Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 06, June - 2017

Topological Analysis of Multilevel Inverter for Photovoltaic System

Pramod Kumar Verma[1]*,
[1]Department of Electrical Engineering,
Integral University,
Lucknow, India

Ahmad Faiz Minai[2] , Mohammad Naseem[3]
[2,3]Department of Electrical Engineering,
Integral University,
Lucknow, India

***Abstract* - The multilevel concept is used to decrease the harmonic distortion in the output waveform without decreasing the inverter power output. This paper presents the important topologies of multilevel inverter like diode-clamped (neutral-point clamped), flying capacitor converter (FLC) and cascaded H-bridge with separate dc sources. This paper compares three different topologies of inverters with respect of power losses, Cost, weight and THD. A five level flying capacitor converter (FLC) and cascaded H-bridge inverter will be simulated with the implementation of PWM techniques and its effect on the harmonic spectrum will be analyzed. Each topology has their own features with corresponding advantages and disadvantages when used in a Renewable Energy Power system.**

Keywords: THD, Diode-Clamped (Neutral-Point Clamped), Flying Capacitor Converter (FLC), Cascaded H-Bridge Multilevel Inverter.

I. INTRODUCTION

In heavy duty industries and high voltage applications, the use of multilevel inverters are becoming common since many of the machinery uses electrical drives. The advantages of multilevel converters is their smaller output voltage step, which results in high voltage capability, lower harmonic components, lower switching losses, better electromagnetic compatibility, and high power quality[1], [2]. Also it can operate at both fundamental switching frequency and high switching frequency PWM. It must be noted that lower switching frequency usually means lower switching loss and higher efficiency [3]. Today, multilevel inverters are extensively used in medium voltage levels with high-power applications [4]). The field of applications includes use in laminators, pumps, conveyors, compressors, fans, blowers, and mills Uninterruptable Power Supply (UPS), DC power source utilization, induction heating, high voltage direct current power transmission, variable frequency drive, etc [5][6][7][8].

One clear disadvantage of multilevel power conversion is the great number of power semiconductor switches needed. Another disadvantage of multilevel power converters is that the small voltage steps are typically produced by isolated voltage sources or a bank of series capacitors. Isolated voltage sources may not always be readily available and series capacitors require voltage balance [9]. Multilevel inverters are more popular than conventional two-level inverters. This is due to two-level limitation when handling high voltage and power. In additions, the two level inverter also produces a quite numbers of higher-order harmonics which is considered as a main drawback [10][11].

II.TOPOLOGIES OF MULTILEVEL INVERTER

The three common topologies of multilevel inverters Diode-Clamped Multilevel Inverter (DCMI, Flying-Capacitor Multilevel Inverter (FCMI) and Cascaded H-Bridge Multilevel Inverter are known as Modular Structured Multilevel Inverters [8].

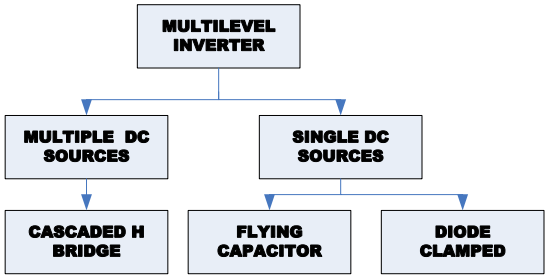

Fig. 1: Classification of MULTILEVEL Inverters

A. Diode Clamped Multilevel Inverter

The diode-clamped multilevel inverter is the name given to neutral-point clamped .A diode transfers a limited amount of voltage, thereby reducing the stress on other electrical devices. The maximum output voltage is half of the input DC voltage.

DCMI uses capacitors in series to divide up the DC bus voltage into a set of voltage levels. DCMI have the voltage unbalance problem and difficult to do real power flow control [8].

