Control Strategies of Multilevel Inverter Based Active Power Filter for Harmonic Elimination

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Abstract–In this paper, support vector machine (SVM) and fuzzy based feedback harmonic elimination technique is proposed. The proposed technique is to 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) builds the logical rules; it 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 proposed method is implemented in MATLAB/simulink working platform and the harmonic elimination performance is demonstrated by the comparison of Neuro Fuzzy Controller (NFC) and Adaptive Neuro Fuzzy Interference System (ANFIS).

Keywords–THD, multilevel inverter, ANFIS, NFC, SVM, FLC, switching angle.

I. INTRODUCTION

A multilevel inversion known by the power conversion approach 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) have materialized as a victorious and practical solution [19]. Non-linear loads like adjustable speed drives; electronically ballasted lighting and the power supplies of the electrical with equipment applied in present offices affect current harmonics in recent electrical allocation systems [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, ability and deficiency of plant system performance happen thus of a raise in the harmonic alteration component of the transformer [7].To diminish the problem of harmonics, different methods have been recognized. A few examples are: 1) Specific Harmonic Elimination (SHE} [18] 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]. Eradication of harmonics in nonlinear system is moreover attained by using a non-natural neural Network [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 [11].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 [12]. 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 [13]. 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 [14-15]. 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 choosey harmonics compensation.[16-17].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.

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II. MULTILEVEL INERTER

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

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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. Here, the harmonic elimination on the multilevel inverter using SVM and fuzzy based technique has been proposed. The proposed method structure is given in the Fig. 1

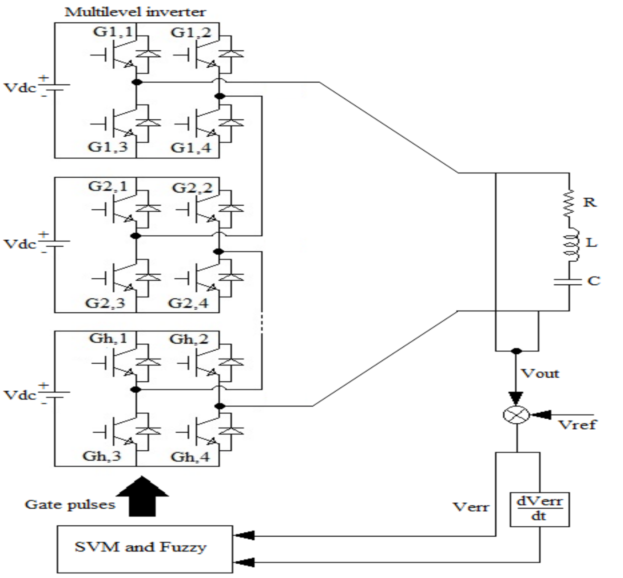


Fig.1: Structure of the proposed method

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 (1).

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

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

$$THD = \sqrt{\frac{\sum_{k=2}^{n}[V_{out}(k)]^2}{V_1}} \qquad (2)$$

where, $V_{out}(k)$ is the multilevel inverter output voltage of the k[th] order, the reduced THD has been achieved by the gate pulses generated from the fuzzy logic and SVM based hybrid technique. The detail explanation about the elimination of harmonic content present in the multilevel inverter output voltage is given in the following section 3.1.

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. Finally the fuzzy values are converted into the output. The general structure of the fuzzy logic controller is given in the following figure.

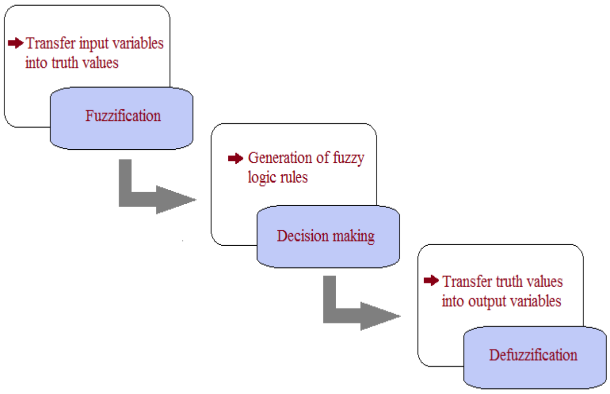


Fig.2: Structure of the fuzzy logic controller

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. 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 (θ) and frequency. Here, the voltage (V) and switching angle (θ) 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 (4).

