Power Quality Improvement in an Cascaded Multilevel Inverter using Fuzzy logic, Neural Network Techniques

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Abstract

The non-linear loads generate serious harmonic currents and reactive power to the distribution and transmission System, which results in a low power factor, leads to voltage notch and reduces the utilization of the distribution system. In this paper, fuzzy logic and neural network based hybrid technique is proposed to eliminate the harmonics ideally. The technique utilizes fuzzy logic and artificial neural network in the optimal selection of switching angles. A hybrid evaluation technique evaluates the obtained optimal switching angles that are attained from the fuzzy inference system as well as neural network. The proposed technique is tested with a seven level H-bridge inverter and the resultant fundamental and harmonics voltage are analyzed. The results reveal the effectiveness of the technique in eliminating the harmonics that are generated from the inverter.

Keywords: *Harmonics, Fuzzy logic, Neural Network, Switching angles, Multilevel inverter.*

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1. Introduction

Uninterruptible Power Supply (UPS) systems are extensively used for supplying emergency power to crucial loads that cannot take up utility failure. Irrespective of variations in the input source or load condition, maintaining a constant voltage and constant frequency supply for critical loads, is the major function of an UPS. UPS supplies the needed uninterruptible AC power to linear and nonlinear loads. Critical equipments, such as computers, automated process controllers, and hospital instruments have widespread application for UPS, which serves as emergency power source. Diode rectifier, Pulse Width Modulation (PWM) inverter, input/output filter, DC-link capacitor, battery charger and battery, battery on/off switch, and load transformer are the major components of this system. For the DC–AC conversion, a full-bridge PWM inverter is employed. A filter is used to obtain the sinusoidal waveform from the PWM inverted pulse waveform.

UPS devices may degrade the power quality by creating harmonic currents although they are economical, flexible and energy efficient. Harmonics are undesirable sinusoidal voltages or currents present in power systems that have frequencies which are integer multiples of the frequencies of the supply system. By polluting the input supply of sensitive equipment harmonics introduced by nonlinear loads, can cause faulty operation of the connected equipments. Current is drawn in a non-sinusoidal manner by the nonlinear loads that are connected to the sinusoidal supply voltage. Harmonic current source and Harmonic voltage source are the two types harmonic sources into which nonlinear loads can be categorized. The source side as well as the load side can generate both types of harmonics. The harmonics contained in voltage supply usually generate the current harmonic and it depends on the type of the load for example resistive load, capacitive load, and inductive load. Harmonics causes malfunctioning of electrical/electronic parts, overheating of neutral wires, transformer heating, and malfunctioning of power factor correction capacitors, power generation and transmission losses, disruption of protection, control and communication networks as well as customer loads.

2. Proposed Method

The proposed adaptive technique reduces the harmonics by combining the fuzzy logic and the neural network. This technique can eliminate harmonics selectively by optimally and adaptively choosing the switching angles of the UPS inverter. By selecting optimal switching angles, harmonics generation can be avoided in inverters that are used in UPS devices. Consider that the UPS utilizes a multi-level inverter with *l N* levels and *Nc*H-bridge converters. The mathematical model of the inverter output voltage can be represented as,

$$V_h = \frac{4V_{dc}}{h\pi} \sum_{j=0}^{N_t-1} (-1)^j \cos(h \square_j)$$

where, V_{dc} is the input DC voltage and a j^{th} is the switching angle for the H-bridge and $V\,h$ is the voltage of the h^{th} order harmonic that is generated by the inverter. The hybrid technique, which selectively eliminates the odd harmonics, is detailed in the following sub-sections.

2.1Fuzzy Rules Based on Switching Angles

In the hybrid technique, fuzzy logic plays a fundamental role in training the neural network according to the switching angles and the harmonics generated by them. In the first stage of the technique, the fuzzy rules are generated based on the switching angles, which are in the range (0,p / 2) . The regular switching angle range is divided into different interims and a fuzzified switching angle pattern is generated. The switching angle interims are determined using the following relation,

$$I_K = \big((k-1)\Delta I, k\Delta I\big); 1 \le k \le N_I$$

where, *NI* is the total number of intervals in the range (0,p / 2) , (*k* −1)D*I* and *K*d*i* are the minimum range and maximum range of the k[th] term, respectively, i.e. *I* (*k*) *I k* = −1 D min and *I k I k* = D max .Here, D*I* is the interim range and it can be determined as,

$$\Delta I = \frac{\left(\frac{\pi}{2}\right) - 0}{NI}$$

After fuzzification, a dataset is obtained with fuzzy variables. For every k^{th} fuzzy class, there are *r N* patterns of switching angles and the corresponding inverter output voltages. The frequency of each voltage pattern present in the RHS of each of the k[th] fuzzy class is determined. The voltage pattern in ever k[th] class that has the maximum frequency is selected as the output pattern of the class and hence the dataset is re-structured as follows,

