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A Brief Survey on Multilevel Inverter Topology

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Abstract- **In this paper, a brief review of different multilevel inverter topologies is discussed. An inverter is a power electronic device that adapts DC power into AC power at desired output voltage and frequency. Multilevel converter nowadays has become an interesting area in the field of industrial applications. Conventional power electronic converters are able to produce an output voltage that switches between two voltage levels only. In the view of Multilevel inverter topology (MLI), several DC voltage levels are added together to generate a continuous output waveform. Multilevel inverter generates the desired output voltage from several DC voltage levels at its input. The input sided voltage levels are usually obtained from renewable energy sources, capacitor voltage sources, fuel cells, etc. The different multilevel inverter topologies are: Cascaded H-bridge converter, Diode clamped inverter and Flying capacitor multilevel inverter. Multilevel inverter nowadays is used for medium voltage and high power applications. The different field of applications includes its use as UPS, High voltage DC transmission, Variable Frequency Drives, in pumps, conveyors, etc. The disadvantage of MLI is the need for isolated power supplies, design complexity and switching control circuits.**

Keyword- Multi-Level Inverter topologies, MLI, PWM, sinusoidal pulse width modulation, THD

I. INTRODUCTION

Multilevel inverter possesses become popular with just out years by reason of the advantages of high power quality waveforms, less harmonic distortion, little common mode voltage, low switching operations, medium high-voltage and high power capability. Typically inverter is a device so that converts DC electrical power to AC form using some electronic circuits.

Usually, simple inverter gives 2 or 3 level output voltage. But multilevel inverter delivers three or more output voltage levels. It outcomes a stepped output voltage with shortened harmonic distortion. When compared to a 2 level inverter. It furnishes higher output voltage levels. The inverter needs DC stable voltage. Which can be seized from the converter. The switching mode DC/DC powered conversion system can be accomplished by different circuit topologies. In dispersion, the buck, boost, buck-boost, and CUK converter are the basic and predominantly used.

One by one of the circuits has its advantages and disadvantages and the choice builds upon a specification for power changeover system. There are two types of classical topologies of the multilevel inverter (diode-clamped and capacitor-clamped type [4,5] and cascaded H-Bridge constructed by the series connection between H-Bridges [6]. In clamped type multilevel inverter the circuit becomes complex but the harmonic distortion are reduced because of the higher number of the voltage level. In cascade structure, the reliability of the system increases but there are more switches and number of inputs.

H-Bridge with four powers switches and individual input are required to increase the two voltage levels in staircase output but its cost is high. One of the most commonly used methods to increase the number of voltage levels is a switch-capacitor (SC) based multilevel circuits but its control becomes more complicated [4-6].

Several topologies with different techniques are available for a cascaded multilevel inverter. Multilevel inverter (MLI) crucial disadvantage is their ramification, demanding an enormous count of power devices and passive components, an averagely complicated control circuitry and a high number of insulated gates bipolar transistors (IGBTs) and hence the total cost is increased [7,8].

Three main types of multilevel inverters are available: the neutral point clamped (NPC) multilevel inverter, the flying capacitor (FC) multilevel inverter and the cascaded H-Bridge (CHB) multilevel inverter. The FC multilevel inverter has a complicated scheme as it has many switching states to regulate the voltage of the capacitor and the number of capacitors increased by increasing the number of voltage levels. The CHB multilevel inverters are divided into two groups; the symmetric and the asymmetric topology. In the symmetric topology, the values of all of the dc voltage sources are equal [9,10].

II. THE CONCEPT OF MULTILEVEL INVERTERS

Conventional two-level inverters generally produce an output AC voltage against an input DC voltage. Pulse width modulation switching schemes is recycled to make the AC output voltage. In the view of Multilevel inverter topology (MLI), several DC voltage levels are added together to generate a continuous output waveform. The gained output waveform has lower dv/dt and harmonic distortions. The circuit design is more complex with the boost in voltage levels. It wishes a sophisticated switching controller circuit also.