$$f_{V,\theta}(x) = w_{V,\theta}.K(x,y) + b_{V,\theta} \tag{3}$$

$$w = \sum_{i=1}^{N} \alpha_i \, y_i \, x_i \tag{4}$$

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, $w_{V,\theta}.x$ is the scalar product between $w_{V,\theta}$ *and* x, $K(x,y)$ is the kernel function and α_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 (4). The equations for kernel functions are described as follow,

Linear kernel function,

$$K(x,y) = (x.y) \tag{5}$$

Gaussian kernel function,

$$K(x,y) = \exp\left(-\frac{\left\|x - x_i\right\|^2}{2\sigma^2}\right) \tag{6}$$

Polynomial kernel function,

$$K(x,y) = (x.y)^p \tag{7}$$

Tangent Hyperbolic kernel function,

$$K(x,y) = \tanh(x.y - \theta) \tag{8}$$

where, σ 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,

$$sign(f_{V,\theta}(x)) = \begin{cases} 1 & f_{V,\theta}(x) > 0 \\ -1 & f_{V,\theta}(x) \le 0 \end{cases} \tag{9}$$

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,

$$f_V(x) = \sum_{V \ne \theta; \theta = 1}^{C} sign(f_{V,\theta}(x)) \tag{10}$$

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.

$$R_{emp}(\alpha) = \frac{1}{m} \sum_{i=1}^{m} L(f(x_i, \alpha), y_i) \tag{11}$$

$$R(\alpha) = \int L[f(x,\alpha), y] dP(x,y) \tag{12}$$

where, (11) is the training error and (12) is the testing error. The process is continued until the training and the testing error gets minimized.

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 multiclass classifier 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 (3). The system output voltage is given in the following (13).

$$V_{out}(t) = V_H \sin(h.2.\pi.f_{SF}.t) \tag{13}$$

where, $V_H = \frac{4V_{dc}}{h\pi} \sum_{k=1}^{N} \cos(h\theta_k)$, f_{SF} is the frequency obtained from the SVM and fuzzy technique.

The harmonic content elimination can be identified using the following conditions

1. If the system output voltage $V_{out}(t)$ is equal to the reference voltage V_{ref}, the harmonic contents has been eliminated.

2. 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.

III. Results And Discussions

The fuzzy and SVM based hybrid technique is implemented in the MATLAB 7.10.0 (2012a). The input dc supply is 230*V*, the bridge IGBT resistance is 0.1 Ω, IGBT diode resistance (R_D) is 0.01 Ω , the load *R*=10, *L*=1*mH*, *C*=1 μF respectively and the reference voltage is 230*V*, 50*Hz*. 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 Fig. 3 and the corresponding results are described in below.