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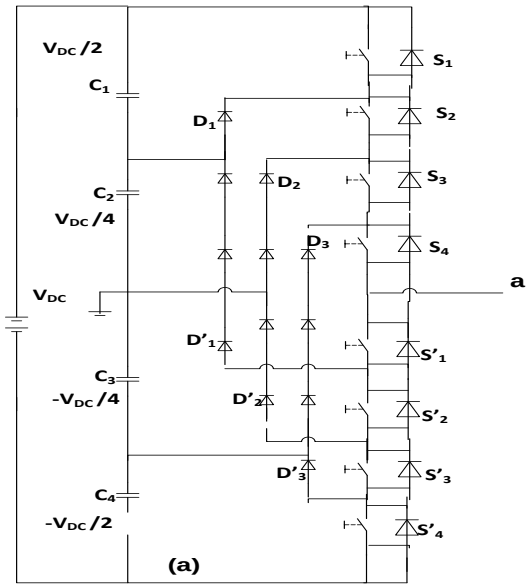

Fig. 3: Five level diode Diode Clamped (NPC) Multilevel inverter

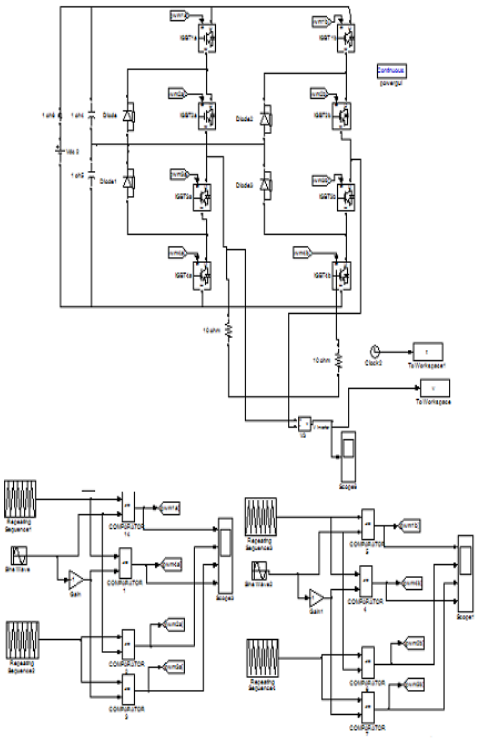

Fig. 2: Simulink model of five level Diode Clamped (NPC) Multilevel Inverter

B. Capacitor Clamped multilevel Inverter

Capacitor Clamped Multilevel Inverter also known as Flying capacitor Multilevel Inverter (capacitors are arranged to float with respect to earth) .Here the voltage levels are determined by the charging and discharging of the flying capacitors connected to the neutral point. Flying capacitor multilevel inverter (FCMI) is an alternative solution of DCMI. FCMI is capable to eliminate the clamping diode problems present in the DCMI. The method is the same as the diode clamped inverter.

