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PERFORMANCE ANALYSIS OF NEUTRAL POINT CLAMPED AND CASCADE H-BRIDGE MULTILEVEL CONVERTER INTERFACED WITH SOLAR PHOTOVOLTAIC SYSTEM TO REDUCE TOTAL HARMONIC DISTORTION

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Abstract:- Present day industrial applications require higher power apparatus for power conversion. At medium voltage grid, to connect only one power semiconductor switch directly is a not practically successful concept to overcome this multilevel power converter has been studied as an alternative in high power and medium voltage applications. Renewable energy sources like photovoltaic, wind, fuel cells can be conveniently interfaced to a multilevel converter system. Solar photovoltaic system becomes more popular among other renewable energy system, therefore Power electronics devices have been become an indispensable part for renewable energy system. This paper demonstrates comprehensive analysis and comparison of the Total harmonics distortion (THD) in detail of multilevel converter for different levels by modelling and simulation when interfaced with Solar Photovoltaic (PV) system. The results presented give an understanding for the implementation of the multilevel converter in the solar PV system. The modular structure for the multi level inverters allows extending higher number of levels easily for future studies with less complexity comparably. The simulation results are carried out using two different topologies for multilevel converter, neutral point clamped (NPC) and cascade H-bridge (CHB). The main focus of this paper is to present physical modelling and simulation of solar PV system and multilevel converter for different levels. The results displayed are such that the output gets smoother as the levels increases and the total harmonics distortion decreases. The solar PV system used is modelled in SIMCAPE library. All the simulation studies are carried out under MATLAB/Simulation environment.

KEYWORDS:- *Solar Photovoltaic (PV) system, Multilevel converter, Total Harmonic distortion (THD), Neutral point clamped, Cascade H-Bridge (CHB).*

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1. Introduction

Recently renewable energy power has drawn extreme attention due to increasing fossil fuel prices, energy demands and clean environment, thus studies on electric power generation and conversion devices become more important. The recent attention in environment protection and preservation increased the interest in electrical power generation from renewable source such as solar energy, wind energy. This paper gives a comparative more efficient way and results for different levels of the multilevel conveter interfaced with the solar photovoltaic system. This makes system cost effective as the power transferred to from the solar PV system with the increased levels of multilevel converter in setup decreases the use of filters. The model simulated for the system makes use of single stage power conversion and PWM control strategy. Several techniques can be found in literature aiming the reduction of the voltage harmonic content [1-5]. The multilevel converters are gradually being used in industrial applications in grid connected system and many more. However, the elementary concept of a multilevel converter to achieve higher power uses series of power semiconductor switches with the several lower voltage DC sources to perform power conversion by synthesizing a staircase voltage waveform. Renewable energy voltage sources, Capacitors, batteries can be used as multiple DC voltage sources.

2. Multilevel converter

Since multilevel converters can synthesize the output voltages by increasing levels they overcome conventional two- and three-level inverters in terms of harmonic distortion. Single phase multilevel converters are roughly into following categories based on design [6] [7].

Although, a number of topologies are proposed in literature, few main techniques are:

- Diode clamped (neutral point clamped).
- Flying capacitors (capacitor clamped).
- Cascaded H-bridge converter.

2.1. Diode clamped multilevel converter (NPC) topology

The diode-clamped inverter provides multiple voltages through connecting the phases to a series capacitors bank. The concept can be extended to number of levels by increasing the number of capacitors. Previously this topology was limited to three levels in which two capacitors connected across the dc bus resulting in one additional level

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that is the neutral point of the dc bus, so the terminology neutral point clamped (NPC) inverter was introduced [8-15].The circuit diagram of the three level NCP is shown in Figure.1.