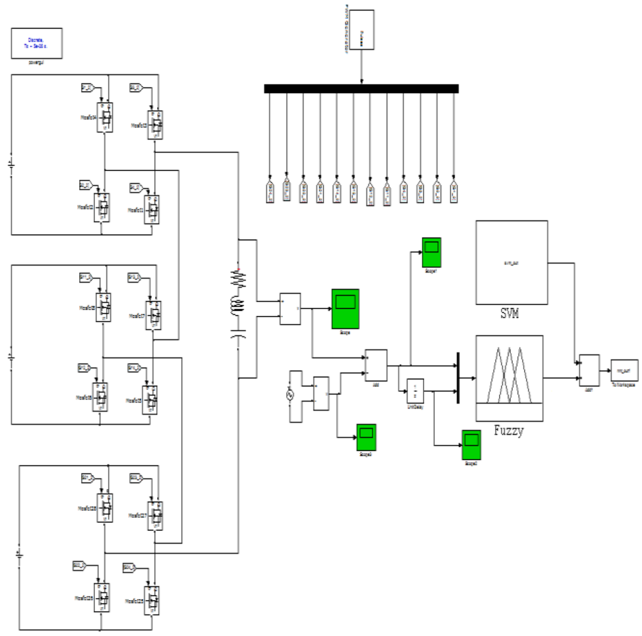


Fig.3: MATLAB model of the proposed technique

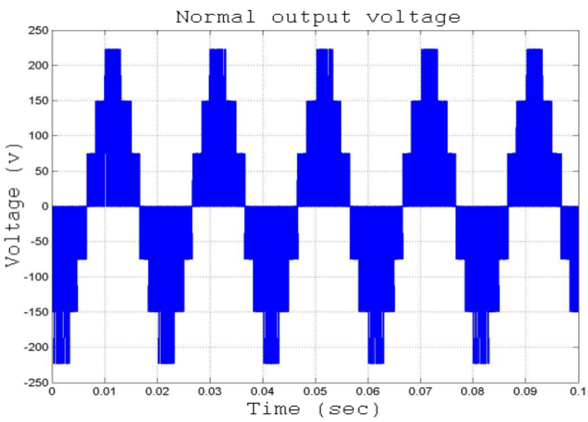


Fig.4: Seven level inverter output voltage without controller

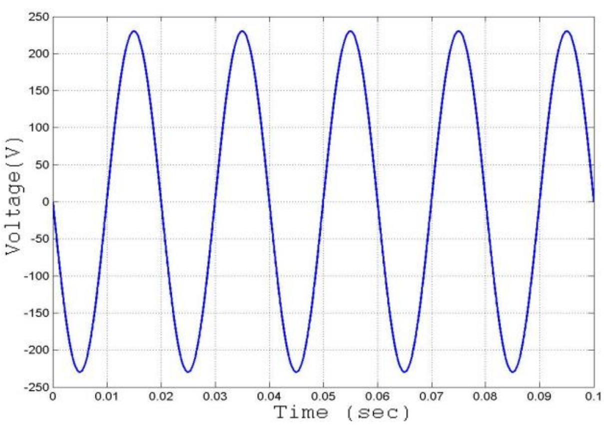


Fig.5: Reference voltage waveform

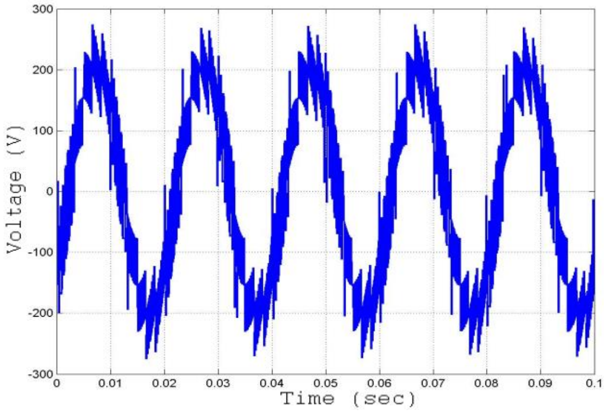


Fig.6: Difference between normal output and reference voltage

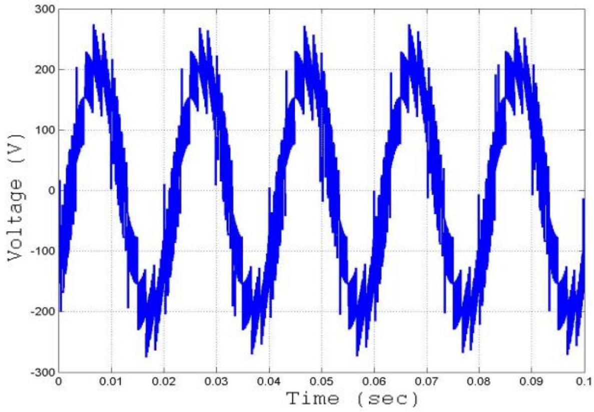


Fig.7: Change in error voltage waveform