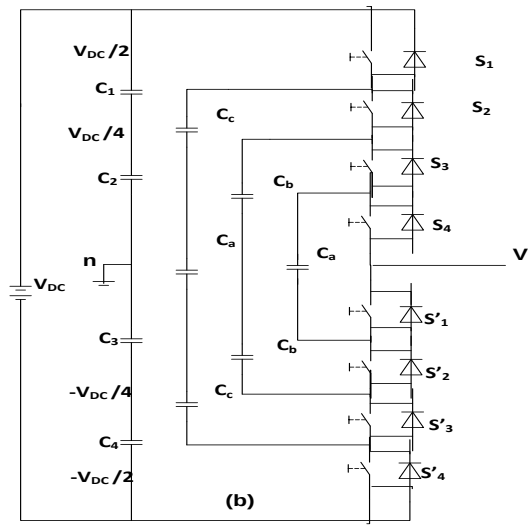

Fig. 4: Five level Flying Capacitor Multilevel Inverter

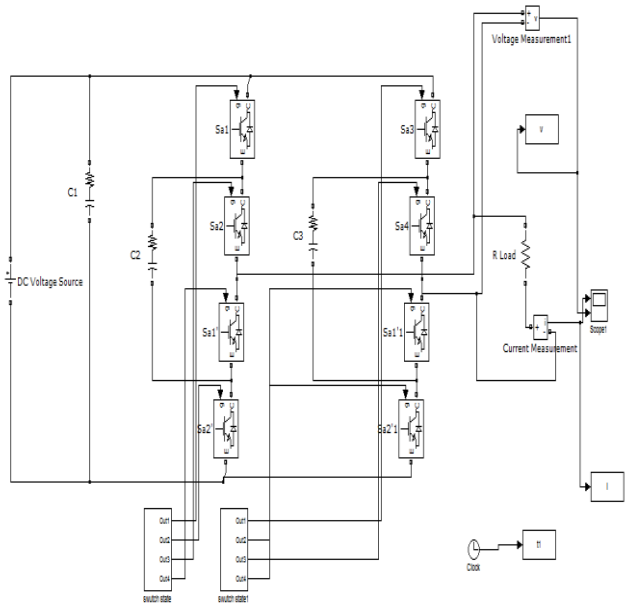

Fig. 5: Simulink model of five level Capacitor Clamped (FLC) Multilevel Inverter

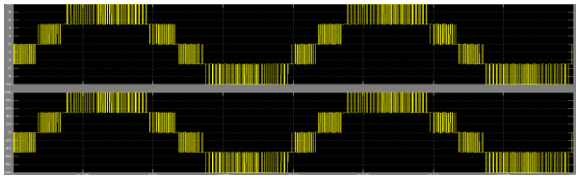

Fig.6: waveform generated by Capacitor Clamped (FLC) Multilevel Inverter

C. Cascaded H-Bridge Multilevel Inverter (CHB-MLI)

CHMI is also known as Modular Structured Multilevel Inverter (MSMI) is based on the series connection of several single phase inverters [13], [14]. CHMI require separate DC source, therefore it is suitable for various applications especially in renewable energy source applications. Inverter Consists of (n–1)/2 or h number of single-phase H-bridge inverters (MSMI modules). MSMI output phase voltage

Vo = Vm1 + Vm2 + …….. Vmh (1)

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Vm1 : output voltage of module 1
Vm2 : output voltage of module 2

