Analysis of Different Topologies of Multilevel Inverters

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Abstract

Multilevel inverters are very popular and have many applications in electric utility and for industrial drivers. As the number of levels in multilevel inverter increases, THD decreases accordingly. The paper compares three different topologies of inverters (Diode clamped inverter, Flying capacitor inverter and Cascaded H-bridge inverter). The comparison is done with respect to cost, power losses and THD. MOSFETs and IGBTs are used a switching devices for analysis. Tradeoff between the power losses and cost is also discussed in this paper. To select a multilevel inverter is a tradeoff between cost, complexity, losses and THD. The most important part is to decide which one is more important.
Keywords: THD, Cascaded H-Bridge Multilevel Inverter, MOSFETs

I. INTRODUCTION

Unfortunately, many places in India lack of reliable power grid. This is a large problem for many reasons, especially in the medical field where reliable power is essential for doctors who need to be able to see and monitor their patients during operations. An important part of backup power supply is the DC to AC inverter which converts DC voltage from battery to an AC voltage that is necessary to operate electronics components. Due to the delicate nature of most of the equipments, an inverter which is capable of producing pure sine wave is necessary to ovoid noise wear on delicate and expensive gear.

An inverter is defined as a device that converts direct current DC into alternating current AC[1].Inverters can come in many different varieties differing in price, power, efficiency and purpose. The multilevel inverter offers several advantages as compared to hard-switched two-level pulse width modulated inverters such as their capabilities to operate at high voltage with lower dv/dt per switching, high efficiency and lower electromagnetic interference [2]-[4]. Multilevel inverter can easily be applied for high power applications such as large motor drivers and utility supply.

High magnitude sinusoidal voltage with less switching losses at fundamental frequency can be produced at output with the help of multilevel inverters by connecting sufficient number of dc levels at input side.[5] There are mainly three types of multilevel inverters; they are 1.Diode clamped multilevel inverter 2. Flying capacitor multilevel inverter 3. Cascaded H-bridge multilevel inverter.

II. TOPOLOGIES OF MULTILEVEL INVERTER

The main concept of this inverter is to use diodes to limit the power devices voltage stress. The voltage over each capacitor and each switch is Vdc. An n level inverter needs (n-1) voltage sources, 2(n-1) switching devices and (n-1) (n-2) diodes.[6]

A. Five Level Diode Clamped Multilevel Inverter

In a 5-level diode clamped multilevel:
n=5
Therefore:
Number of switches=2(n-1) =8
Number of diodes= (n-1) (n-2) =12
Number of capacitors= (n-1) =4

A 5-level diode clamped multilevel inverter is shown in Fig. 1. Switching states are shown in Table.1. For example to have Vdc/2 in the output, switches S1 to S4 should conduct at the same time. For each voltage level four switches should conduct. As it can be seen in Table.1 the maximum output voltage in the output is half of the DC source. It is a drawback of the diode clamped multilevel inverter. This problem can be solved by using a two times voltage source or cascading two diode clamped multilevel inverters. The output voltage of a 5-level diode clamped multilevel inverter is shown in Fig.5. As can be seen in Fig.5 all of the voltage level should have the same voltage value. The switching angles should be calculated in such a way that the THD of the output voltage becomes as low as possible.

Table - 1
Switching states of diode clamped multilevel inverter

V_0	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
$V_{dc}/2$	1	1	1	1	0	0	0	0
$V_{dc}/4$	0	1	1	1	1	0	0	0
0	0	0	1	1	1	1	0	0
$-V_{dc}/4$	0	0	0	1	1	1	1	0
$-V_{dc}/2$	0	0	0	0	1	1	1	1

