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Review of Multi-Level Inverter and Various Suitable PWM Techniques

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ABSTRACT: A Multilevel Inverter is a power electronic device which is capable of providing desired alternating voltage level at the output using multiple lower level DC voltage sources as an input with help of different power semiconducting switching elements. The converted voltage is having wide linearmodulation range, reduced switching loss and lesser Total Harmonic Distortion (THD) in the spectrum of switching waveform. The Multilevel Inverter (MLI) performance or efficiency will be decided not only by the types and levels of MLI and also by the usable Pulse Width Modulation(PWM) techniques. Depends upon the usage of PWM techniques the THD value will also get varied. This review paper will be more helpful for selecting a suitable MLI and PWM Techniques for any Renewable Energy Sources.

KEYWORDS: Multilevel Inverter, PWM Techniques, Total Harmonic Distortion, Renewable Energy Sources.

I.INTRODUCTION

Recently, the multilevel inverters have expected much attention because of their major essential features such as high power quality output waveform with low harmonic components, enhanced electromagnetic consistence, less circuit complexity, lower dv/dt ratio and reduction in switching losses. In case of two level inverter it converts single voltage level Vdc to two different voltage levels at the output side i.e. +Vdc/2 and –Vdc/2 for the load in order to develop an AC voltage. Now the question arises what’s the need of using multilevel inverter when we have this kind of two-level inverter for converting DC to AC voltage. Although this method of converting AC is effective but it has some drawbacks as it creates harmonic distortions in the output voltage waveform and also has a high dv/dt ratio as compared to that of a multilevel inverter.

The concept of MLI is nothing but it is a kind of updated version of two-level inverter. MLI creates a smoother stepped output waveform rather than two level output. More than two voltage levels are combined together and the necessary output waveform obtained, in this case it has lower dv/dt and also low harmonic distortions. When the voltage level increases the harmonic distortions will reduce accordingly, but eventually complexity of controller circuit and components also increases along with the increased voltage levels. Most commonly there are three types of MLIs are available, there are 1.Diode Clamped multilevel inverters 2.Flying Capacitor multilevel inverters and 3.Cascaded H-bridge multilevel inverters[1,2]. The following sections will express the selection of MLI among different MLI topologies with suitable PWM techniques.

II. DIFFERENT TOPOLOGIES OF MULTI LEVEL INVERTER

Diode clamped multilevel inverters use clamping diodes in order to limit the voltage stress of power devices in a particular power circuit. It was first proposed in the year of 1981 and it is also called as neutral point converter. Naturally, A k level diode clamped inverter needs $(2k – 2)$ switching devices, $(k – 1)$ input voltage source and $(k – 1)(k – 2)$ diodes in order to operate [3, 4]. The two notable drawbacks of this type of inverter are Clamping diodes are increased with the increase of each level and DC level will discharge when control and monitoring are not much precise. Some of the advantages over other type of inverters are back to back inverters can be used, capacitors used here are pre charged and at fundamental frequency the efficiency is high. This inverter is mostly applied in high voltage power drives and in power compensators [5].

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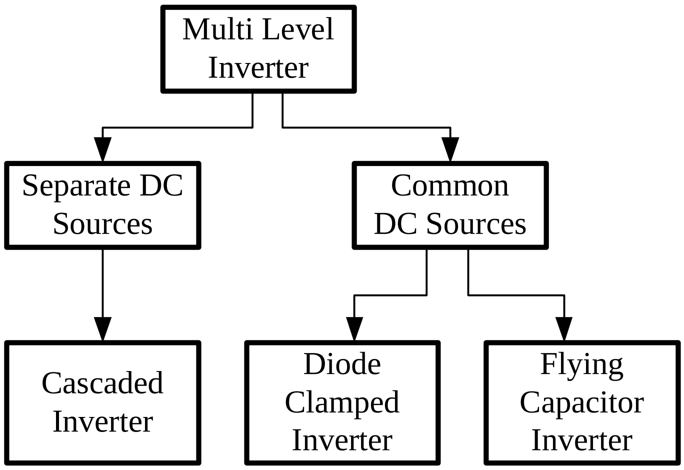