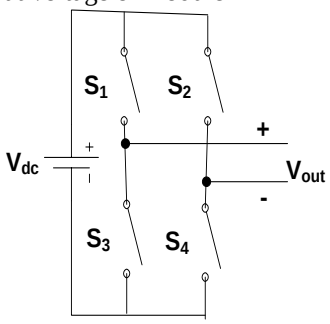

Fig. 7: Single H-bridge topology

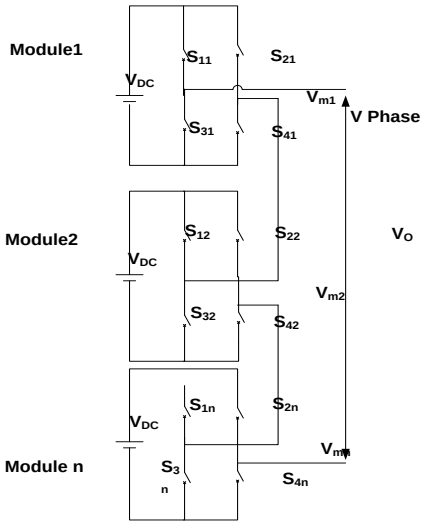

Fig. 8: Structure of a single-phase nl-level MSMI

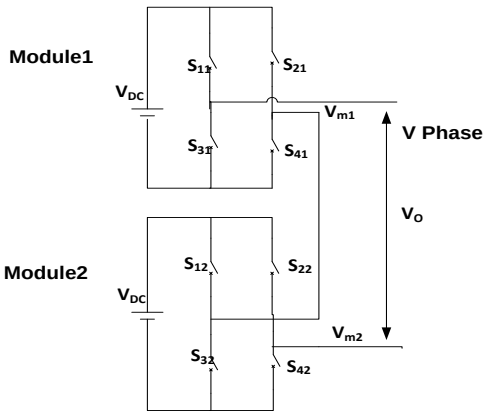

Fig. 9: Single-phase five-level CHMI configuration

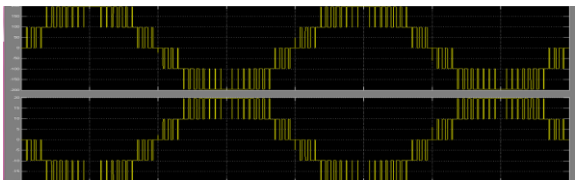

Fig. 10: Staircase sinusoidal waveform generated by H-bridge cascaded Multilevel converter

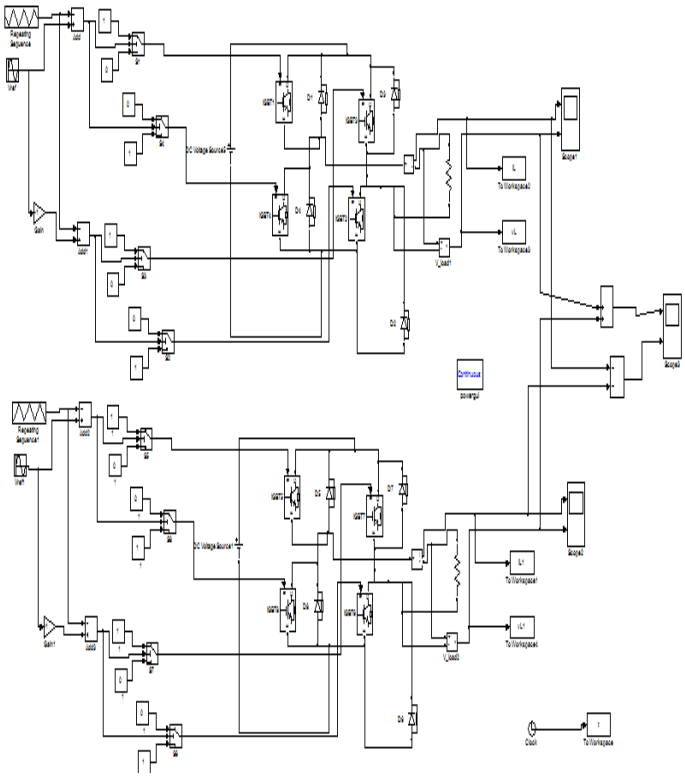

Fig. 11: Simulink model of Cascaded H-bridge (CHB) Multilevel Inverter

III. RESULT ANALYSIS

A. Power Losses Calculations

An induction motor is used as a load for balanced three phase system. Result analysis is given below;
All the Loss calculations is done for IGBT.
Mathematical equations for power losses calculations

$P_{ci}=U_{CEO}.I_{Iav}+r_c.I^2_{Irms}$ (2)

$P_{cd}=U_{DO}.I_{Dav}+r_D.I^2_{Drms}$ (3)

Since the number of switches are same in all the three considered topologies of five level inverters so comparative study of power loss in switches and diode are as follows-

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 (2) and for one switch, the power losses are:

P_{sw}= 17.7982W

There are 24 switches for three phases so:

P_{sw}=427.1566W

For the diode clamped multilevel inverter, the diode power losses should be calculated by (3). 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

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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 (2) and for one switch, the power losses are:

P_{sw}= 19.1105W

There are 24 switches for three phases so:

P_{sw}=458.6523W

3) 5-Level Cascaded H-Bridge Multilevel Inverter

According to (2) and (3) the power losses are:

P_{sw}= 1491.2W

P_{cD}= 209.3593W

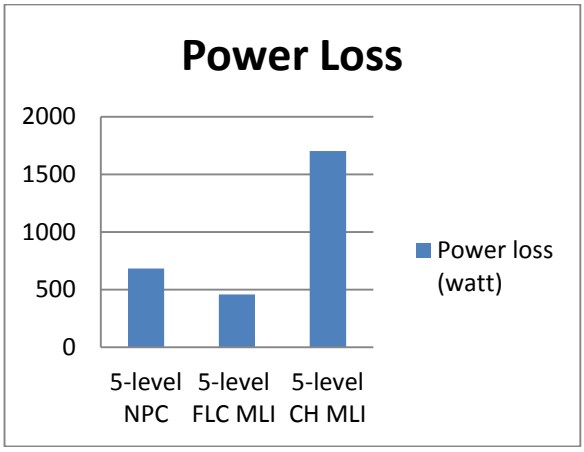

Fig. 12: Power losses comparison for IGBT FD300R06KE3 for 5-level Inverters

B. Weight and Cost Calculations

Weight comparison is done for each topology by calculating the weight of all of the components of the inverters. The same switch is considered for all of the topologies to have a more accurate comparison. The IGBT FD300R06KE3 is used for all of the topologies. In the 5-level diode clamped multilevel inverter, the 5-level flying capacitor, the 5-level cascaded H-bridge the capacitor C4DEFPQ6380A8TK is used, since the DC input voltages are higher, so a capacitor with higher voltage tolerance is needed. In the 9-level diode clamped multilevel inverter, the 9-level flying capacitor multilevel inverter and the 9-level cascaded H-bridge multilevel inverter the capacitor FFV34E0107K is used, since the DC input voltages are lower, so a capacitor with lower voltage tolerance is needed. Table.1 shows the total weight and the total cost of all types of inverters. To have a better understanding of different types of inverters, comparison are shown in the charts in Fig.13-17.

Table. 1: Weight and Cost Comparison

Type of inverter	Number of switches	Number of capacitors	Number of diodes	Weight(Kg)	Cost(Rs.)
5-level NPC	24	12	36	13.8	4493.3
5-level FLC MLI	24	30	0	20.73	5894.2
5-level CH MLI	24	6	0	10.67	3722.5

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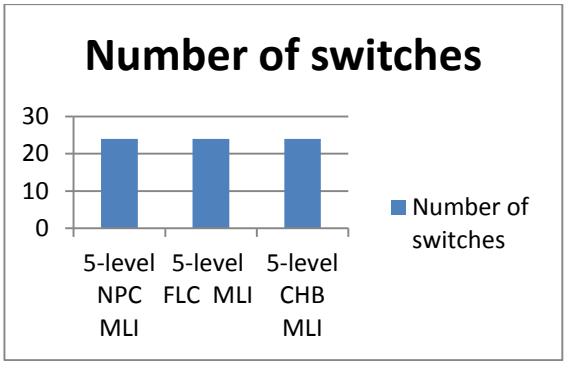

