A Review on Cascaded Multilevel Inverter with Different Levels

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Abstract— In recent years, most of the industrial and residential loads are connected to the power line through cost effective power converters, which enhance the overall system efficiency, performance and reliability. Multilevel inverter is strongly known as an unconventional voltage medium, which converts DC power to AC power. However, the occurrence of harmonics would degrade the inferiority of the voltage produce by the inverter. This paper discusses about three phase Cascaded multilevel Inverter with Separated dc Source (CISS) which eliminates the harmonics by three different levels i.e. 3, 5 and 7 levels. Total harmonic distortion is also discussed for these 3-level CISS model.

Keywords ***Multilevel Inverter, Single-phase, Three-phase, Cascaded multilevel Inverter with Separated dc Source (CISS), Total Harmonic Distortion (THD).***

I. INTRODUCTION

In recent years, most of the industrial and residential loads are connected to the power line through cost effective power converters, which enhance the overall system efficiency, performance and reliability [1].

Multilevel inverters have received more and more attention because of their capability of high voltage operation, high efficiency, and low electromagnetic interference (EMI). The desired output of a multilevel converter is synthesized by several sources of dc voltages. With an increasing number of dc voltage sources, the converter voltage output waveform approaches a nearly sinusoidal waveform while using a fundamental frequency switching scheme. This results in low switching losses, and because of several dc sources, the switches experience a lower. As a result, multilevel converter technology is promising for high power electric devices such as utility applications. For these applications, the output voltage of the inverters must meet maximum total harmonic distortion (THD) limitations; some kind of method must be used to control the harmonics [2].

II. INVERTERS

The inverters have to be designed to obtain a quality output voltage or a current waveform with a minimum amount of ripple content. In high power and high voltage applications the conventional two level inverters, however, have some limitations in operating at high frequency mainly due to switching losses and constraints of the power device ratings [3].

Numerous industrial applications have begun to require high power apparatus in recent years. For the control of electric power or power conditioning the conversion of electrical power from one form to another is necessary and the switching characteristics of the power devices permits these conversions. Inverters are the devices that are used for conversion of DC to AC. The output voltage of an inverter can be fixed type or variable type at fixed or variable frequency. A variable output voltage can be obtained by varying the input dc voltage and maintaining the gain of the inverter constant. On the other hand, if the dc voltage is fixed variable output voltage can be obtained by varying the gain of the inverter. Inverter gain is defined as the ratio of ac output voltage to dc input voltage. In the conventional two level inverters the input DC is converted into the AC supply of desired frequency and voltage with the aid of semiconductor power switches. Depending on the configuration, four or six switches are used. A group of switches provide the positive half cycle at the output which is called as positive group switches and the other group which supplies the negative half cycle is called negative group.

A. Limitations of Conventional Inverters

1. The classical two level inverter produces output with level either 0 or +Vdc or – Vdc
2. They cannot be used in high power and high voltage applications because of higher frequency and there will switching losses.
3. The output voltage waveform of ideal inverter should be sinusoidal but the waveform of conventional inverters is non-sinusoidal and contains certain harmonics.
4. Large capacitor will be connected across the DC voltage source which is costly and requires more space.

In order to overcome these drawbacks multilevel inverters are introduced.

B. Multilevel Inverters

Multilevel inverters have attracted much attention in high power electronics applications as the solution of needs for higher power ratings and the reduction of the output harmonic distortion, voltage stress (dv/dt) and EMI phenomenon. Multilevel began with the 3-level converter, then several multilevel converter topologies has been developed. Multi-level inverters provide more than 2 voltage levels. The basic principle of a multilevel inverter is to connect semiconductor switches in series so that the converter can operate with power ratings of several megavolt amperes and at medium voltage levels (1kv to 35kv) that exceed the individual switch voltage ratings. The output voltage waveform will be synthesized from several levels of capacitor voltage sources. As the number of levels increases, the obtained output waveform approaches the sinusoidal wave with less distortion, less switching frequency, higher efficiency etc [4].

For an m-level inverter needs (m-1) capacitors. The most attractive features of multilevel inverters are as follows.