Fig.1.Types of Multi Level Inverter

The flying capacitor MLI is used capacitors in order to limit the voltage instead of diodes. While using capacitors instead of diodes it experiences some drawbacks, i.e. Diodes have the capability to block the reverse flow of voltage but here capacitors are incapable to do it, cost of capacitors also higher than the diodes. The number of switches also increases in flying capacitor MLI; it leads to poor switching efficiency. The input DC voltages are divided by the capacitors here. The voltage over each capacitor and each switch is *Vdc*[6,7].

A k level flying capacitor inverter with $(2k - 2)$ switches will use $(k - 1)$ number of capacitors in order to operate. Figure below shows a five level flying capacitor multilevel inverter. The one of the best application of this type of inverters is in Static VAR compensators for controlling the real and reactive power flow. Because of its ladder structure voltage on each capacitor is differing from the next, since voltage control of all the capacitor is difficult.

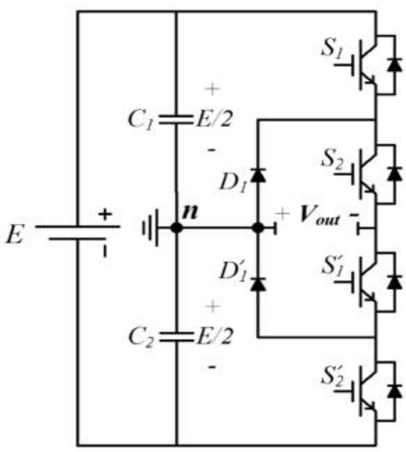

Fig.2. Diode Clamped MLI

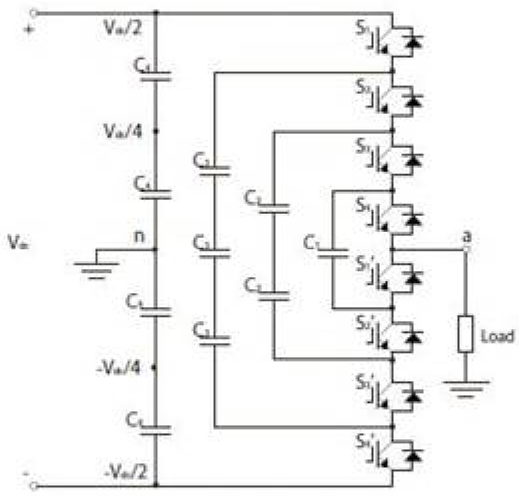

Fig.3. Flying Capacitor MLI

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The Cascaded H-bridge MLI is more popular than other two types of MLI. The reason behind this statement and the other relevant details about Cascaded H-bridge MLI is explained in the following section with necessary diagram and tabular representation [8- 10].

III.CASCADED H-BRIDGE MULTI LEVEL INVERTER

Cascaded H-Bridge MLI uses several H-bridge inverters connected in series to provide a sinusoidal output voltage. Each of its cells contains one H-bridge and the output voltage generated by this multilevel inverter is actually the sum of all the voltages generated by each of its cells, the corresponding calculations are as follows, if there are k cells in a H-bridge multilevel inverter then number of output voltage levels will be 2k+1.

The reason for the popularity of this inverter over other two types of invertersare as it requires less number of power semi conducting switching components as compared to the other two types of inverters and so its overall switching efficiency, weight and price is also less than other two types of inverters.The switching angles of this H-Bridge inverter can be chosen insucha way that the total harmonic distortion isminimized [11- 13].