Fig. 13: Switch comparison for all types of Inverter

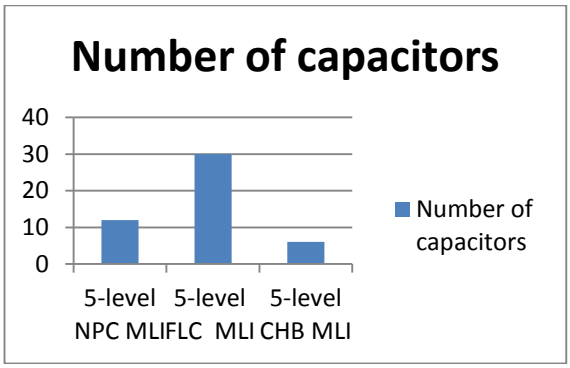

Fig. 14: Capacitor Comparison for all types of Inverter

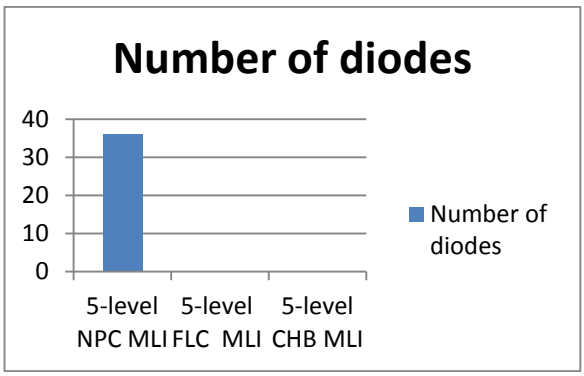

Fig. 15: Diode comparison for all types of Inverter

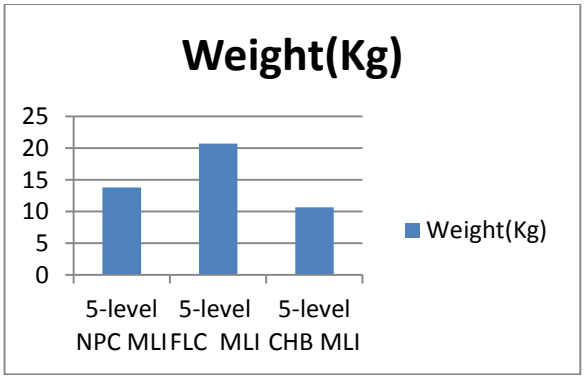

Fig. 16: Weight Comparison for all types of Inverter

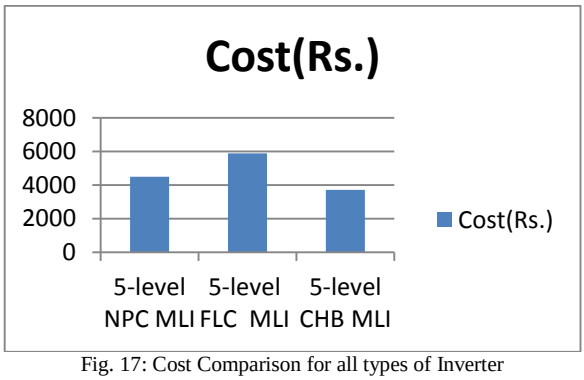

Fig. 17: Cost Comparison for all types of Inverter

C. THD Analysis

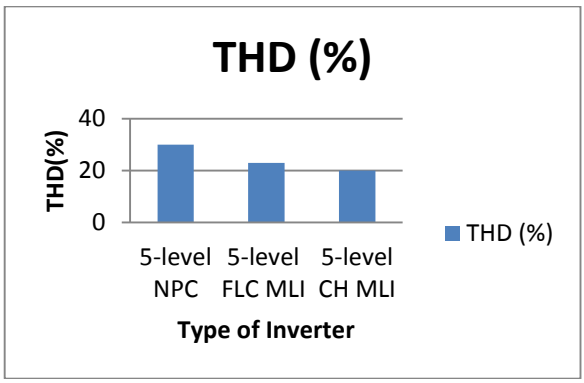

Fig. 18: THD comparison

The total harmonic distortion in diode clamped inverter (NPC) is much more than Flying capacitor multilevel inverter (FLC) and Cascaded H-Bridge Multilevel Inverter (CHBMLI), so for further studies regarding modulation index only FLC and CHB multilevel inverter are considered.

THD calculations obtained from the SIMULINK file. All of the THDs are for stator current in the electrical motor. The THD comparison between the 5-level Cascaded H-Bridge Multilevel Inverter and Flying capacitor multilevel inverter has been done which shown in table.2 and by Fig.19. The output voltage of all the 5-level topologies is the same, since the same switching pattern is used for all of them.