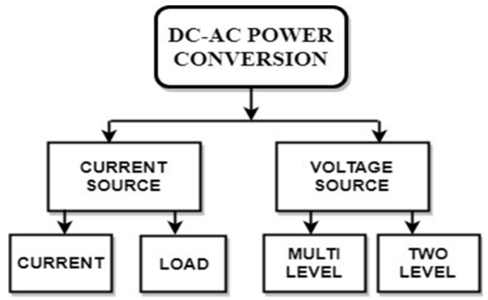

Fig. 1, DC-AC power conversion

DC-AC power conversion comprises of two types. They are a current source inverter (CSI) and voltage source inverter (VSI) as shown in fig. 1.

Difference between voltage and current source inverter are described in table1. In this multilevel inverter comes from the voltage source. In voltage source inverter gives good and satisfactory behavior in the transient and dynamic state. Fig. 2, shows a five-level output waveform at a fundamental switching frequency.

Table 1: The difference between VSI and CSI

S.NO	VSI	CSI
1	Input voltage is maintained constant.	The input current is constant.
2	Output voltage does not depend upon Load.	The output current is independent of load.
3	Commutation circuit is complex.	Commutation circuit is simple
4	Freewheeling diodes are essential.	A freewheeling diode is not essential.
5	Open loop and closed loop operation are possible.	Only closed loop control is possible.
6	Pulse width modulation (PWM) techniques are used.	The PWM technique is not used in CSI.

The input sided DC voltage sources are gathered against batteries, capacitor, renewable energy system, etc. Hence the interesting appearance can shorten as follows,

1. Shorten harmonic distortion.
2. Higher number of voltage level
3. Staircase waveform quality
4. Operate at both high switching frequency pulse width modulation and fundamental.
5. Decreased switching losses.
6. Superior electromagnetic compatibility
7. Increment powers quality.

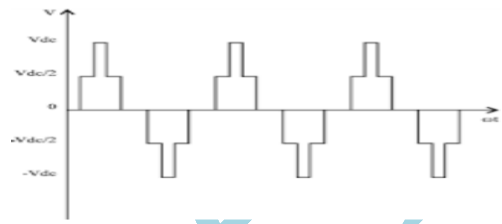

Fig. 2, A five-level output waveform at a fundamental switching frequency

III. DIFFERENT MULTI-LEVEL INVERTER TOPOLOGIES

In a 2-level inverter, the output voltage waveform is obtained by Pulse-width modulation scheme for two levels of voltage. This result from lower THD because of the distorted output waveform. Due to the sinusoidal nature of the output in a three-level inverter, THD obtained is far better than a 2-level and 3-level inverter.

Table.2. show the difference between a 2-level and 3-level inverter. There are mainly three different multilevel converter structures are being focused on industrial applications: Cascaded H-bridge converter with separate dc sources, diode clamped inverter and flying capacitor Multilevel inverter. Fig. 3, Show the classification of multilevel inverter topologies according to their use of power conversions.

Multi-level inverters are able to synthesize a higher output voltage compared to the voltage rating of each incorporated switching device and allow for a much smoother output wave.

Table 2: The difference between a 2-level and a 3-level inverter

SI. NO	Conventional Inverter	Multilevel Inverter
1	THD is high in the output waveform	THD is low in the output waveform
2	High Switching stress	Low Switching stress
3	Not used for high voltage applications	Used for high voltage application

4	High voltage levels cannot be produced	High voltage levels can be produced
5	High dv/dt and EMI	Low dv/dt and EMI
6	High switching frequency, increased switching losses	Lower switching frequency, reduced switching losses.

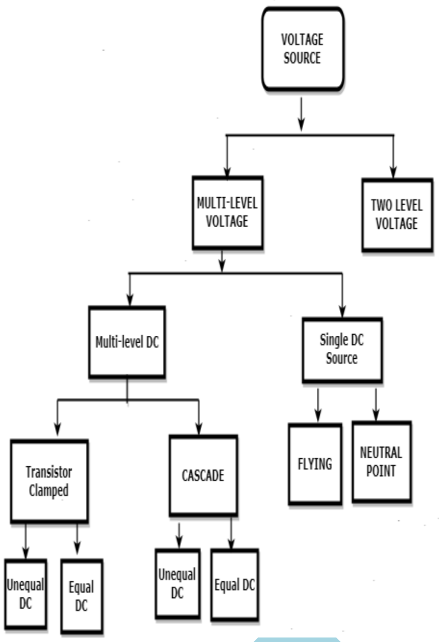

Fig. 3,Multilevel inverter topology

A. Diode-clamped inverter:

Also, the harmonic distortion is reduced. Different types of multi-level inverters are available these days. There are three main multi-level inverters; a diode-clamped inverter, flying capacitor inverter and cascade H-Bridge inverter [15,12]. This topology is the most common one used as it has high voltage levels and highly efficient operation.