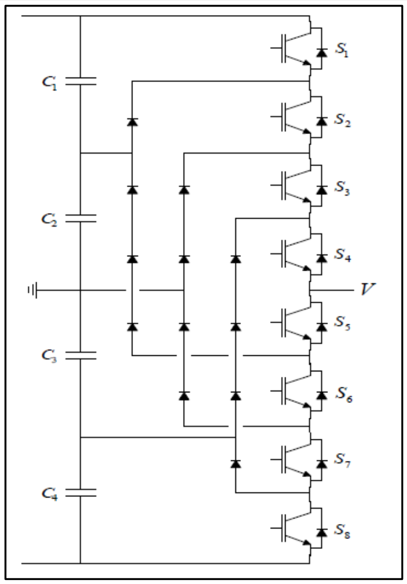

Fig. 1: Diode clamped inverter

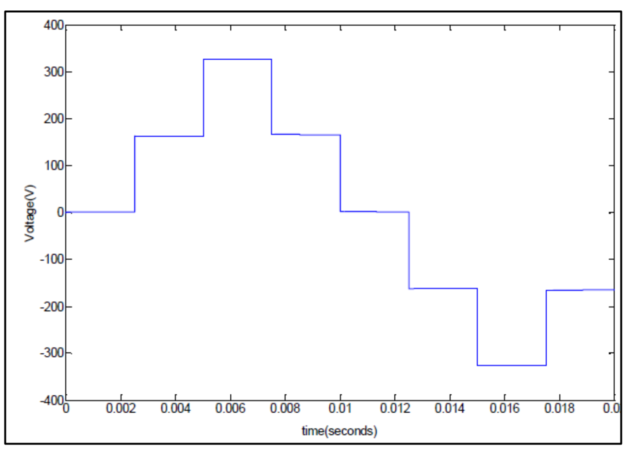

Fig. 2:

B. Five Level Flying Capacitor Multilevel Inverter

This inverter uses capacitors to limit the voltage of the power devices. The configuration of the flying capacitor multilevel inverter is like a diode clamped multilevel inverter except that capacitors are used to divide the input DC voltage. The voltage over each capacitor and each switch is Vdc.

For a 5-level flying capacitor multilevel inverter:

n=5

Therefore:
Number of switches=8
Number of capacitors= 10

Fig. 3shows a five level flying capacitor multilevel inverter. The switching states in this inverter are like in the diode clamped multilevel inverter. It means that for each output voltage level 4 switches should be on. Table.2 shows the switching states for a 5-level flying capacitor clamped multilevel inverter. The output voltage was shown before in Fig.2.

The switching angles like the diode clamped multilevel inverter should be calculated in such a way that the THD of the output voltage becomes as low as possible. The method is the same as the diode clamped inverter.

Table - 2
Switching states of flying capacitor multilevel inverter

V_0	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
$V_{dc}/2$	1	1	1	1	0	0	0	0
$V_{dc}/4$	1	1	1	0	1	0	0	0
0	1	1	0	0	1	1	0	0
$-V_{dc}/4$	1	0	0	0	1	1	1	0
$-V_{dc}/2$	0	0	0	0	1	1	1	1

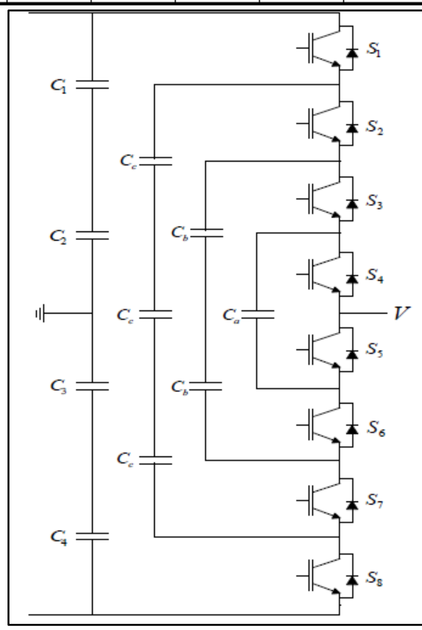

Fig. 3: Flying capacitor inverter

C. Cascaded H-Bridge Multilevel Inverter

The concept of this inverter is based on connecting H-bridge inverters in series to get a sinusoidal voltage output. The output voltage is the sum of the voltage that is generated by each cell. The number of output voltage levels are 2n+1, where n is the number of cells. The switching angles can be chosen in such a way that the total harmonic distortion is minimized. One of the advantages of this type of multilevel inverter is that it needs less number of components comparative to the Diode clamped or the flying capacitor, so the price and the weight of the inverter is less than that of the two former types. Fig.4 shows an n level cascaded H-bridge multilevel inverter. The switching angles calculation method that is used in this inverter is the same as for the previous multilevel inverters. An n level cascaded H-bridge multilevel inverter needs 2(n-1) switching devices where n is the number of the output voltage level.