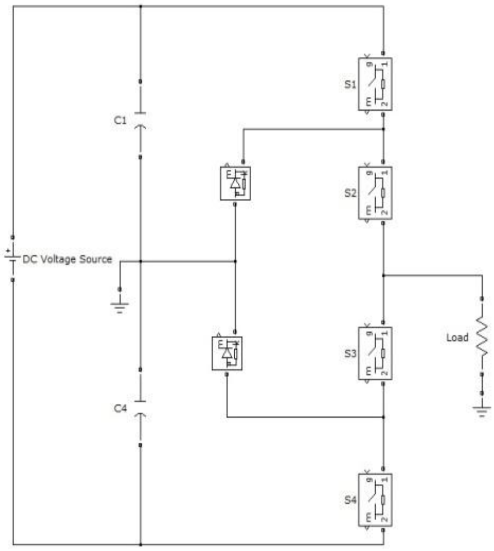

Figure 1.Diode clamped multilevel converter (NPC)

2.2. Flying capacitor Topology

This multilevel topology the flying capacitor involves series connection of capacitor clamped switching cells. This topology has several attractive features when compared to the diode clamped converter. One feature is that added clamping diodes are not needed. Furthermore, the flying capacitor converter has switching redundancy within the phase which can be used to balance the flying capacitors so that only one dc source is needed [8-15]. The circuit diagram of the three level Flying capacitor is shown in Figure.2.

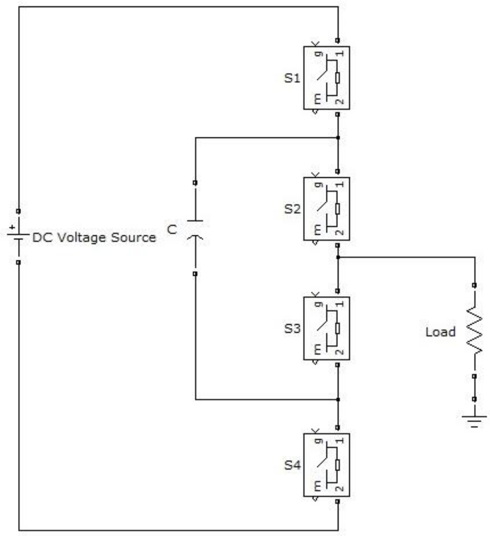

Figure 2.Three level flying capacitor Topology

2.3. Cascade H-bridge multilevel inverter topology

The cascade H-bridge inverter pictured in 1975, there are several patterns for this topology as well. This topology consists of series power conversion units, the voltage and power level may be conveniently scaled. A noticeable disadvantage of this cascade H-Bridge topology is large number of isolated voltages required to supply each cell unit. However, the cells can be supplied by phase-shifted transformers in medium-voltage systems in order to provide high power quality at the utility connection [8-15].The circuit diagram for the three level CHB is shown in Figure.3.

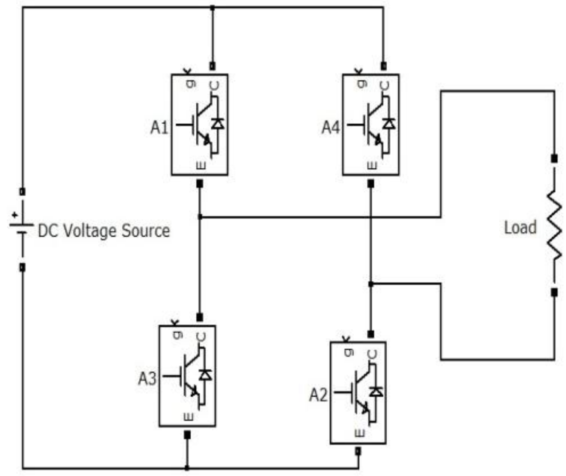

Figure 3.Cascade H-bridge multilevel inverter topology

2.4 Advantages of multilevel converter

Multilevel converters attractive features over a conventional two-level converter by use of high switching frequency pulse width modulation (PWM):

Staircase waveform quality: Multilevel converters generate the output voltages with very low distortion, and also can reduce the dv/dt stresses; therefore problems of electromagnetic compatibility (EMC) can also be reduced.
Common-mode (CM) voltage: Multilevel converters generate smaller CM voltage which results in reduced stress in the bearings of a motor connected to a multilevel motor drive. Furthermore, by using the advanced mode technology the CM voltage can be reduced.
Switching frequency: Multilevel converters can operate at both fundamental switching frequency and high switching frequency Pulse width modulation (PWM). It should be noted that lower switching frequency usually means lower switching loss and higher efficiency.
Input current: Multilevel converters can draw input current with low distortion comparatively [11-16].