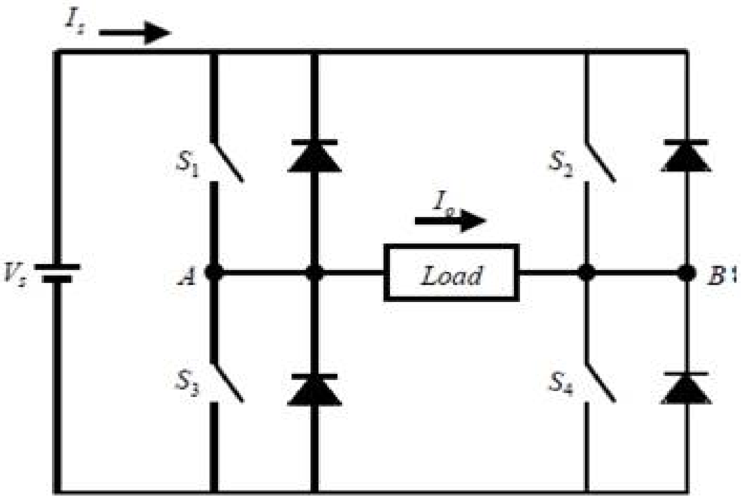

Fig.4. Cascaded H-Bridge MLI

The above diagram shows the structure of Cascaded H-Bridge Inverter, each H-Bridge Cell consists of four switches and four diodes as shown in the picture. Like every H-Bridge, different combinations of switch positions determine different voltages such as + V, -V and 0. S1 and S2 are connected to positive voltage and S3 and S4 are connected to negative voltage.This multilevel inverter uses a series of full H-Bridges connected in series to convert inverted AC from separate DC sources.

These DC sources can be any natural resource such as solar, wind, fuel cell or anything.It does not need any capacitors or diodes for clamping; the output waveform getting from this inverter is quite sinusoidal in nature even without any filter.At least three voltage levels are required for designing a multilevel inverter as discussed as above voltage levels. This can be accomplished by a single H-Bridge unit in Cascaded H-Bridge MLI.

Even in some cases the usage of semi conducting switches may get reduced further to attain high efficiency than the conventional Cascaded H-Bridge MLI. Nowadays this kind of research is widely popular in MLI sector. The following table explains the usage of power semiconducting materials, clamping diodes and capacitors in detail.

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TABLE 1
Comparison of Multi Level Inverter Topologies

S.No.	Topology	Diode Clamped	Flying Capacitor	Cascaded H-Bridge
1.	Power Semiconductor Switches	**2(k-1)**	**2(k-1)**	**2(k-1)**
2.	Clamping Diodes per phase	**(k-1)(k-2)**	**0**	**0**
3.	DC Bus capacitors	**(k-1)**	**(k-1)**	**(k-1)/2**
4.	Balancing capacitors per phase	**0**	**(k-1)(k-2)/2**	**0**
5.	Voltage Unbalancing	**Average**	**High**	**Very Small**

The above mathematics templates will be useful for designing a various MLI, based on the applications the number of semiconductor switches may get varied but the above equations can be used as it is. Depends on the number of switching devices obviously switching loss and output efficiency may get differed. In addition to the above factors the usage of PWM techniques is getting more impact on the output efficiency and THD value. PWM techniques are having very high dependency on harmonics of the output waveform. So, selection of a suitable PWM technique is essential in MLI applications. Let us discuss about it in detail in the following chapters.

IV.ROLE OF PWM TECHNIQUES IN MULTI LEVEL INVERTER

PWM control method is nothing but a fixed dc input voltage is given to the inverters and a controlled ac output voltage is obtained by adjusting the on and off periods of the inverter switching devices. This is the most popular method for controlling and converting the necessaryrequired output voltage. There are four different types of PWM control technique are available there are 1) Single pulse width modulation (Single PWM). 2) Multiple pulse width modulation (MPWM). 3) Sinusoidal pulse width modulation (SPWM). 4) Modified Sinusoidal pulse width modulation (MSPWM). Among these four techniques SPWM and MSPWM are having more advantages by proving better output waveform. In this paper the detailed view of SPWM is presented [12, 13].

