Multilevel Inverter Topologies and Switching Control: A Review

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***Abstract*— Numerous Industrial applications have started to require high power. Some apparatus in industries requires medium or low power for their operation, utilizing high power hotspot for all modern loads might be useful for a few appliances requiring high power, while it might harm other appliances. The need of multilevel inverter is to give high yield control from medium voltage sources like batteries, super capacitors, ultra capacitors, fuel cell and solar panels. The multilevel inverter has been presented as an option in high power and medium voltage circumstances. The Multilevel Inverter consists of several switches and the arrangements of switching angles are very important. Common mode voltage, input current with low distortion and reduced total harmonic distortion (THD) are some of the advantages of multilevel inverters**.

***Keywords*— Multilevel Inverter, Clamping Diode, Flying Capacitor, Cascaded H-Bridge, Harmonic, Total Harmonic Distortion (THD), DC Source, Switching.**

I. INTRODUCTION

The Voltage source inverter which is having output voltage or current with levels 0 or ± Voltage DC source [2]. A quality output voltage or current waveform across the load with less amount of ripple content, they require high switching frequency. A cascade multilevel inverter is a power electronics device which is used to get desired AC voltage from DC source. A multilevel converter is presented in which two separate DC source, where the secondaries of two transformers coupled to the AC power.

Each phase of a cascade multilevel inverter requires 'n' DC source for '2n+1' level. In application that involves real power transfer, the demand for high voltage and high power inverter is increasing and it is connected with a power semiconductor switch to a high voltage network [4]. Increasing number of voltage source in the input side, a sinusoidal waveform can be generated at the output and the total harmonic distortion (THD) decreases so the output quality will increase.

II. TYPES OF MULTILEVEL INVERTER

Different types of Multilevel Inverters are listed below [1]:

A. Diode Clamped Multilevel Inverter.
B. Flying Capacitors Multilevel Inverter.
C. Cascaded H-Bridge Multilevel Inverter.

A. Diode Clamped Multilevel Inverter

Diode Clamped Multilevel Inverter consists of (m-1) capacitors on DC bus and m-levels on the phase angle. In a full bridge n-levels diode clamped inverter topology, the number of switches required is 2(m-1) i.e. S_{u1}, S_{u2}, S_{u3}, S_{u4}, S_{l1}, S_{l2}, S_{l3} and S_{l4}. The DC bus consists of four Capacitors C_1, C_2, C_3 and C_4. The voltage across each capacitor is $V_{dc}/4$. A Multilevel Inverter leg requires (m-1) Capacitors, 2(m-1) switching device and (m-1)*(m-2) clamping diodes i.e. D_{u1}, D_{u2}, D_{u3}, D_{l1}, D_{l2} and D_{l3}.

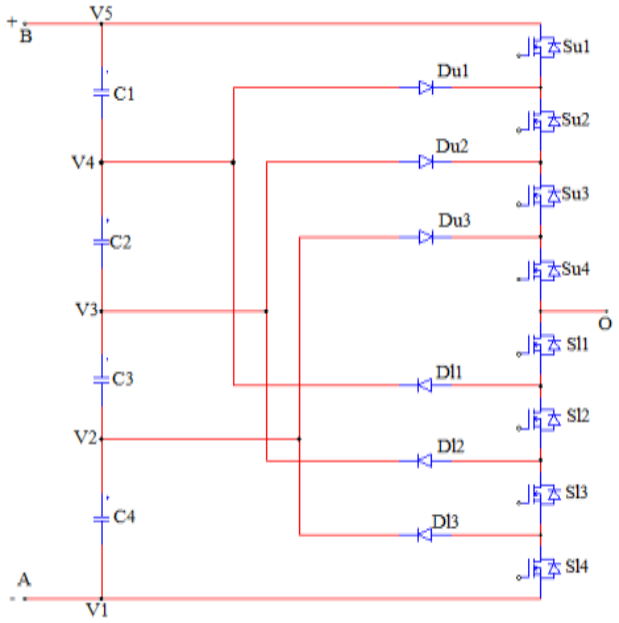

Fig. 1 Diode Clamped Multilevel Inverter Topology

B. Flying Capacitors Multilevel Inverter

A single phase full bridge m-level converter based on Flying Capacitor Multilevel Inverter is as shown in Fig.2. The number of switches required for this topology is 2(m-1) i.e S_{u1}, S_{u2}, S_{u3}, S_{u4}, S_{l1}, S_{l2}, S_{l3} and S_{l4}. The voltage level for the Flying Capacitor converter is similar to that of Diode Clamped type of converter. Flying capacitors C_{F1}, C_{F2} and C_{F3}.