Multilevel converters has few disadvantages like it require more devices which increases system cost comparatively hence probability of a device failure increases [18-20].

3. Solar Photovoltaic system

Photovoltaic is the most promising renewable energy in nature due its abundant quantity, it is gaining more attention during the last several years as a source of energy. The noticeable disadvantage of PV system are the lower conversion efficiency and high cost of installation of solar panels .But with the help of new techniques of manufacturing crystalline design and the use of upgraded devices it is possible to make the PV system cost effective. PV energy system will have more impact in the future due to the development of economic power conversion equipment [20-26]. A solar panel which is consisting 36 cells in series is used in the study which produces approximately 21.6 V in maximum sunlight condition (1000 W/m^2). Solar cell has been simulated in SIMSCAPE library for different levels of multilevel converter.

3.1. Modelling of photovoltaic system

The output of PV cell is a function of photon current that can be also determined by load current depending upon the solar isolation during its operation. The figure 4 shows the equivalent circuit for the photovoltaic cell.

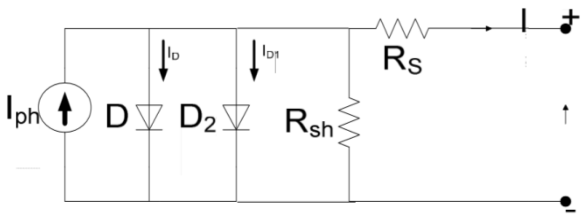

Figure 4. Electrical equivalent circuit of a PV cell

Figure 5 shows the current versus voltage (I-V) characteristic of the solar module which is interfaced with the multilevel inverter.

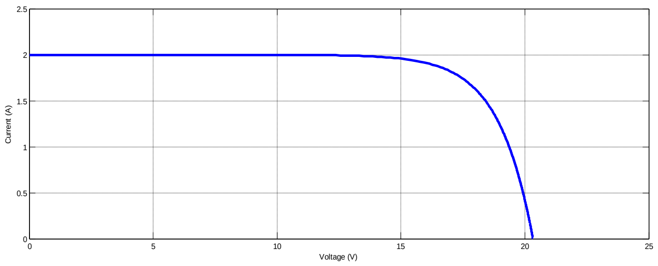

Figure 5. I-V characteristics of solar module

Figure 6 shows the power versus voltage (P-V) characteristic of the solar module.

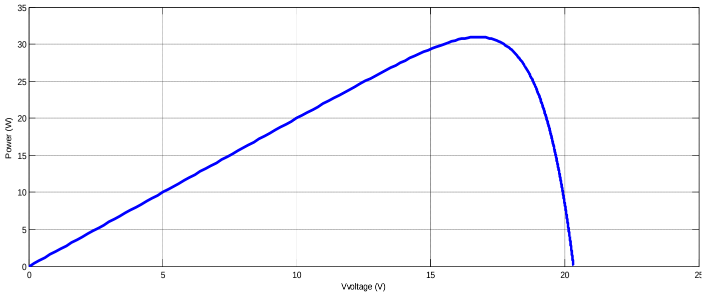

Figure 6. P-V characteristics of solar module

4. Pulse width modulation (PWM)

Telecommunications, Power delivery, Voltage regulation, Audio effects and amplification are the few application of PWM. Pulse width modulation (PWM) methodologies used in the multilevel converter modulation can be classified according to switching frequency. The three multilevel PWM methods most discussed in the literature have been multilevel carrier-based PWM, selective harmonic elimination, and multilevel space vector PWM; all are extensions of traditional two-level PWM strategies to several levels [27-30].