A. SINUSOIDAL PULSE WIDTH MODULATION

The gating signal is generated by comparing a sinusoidal modulating reference signal with a triangular carrier wave and the width of each pulse varied proportionally to the amplitude of a sine wave used as a reference one. The triangular waveform is unidirectional in its nature. The output frequency (fo) of the inverter can be found by using thefrequency of the reference signal (fr). The rmsoutput voltage (vo) can be controlled by modulation index M and in turn modulation index is controlled by peak amplitude (Ar).The various types of SPWM techniques are charted in the following diagram. The possible type of modulating signal and carrier signal is expressed in detail in the following diagram [10, 11].

Depends on the usage of modulating and carrier signal the output waveform performance will get changed, the harmonic content present in the output waveform will vary corresponding to the signal used.

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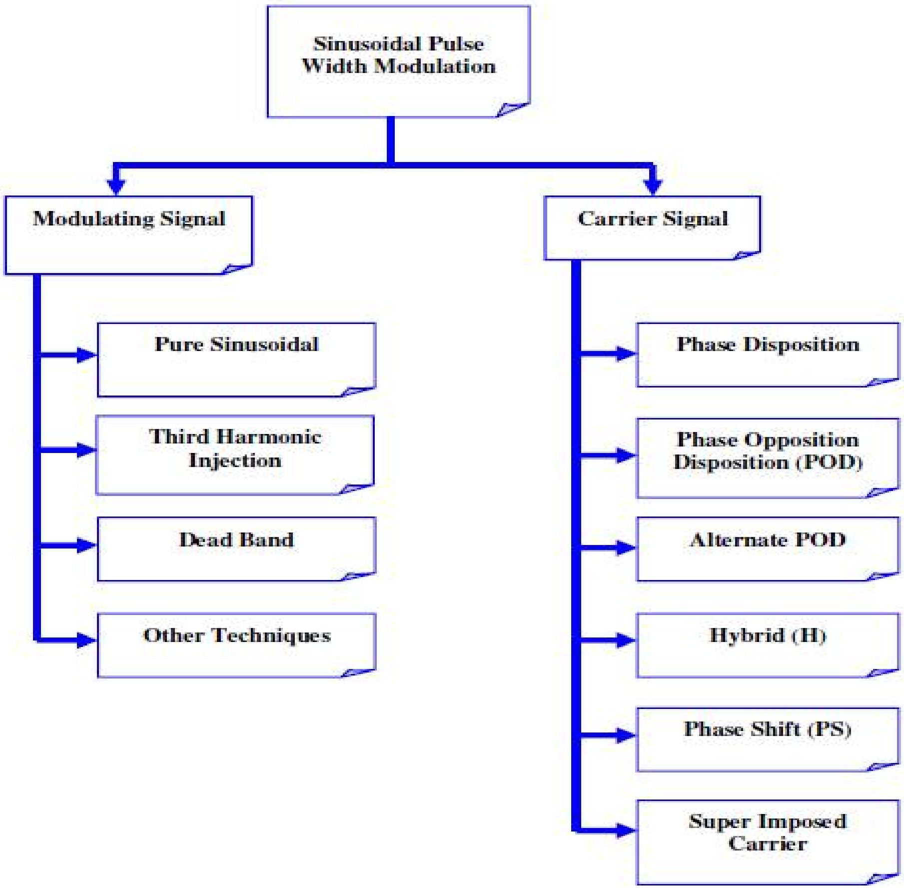

Fig.5. Types of Modulating and Carrier Signal of SPWM

A very popular SPWM methods used in major research application is Multi-Carrier based PWM (MCPWM) technique, many types of modulation techniques are possible today [8,9].

