

# A Literature Assessment of Multi-Level Inverters

P. Kiruthika, K. Ramani

**Abstract**—Multi-Level Inverter technology has been developed in the area of high-power medium-voltage energy scheme, because of their advantages such as devices of lower rating can be used thereby enabling the schemes to be used for high voltage applications. Reduced Total Harmonic Distortion (THD). Since the  $dv/dt$  is low; the Electromagnetic Interference from the scheme is low. To avoid the switching losses Lower switching frequencies can be used. In this paper present a survey of various topologies, control strategy and modulation techniques used by these inverters. Here the regenerative and superior topologies are also discussed.

**Keywords**—Cascaded H-bridge Multi-Level Inverter, Diode Clamped Multi-Level Inverter, Flying Capacitors Multi-Level Inverter, Multi-Level Inverter, Total Harmonic Distortion.

## I. INTRODUCTION

MULTI-Level Inverters (MLI) are becoming popular than two level inverter in high power applications. Multilevel output is synthesized by small dc voltage level. In multilevel inverters all the switches are connected in series which allows operation at higher voltage level [1], [2]. A multilevel converter not only achieves high power ratings, but also enables the exercise of renewable energy sources. The word multilevel begins with the three-level converter. Multilevel inverters have become more popular over the years in electric high power application with the promise of less disturbances and the possibility to function at lower switching frequencies than ordinary two-level inverters.

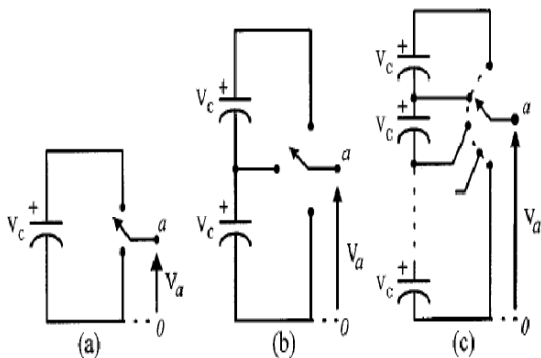


Fig. 1 One Phase Leg of an Inverter with (a) Two Levels, (b) Three Levels, and (c) N Levels

P.Kiruthika is doing PG Power Electronics and Drives at K.S.Rangasamy college of Technology, Tiruchengode 637215 Tamilnadu (mobile: 8012365494; e-mail: kiruthikamahesh510@gmail.com).

Dr.K.Ramani is working as Associate Professor, Department of Electrical and Electronics Engineering, K.S.Rangasamy college of Technology, Tiruchengode 637215 (mobile: 9788518536; e-mail: kreee82@gmail.com).

Nowadays, there exist three commercial topologies of multilevel voltage-source inverters Diode clamped (DC) [3], Flying Capacitors (FCs) [5], and Cascaded H-bridge (CHB) [4]. The proposed scheme of MLI having some modulation techniques to control the output voltage and it can be used to reduce the total harmonic distortion. The purpose of this paper is to give a detailed comparison of different techniques for control and the topology of MLI.

## II. TOPOLOGY OF MULTILEVEL INVERTER

### A. Diode Clamped Multi-Level Inverter

The main concept of this inverter is to use diodes and provides the multiple voltage levels through the different phases to the capacitor banks these are series. A diode transfers a voltage in the limited amount, thereby dropping the stress on other electrical devices. Half of the input DC voltage is the maximum output voltage. Negative feature of the DCMLI can be eliminated by increasing the switches, diodes, and capacitors [6-10]. These are limited to the three levels, because of the capacitor balancing issues and it provides the high competence due to the fundamental frequency used for all the switching devices and it is a simple method of the back to back power transfer systems. Ex: 5- Level diode clamped multilevel inverter, 9- level diode clamped multilevel inverter. The 5- level diode clamped multilevel inverter uses switches, diodes and a single capacitor. As compared to the 5-level diode clamped inverters, the 9- level diode clamped multilevel inverters having two times extra switches, diodes, capacitors.