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Table .2: THD Comparison of Flying Capacitor Multilevel Inverter and Cascaded H-Bridge Multilevel Inverter

Cascaded H-Bridge Multilevel Inverter			Flying capacitor multilevel inverter		
M_{A1}	M_{A2}	THD (%)	M_{A1}	M_{A2}	THD (%)
.4	.4	76.77	.4	.4	92.92
.2	.8	52.43	.2	.8	63.80
.8	.2	51.81	.8	.2	63.33
.6	.6	44.15	.6	.6	50.44
.8	.6	41.79	.8	.6	44.57
.8	.8	38.31	.8	.8	42.40
.8	1.2	31.68	.8	1.2	37.67
1	1	26.89	1	1	36.13
1.8	1.8	25.3	1.8	1.8	24.28
1.6	1.6	23.6	1.6	1.6	25.46
1.2	1.2	21.71	1.2	1.2	29.94

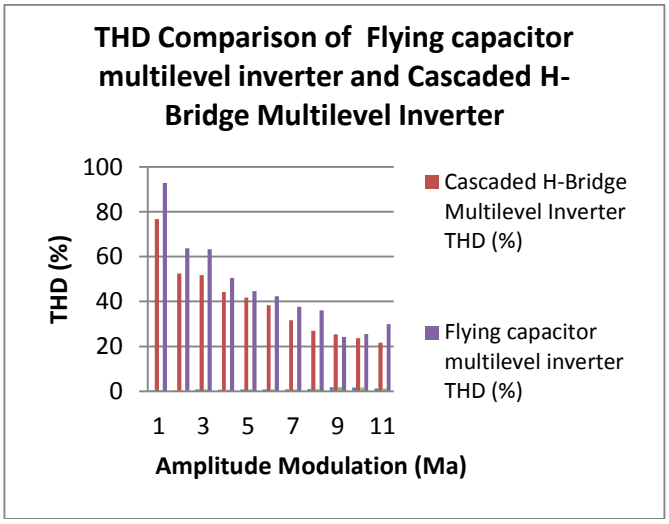

Fig. 29: THD Comparison of Flying Capacitor Multilevel Inverter and Cascaded H-Bridge Multilevel Inverter

IV. CONCLUSIONS

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. Compared to m-level DC-MLI, FC-MLI uses m-1 capacitors on the dc bus, the CMI uses only (m-1)/2 capacitors for same m-level. Clamping diodes are not required for FCMI and CMC. But balancing capacitors are must for FCMI. But for CMI such balancing – capacitors are completely absent. 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. It is seen from the study of diode clamped, flying capacitor clamped multilevel inverter, Cascaded H-Bridge Multilevel inverters that cascaded inverters have better THD. Due to decrease in the price of switching devices Cascaded H-Bridge MLI is more promising for Photo-voltaic (PV) applications. A multilevel cascaded inverter is also given preference over others because it utilizes two or more than two different strings of SPV array as a voltage source for each cell of a multilevel inverter.

The Flying capacitor clamped inverter has the lowest power losses between all of the other topologies, since there is no diode in its topology. It has two big problems. First is that it is heavier than the other topologies. Also the cost of this inverter is more than other inverters.

The diode clamped multilevel inverter's power losses are lower than cascaded H-bridge 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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About the Auorth

Pramod Kumar Verma was born in Lucknow, Uttar Pradesh, India, on 20 June 1986. He Received the Bachelor's Degree from Uttar Pradesh Technical University (UPTU), Lucknow and M.Tech from Integral University. He is with the ITM Group of Insititution,Lucknow , as Assistant Professor in the Electrical and Electronics Engineering Department from August, 2012.

Ahmad Faiz Minai Received the Master's Degree from Aligarh Muslim University, Aligarh and pursuing PhD from Integral University, Lucknow, U.P. India. He is with the Integral University, as an Associate Professor in the Electrical and Electronics Engineering Department from July, 09.