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Reduction of Harmonics in Multilevel Inverter with Non-Linear Load Using Fuzzy logic Controller

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ABSTRACT

Multilevel converters are widely used in high voltage and high power applications because of their ability to generate staircase output voltage close to a sinusoidal waveform with lower harmonic distortion, higher output voltage levels and reduce switching losses with Electromagnetic Interference (EMI) problem. In this paper a new modulation technique has been introduced based on elimination of harmonic in multilevel inverter with nonlinear load by using fuzzy logic techniques. The fuzzy logic controller has been used for closed loop operation and the performance of proposed multilevel inverter has been estimated. Fundamental Switching scheme and Selective Harmonics Elimination were used to reduce the Total Harmonics Distortion (THD) value. This new technique has better effect on output voltage quality and less Total Harmonic Distortion (THD) than other modulation techniques. In order to verify the proposed modulation technique, MATLAB simulations are carried out for an inverter system.

KEYWORDS: Multilevel inverter, Fuzzy Logic, THD, SPWM

INTRODUCTION

Multilevel Inverters are used in high power and high voltage applications due to their attractive benefits in generating high quality output voltage. Increasing the number of voltage levels can lead to a reduction in lower order harmonics. Therefore high power and medium voltage inverter has recently become a research focus. Various modulation and control techniques are introduced for multilevel converters like Space Vector Modulation (SVM), Sinusoidal Pulse Width Modulation (SPWM) and Harmonic Elimination (HE) methods. The multilevel concept is used to decrease the harmonic distortion in the output waveform without decreasing the inverter power output. A simple uniform PWM control of the output voltage is seen to be sufficient to practically remove all remaining harmonics the harmonic elimination in multilevel cascaded inverter systems using carrier phase shifting are investigated and presented [1-4]. Kang *et al* [5] have presented the five-level cascade inverter and the harmonic characteristics for each multi-carrier PWM technique was compared with simulation. This method was reduced the amount of calculation and simplified the process. There is no analysis for the load changes and order of harmonics.

Palanivel, P *et al* [6] have demonstrated the various carrier pulse width modulation techniques, which can minimize the total harmonic distortion and enhances the output voltages from five level inverter. Phase shifted pulse width modulation (PSPWM) concepts are propose, The Field programmable gate array (FPGA) have been chosen to implement the pulse width modulation techniques. The simulation and experimental results are presented. The harmonics eliminations of the multilevel inverter with non linear load were not presented. Rosas-

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Caro, J.C *et al* [7] have demonstrated the DC-DC multilevel boost converter using pulse-width modulation (PWM) techniques with DC-DC converter. The analyses of multilevel inverter with harmonics are not presented. The comparison between simulation and hardware was present. The different multilevel inverter topologies and their comparison have been presented. the harmonic content was reduced in the output voltage by incorporating different multi level inverter topologies using sinusoidal PWM technique were presented by Karnik, N. *et al* [8].

Later Deepa, K *et al* [9] have developed the Modified Cascaded Multilevel Converters with reduced number of dc voltage source in output voltage as compared to conventional cascaded converters. The output voltage was obtained with different load conditions. The harmonics analysis of the converter was presented. Merry Geisa, J *et al* [10] have demonstrated the harmonics elimination in three levels H bridge multilevel inverter with fuzzy logic controller. The simulation and experimental result were presented. The THD analysis of the inverter was not present. Later Gobinath.K *et al* [11] have demonstrated the Seven level switches topology has been reduced only seven switches. The simulation analysis of the inverter was not present and also there is no evaluation of the harmonics analysis. J. N. Chaisson *et al* [12] have developed the harmonics elimination equation for multilevel inverter. There is no estimation analysis for simulation and implementation. S. Sirisukprasert *et al* [13] have demonstrated the Harmonic Reduction with a Wide Range of Modulation Indexes for Multilevel Converters. The analysis of the total harmonics distraction of the multilevel inverter was not presented. The harmonics elimination equations are more complicated. Lower order harmonics elimination equation was presented by S. Jian *et al* [14]. The above literature does not deal with fuzzy logic controlled seven level inverter system. This work proposes FLC for multilevel inverter.