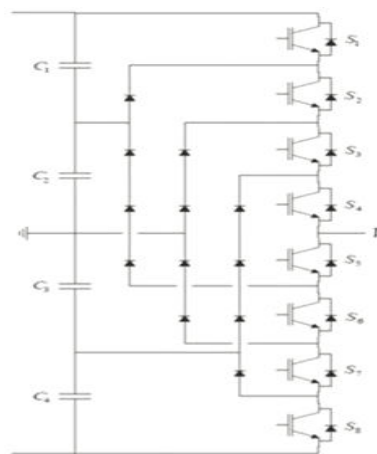


Fig. 2 Five-Level Diode Clamped Multilevel Inverter

Here the main application of the DCMLI is Static VAR compensation, Variable speed motor drives, High voltage system interconnections, High voltage DC and AC transmission lines.

*B. Flying Capacitors Multi-Level Inverter*

The main concept of this inverter is to use capacitors and it can connect in series. The capacitors transfer the partial quantity of voltage to electrical devices. Switching states of these inverters are like as the diode clamped inverter switching states. The input voltage is higher than half of the output DC voltage [11]-[16]. It is weakness of the FCMLI. It also has the switching redundancy within phase to balance the flying capacitors. Both the active and reactive power flow can be controlled. Due to this high switching frequency, switching losses will takes place. Ex: 5-level flying capacitors multilevel inverter, 9-level flying capacitors multilevel inverter. This inverter is same like that diode clamped multi inverter. Only switches and capacitors are used in these inverters.

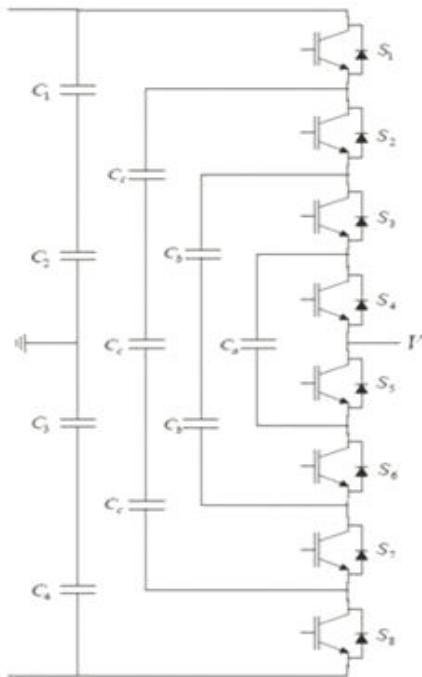


Fig. 3 Five-Level Flying Capacitors Multilevel Inverter

Here the FCMLI is used in the applications of Induction motor control using DTC (Direct Torque Control) circuit, Static var generation, Both AC-DC and DC-AC conversion applications, Converters with Harmonic distortion capability, Sinusoidal current rectifiers.

*C. Cascaded H-Bridge Multilevel Inverter*

The cascaded H-bridge multi-level inverter is to use capacitors and switches and requires less number of components in each level. It consists of series of power alteration cells and power can be scaled easily. The capacitors and switches pairs are called an H-bridge and each H-bridge gives the separate input DC voltage and offers three different voltages like zero, positive DC and negative DC voltages. One of the rewards of this type of MLI needs less number of components compared with DC MLI and FC MLI. The cost

and weight of the inverter are less than other 2 types. Soft-switching is feasible by the new switching methods [17]-[22]. Bulky transformers can be eliminated by using these inverters. Large number of isolated voltages is required to supply the each cell. Ex: 5- H-bridge multi level inverter, 9- H-bridge clamped multi level inverter. This inverter is also same like that diode clamped multi inverter.

