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Control of Cascaded H-Bridge Multilevel Inverter in Different Levels Using Fuzzy Logic Controller

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Abstract: Cascaded H-bridge multilevel inverter is a promising topology and is increasingly being considered for high power applications because of their ability to operate at higher output voltages while producing lower levels of harmonic components in the switched output voltages. A small total harmonic distortion is the most important feature of these inverters. This study compares the total harmonic distortion in 5, 7, 9 and 11 levels of cascaded H-bridge multilevel inverter employing sinusoidal pulse width modulation control technique and photovoltaic power source as input to the system. Fuzzy logic controller is used to control this system to get the required output voltage. The results gained in this research prove the validity of the proposed controller of having an output voltage with minimum distortion. Hence, the efficiency of the system will be improved. The analysis has been studied by the MATLAB/SIMULINK. The simulated output shows very favorable result.

Key words: Multilevel inverter, cascaded H-bridge multilevel inverter, total harmonic distortion, photovoltaic cell, sinusoidal pulse width modulation

INTRODUCTION

In recent years, multilevel inverters have become more attractive for researchers and manufacturers due to their advantages over conventional 3-level Pulse Width-Modulated (PWM) inverters. They offer improved output waveforms, smaller filter size, lower EMI, lower Total Harmonic Distortion (THD) and others (Carrasco *et al*., 2006; Agelidis *et al*., 1997; Kouro *et al*., 2007; Park *et al*., 2003; Tolbert and Habetler, 1999; Calais *et al*., 2001; Choi *et al*., 1991; Carrara *et al*., 1992). The three common topologies for multilevel inverters are as follows: diode clamped (neutral clamped) (Nabae *et al*., 1981; Pou *et al*., 2005; Alepuz *et al*., 2006); capacitor clamped (flying capacitors) (Meynard and Foch, 1992; Kang *et al*., 2005; Lin and Huang, 2006) and cascaded H-bridge inverter (Marchesoni *et al*., 1988; Rodriguez *et al*., 2005; Kou *et al*., 2006). In addition, several modulation and control strategies have been developed or adopted for multilevel inverters including the following: multilevel sinusoidal (PWM), multilevel selective harmonic elimination and spacevector modulation (Kouro *et al*., 2007; McGrath and Holmes, 2002).

A typical single-phase 3-level inverter adopts full-bridge configuration by using approximate sinusoidal modulation technique as the power circuits. The output voltage then has the following three values: zero, positive (+Vdc) and negative (-Vdc) supply dc voltage (assuming that Vdc is the supply voltage). The harmonic components of the output voltage are determined by the carrier frequency and switching functions. Therefore, their harmonic reduction is limited to a certain degree (Park *et al*., 2003).

To overcome this limitation, this study presents a 11-level inverter whose output voltage can be represented in eleven levels. As the number of output levels increases, the harmonic content can be reduced. This inverter topology uses five reference signals, instead of one reference signal, to generate PWM signals for the switches.

Reduction of THD can be considered from three different perspectives, namely by considering new switching strategies, by designing alternative circuit topological structures and by proposing appropriate control techniques. The third perspective, i.e., proposition of appropriate control technique is an alternate solution for THD reduction is discussed in this study. In view of the inherent advantages, the sinusoidal PWM switching strategy and cascaded inverter structure are employed in this research. A fuzzy logic control scheme is used here to improve the transient response as well as to regulate the output voltage with zero steady-state error under disturbances with minimum THD. The simulations have been carried out for non-linear loads. The waveforms of output voltage and current along with the harmonic spectra of output voltage are presented and evaluated.

CASCADED H-BRIDGE MULTILEVEL INVERTER

The structure of single cell of multilevel-cascaded H-bridge configuration is shown in the Fig. 1 (Lipo and

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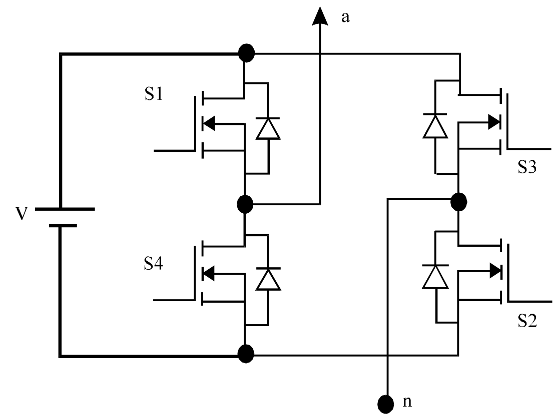