It is clear from the above literatures that the harmonics elimination in output voltage have important role in multilevel inverter. In the proposed system the harmonic elimination using PWM technique with fuzzy logic controller is presented. This research paper deals with a comparative study of harmonic analysis in SPWM techniques in multilevel inverter. There are many modulation techniques for multi-level inverters. Carrier based modulation (SPWM) technique is easy and efficient. Phase-shifted multicarrier techniques for obtain multilevel output voltages are commonly used in real industrial applications. PWM methods generally have the following features: good utilization of dc-link voltage, low current ripple, and easy hardware implementation by a digital signal processor (DSP). Due to all this advantages SPWM is becoming popular choice for high-voltage high power applications. From this study it is found that the total harmonic distortion is low for higher levels of multilevel inverter and hence the efficiency of the system will be improved. The harmonic contents in output voltage and load current has been analyzed in 5^{th} and 7^{th} harmonics in SPWM techniques and has been studied by the MATLAB/Simulink.

II. Harmonics Elimination:

In industry and electronics application one of the biggest problems in power quality aspects is the harmonic contents. Generally, harmonics may be divided into two types: 1) voltage harmonics, and 2) current harmonics. A current harmonic are usually generated by harmonics contained in voltage supply and depends on the type of the load such as resistive load, capacitive load, and inductive load. Both harmonics can be generated by either the source or the load side. Harmonics generated by load are caused by nonlinear operation of device, including power converters, furnaces, gas discharge lighting devices, etc. Load harmonics can cause the overheating of the magnetic cores of transformer and motors. The harmonics are mainly generated by power supply with non-sinusoidal voltage or non-sinusoidal current waveforms. Voltage and current source harmonics involve power losses, Electro-Magnetic Interference (EMI) and pulsating torque in loads. There are several methods to indicate the quantity of harmonics contents. The most widely used measure is the total harmonics distortion (THD), which is defined in terms of the magnitudes of the harmonics, Nn at pulsation, where w is pulsation of the fundamental component whose amplitude is N1 and n is an integer. The THD is mathematically given by

$$THD = \frac{\sqrt{\sum_{n=2}^{\infty} N_n^2}}{N_1}$$

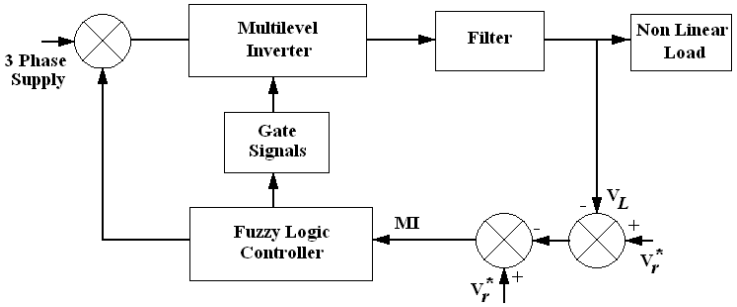

Fig. 1: Block diagram of the proposed system

Multilevel inverters have drawn tremendous interest in the power industry. They present a new set of feature that is well suited for use in reactive power compensation. Multilevel inverters will significantly reduce the magnitude of harmonics and increases the output voltage and power without the use of step-up transformer. A multilevel inverter consists of a bridge inverter units connected to non linear load. The general function of this multilevel inverter is to synthesize a desired voltage from several DC sources. The AC terminal voltages of each bridge are connected in series. Unlike the diode clamp or flying capacitors inverter, the cascaded inverter does not require any voltage clamping diodes. This configuration is useful for constant frequency applications such as active front-end rectifiers, active power filters, and reactive power compensation. The overall block diagram of the proposed inverter as shown in figure.1.