Multilevel PWM methods uses high switching frequency carrier waves in comparison to the reference waves to generate a sinusoidal output wave. To reduce harmonic distortions in the output signal phase-shifting techniques are used There are several methods that change disposition of or shift multiple triangular carrier waves. The number of carrier waves used is dependent to the number of switches to be controlled in the inverter. In addition to the sinusoidal carrier wave modulation methods presented there are two alternative methods are Position Opposition Disposition (APOD) and Phase Opposition Disposition (POD) [27-30].

In our study we will focus on the Phase Opposition Disposition (POD) technique in detail.

4.1. Phase Opposition Disposition PWM (PODPWM)

In Phase Opposition Disposition (POD), the carrier signal above the zero axes is in phase with each other having same frequency and same amplitude [21]. Consecutively below the zero axis the carrier wave have phase shifted 180 degree with the same frequency and same amplitude as the above zero axis. The figure demonstrates the PODPWM. The three level multilevel converter simulation sine wave and the triangular carrier shown in figure 7.

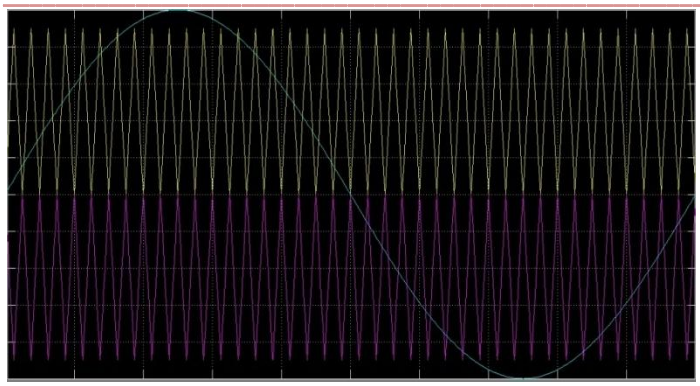

Figure 7. POD of three level multi level converters

5. Matlab/Simulation and results

5.1. Solar PV system interfaced with five level neutral point clamped multilevel converter

Neutral point clamped multilevel converter interfaced with solar PV system of 21.6V (36 cell of 0.6 V each connected in series), are displayed from figure 8 to figure 11. As shown in figure 8 in NPC topology the total voltage or input voltage V_{dc} divides across the capacitor after that the operation of switches decides the output voltage that is the five level converter voltage is divided in four part across C_1 C_2 C_3 and C_4 i.e. $+\frac{Vpv}{4}, +\frac{Vpv}{2}, -\frac{Vpv}{4}, and -\frac{Vpv}{2}$. And the fifth level is defined as zero potential.

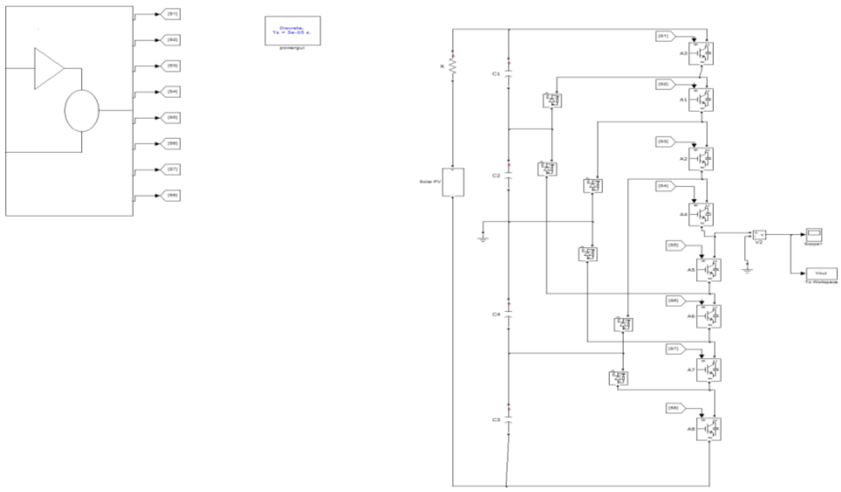

Figure 8.Solar PV system interfaced with five level neutral point clamped multilevel converter