Fig. 1: Single cell of multilevel cascaded inverter

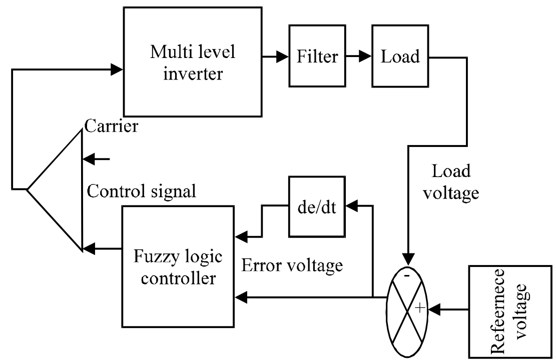

Fig. 2: Cascaded MLI with fuzzy controller

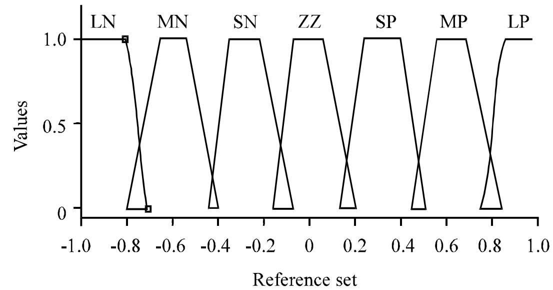

Fig. 3: Fuzzy reference sets

Manjrekar, 1999). The output of this cell will have 3-levels namely +V, 0 and -V. Using one single H-bridge, a 3-level inverter can be realized. This circuit requires about four switching devices.

To realize higher levels of output voltage, the H-bridge circuits are cascaded. The circuit has many advantages like simple, modular, improved waveform which results in reduced total harmonic distortion. The cascaded multilevel inverter circuit provides high quality output when the number of levels in the output increases and also this reduces the filter components size and cost.

CASCADED H-BRIDGE MULTILEVEL INVERTER WITH FUZZY CONTROLLER

The fuzzy logic approach has been objected of an increasing interest and has found application in many domains of control problem. The main advantages of fuzzy logic control method as compared to conventional control techniques resides on the fact that no mathematical model is required for controller design and also it does not suffer much from the stability problem but it needs the experts experience. Fuzzy logic can be considered as an alternative approach to conventional feedback control. In a closed-loop operation the system remains stable even when external disturbances occur. Compared with open-loop control, closed-loop control has the advantage of gaining precise inverter output voltage. Fuzzy logic control is developed in this research to obtain desired output voltage and minimize the harmonics of the chosen inverter (Fig. 2). The control action is determined in a FLC through the evaluation of a set of simple linguistic rules. The development of the rules requires a thorough understanding of the process to be controlled. A rule-based fuzzy logic controller is used as shown in Fig. 3 to track the reference voltage for any load condition. The inputs for the fuzzy logic controller are error and rate of change in error. The controller and the inverter of the system are completely built in Matlab/Simulink environment. The fuzzy logic controller consists of three basic blocks. Fuzzifier; inference engine and defuzzifier (Chitra *et al*., 2011).

Fuzzifier: The fuzzy logic controller requires that each control variables which define the control surface be expressed in fuzzy set notations using linguistic labels. Seven classes of linguistic labels ((Large Positive) LP, (Medium Positive) MP, (Small Positive) SP, (Very Small) ZZ, (Small Negative) SN, (Medium Negative) MN, (Large Negative) LN)) characterized by membership grade are used to decompose each system variable into fuzzy regions. The membership grade denotes the extent to which a variable belongs to a particular class/label. This process of converting input/output variable to linguistic labels is termed as fuzzification. It is executed using reference fuzzy sets shown in Fig. 4 and used to create a fuzzy set that semantically represents the concept associated with the label. In the proposed controller, the error in voltage e = (Vre, -Vo) and its rate of change are normalized, fuzzified and expressed as fuzzy sets (Table 1).

