THD of each method are analyzed in the figures 11, 12 and 13. During the THD analysis, the 5 cycles of the output voltage is selected and the corresponding THD range is analyzed. In the figure 14 the NFC based harmonic elimination has been analyzed. Here, the measured THD range is 12.86% for the required frequency 50Hz. Similarly ANFIS based harmonic elimination is described in the figure 15 and the measured THD at the required frequency level is 10.85%. Also the proposed hybrid technique based harmonic elimination has been illustrated in the figure 16 and the measured harmonic range is 9.28%. From the analysis, we observed the proposed hybrid method attains reduced THD; it can be used to eliminate the harmonic contents present in the output voltage of the multilevel inverter. Finally the THD at various load conditions are given in the table 1 and figure 17.

<table>
<thead>
<tr>
<th>S.no</th>
<th>Non linear load</th>
<th>THD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R  L  C</td>
<td>NFC</td>
</tr>
<tr>
<td>1</td>
<td>1 1e-5 1e-8</td>
<td>13.62</td>
</tr>
<tr>
<td>2</td>
<td>5 1e-4 1e-7</td>
<td>13.22</td>
</tr>
<tr>
<td>3</td>
<td>10 1e-3 1e-6</td>
<td>13.36</td>
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<tr>
<td>4</td>
<td>15 1e-2 1e-5</td>
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<td>20 1e-1 1e-4</td>
<td>13.84</td>
</tr>
<tr>
<td>6</td>
<td>25 0.5 1e-3</td>
<td>13.42</td>
</tr>
<tr>
<td>7</td>
<td>30 1.1 1e-2</td>
<td>13.87</td>
</tr>
</tbody>
</table>

The above figure shows the THD range at the various load levels at different methods, i.e., NFC, ANFIS and proposed method. Here, the nonlinear load is gradually increased and analyze the THD at considered methods. In that the Newton-Raphson(N-R), NFC and ANFIS has 13.84%, 12.78% and 10.86% THD respectively but the proposed hybrid technique SVM contains 9.20% THD. From the comparison graph and table we concluded that the proposed method SVM is the effective technique to eliminate the harmonics contents present in the multilevel inverter output voltage and which is competent over the NFC and ANFIS.
VI. CONCLUSION

The SVM and fuzzy based hybrid feedback controller technique for harmonic content elimination of multilevel inverter was proposed in this paper. Here, the FLC develops the logical rules depending on the error and change of error voltage. From the fuzzy rules the optimum switching angle and frequency were predicted by the SVM technique. By using the selected switching angle the harmonic contents present in the multilevel inverter has been eliminated. Then the proposed method performances are compared to the NFC and ANFIS at various nonlinear load levels. In that the NFC and ANFIS has 12.78% and 10.86% THD respectively but the proposed hybrid technique contains 9.20% THD only. Hence the comparison results proved that the proposed method is the most effective technique to eliminate the harmonic content present in the multilevel inverter and which is competent over the other techniques.

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REFERENCE


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