The re-structured fuzzified dataset *DF* is used to train the fuzzy inference system (FIS). Once the training process is completed, the FIS is ready for use and obtains the output voltage status, for any given switching angle.

2.2 Hybrid Evaluation of Switching Angles

The proposed technique performs a hybrid evaluation to determine the optimal switching angles, whichcan reduce the generation of harmonics in the UPS inverter. To perform this, we utilize an iterative approach, which initiates arbitrary search and concludes with optimal switching angles after *g N* iterations. The entire technique considers the requirement of eliminating the harmonics generation by selectively mitigating any of the harmonics. In other words, the technique can mitigate the selected harmonics and so the entire harmonics generation. When a harmonic is to be strictly mitigated, SAY*H* : [1,] *H H* Î *N* , then it must be indirectly given as input to the technique. Accordingly, the technique determines the voltage pattern that has minimum Hth order harmonics voltage. For instance, if the 5th order and 7th order harmonics are to be strictly mitigated in eliminating the harmonics generation, the harmonic voltage 5 *V* and 7 *V* should be very small. From the data set the switching angle pattern corresponding to the selected harmonic voltage pattern is determined. To perform the selective mitigation, the selection factors have to be given as input. Then, iterative approach is initiated with the generation of switching angles in their intervals. In the approach, a pool of arbitrary vectors are generated as follows

$$Z_a = [\alpha_0^{(a)}\ \alpha_1^{(a)} \dots\dots\dots \alpha_{N_I-1}^{(a)}]; \quad 0 \le a \le P_{size} - 1$$

where, Z_a is the a^{th} vector present in the pool and $\alpha_j^{(a)}$ is the jth switching angle of a^{th} vector. Every vector in the pool needs to satisfy the constraint,

$$\alpha_0^{(a)} < \alpha_1^{(a)} < \dots < \alpha_{I-1}^{(a)}$$

The generated vector is evaluated by inputting vector to the trained FIS and the neural network. From the obtained output vectors, the evaluation factor is determined as follows

$$E_f^{(a)} = 0.3\ \beta_1 THD_a^{net} + \beta_2 THD_a^{FIS} + (THD_a^{net} - THD_a^{FIS})^2]$$

where, $E_f^{(a)}$ is the evaluation factor for every arbitrary vector, THD_a^{net} and THD_a^{FIS} are the total harmonic distortion, when the a[th] vector is the switching angle pattern estimated by the neural network and FIS, respectively and b1 and b2 are constants. The THD can be determined as follows

$$THD_a^{net} = \frac{1}{\left|V_{out_1}^{(a)}\right|}\sqrt{\sum_{H=3,5..}^{N_H} \sigma_H \left|V_H^{(a)}\right|^2}$$

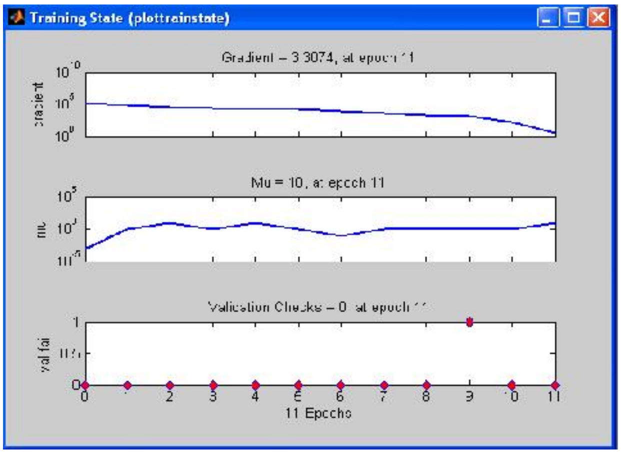
where, $V_{out_1}^{(a)}$ and $V_H^{(a)}$ are the fundamental voltage estimated by the neural network for the a[th] vector and the h[th] order harmonics voltage respectively and σ_H is the selection factor for h[th] order harmonics. From the pool, $P_{size}/2$ vectors that have minimum evaluation factor are selected and subjected to vector replacement. In the vector replacement operation, the vector that has the least evaluation factor is obtained. Based on the vector, the replacement of elements of the remaining vector are performed as follows