5.1.1 The Simulated responses of Neutral point clamped multilevel coverter

The simulated response for three level, five level, seven level and nine level solar PV system fed multilevel converter are displayed in Figure 9, 10, 11 and 12 respectively.

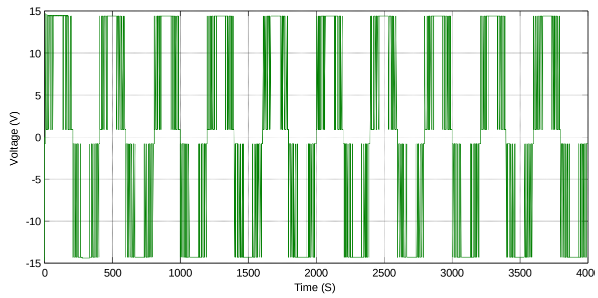

Figure 9.Waveform of output-voltage with respect to time of three level neutral point clamped multilevel converter interfaced with solar PV system

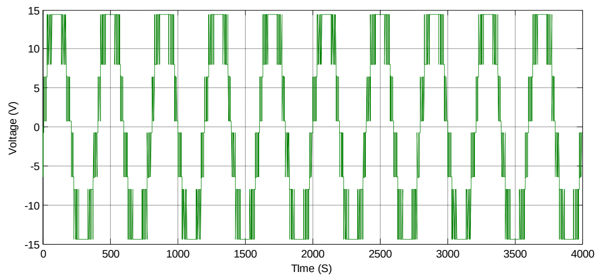

Figure 10.Waveform of output-voltage with respect to time of five level neutral point clamped multilevel converter interfaced with solar PV system

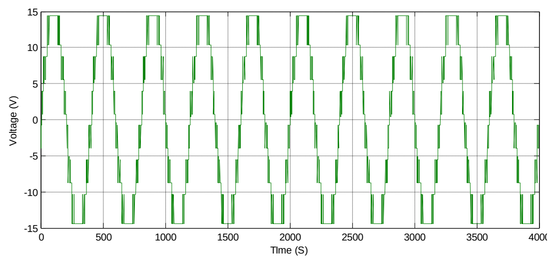

Figure 11.Waveform of output-voltage with respect to time of seven level neutral point clamped multilevel converter interfaced with solar PV system

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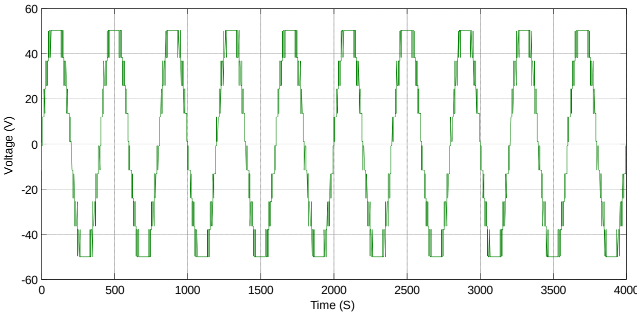

Figure 12.Waveform of output-voltage with respect to time of nine level neutral point clamped multilevel converter interfaced with solar PV system

5.2. For Cascade H-bridge multilevel Converter

For Cascade H-bridge topology shown below when interfaced with solar panel (36 cell of 0.6 V each connected in series), if considering five level inverter two solar panels of 21.6 V can produce five level i.e. +43.2, +21.6, 0, - 21.6 and -43.2 as shown in figure 13.