The phase voltage V_{ao} of a multilevel converter and the line voltage V_{ab} has (2m-1) level. Each capacitor has same voltage rating as the switching device. The DC bus (m-1) capacitor for 'm' level converter is needed. The number of capacitor required for each phase is given by

$$N_c = \sum_{k=0}^{m} (m - j) \quad (1)$$

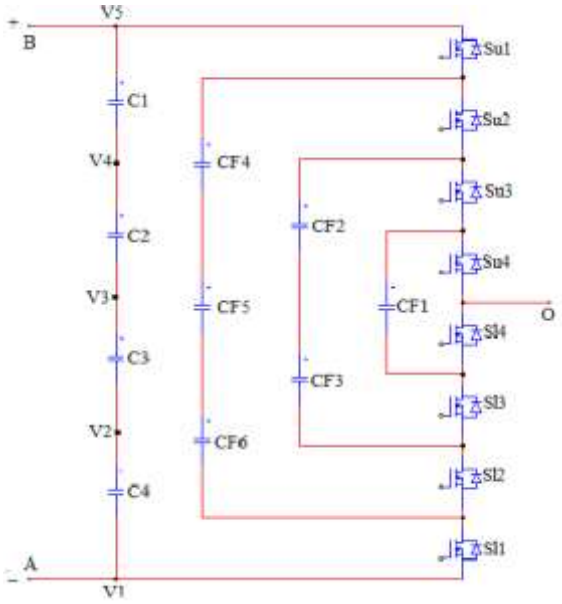

Fig. 2 Flying Capacitors Multilevel Inverter Topology

C. Cascaded H-Bridge Multilevel Inverter

It consist of a series connected H- bridge inverter units, the general function of Multilevel Inverter is to get desired voltage from several separate DC sources. This may be batteries, fuel cells and solar cells. The basic structure of single phase cascaded inverter with Several Separate DC Source (SDCS) is as shown in Fig.3.

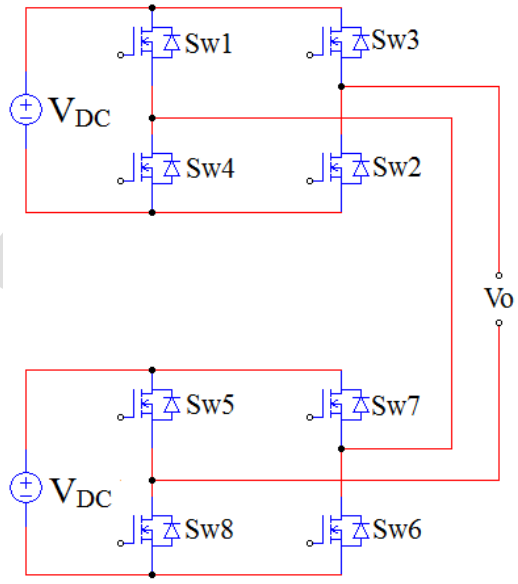

Fig. 3 Cascaded H-Bridge Multilevel Inverter Topology

Several Separate DC Source (SDCS) is connected to an H-bridge Inverter. The AC terminal voltage of different level inverters is connected in series.

III. Switching Pattern of Different Types of Multilevel Inverter Topologies

A. Switching Pattern of Diode Clamped Multilevel Inverter

In Multilevel Inverter, switching of each switch is conducted for a fixed duration of time. As the number of levels in Multilevel Inverter increases, it becomes more complex switching pattern. Diodes are used in this converter as it provides multiple voltage level through different phases of capacitors banks used in series. The switching pattern of Diode Clamped Multilevel inverter is as shown in Table I.

TABLE I
Switching Pattern of Diode Clamped Multilevel Inverter.

Output Voltage	Switch							
	S_{u1}	S_{u2}	S_{u3}	S_{u4}	S_{l1}	S_{l2}	S_{l3}	S_{l4}
0	0	0	0	0	1	1	1	1
$V_{dc}/4$	0	0	0	1	1	1	1	0
$V_{dc}/2$	0	0	1	1	1	1	0	0
$3V_{dc}/4$	0	1	1	1	1	0	0	0
V_{dc}	1	1	1	1	0	0	0	0

B. Switching Pattern of Flying Capacitors Multilevel Inverter

Flying capacitor is the series of connection of capacitor clamped switching cells. It can control both active and reactive power flow but due to high frequency switching, losses takes place. The switching pattern of flying capacitor multilevel inverter is as shown in Table II.

TABLE II
Switching Pattern of Flying Capacitors Multilevel Inverter.

Output Voltage	Switch							
	S_{u1}	S_{u2}	S_{u3}	S_{u4}	S_{l1}	S_{l2}	S_{l3}	S_{l4}
0	0	0	0	0	1	1	1	1
$V_{dc}/4$	1	0	0	0	1	1	1	0
$V_{dc}/2$	1	1	0	0	1	1	0	0
$3V_{dc}/4$	1	1	1	0	1	0	0	0
V_{dc}	1	1	1	1	0	0	0	0

C. Switching Pattern of Cascaded H-Bridge Multilevel Inverter

A Cascaded H-Bridge Multilevel Inverter is made when more than two H-Bridge inverters are connected in cascade connection. Each H-Bridge can provide three different voltage level like zero, positive DC and negative DC voltage. One of the advantages of cascaded H-bridge inverter is that, it

contains less number of components as compare to others. The switching pattern of Cascade Multilevel inverter is as shown in Table III.