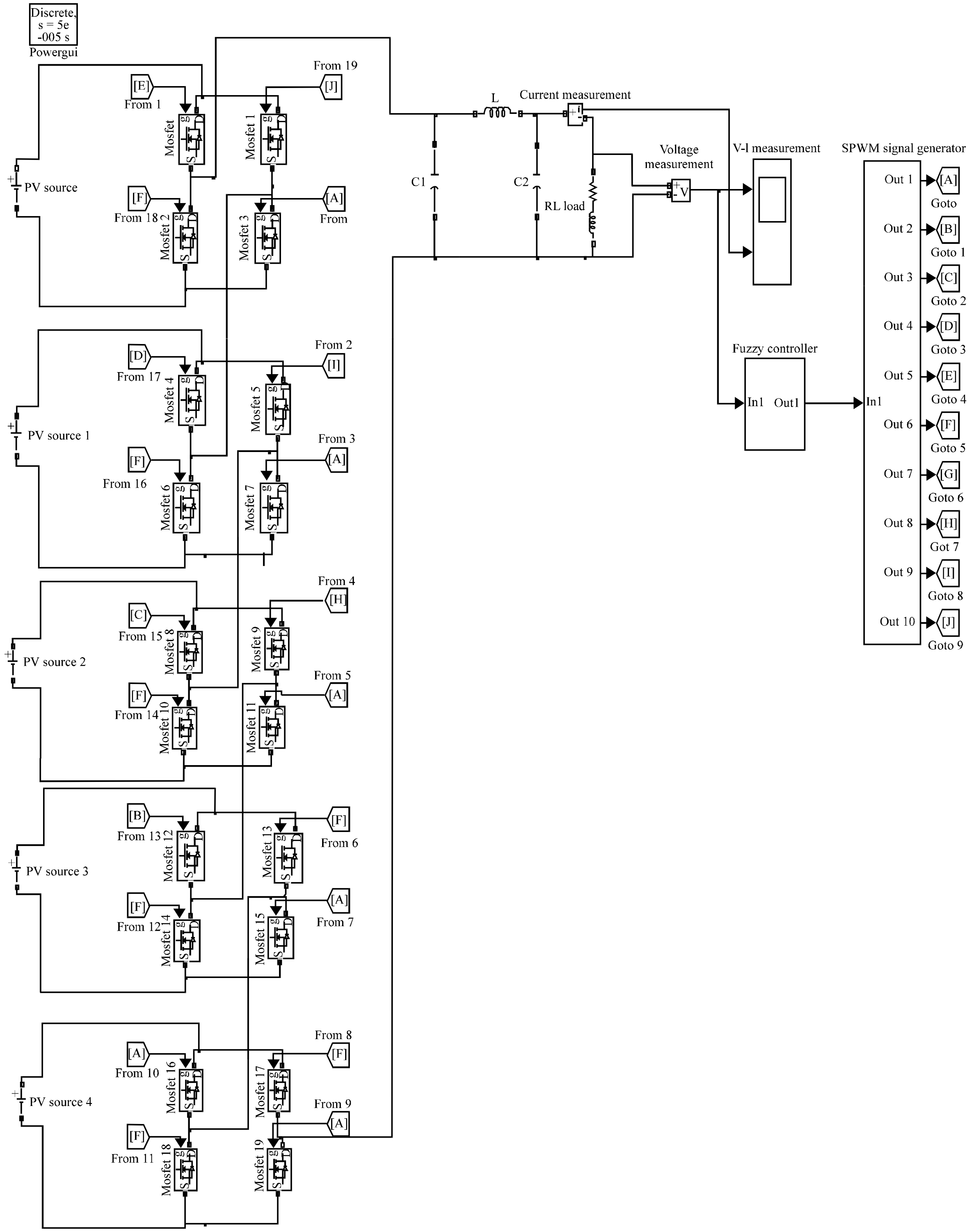

Fig. 4: SIMULINK Model of the eleven level inverter (closed loop)

Table 1: Rule base of FLC developed for cascaded MLI

	Rate of change of error						
Error	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	SP	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

Inference engine: The behavior of the control surface which relates the input and output variables of the system is governed by a set of rules. The set of rules for the fuzzy controller is shown in Table 1 which proposes a definite control action for a given error e and its rate of change error. When a set of input variables are read each of the rule that has any degree of truth (a nonzero value of membership grade) in its premises is fired and contributes to the forming of the control surface by appropriately modifying it. When all the rules are fired, the resulting control surface is expressed as a fuzzy set (using linguistic labels characterized by membership grades) to represent the controller's output.