It was first recommended by Nabae, Takashi, and Akagi in 1981. A single phase leg of a diode-clamped multi-level inverter is fabricated from two pairs of switches and two diodes. Each switch pair works in complementary mode and the diodes are utilized to provide access to mid-point voltage.

The DC bus is separated out three distinct voltage levels by using two series connections to DC capacitors. Each of the capacitors is supposed to be equal to DC voltage and each voltage stress is contained to one capacitor level through two clamping diodes. If it is supposed that the total DC link voltage is V_{dc} and mid-point is regulated to half of the DC link voltage, the voltage across each of the capacitors will be given by $V_{dc}/2$ ($Vc1=Vc2=V_{dc}/2$).

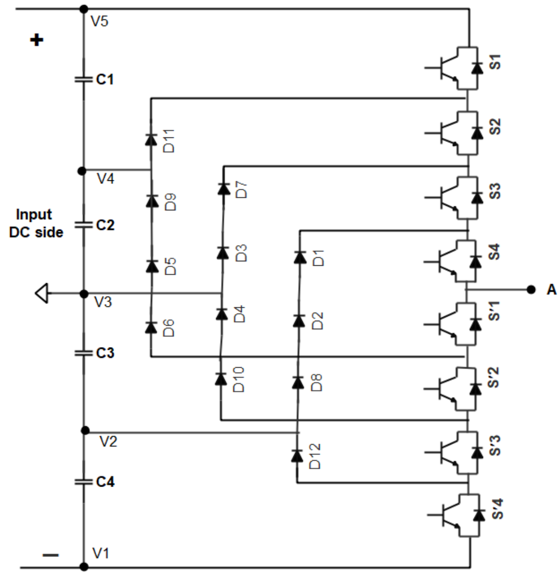

Fig. 4, Diode clamped MLI with diodes in series.

A diode-clamped multilevel (m-level) inverter (DCMLI) typically consists of (m-1) capacitors on the dc bus and produces m levels on the phase voltage. Fig. 4, shows a single phase bridge with one leg (A) with a diode-clamped multilevel inverter with diodes in series. The numbering order for the switches is S_1, S_2, S_3, S_4, S'_1, S'_2, S'_3 and S'_4.

The dc bus consists of four capacitors are $V_{dc}/4$, each device voltage stress is limited to one capacitor voltage level $V_{dc}/4$ through clamping diodes. An m-level inverter one leg requires (m-1) capacitors, 2(m-1) switching devices and (m-1)×(m-2) clamping diodes. In this inverter, possible switching states are in table 3. switching states is clearly explained with the help of this table. This describes, switching states corresponds to the output voltages.

Diode-Clamped Inverter major features are as follows:

- High voltage rating for blocking diodes
- An unequal switching device rating
- Capacitor voltage unbalances.

The major merits:

- Harmonic content is low when the number of levels is large to hide the need for filters.
- Inverter efficiency is large by reason of all devices are switched at the fundamental frequency.
- The control method is simple.

The major demerits of the diode-clamped inverter can be summarized as follows:

- When the number of levels is high Excessive clamping diodes are required.
- It is difficult to control the real power flow of the individual converter in multi-converter systems.

Table 3: Diode-clamped Voltage Levels and their switch state

Output Vo	S1	S2	S3	S4	S'1	S'2	S'3	S'4
V5= V_{dc}	1	1	1	1	0	0	0	0
V4= $3V_{dc}/4$	0	1	1	1	1	0	0	0
V3= $V_{dc}/2$	0	0	1	1	1	1	0	0
V2= $V_{dc}/4$	0	0	0	1	1	1	1	0
V1=0	0	0	0	0	1	1	1	1

B. Flying-capacitor inverters:

The voltage level for the flying-capacitors converter is similar to that of the diode-clamped type converter. It is an alternative to the diode-clamped MLI topology. Here capacitors are used to limit the voltage. Fig. 5, shows a five-levels flying capacitor. The presence of capacitors makes it different from that of diode-clamped MLI. The capacitor divides the input DC voltages. The voltage across each capacitor and switch is V_{dc}.