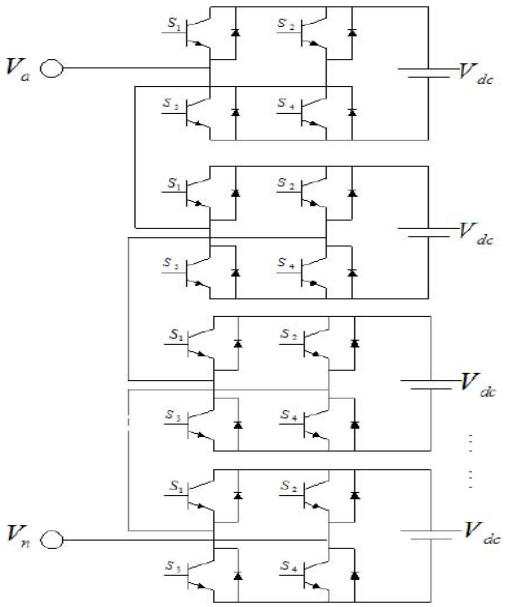

Fig. 2: Circuit Diagram of multilevel inverter

A. Mathematical Method of Harmonics Elimination:

In order to verify the ability of the proposed multilevel inverter topology to synthesize an output voltage with a desired amplitude and better harmonic spectrum, programmed PWM technique is applied to determine the required switching angles. It has been proved that in order to control the fundamental output voltage and eliminate h^{th} harmonics, therefore h+1 equation is needed. Therefore, 7-level inverter, for example, can provide the control of the fundamental component beside the ability to eliminate or control the amplitudes of two harmonics, not necessarily to be consecutive. The method of elimination will be presented for 7-level inverter such that the solution for three angles is achieved. The Fourier series expansion of the output voltage waveform using fundamental frequency switching scheme in equation is

$$V(\omega t) = \left(\frac{4V_{DC}}{\pi}\right)\sum[\cos(h\theta_1) + \cos(h\theta_2) + \cos(h\theta_3) + \ \ldots\ldots\ldots + \cos(h\theta_n)]\ \sin(h\omega t) \quad (1)$$

Where h= 1,3,5,7,…

Where n is the number of dc sources in the multilevel inverter. Ideally, given a desired fundamental voltage V1, to determine the switching angles $\theta_1,\theta_2,\ldots\theta_n$ so that

$$V_0(\omega t) = V_1\ \mathrm{Sin}(\omega t) \quad (2)$$

and a specific higher harmonics of $V_h(\omega t)$ are equal to zero. To eliminate 5th, 7th, and 9th order harmonics, the firing angles for each level is found by solving with the use of above equation.

$$\cos(\theta_1) + \cos(\theta_2) + \cos(\theta_3) = m \quad (3)$$

$$\cos(5\theta_1) + \cos(5\theta_2) + \cos(5\theta_3) = 0 \quad (4)$$

$$\cos(7\theta_1) + \cos(7\theta_2) + \cos(7\theta_3) = 0 \quad (5)$$

Where modulation index is

$$MI = \frac{V_1}{\frac{4V_{DC}}{\pi}} \quad (6)$$

RESULTS AND DISCUSSION

A. Design of Fuzzy logic Controller:

The fuzzy logic controller (FLC) unlike conventional controllers does not require a mathematical model of the system being controlled. However, an understanding of the system and the control requirements is necessary. The fuzzy controller designer must define what information flows into the system, now the information is processed, and what information flows out of the system. Fuzzy control involves three stages: fuzzification, inference or rule evaluation and defuzzification as shown in fig.3. Multilevel inverter is modeled using Mat lab software. Fuzzy control is developed using the fuzzy toolbox. The fuzzy variables e, ce and Δu are described by triangular membership functions. Seven triangular membership functions are chosen for simplicity. Table 1 shows the fuzzy rule base created in the present work based on intuitive reasoning and experience. Fuzzy memberships LP, MP, SP, ZZ, SP, MP, LP.

Table 1: Rule Table

	LP	MP	SP	ZZ	SN	MN	LN
LP	LP	LP	LP	LP	MP	SP	ZZ
MP	LP	LP	MP	MP	SP	ZZ	SN
SP	LP	MP	MP	SP	ZZ	SN	MN
ZZ	MP	MP	SP	ZZ	SN	MN	MN
SN	MP	SP	ZZ	SN	SN	MN	LN
MN	SP	ZZ	SN	MN	MN	LN	LN
LN	ZZ	SN	MN	LN	LN	LN	LN