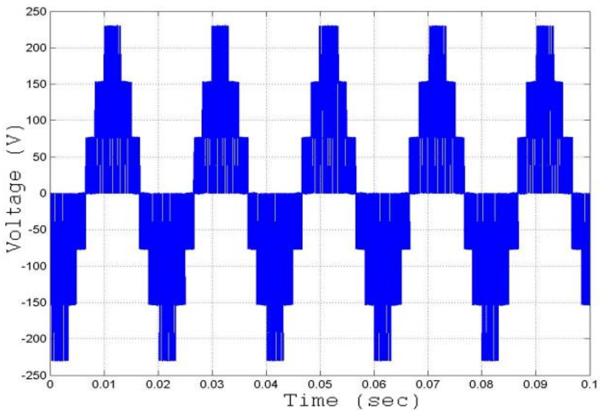


Fig8: Multilevel inverter output voltage with NFC

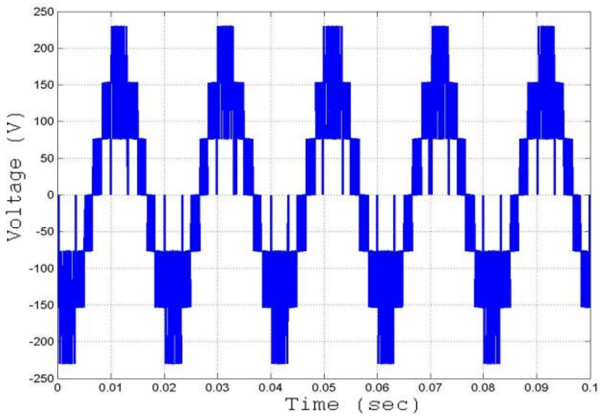


Fig.9: Multilevel inverter output voltage with ANFIS

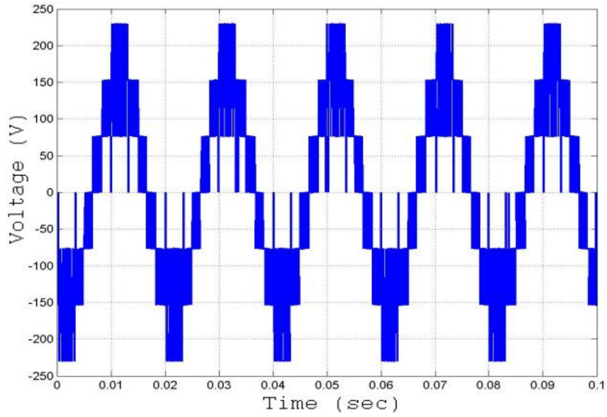
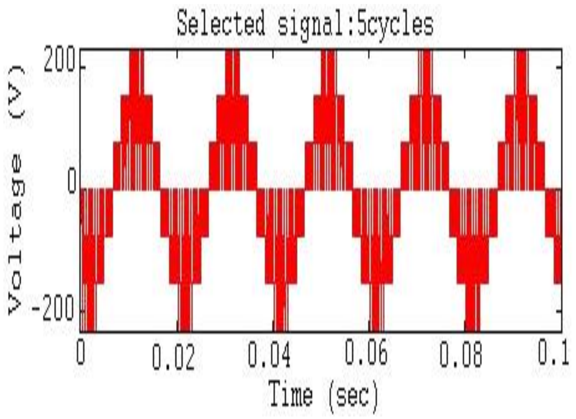


Fig.10: Multilevel inverter output voltage with proposed technique



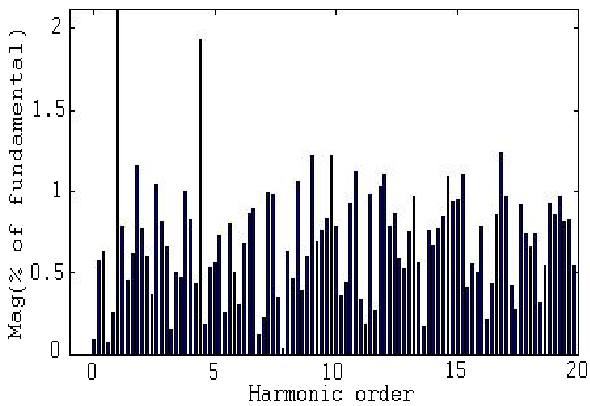
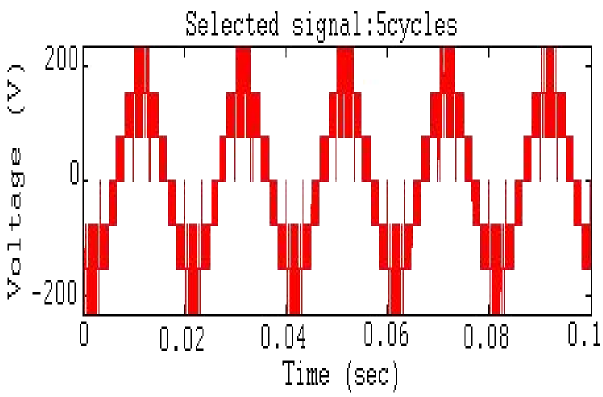
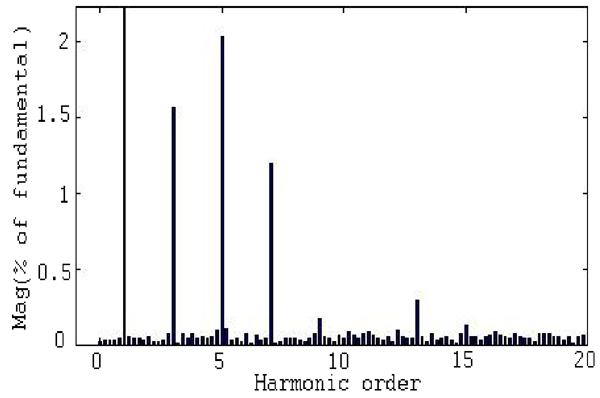