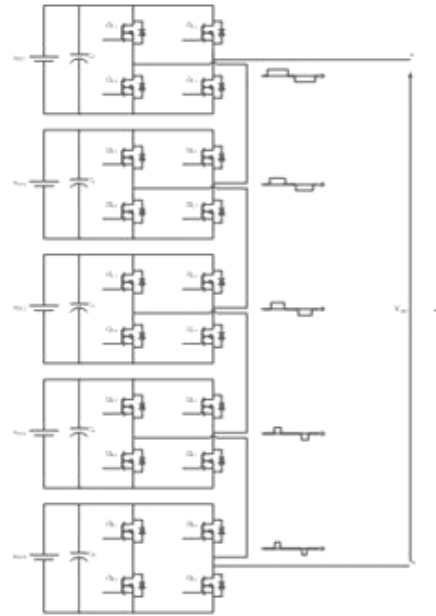


Fig. 4 Five-Level H-Bridge Multilevel Inverter

Here the CHB is used for the following applications Motor drives, Active filters, Electric vehicle drives, DC power source utilization, Power factor compensators, Back to back frequency link systems Interfacing with renewable energy resources.

TABLE I  
COMPARISON BETWEEN IMPLEMENTATION FACTORS

	DC MLI	FC MLI	CHB MLI
Exact needs	Clamping diodes	Additional capacitors	Isolated dc sources
Modularity	Low	High	High
Design and execution	Low	Medium (capacitors)	complexity (transformer)
Control concerns	Voltage balancing	Voltage setup	Power sharing
Blunder charity	Difficult	Easy	Easy

III. CONTROL STRATEGIES

To Control the output voltage of the inverter, we can go for the PWM technique [23]-[30]. It can be used to carrying information on gate pulses and it is encoded in the width of each pulses. By using this technique constant voltage can be maintained. A modulation approach for MLI is given in Fig. 5.

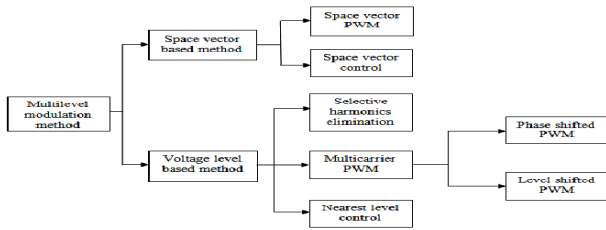


Fig. 5 Modulation Techniques for MLI

### A. Sinusoidal Pulse Width Modulation

The control principle of the SPWM is to use several triangular carrier signals keeping only one modulating sinusoidal signal. For an  $m$ -level inverter, Equation (2) is given the  $(m-1)$  triangular carriers are needed for set the frequency and amplitude value. The carriers have the same frequency  $f_c$  and the same peak-to-peak amplitude  $A_c$ . The modulating signal is a sinusoid of frequency  $f_m$  and amplitude  $A_m$ . Each carrier signal is compared with the modulating signal at every instant [31]-[35]. Each comparison switches the switch "on" if the modulating signal is greater than the triangular carrier assigned to that switch. The main parameters of the modulation process are the frequency ratio  $k=f_c/f_m$ , where  $f_c$  is the frequency of the carriers, and  $f_m$  is the frequency of the modulating signal. The definition of Modulation Index(MI) can be clarified in the Equation (1) is given by,

$$MI = A_m / (m * A_c) \quad (1)$$

Where  $A_m$  the amplitude of the modulating signal,  $A$  is the peak-to-peak value

$$m' = (m - 1) / 2 \quad (2)$$

Where  $m$  is the number of level (which is odd).

### B. Space Vector PWM

Two discontinuous multilevel space vector modulation (SVM) techniques are implemented for DVR control to reduce inverter switching losses maintaining virtually the same harmonic performance as the conventional multilevel SVM for high number of levels. [35], two carrier-based modulation techniques for a dual two-level inverter with power sharing capability and proper multilevel voltage waveforms were introduced. Their main advantage is a simpler implementation compared to SVM. [36] Focused a novel 3-D space modulation technique with voltage balancing capability for a cascaded seven-level rectifier stage of SST. Switching strategy for multilevel cascade inverters, based on the space-vector theory. The proposed switching strategy generates a voltage vector with very low harmonic distortion and reduced switching frequency. [41], PWM technique for induction motor drives involving six concentric dodecagonal space vector structures is proposed. [42], novel space vector modulation (SVM) technique for a three-level five-phase inverter is based on an optimized five vectors concept. [44], switching strategy for multilevel cascade inverters, based on

the space-vector theory generates voltage vector across the load with minimum error with respect to the sinusoidal reference with high performance.