Defuzzifier: The fuzzy set representing the controller output in linguistic labels has to be converted into a crisp solution variable before it can be used to control the system. This is achieved by using a defuzzifier. The most commonly used method for the control applications in defuzzification process is centre of area method and it is used here. The centre of area method computes the centre of gravity of the final fuzzy space (control surface) and produces a result which is sensitive to all the rules executed. Hence, the results tend to move smoothly across the control surface.

SINUSOIDAL PULSE WIDTH MODULATION TECHNIQUE

PWM technique is extensively used for eliminating harmful low-order harmonics in inverters. In PWM control, the inverter switches are turned ON and OFF several times during a half cycle and output voltage is controlled by varying the pulse width (Pou *et al*., 2005).

In the SPWM technique, a triangular carrier wave at a high witching frequency is compared with the sinusoidal reference wave at a fundamental output frequency. The control principle of the SPWM is to use several triangular carrier signals keeping only one modulating sinusoidal signal. Two and four triangular carrier signals are needed for three and 5-level inverters, respectively. The carriers have the same frequency fc and the same peak to peak amplitude Ac. The zero reference is placed in the middle of the carrier set. The modulating signal is a sinusoid of frequency fm and amplitude Am. At every instant, each carrier is compared with the modulating signal. Each, comparison switches the switch on if the modulating signal is greater than the triangular carrier assigned to that switch.

SIMULATION RESULTS

Fuzzy logic provides a better alternative as it does not require any mathematical model of the system. The rule based fuzzy logic controller is built in Matlab/ Simulink based on the information collected from the system. The cascaded H-bridge MLI with fuzzy controller has been designed and simulated. The simulation results of the cascaded H-bridge 11-level inverter is shown in Fig. 4 and the subsystem is shown in Fig. 5 and 6 show the generated gate pulses using sinusoidal pwm control technique to the multilevel inverter switches. From the gate pulse turn on period it is observed that each switches turned on at different time period to synthesize required output voltage. The proposed circuit needs independent dc source which is supplied from photovoltaic cell. For each of the H-bridges in the cascaded multilevel inverter, 12 V photovoltaic power source is used. The switching device used is 400 V, 10 A MOSFET. In case of 5-level inverter requires eight switches to get the 5-level output voltage and the simulated line voltage and THD analysis for 5-level H-bridge inverter is shown in Fig. 7 and 8. The simulated value of THD is 40.19%. In case of 7-level inverter requires twelve switches to get the 7-level output voltage and the simulated line voltage and THD analysis for 7-level H-bridge inverter is shown in Fig. 9 and 10. The THD value is 20.33%. In case of 9-level inverter requires sixteen switches to get the 9-level output voltage and the simulated line voltage and THD analysis is shown in Fig. 11 and 12. The THD value is 11.37%. In case of 11-level inverter requires twenty switches to get the 11-level output voltage and the simulated line voltage and THD analysis is shown in Fig. 13 and 14. The THD value is 2.19%. Thus, the performance of the cascaded MLI with Fuzzy controller employing sinusoidal pulse width modulation technique is found to be superior when compared with the cascaded MLI with fuzzy controller employing multicarrier pulse width modulation technique.