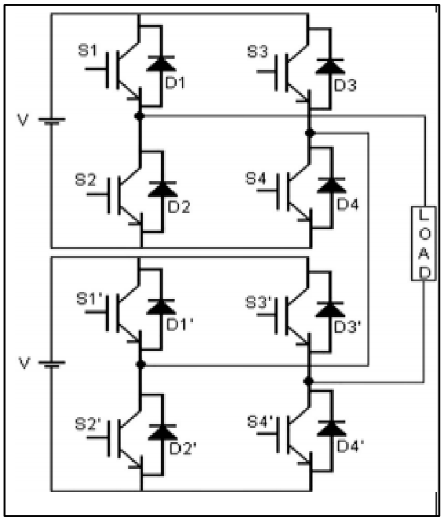

Fig. 4: Cascaded H-Bridge inverter

III. EXPERIMENT AND RESULT

A. Power Losses Calculations

All the Loss calculations is done for IGBT FD300R06KE3.
Mathematical equations for power losses calculations

$$P_{ci} = u_{CE0}. I_{Iav} + r_c. I_{Irms}^2 \quad (1)$$

$$P_{cd} = u_{D0}. I_{Dav} + r_D. I_{Drms}^2 \quad (2)$$

1) 5-Level Diode Clamped Multilevel Inverter

The RMS current that is passing through one of the switches is 48.19A and the average current that is passing through one of the switches is 15.99A.

I_{Iav}=15.99A

I_{IRMS}=48.19A

No current passes through the anti parallel diodes in full load, so the conduction losses of anti parallel diodes are equal to zero. According to (1) and for one switch, the power losses are:

P_{cI}= 17.7982W

There are 24 switches for three phases so:

P_{cI}=427.1566W

For the diode clamped multilevel inverter, the diode power losses should be calculated by (2). The power losses for one diode are:

P_{cD}= 7.0697W

There are 36 diodes in the 5-level diode clamped multilevel inverter, so the total power losses are:

P_{cD}= 254.5108W

Since the switching frequency is 50Hz, the switching losses are neglected in this paper.

2) 5-Level Flying Capacitor Multilevel Inverter

The RMS current that is passing through one of the switches is 49.02A and the average current that is passing through one of the switches is 17.28A.

I_{Iav}=17.28A

I_{IRMS}=49.02A

No current passes through anti parallel diodes in full load, so the conduction losses of anti parallel diodes are equal to zero. According to (1) and for one switch, the power losses are:

P_{cI}= 19.1105W

There are 24 switches for three phases so:

P_{cI}=458.6523W

3) 5-Level Cascaded H-Bridge Multilevel Inverter

According to (1) and (2) the power losses are:

P_{cI}= 1491.2W

P_{cD}= 209.3593W

P_{cTot}=1700.6W

B. Weight and Cost Calculation

Weight and cost comparison is done for 5 level inverters. It can be used as comparison for any multilevel inverters.

Table 3:
Weight and cost comparison

Type of inverter	*Number of switches*	*Number of capacitors*	*Number of diodes*	*Weight*	*Cost*
5-level diode clamped inverter	*24*	*12*	*36*	*Medium*	*Medium*
5-level flying capacitor inverter	*24*	*30*	*0*	*More*	*More*
5-level H-Bridge inverter	*24*	*6*	*0*	*Less*	*Less*

C. THD Analysis

All the simulations are done in Matlab 14.0.