### C. Selective Harmonic Elimination

A method to obtain initial values for the SHE-PWM equations according to the reference modulation index  $M$  and the initial phase angle of output fundamental voltage is investigated thoroughly. [37], the elimination of harmonics in a cascade multilevel inverter by considering the non-equality of separated dc sources by using particle swarm optimization is presented. [38], new formulation of selective harmonic elimination pulse width modulation (SHE-PWM) technique suitable for cascaded multilevel inverters with optimized DC voltage levels. [39], [40], a control strategy is proposed to regulate the voltage across the FCs at their respective reference voltage levels by swapping the switching patterns of the switches based on the divergence of the output current, the divergence of the FC voltage, and the divergence of the fundamental line-to-neutral voltage under selective harmonic elimination pulse width modulation [43], [44], suggested a novel space vector modulation (SVM) technique for a three-level five-phase inverter, based on an optimized five vectors concept [45].

### D. Multi-Carrier Pulse Width Modulation

Level shifting and Phase shifting is the major technique of the MCPWM. The constant switching frequency pulse width modulation technique is most popular and very simple switching scheme. For  $m$  level inverter, all  $(m-1)$  carriers use same frequency  $f_c$  and the same amplitude  $A_c$  and they are disposed such that the bands they occupy are contiguous. Level shifting technique can be used mostly [46]. It can be classified into Phase Disposition PWM (PDPWM), Phase Opposition Disposition PWM (PODPWM), Alternate Phase Opposition Disposition PWM (APODPWM)[47-50]. In PDPWM technique; all triangular carriers are arranged in phase [51]-[53]. In PODPWM technique, the carriers above the zero reference are in phase, but shifted by 180 below the zero reference. In APODPWM technique, each triangular carrier is shifted by 180 from its adjacent carrier [54]-[56].

TABLE II  
COMPARISON TABLE FOR MLI TOPOLOGIES AND MODULATION TECHNIQUES  
BASED ON THE IMPLEMENTATION FACTORS

	DC MLI	FC MLI	CHB MLI
SPWM	Applicable	Applicable	Applicable
LS-PWM	Applicable	Applicable	Applicable/optional
PS-PWM	Not applicable	Applicable	Applicable
SHE	Applicable	Applicable	Applicable
SVM	Applicable/optional	Applicable	Applicable

## IV. ANALYSIS OF THE PROPOSED PAPER

### A. Summary of Multi-Level Inverter

In Table III is concluded that the 26.37% of total literatures are summarized based on Diode Clamped Multilevel Inverter, 42% of total literatures are summarized based on Cascaded H-bridge Multilevel Inverter, 29.83 % of total literatures are

summarized based on Flying Capacitor Multilevel Inverter [57]-[65]. Fig. 6 shows the chart for the Table III.

TABLE III  
MLI LITERATURE REVIEW PAPERS

Parameters	Total No. of Literature reviews in MLI Topology	% of Literature reviews in MLI Topology
DCMLI	11	26.37
FC MLI	13	29.83
CHB MLI	20	42

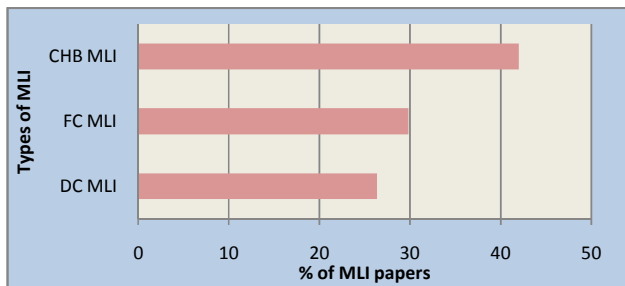


Fig. 6 Percentage (%) of Literature reviews in MLI Topology

#### B. Summary of Modulation Techniques

From Table IV shows that the 26.32% of total literature reviews based on Sinusoidal PWM Technique, 28.95% of total literature review based on Space Vector PWM Technique, 34.21% of total literature review based on Selective Harmonic Elimination PWM Technique [66]-[80]. Fig. 7 shows the graph of the Table IV.