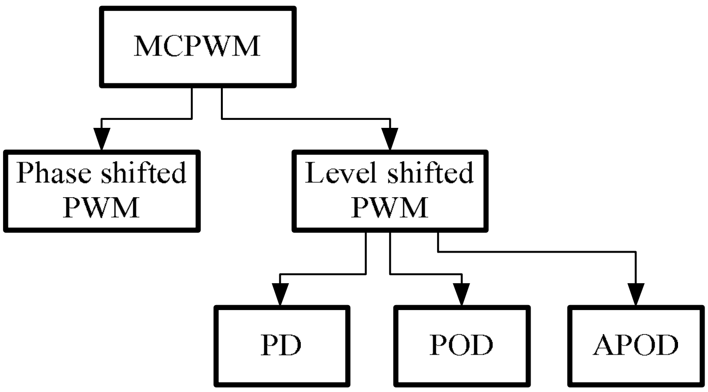

Fig.6. MCPWM Classification

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Usually, based on the carrier switching frequency selection the total control mechanism will get changed. There are about two types of carrier frequency selection is made, one is in high frequency range, which is above 3 KHz to 11 KHz and other one is low frequency range, which is near to the fundamental frequency i.e. 100 Hz. in the conventional PWM methodology, While searching the reason to move on to the high carrier switching frequency is to reduce the lower order harmonics, but at the same time high switching loss will occur because of fast switching operations. To overcome the switching losses low carrier switching may prefer, but there will be high lower order harmonics in the output waveform. Also, single carrier and multi carrier configurations are available. The commonly used three MCPWM techniques are PD, POD and APOD. Where in PD technique all carrier waveforms are in phase, in POD all carrier waveforms above zero reference arein phase and are 180° out of phase with those below zero and in APOD every carrier waveform is in out of phase with its neighbour carrier by 180°.By increasing the number of levels, the output waveform increases gets smoothen almost converting to the sine waveform. Improvising the output waveform is also linked with increase in the number of output levels.In a given simulation result nine level multilevel inverter has lesser THD levelcompared to 5 or 3 level multilevel inverter. Reducing the carrier switching frequency also reduces the THD level. When the inverter is switched at a high switching frequency, the waveform becomes little distorted because of large number of ON and OFF. Thus PWM technique with lower switching frequency is the alternate way to overcome this demerit [14].

TABLE 2 & 3
Simulation Results[14]

Low Carrier Wave Frequency (100 Hz)						
Parameter	Without MPPT			With MPPT		
	PD PWM	POD PWM	APOD PWM	PD PWM	POD PWM	APOD PWM
2nd Harmonics	7.71	0.21	0.19	7.35	0.11	0.10
3rd Harmonics	0.18	4.85	1.46	1.37	3.46	1.18
4th Harmonics	3.30	0.01	0.24	3.46	0.01	0.01
5th Harmonics	0.68	5.01	2.12	0.33	5.42	2.53
THD%	13.25	**11.42**	11.98	13.12	**11.19**	12.10

High Carrier Wave Frequency (3KHz)						
Parameter	Without MPPT			With MPPT		
	PD PWM	POD PWM	APOD PWM	PD PWM	POD PWM	APOD PWM
2nd Harmonics	0.44	0.18	0.14	0.39	0.10	0.06
3rd Harmonics	0.71	0.97	0.88	1.88	2.27	2.07
4th Harmonics	0.24	0.29	0.46	0.23	0.28	0.48
5th Harmonics	1.00	0.87	0.94	1.19	1.05	1.13
THD%	15.63	15.22	**15.07**	15.71	15.22	**15.17**

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V. CONCLUSION

Multilevel inverters are adopted because of the lesser total harmonic distortion level than that of the conventional inverter topology. The reduction of THD can be done by increasing the number levels,improvising the output waveform and using adequate PWM technique. Lesser THD level in the inverter output will exhibit better performance of the inverter unit. Therefore an optimal selection of the PWM switching technique is necessary to reduce both THD and switching losses. From the above stated reference simulation results, it is clear that Low Carrier Frequency POD PWM produces lesser THD value compared to high carrier frequency POD PWM. And also the Low Carrier Frequency POD PWM switching will reduce the switching losses due to lesser switching operation.

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