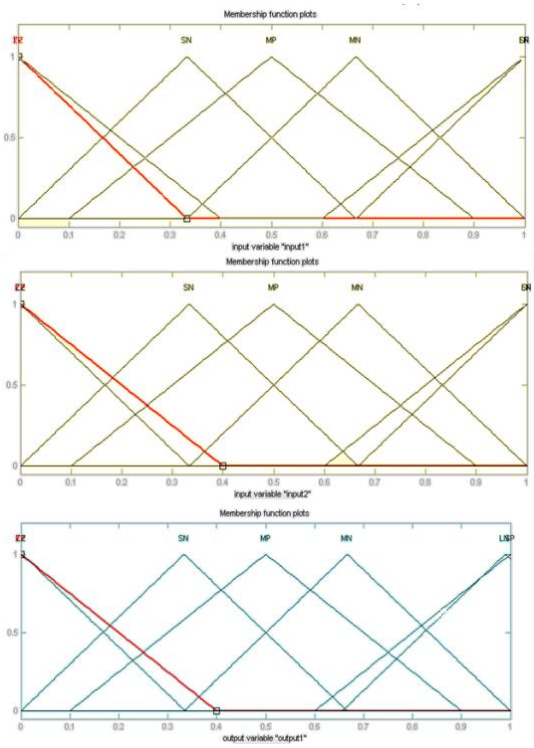

Fig. 3: Fuzzy Membership Function

The control rules that relate the fuzzy output to the fuzzy inputs are derived from general knowledge of the system behavior, perception and experience. It can inferred that the output voltage is far from the reference value, then the change of switching frequency (Δu) must be large so as to bring the output to the reference value quickly. The output voltage approaches the reference value, and then a small change of switching frequency is necessary and if the output voltage is near the reference value and is approaching it rapidly, then the frequency must be kept constant so as to prevent overshoot. It is also seen that if the output voltage changes even after reaching the reference value then the change of frequency must be changed by a small amount to prevent the output from moving away. The Graphical representations for the fuzzy rules are shown in Fig.4.

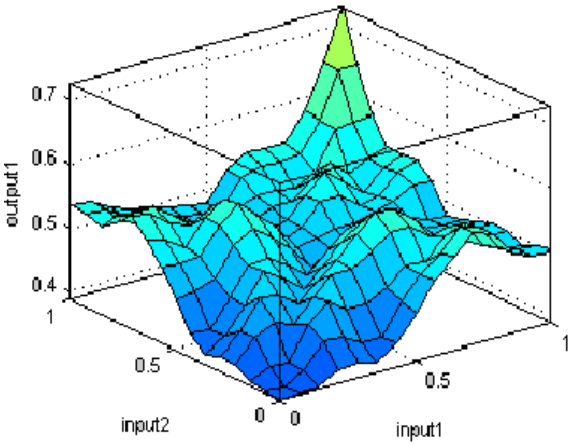

Fig. 4: Graphical representations for the fuzzy rules

At every sampling interval, the instantaneous RMS values of the sinusoidal reference voltage and load voltage are used to calculate the error (e) and change in error (ce) signals that act as the input to the FLC. The stage of fuzzification, fuzzy inference and defuzzification are then performed.

B.Simulation Results:

The seven-level inverter is simulated using MATLAB/Simulink and switching signals are generated using S-function block by employing the proposed modulation strategy. The simulation is carried out for different modulation index and carrier frequency values. The multilevel inverter is simulated using Fuzzy logic controller is carried out using Simulink. Depending on error and the change in error, the value of change of switching frequency is calculated. The Fuzzy set parameters instruction and function blocks available in MATLAB are used to update the new switching frequency of the pulse generators. The simulated structure of fuzzy controller in inverter side is shown in Fig.5. Switching signals for multilevel inverter using SPWM strategies are simulated and shown in fig.6. Simulations were performed for different values of Modulation Index ranging from 0.8 to 1 and the corresponding %THD is measured using the FFT block. Figure 7 to10 show the simulated output voltage of multilevel inverter and their corresponding harmonic spectrum. The parameters used for simulation are given in Table-2.

Table 2: Parameters Used For Simulation

Parameter	Value
Input Voltage (V DC)	200 V
Modulation Index	1.0
Inductance	30µ H
Capacitance	70Mf
3 Phase RL Load	100 Ohms, 100 Mh
Switching Frequency	50Hz
Reference Voltage	200 V