TABLE III
Switching Pattern of Cascade H-Bridge Multilevel Inverter

Output Voltage	Switch							
	Sw_1	Sw_2	Sw_3	Sw_4	Sw_5	Sw_6	Sw_7	Sw_8
$2V_{dc}$	1	1	0	0	1	1	0	0
$1V_{dc}$	1	1	0	0	1	0	1	0
0	0	0	0	0	0	0	0	0
$-1V_{dc}$	0	0	1	1	0	1	0	1
$-2V_{dc}$	0	0	1	1	0	0	1	1

IV. OUTPUT WAVEFORM OF DIFFERENT TYPES OF MULTILEVEL INVERTER TOPOLOGIES

A. *Output Waveform of Diode Clumped Multilevel Inverter*

Output Waveform (Output Voltage V/S Time) of Diode Clamped Multilevel Inverter topology is as shown in Fig.4 which is measured between point A and O as shown in Fig.1.

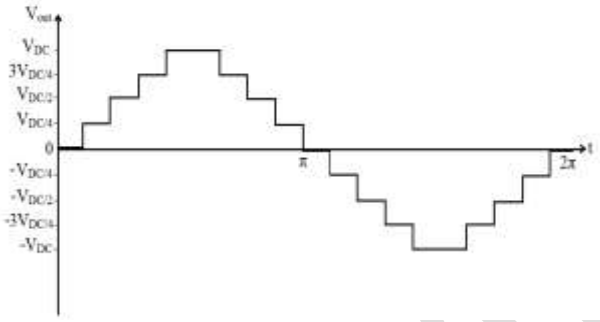

Fig. 4 Output Waveform of Diode Clamped Multilevel Inverter

B. *Output Waveform of Flying Capacitors Multilevel Inverter*

Output Waveform (Output Voltage V/S Time) of Flying Capacitors Multilevel Inverter topology is as shown in Fig.5 which is measured between point A and O as shown in Fig.2

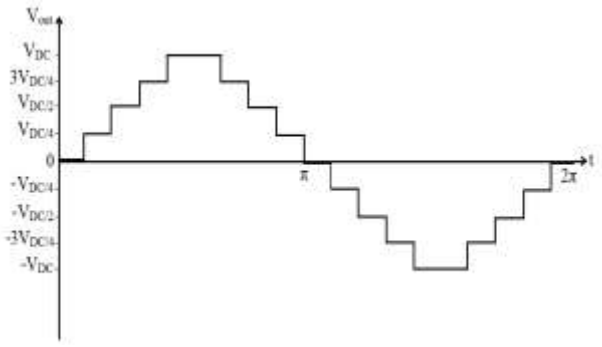

Fig. 5 Output Waveform Flying Capacitors Multilevel Inverter

C. *Output Waveform of Cascaded H-Bridge Multilevel Inverter*

Output Waveform of (Output Voltage V/S Time) Cascaded H-Bridge Multilevel Inverter topology is shown in Fig.6 which is measured across the load.

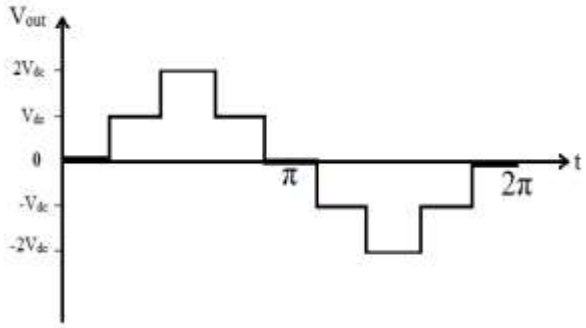

Fig. 6 Output Waveform of Cascade Multilevel Inverter

V. COMPARISON OF DIFFERENT TYPE OF MULTILEVEL INVERTER TOPOLOGIES

Number of Levels, Number of Diodes, Number of Switches, Number of Capacitors and Number of DC Sources which is required for the topology of inverter is as shown in Table IV.

TABLE IV
Comparison of Different Type of Multilevel Inverter Topology

Name of Parameter	**Diode Clamped Multilevel Inverter**	**Flying Capacitors Multilevel Inverter**	**Cascade Multilevel Inverter**
Number of Level	m	m	m
Number of Diode	2(m-2)	-	-
Number of Switches	2 (m-1)	2 (m-1)	2 (m-1)
Number of Capacitors	(m-1)	2m	-
Number of DC source	1	1	2

VI. CONCLUSION

Different topologies for the multilevel inverter are discussed in detail and the switching control of each topology is shown for the same. Switching time of each switch of each topology and the number of levels are discussed in detail. Controlling of each switch in Cascaded H-bridge Inverter topology is simple as compared to other topologies of Multilevel Inverter. As the number output voltage level increases the Total Harmonic Distortion (THD) decreases.

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