An m level flying capacitor inverter needs,

Switches: (m-1)×2

Number of capacitors: (m-1)

The capacitor clamped switching cells is connected with series. The switching states are same as that of the diode-clamped inverter. No clamping diodes are required in this inverter. The output voltage is just half of the input DC voltage.

In this inverter, possible switching states are in table 4. An m-level inverter, one leg requires (m-1) DC bus capacitors, (m-1)(m-2)/2 Balancing capacitor, 2(m-1) switching devices and zero clamping diodes.

The main features of Flying-capacitor Inverter are as follows:

- Large number of capacitors
- Balancing capacitor voltages

The major merits of the flying-capacitor inverter can be summarized as follows:

- A lot of repository capacitors can provide capabilities at the time of power outages.
- These inverters provide switch combination redundancy for matching various voltage levels.

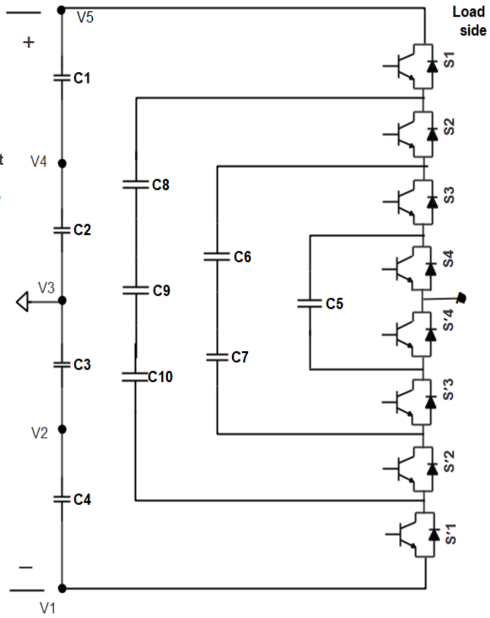

Fig. 5, Five level flying capacitor MLI.

Table 4: One Possible Switch Combination of the Flying-capacitors Inverter

Output Vo	S1	S2	S3	S4	S'4	S'3	S'2	S'1
V5=V_{dc}	1	1	1	1	0	0	0	0
V4=$3V_{dc}/4$	1	1	1	0	1	0	0	0
V3=$V_{dc}/2$	1	1	0	0	1	1	0	0
V2=$V_{dc}/4$	1	0	0	0	1	1	1	0
V1=0	0	0	0	0	1	1	1	1

- Like the diode-clamp inverter with more levels, the harmonic content is low enough to avoid the need for filters.
- Control from real and reactive power flows.
- Additional switching states help to maintain the charge balance in the capacitor.

The major demerits of the flying-capacitor inverter can be summarized as follows:

- An enormous number of repository capacitors is needed when the number of levels is great. High-level inverters are tougher to package with the large power capacitors and are more expensive too.
- Lower switching frequency and voltage control all the capacitors is difficult.
- Complex start-up
- Lower switching efficiency.

C. Cascaded Multilevel Inverter:

A series of H-bridge inverter units consist of a cascaded multilevel inverter. The general function of this multilevel inverter is to synthesize the desired voltage from several separate dc sources (SDCS), which may be obtained from batteries, fuel cells or solar cells.

The Fig. 6, shows the basic structure of a single-phase cascaded inverter with SDCS. H-bridge inverter is connected with the help of each SDCS. The cascaded inverter does not require any voltage-clamping diodes or voltage-balancing capacitors, unlike the diode-clamped or flying-capacitors inverter. The cascaded H-bridge inverter uses separate DC source or capacitor. It requires only less number of components in each level.

There is a series connection to power conversion cells. The inverter uses series connected H-bridge cells, each providing three different levels of Dc voltages (zero, positive DC, and negative DC voltages). The output voltage is the sum of all the generated voltages from each H-Bridge cell. If m cells are present, the numbers of output voltage levels will be 2m+1.