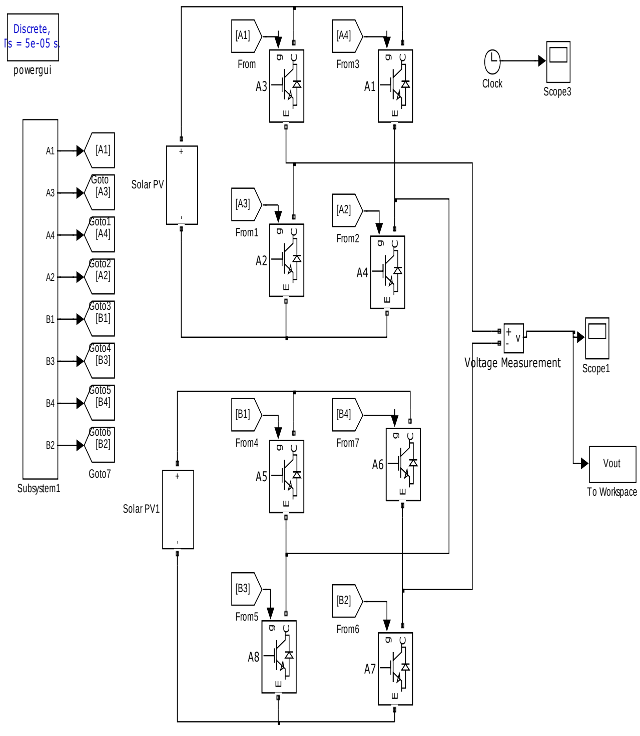

Figure 13.Solar PV system interfaced with five level cascade H bridge multilevel converter

5.2.1. The Simulated responses of Cascade H-Bridge multilevel converter

The simulated response for three level, five level, seven level and nine level solar PV system fed multilevel converter are displayed in Figure 14,15,16 and 17 respectively.

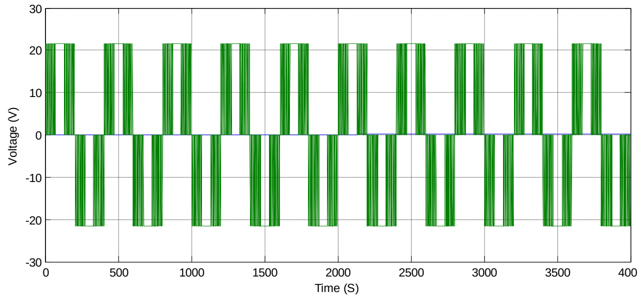

Figure 14.Waveform of output-voltage with respect to time of three level cascade H-bridge multilevel converter interfaced with solar PV system

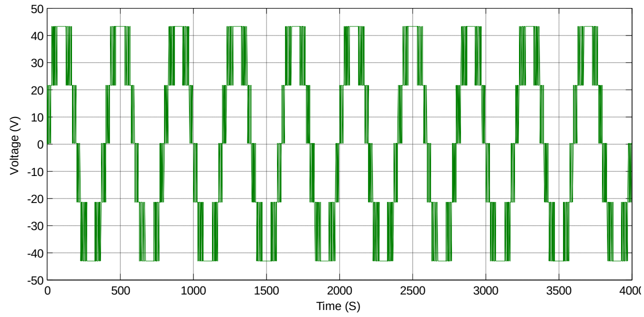

Figure 15.Waveform of output-voltage with respect to time of five level cascade H-bridge multilevel converter interfaced with solar PV system

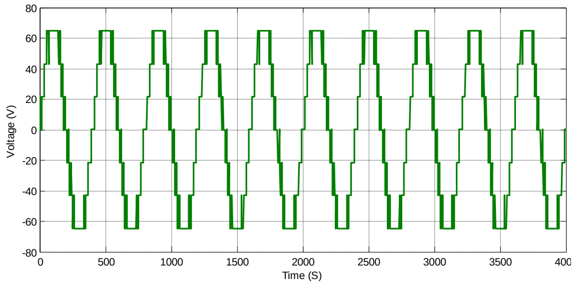

Figure 16.Waveform of output-voltage with respect to time of seven level cascade H-bridge multilevel converter interfaced with solar PV system