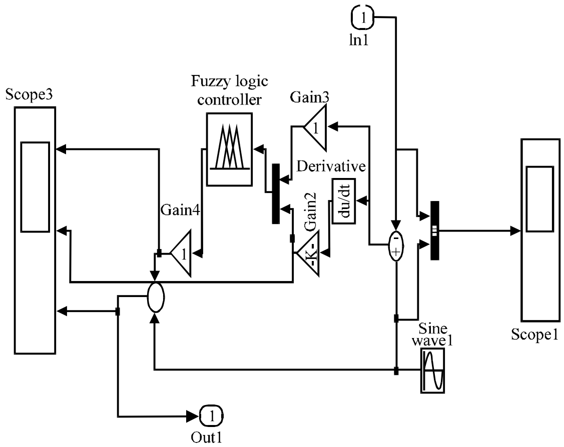

Fig. 5: Subsystem

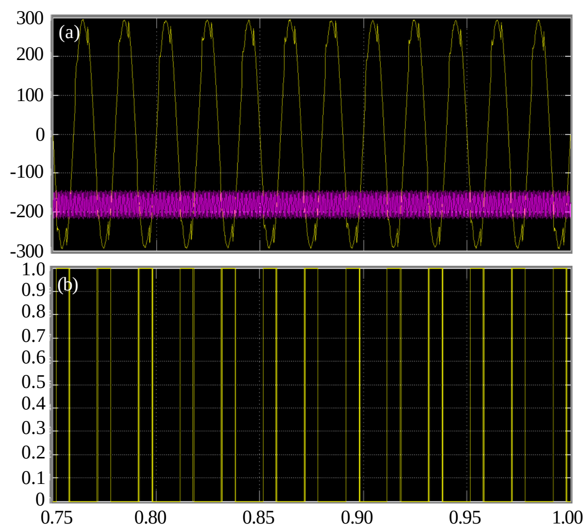

Fig. 6: Gating pulses

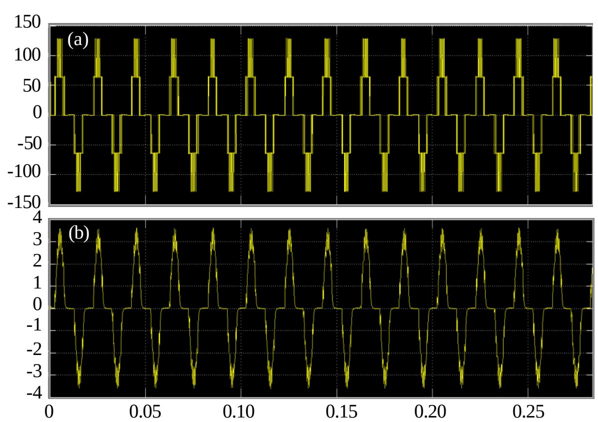

Fig. 7: Output voltage waveforms of 5-level inverter; a) Output voltage of 5-level inverter and b) Filtered output voltage of 5-level inverter

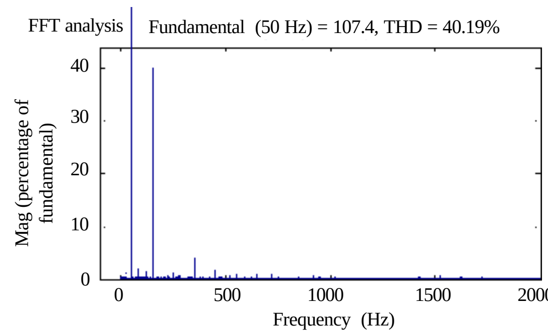

Fig. 8: THD analysis of 5-level inverter

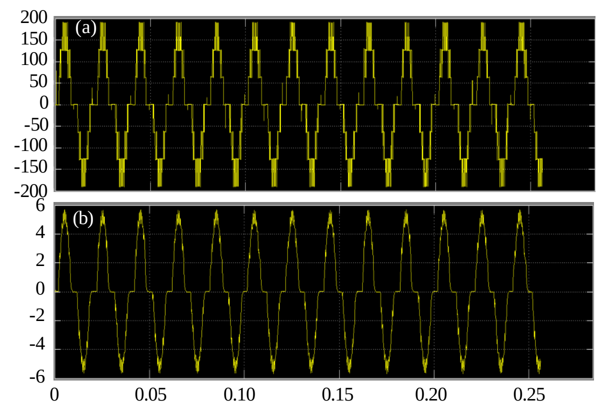

Fig. 9: Output voltage waveforms of 7-level inverter; a) Output voltage of 7-level inverter; b) Filtered output voltage of 7-level inverter

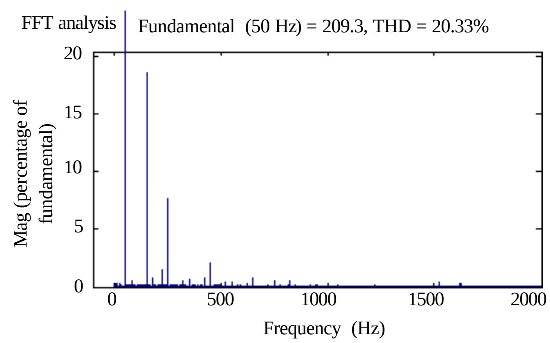

Fig. 10: THD analysis of 7-level inverter

Here, load is taken as RL load so that the total harmonic distortion is very low as achieved by R load. Table 2 shows the cascaded H-bridge multilevel inverter topology employing sinusoidal pwm technique of various levels.