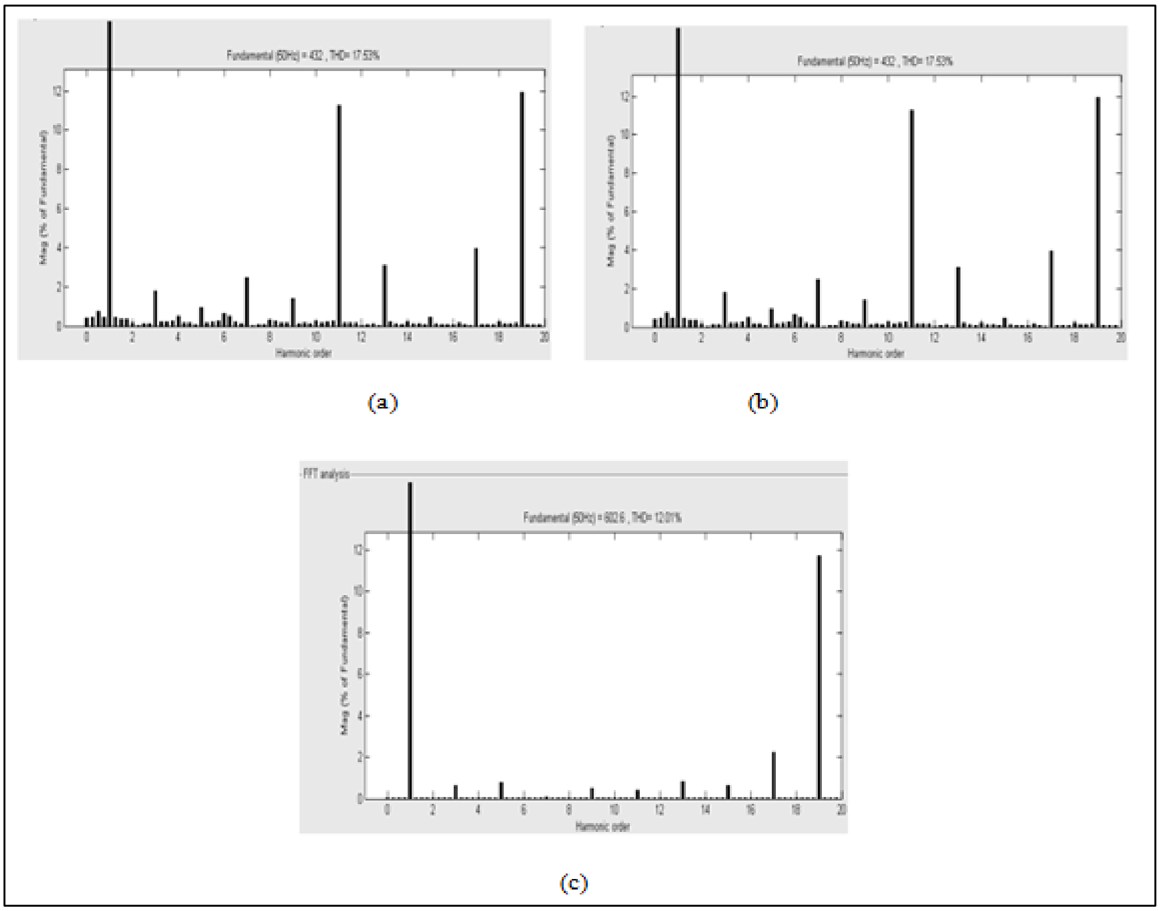

Fig. 4: THD for (a) Diode clamped inverter (b) Flying capacitor inverter (c) Cascaded H-bridge inverter

IV. CONCLUSION

The choice of topology for each inverter should be based on what is the usage of the inverter. Each topology has some advantages and disadvantages. By increasing the number of levels, the THD will be decreased but on the other hand cost and weight will be increased as well. Also since the switching angles for switches are not the same, the drive circuit for each switch is separate from other switches.

The cascaded H-bridge has the lowest weight and cost between the multilevel inverters, but its power losses is more that all the other topologies. For example at compared to the other topologies its power loss is more. This topology can be used in applications where the weight and the cost of the application is more important than its power losses.

The Flying capacitor clamped inverter has the lowest power losses between all of the other topologies, since there is no diode in its topology. For example the power losses in the 5-level flying capacitor multilevel inverter in full load are 625W, but it has two big problems. First is that it is heavier than the other topologies. It is not practical to use this heavy inverter in applications that are going to be used in applications that are not stable. Also the cost of this inverter is more than other inverters. It seems that the flying capacitor clamped multilevel inverter can be used in applications where the power losses are more important compared to the weight and cost.

The diode clamped multilevel inverter's power losses are lower than cascaded H-bridge. The diodes that were used can be of less cost, so the cost will not be that much higher than the cascaded H-bridge. It seems that diode clamped inverter is a topology between all other topologies that THD, cost and power losses are between other types of inverters.

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