Fig.11: THD analysis of output voltage with NFC (a) Selected 5 cycles of voltage (b) THD

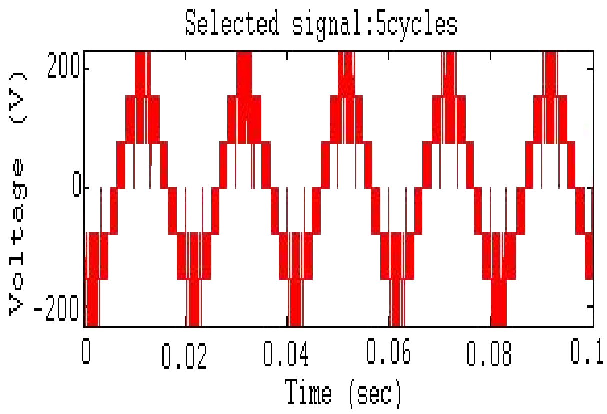


(a)

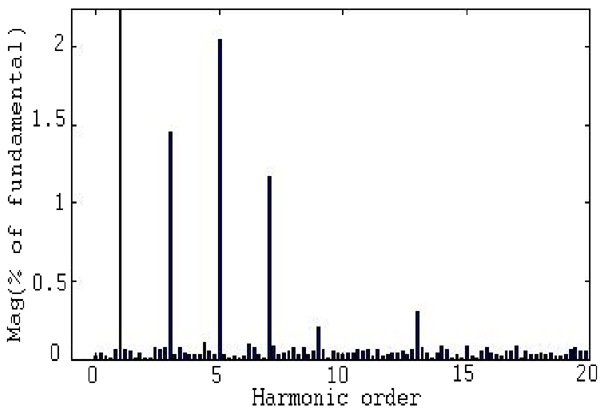


(b)

Fig.12: THD analysis of output voltage with ANFIS (a) Selected 5 cycles of voltage (b) THD



(a)



(b)

Fig.13: THD analysis of output voltage with proposed method (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=0.1sec. Initially the multilevel inverter produced the output which is sinusoidal staircase waveform, which is illustrated in the Fig. 4. The output voltage of the multilevel inverter is given to the non linear RLC load (R=10, L=1mH, C= μF). 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 Fig. 5. 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. The error voltage is demonstrated in various time intervals which is shown in Fig. 6. 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 Fig. 8.

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 Fig. 8, 9 and 10 respectively. Then the THD of each method are analyzed in the Fig. 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 Fig. 11 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 Fig. 13 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 Fig. 12 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 Fig.14.

Table 1: Comparison of THD at different loading conditions

	Non linear load			THD (%)		
	R	L	C	NFC	ANFIS	Proposed
1	1	1e-5	1e-8	12.83	10.87	9.27
2	5	1e-4	1e-7	12.78	10.86	9.20
3	10	1e-3	1e-6	12.80	10.85	9.26
4	15	1e-2	1e-5	12.88	10.8	9.29
5	20	1e-1	1e-4	13.15	11.02	9.54
6	25	0.5	1e-3	12.83	10.88	9.28
7	30	1.1	1e-2	13.47	10.88	9.69

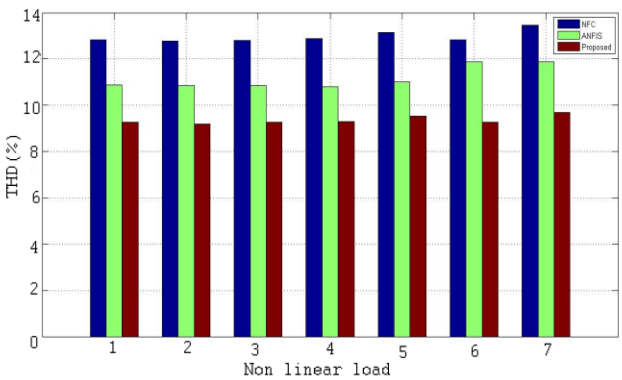


Fig.14: THD comparison of NFC, ANFIS and proposed method

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 NFC and ANFIS has 12.78% and 10.86% THD respectively but the proposed hybrid technique contains 9.20% THD. From the comparison graph and table we concluded that the proposed method 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.

IV. 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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