From the above simulated analysis, it is found that the total harmonic distortion of the system will be

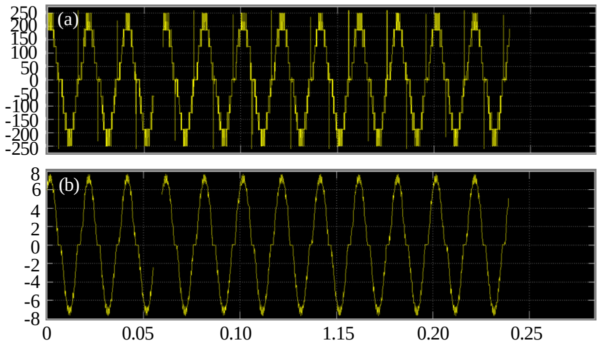

Fig. 11: Output voltage waveforms of 9-level inverter; a) Output voltage of 9-level inverter and b) Filtered output voltage of 9-level inverter

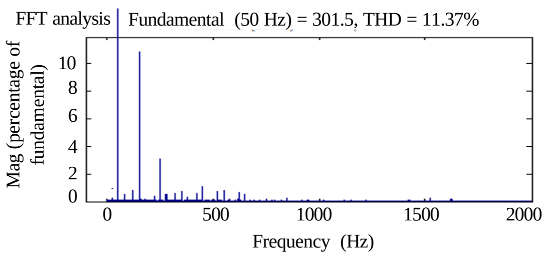

Fig. 12: THD analysis of 9-level inverter

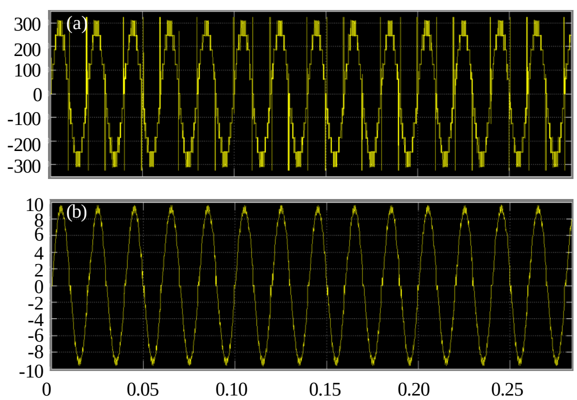

Fig. 13: Output voltage waveforms of 11-level inverter; a) Output voltage of 11-level inverter and b) Filtered output voltage of 11-level inverter

Table 2: Cascaded H-bridge multilevel inverter topology

Levels	DC sources	Bridges	Switches	THD (%)
5	2	2	8	40.19
7	3	3	12	20.33
9	4	4	16	11.37
11	5	5	20	2.19

reduced by increasing the number of levels in the output waveform and hence the efficiency of the system will be improved.

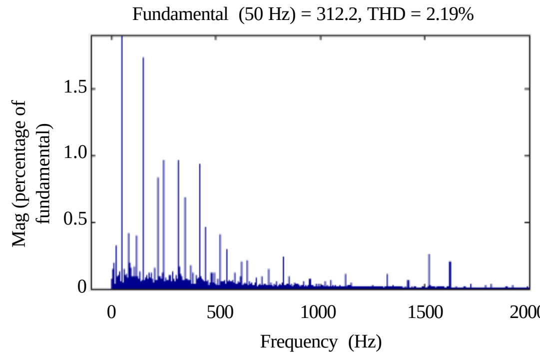

Fig. 14: THD analysis of 11-level inverter

CONCLUSION

This research focus on the detailed harmonic distortion analysis in 5, 7, 9 and 11 levels of cascaded H-bridge multilevel inverter. A sinusoidal pulse width modulation control technique is adopted in the firing circuit to provide an acceptable control in the inverter output voltage. The performance of the cascaded MLI with fuzzy controller employing sinusoidal pulse width modulation technique is found to be superior when compared with the cascaded MLI with fuzzy controller employing multicarrier pulse width modulation technique. The simulation results prove that with this inverter strategy, the low order harmonics are substantially reduced.

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