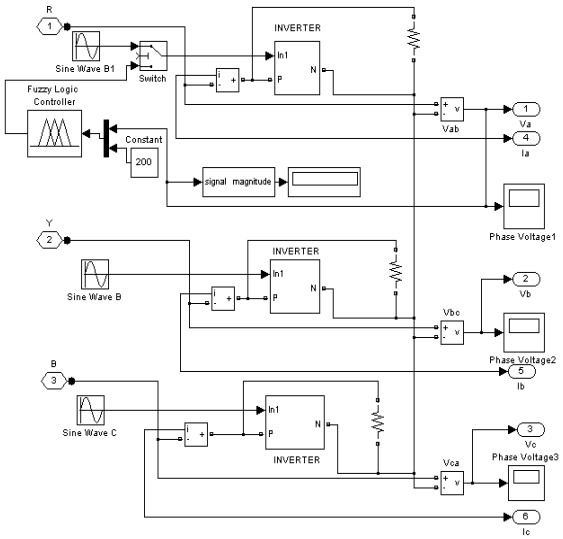

Fig. 5: Simulink Model of the proposed multilevel inverter with Fuzzy controller

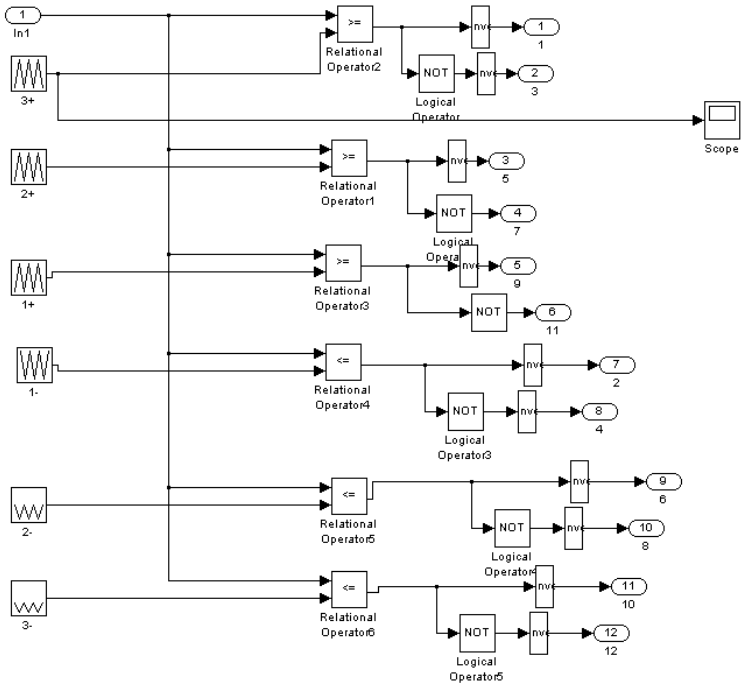

Fig. 6: Simulink diagram of Sample PWM generation

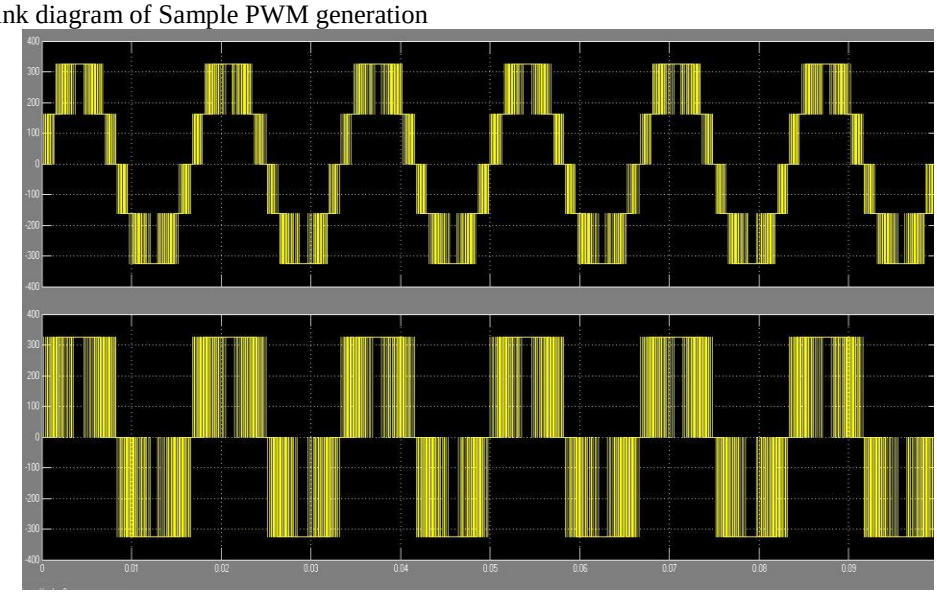

Fig. 7: Output Voltage of Five Level Multilevel inverter

The output voltage wave of the five level and seven level inverter for five cycles with a switching frequency of 3 kHz is shown in fig7 and 8 respectively. Multi Level Inverter has better counterparts to the Single pulse width modulated inverters to overcome switching losses, requirement of switches with low turn-on and turn-off times. In addition they offer the advantage of less switching stress on each device for high voltage, high power applications with reduced harmonic content at low switching frequency.