TABLE IV  
LITERATURE REVIEW PAPERS FOR MODULATION TECHNIQUES

Parameters	Total No. of Literature reviews in Modulation Techniques	% of Literature reviews in Modulation Techniques
SPWM	10	26.32
SVM	11	28.95
SHE-PWM	13	34.21

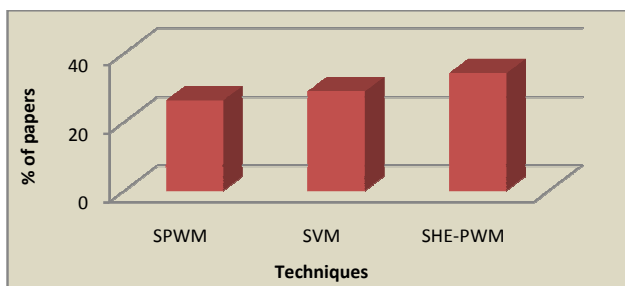


Fig. 7 Percentage (%) of Literature reviews in Modulation Technique

Fig. 8 shows the comparison of the MLI technologies and Modulation Technologies of the proposed paper. Number of techniques presented in the x axis and % of papers presented in the y axis.

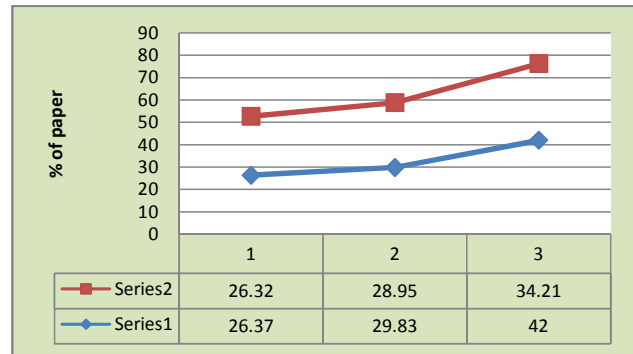


Fig. 8 Percentage (%) of MLI Papers and Modulation Topology

#### V. CONCLUSION

This paper has been proposed as an investigation of several technological literatures anxious with Multilevel Inverter Topologies and their Modulation Techniques. Nowadays, more and more profitable products are based on the multilevel inverter structure, and more and more universal research and enlargement of multilevel inverter-related technologies is stirring. This paper anticipated with the fundamental principle of different multilevel inverters in this paper many topologies and control techniques have been reviewed, which helps the researchers to use proper techniques to control multilevel converters for renewable energy sources grid integration.

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**P.Kiruthika** was born in Coimbatore District, Tamilnadu, India. She received his B.E degree in Electrical and Electronics Engineering in 2013 from Sri Ramakrishna Institute of Technology Coimbatore District. At present, she pursuing his M.E degree in Power Electronics and drives from K.S.Rangasamy college of Technology- Tiruchengode, Namakkal District. Her current research interests involved in Multi-level Inverters, and Renewable Energy System.



**Dr.K.Ramani** was born in Vedaranyam Nagapattinam District. He is Under Graduated in 2004 from Bharathiar University, Coimbatore and Post Graduated in 2006 at Anna University, Chennai-25. He is awarded Ph.D degree in 2012 from Anna University, Chennai-25. He is currently working as a Associate Professor in the department of EEE at K.S.Rangasamy College of Technology, Tiruchengode from January 2006 onwards.

He has published 58 International/National Conferences, Journals. His research interest involves in power electronics, multilevel inverters, modeling of induction motor and optimization techniques. He is Editor in chief, Journal of Asian Scientific research and International and Journal of Advances in Engineering and Technology (USA). He is reviewers in IEEE Transaction of Industrial Electronics, International Review of Electrical Engineering, International Journal of the Physical Sciences and various IEEE international conferences. He obtained best teacher award in KSRCT in the academic year 2011-12. Also he obtained *Career Award for Young Teachers* from AICTE, New Delhi (F.No.11.8/AICTE/RIFD/ CAYT/POL-1/2013-14). He is life member of ISTE, IETE and MIEEE.