$$\alpha_j^{new} = \begin{cases} \dfrac{\alpha_j^{2} + 1}{\alpha_j} & ; \alpha_j < \alpha_j^{least} \\ \alpha_j\ ; & \alpha_j = \alpha_j^{least} \\ \dfrac{\alpha_j^{2} - 1}{\alpha_j} & ; \alpha_j > \alpha_j^{least} \end{cases}$$

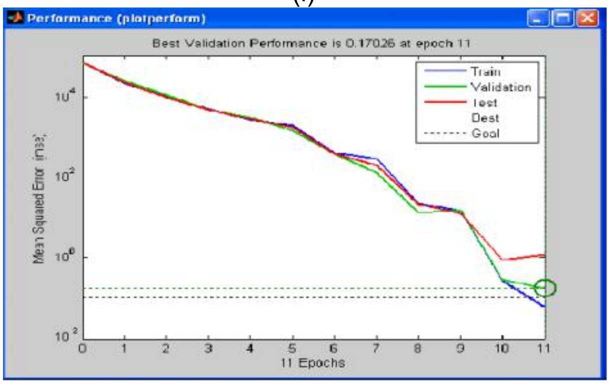
where, α_j^{new} is the j[th] new switching angle and α_j^{least} is the j[th] switching angle, which is obtained from the vector that has the least evaluation factor. Thus obtained new vectors are subjected to satisfy the constraint given in above equation. Once the vector elements replacement is done, $P_{size}/2$ vectors are obtained. They are placed in the pool along with the selected $P_{size}/2$ vectors so as to make the pool size to be *P size* . The entire process is repeated until the number of iterations reaches I_{max} . Once the maximum number of iterations is reached, the process is terminated and the vector which has the least evaluation factor is obtained from the pool. The resultant vector has the optimal switching angles that can prevent the generation of harmonics for the given UPS inverter, by selectively mitigating the given harmonic elements.

3.Implementation Results

The implementation of the proposed technique is performed in the working platform of MATLAB (version 7.10) and we have utilized the provided fuzzy and neural network toolboxes. In the evaluation phase, we have considered that the UPS has the inverter type of H-bridge inverter, which is responsible for generating the harmonics affected voltage waveforms. The inverter has 3 H-bridges and so 3 switching angles α_0, α_1 and α_2 are need to be selected optimally. The technique is implemented in such a way that it can eliminate the 3[rd] order and 5[th] order harmonics and so it can minimize the total harmonic distortion. During the generation of fuzzy rules, $N_I = 5$ is considered and accordingly the rules are generated for the corresponding $N_I = 5$ classes. Once the fuzzy rules have been generated, the network training process has also been performed. The performance of the network in its training stage is depicted in Fig.1. In the hybrid evaluation of switching angles, the iterative approach is tested for different number of iterations. The output voltage obtained for those attained optimal switching angles are given in output waveforms.



(i)



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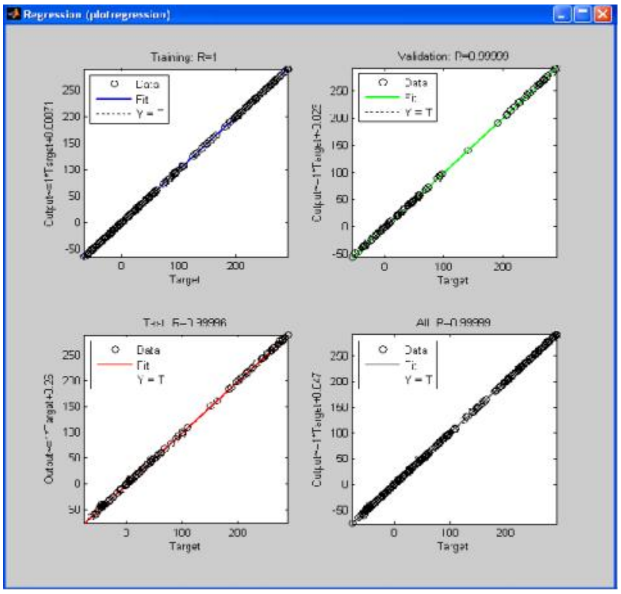