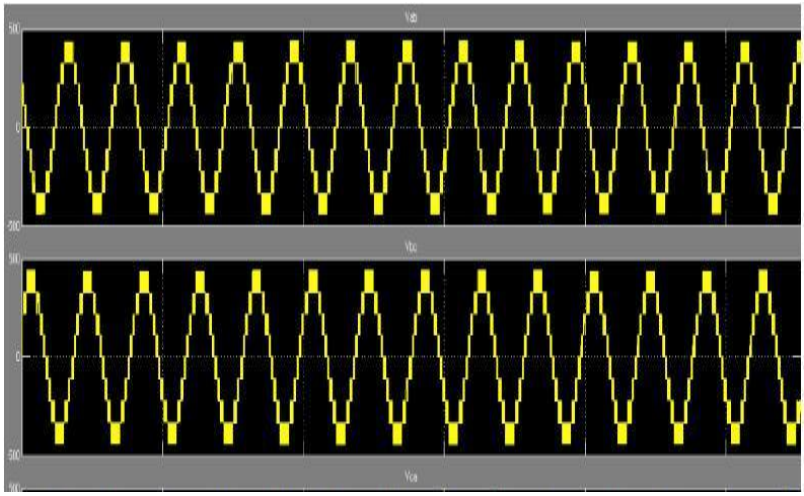

Fig. 8: Output Voltage of Seven Level Multilevel inverter

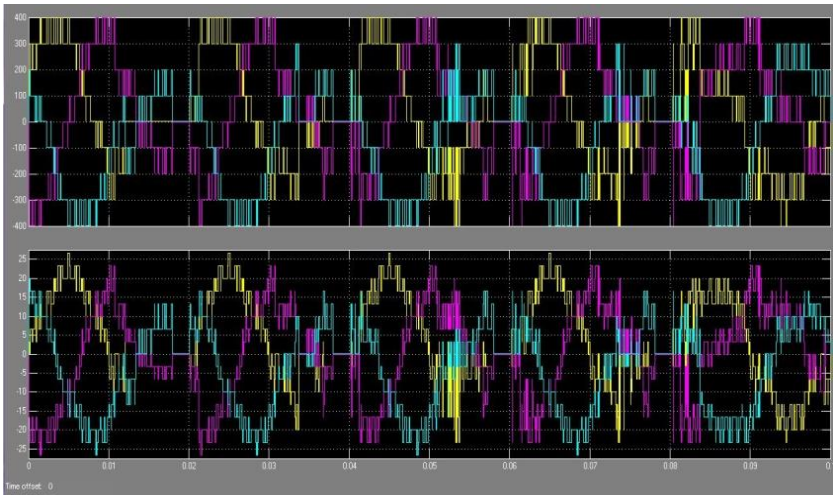

Fig. 9: Line voltage and Line Current waveforms for seven Level Multilevel inverter