Comparison of component requirements per Leg of three multilevel converter are discussed in table.5. This table given more information about the main switching devices, main diodes, clamping diodes and Dc bus capacitor of three different type of the Multi-level inverter topologies.

Features of Cascaded Multilevel Inverter are as follows:

- The cascaded inverters need separate dc sources for conversions from ac to dc and then dc to ac. The design of separate dc sources is well suited for various renewable energy sources such as fuel cell, photovoltaic and biomass.
- Connecting dc sources between two converters in a back-back fashion is not possible because a short circuit can be introduced. When two back-back converters are not switching synchronously.

The major merits of the cascaded multilevel inverter can be summarized as follows:

- Compared with the diode-clamped and flying–capacitors inverters, it requires the least number of components to obtain the same number of voltage levels.
- Optimized circuit layout and packaging are possible.
- Soft-switching techniques can be used to reduce switching losses and device stresses.

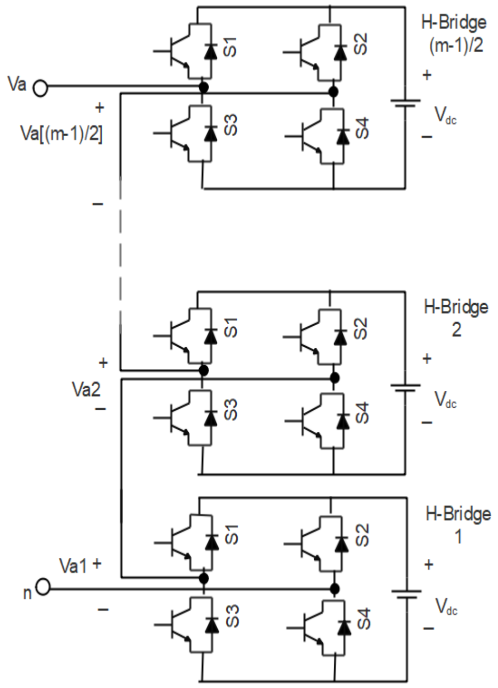

Fig. 6, Single phase multilevel cascaded H-bridge inverter

Table.5 Comparisons of Component Requirements per Leg of three Multilevel Converter

Converter Type	Diode Clamp	Flying Capacitors	Cascaded Inverters
Main switching devices	(m-1)×2	(m-1)×2	(m-1)×2
Main diodes	(m-1)×2	(m-1)×2	(m-1)×2
Clamping diodes	(m-1)×(m-2)	0	0
Dc bus capacitors	(m-1)	(m-1)	(m-1)/2
Balancing capacitors	0	(m-1)×(m-2)/2	0

The major demerits of the cascaded multilevel inverter can be summarized as follows:

- It needs separate DC sources, or capacitor is required for each module.
- A more complex controller is required due to the number of capacitors.

IV. FEATURES AND APPLICATION OF MULTI-LEVEL INVERTERS

A multilevel inverter can exclude the need for the step-up transformer and reduce the harmonics produced by the inverter. Although the multilevel inverter structure was initially introduced as a means of reducing the output waveform harmonic content, it was found [13] that the dc bus voltage could be increased apart from the voltage rating of an individual power device by the use of a voltage clamping network consisting of diodes. A multilevel structure of more than three levels can significantly reduce the harmonic content [14,15]. The key features of a multilevel structure follow:

- The output voltage and power increase with a number of levels. Adding a voltage level involves adding the main switching device to each phase..
- With additional voltage levels, the voltage waveform has more free-switching angles, which can be preselected for harmonic elimination.

Applications of MLI:

Reactive power compensation, back-to-back intertie, variable speed drives are the most common applications of multilevel converters.

V. CONCLUSION

The paper presents a brief discussion on basic multi-level inverter topologies. Fundamental multilevel converter structures including the features, merits, and demerits of each technique have been discussed. The main advantage of MLI family is that it finds a solution to the problems of total harmonics distortion, EMI (Electromagnetic Interference), and dv/dt stress on the switch. In industrial and commercial market areas, more and more product is available that depends on the multi-level inverter topologies. Research works are in progress considering the structural complexity and control circuits. This helps to reduce the power electronics components and improve total harmonics profile and total cost of the system.

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