1. They can generate output voltages with extremely low distortion and lower dv/dt.
2. They draw input current with very low distortion.
3. With a lower switching frequency they can be operated.
4. A multilevel inverter can eliminate the need for the step-up transformer and reduce the harmonics produced by the inverter.
5. With additional voltage levels, the voltage waveform has more free-switching angles, which can be preselected for harmonics elimination. The main disadvantage of multilevel inverter is that they require greater number of switches.

III. CASCADED INVERTERS

Cascaded inverter also known as H-bridge inverter. Cascaded multilevel Inverter with Separated dc Source (CISS) is the simplest inverter to produce the output waveform with least harmonics compared with conventional inverters. This inverter is made up of H-bridge topology that consists of four switches and each has their own DC source. Cascaded inverter able to produce complete sinusoidal output waveform. CISS able to construct up to a boundless number of levels, which eliminates more unwanted harmonics. Cascaded inverter became the significant inverter to use in the industry because it has a great power performance with cheaper manufacturing cost [3]. The voltage level of CISS can be determined by the formula:

$m = 2 (N_{dc}) + 1$

where = N_{dc} are the numbers of DC source.

The output voltage formula is:

$V_{out} = V_{1dc} + V_{2dc} + V_{3dc} + \ldots + V_{(m-1)}{}^{2}{}_{dc}$

The angle controlling at different level can define the quality of the output voltage. Figures 1, 2 and 3 are the topology for 3-level, 5-level and 7-level CISS.

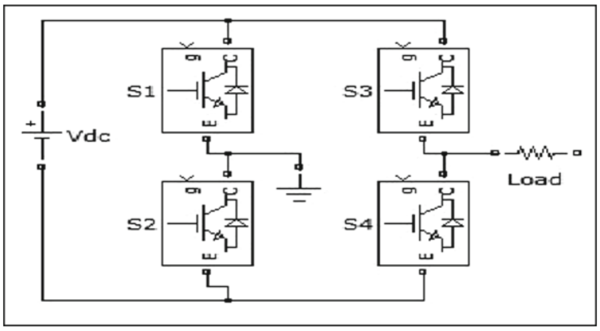

Figure 1: 3-Level CISS

The circuit in Figure 1 shows a single phase 3-level inverter that is connected in series as a single phase circuit topology. This circuit consists of four IGBT switches and single DC source. This level of the inverter can generate three voltages at the output, which are +Vdc, 0, and −Vdc. Four IGBT switches are connected to dc source at the output terminal. This occurs in each level of inverter and four IGBTs represent a single cell [4].

Three level inverter produces three different voltages at the output based on previous research [4]. Table 1 shows the output voltage produced which are $+V_{dc}$, 0, and $-V_{dc}$ when the switches are triggered.

Table 1: Switching Condition for 3-level of CISS

Voltage Output, V_{out}	Switching States			
	S_1	S_2	S_3	S_4
$+V_{dc}$	on	off	off	on
0	on	on	off	off
$-V_{dc}$	off	on	on	off

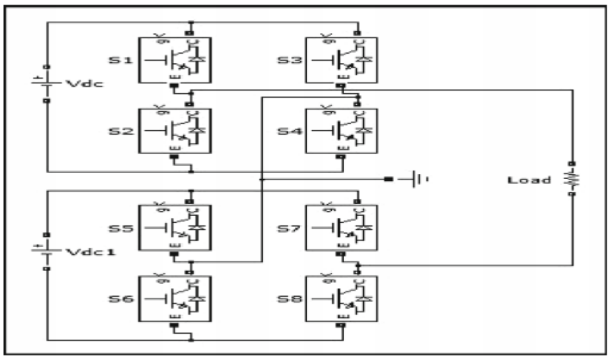

Figure 2: 5-Level CISS

The circuit shown in Figure 2 is a 5-level inverter that has two separate DC sources and eight IGBT. It generates an output voltage, which are +2Vdc, +Vdc, 0Vdc, −Vdc, −2Vdc [5]. A combination of two cells that has four IGBT diodes produce 5-level of output voltages.

Since this is five level inverter, there are five output voltages were shown in Table 2 which are +2Vdc, +Vdc, 0, −Vdc, and −2Vdc when the switches are triggered.