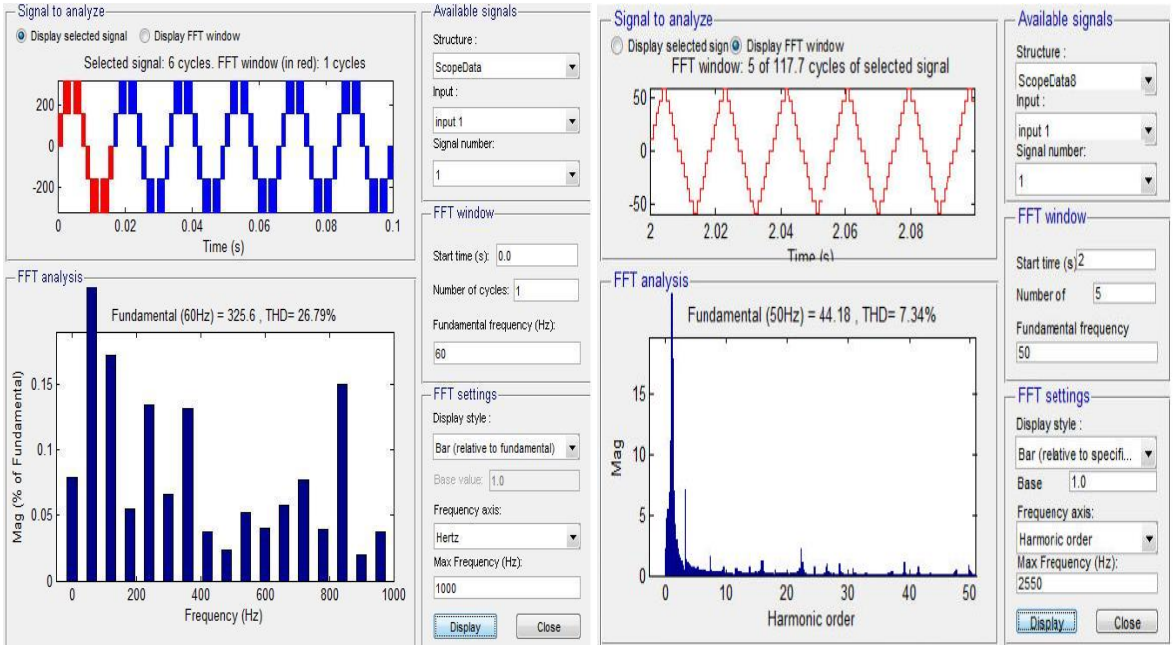

Fig. 10: FFT analysis for 5 level and 7 level MLI

Fig.10. presents THD of the 5 level and 7 level multi level inverter output voltage. These results show that the SPWM method gives harmonic reduction for individual harmonic. The main advantage of the proposed technique is that the number of switching per cycle is same for all the levels. For balancing the switching actions, the choice of the carrier frequency is very important. Hence, the SPWM scheme is more favorable than the conventional PWM technique. For proposed topology the harmonic spectrum of the simulation system are compared and presented in the Table 3 at various levels

Table 3: Thd Analysis Of Five And Seven Level Inverter

Parameters	Multilevel Inverter	
	5 Level	7 Level
Voltage Level	210.4	222.4
THD %	26.79	7.34

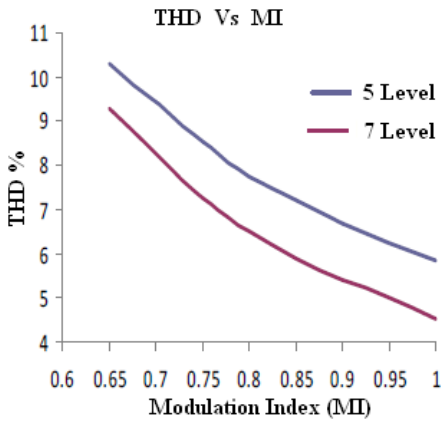

Fig. 11: THD Vs Modulation Index from 0.6 to 1

The THD vs modulation index is shown in fig.12. it is clear from the chart the TDH value is less in numbers level to be increased. It is obvious that SPWM technique shows a better performance for the seven-level inverter. The THD of the SPWM is shown with fuzzy controller which minimizes the amount of harmonics. The main advantage of the proposed technique is that the number of switching per cycle is same for all the levels. For balancing the switching actions, the choice of the carrier frequency is very important. Hence, the SPWM scheme is more favorable than the PWM technique

Conclusion:

A model of the closed loop system for MLI with Fuzzy controller has been developed and simulated to study the system response. With the familiar knowledge a rule based fuzzy logic controller is developed to enhance the system performance. A comparative study of THD of the output voltage waveform and switching losses of five level and seven level three phase multilevel inverter has been presented using SPWM techniques. It has been observed that THD decrease with the increase in the number of levels in the output voltage. It is also seen that the proposed Fuzzy logic controller can offer low THD under nonlinear loading condition and good dynamic response under transient loading condition. The Multilevel Inverter with the proposed Fuzzy logic controller is found to be suitable for utility applications where the load introduces periodic distortions. The scope of the present work is to compare performance of five level and seven level systems. The hardware will be implemented in near future.

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