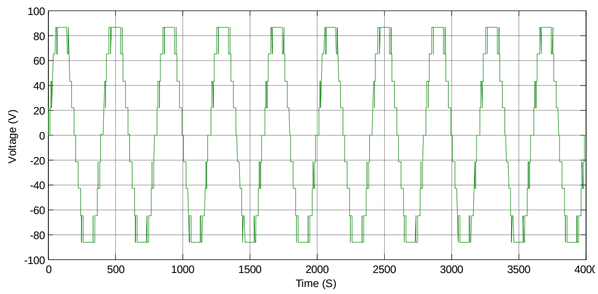

Figure 17.Waveform of output-voltage with respect to time of nine level cascade H-bridge multilevel converter interfaced with solar PV system

6. Comparative analysis of multilevel converter topologies fed Solar PV Supply

Table 1 gives the total harmonic distortion of Neutral point clamped and Cascade H-bridge topology of multilevel

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converter for three, five, seven and nine level when fed from solar PV system of 36 cells having total voltage of 21.6V.

Table 1 Comparative analysis NPC and CHB topology of multilevel converter fed solar PV supply in terms of Total Harmonic Distortion:

Levels of Multilevel converter	Total harmonics distortion%	
	Cascade H bridge	Neutral point clamped
3	53.41	40.21
5	25.69	19.66
7	15.09	12.64
9	11.56	9.78

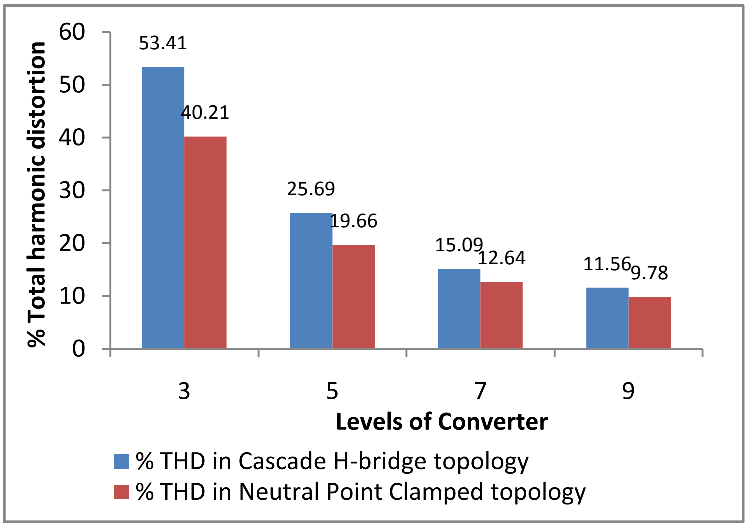

FIg. 18. Graph showing percentage THD for three, five, seven and nine level converter

7. Conclusion

This paper presents simulation of cascade H-bridge and Neutral point clamped multilevel converters up to nine level with their control strategies when interfaced with the solar PV system. As there is increase in the voltage levels through NPC and Cascade H-bridge topology it reduce harmonics. The performance gets better dimensions in the sense it facilitates more or less a sinusoidal output voltage. Increasing the number of levels by these topologies is easily possible to large extends which is a new direction in this domain. Future research scope should be focused on developing optimal control for such topologies. A multilevel approach for converters guarantees a reduction of output harmonics due to sinusoidal output voltages thus leads to reduce grid filters, system cost and complexity reduction. The aim of this study was to analysis the multilevel converter for different levels using Neutral point clamped and Cascade H-bridge topology fed from solar PV system and to analyse their Total harmonics distortion (THD).

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