Table 2: Switching Condition for 5-level of CISS

Voltage Output, V_{out}	Switching States							
	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
$+2V_{dc}$	on	off	off	on	on	off	off	on
$+V_{dc}$	on	off	off	on	on	on	off	off
0	on	on	off	off	on	on	off	off
$-V_{dc}$	off	on	on	off	off	off	on	on
$-2V_{dc}$	off	on	on	off	off	on	on	off

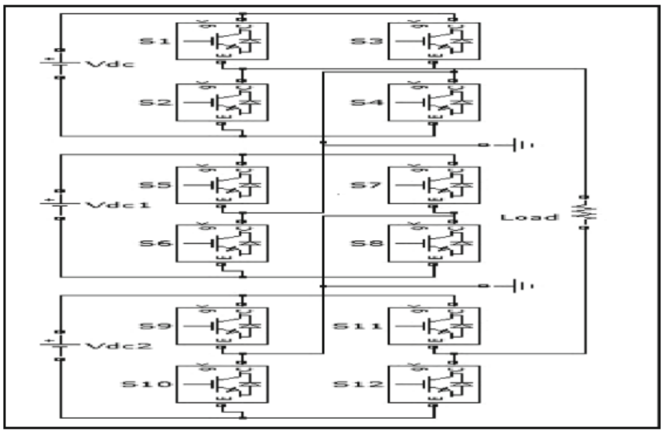

Figure 3: 7-Level CISS

The 7-level inverter as shown in Figure 3 requires twelve IGBT switches and three DC sources. Each CISS has the same structure as a distinctive single phase inverter. This level of the inverter can generate an output voltage with seven levels of output with three cells IGBT combination [6].

Table 3: Switching Condition for 7-level of CISS

Voltage Output, V_{out}	Switching States											
	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}
$+3V_{dc}$	on	off	off	on	on	off	off	on	on	off	off	on
$+2V_{dc}$	on	off	off	on	on	off	off	on	on	on	off	off
$+V_{dc}$	on	off	off	on	on	on	off	off	on	on	off	off
0	on	on	off	off	on	on	off	off	on	on	off	off
$-V_{dc}$	off	on	on	off	on	on	off	off	on	on	off	off
$-2V_{dc}$	off	on	on	off	off	on	on	off	on	on	off	off
$-3V_{dc}$	off	on	on	off	off	on	on	off	off	on	on	off

IV. ADVANTAGES AND DISADVANTAGES OF CISS

Advantages of CISS are:

1. It needs the smallest number of components between all multi- level inverters to obtain the similar number of voltage level.
2. The circuit design can be modularized because each level consumes the same structure, and there are no additional clamping diodes or voltage balancing capacitors.
3. CISS also can be used in this structure to evade lossy resistor-capacitor-diode snubbers.

Disadvantages of CISS are:

1. It needs an isolated DC source for real power conversion and the applications are inadequate.
2. Limits its highest output voltage when maintaining the capacitors' voltages.

V. TOTAL HARMONIC DISTORTION

Based on Levels of Inverter Table 4 shows the value of THD value based on levels of inverter between single phase and three phases. As for single phase, the THD value decreases as the number of level increases, same as for three phase. It can be concluded that the number of levels and phase of inverter affects the THD value of the inverters. Based on previous studies, it shows that three phase inverter eliminates more harmonics compared to single phase inverter. Therefore, the simulation carried out in this paper were done in three phase circuit topology.

Table 4. Total Harmonic Distortion (THD) Based on Levels of Inverter [5,6,7]

Levels	3	5	7
THD (single phase)	48.34%	23.86%	16.16%
THD (three phase)	35.33%	14.55%	12.22%

VI. CONCLUSION

This paper presents the difference of THD between 3, 5, and 7-level three phases of a cascaded multilevel inverter with separated dc sources (CISS). Based on the papers of conventional multilevel inverter topologies given in the previous research, the THD value is decreased as the number of CISS level is increased. As the switches were triggered at steady intervals, plenty of computations are required to generate the pulses. This can be avoided by relating the PWM methods in multilevel inverters in the future. Percentage of harmonics can be reduced by designing the PWM control techniques because it allows a decline in the switching frequency of each cell, thus reducing the switching losses.

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