(iii)

Fig1: The performance of the neural network training process in the proposed technique

4. Results and Discussion

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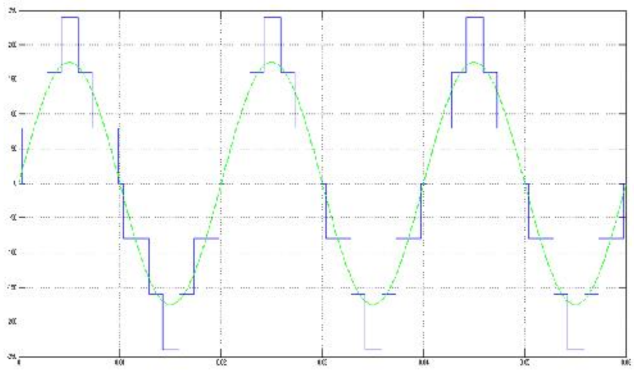

Fig3: Final output waveform from the inverter

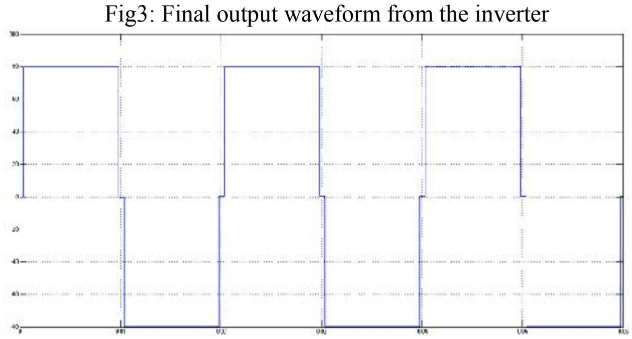

Fig4: Output waveform switching angles of inverter bridge1

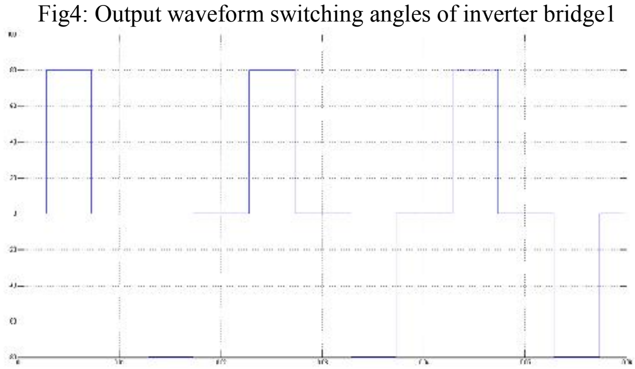

Fig5: Output waveform switching angles of inverter bridge2

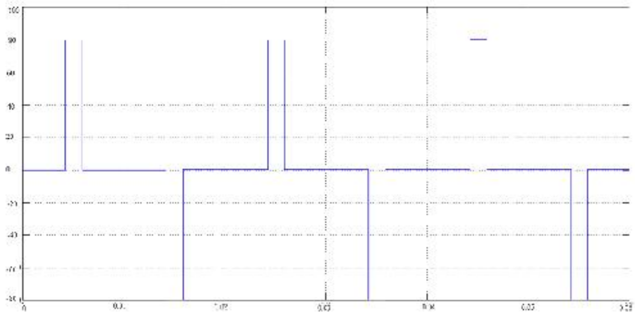

Fig6: Output waveform switching angles of inverter bridge3

Conclusions

In this project, a hybrid technique has been proposed to eliminate the harmonics that are generated from the UPS's multilevel inverters. The technique was implemented to evaluate its performance in the elimination of harmonics in a 7-level 3 H-bridge inverter. The performance was evaluated in different iteration levels of the hybrid evaluation technique. From the results, it has been shown that the proposed technique can reach a remarkable level in harmonics elimination by mitigating the dominant odd order harmonics. The results analysis has shown that the suggested optimal switching angles can avoid the generation of harmonics and so the generated voltage waveform can maintain its harmonics free shape. By using the obtained switching angles, the harmonics generation can be avoided and so the subjected UPS can offer uninterruptible power supply with very less risk factors to the utilities.

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