Comparison of 5-level and 11-level Cascaded Inverter using Sinusoidal Pulse Width ModulationTechnique

Tejas Maniar, Mansi P.Kothari
Dept. of Electrical Engg. SSEC Bhavnagar, Gujarat. India
Dept. of Electrical Engg. GEC Bhavnagar, Gujarat India

***Abstract*— Multilevel inverters are the backbone of the industrial world in this age of technological revolution. It finds its application in several fields including medium voltage high power drives, integration of distributed generation and power utility applications in flexible AC transmission to name a few. Cascaded multilevel inverters (MI) stand out among all other MI for being the pioneer in MI technology and for being the forerunner in the practical application till date. Hence this paper represents 5-level and 11-level cascaded inverter's simulation using sinusoidal pulse width modulation technique in MATLAB. Compare total harmonic distortion [THD] of 5-level and 11-level cascaded inverter's phase voltage and line-to-line voltage.**

Keywords-Cascaded inverter, SPWM, THD.

I. INTRODUCTION

Multilevel inverters [MI] have changed the face of technology and hence its application has been growing at a tremendous pace. One can see its presence being felt in the power industry especially in the interaction of the distributed generation with the main line utility grid [1]. Yet another aspect of its impact is visible in the reactive power control of power transmission lines for voltage control [2]. Thus, MIs have a key role to play in the fast advancing technology of flexible AC transmission system power electronics based controllers. Other than the power industry, MI finds its application in medium voltage high power drive systems which sums most of the high ended industrial applications [3]. Such a scenario makes it important to understand the crucial aspects of the different multilevel inverters.

Nowadays multilevel inverters are the promising alternativeand cost effective solution for high voltage and high power applications including power quality and motor drive problems. Multilevel structure allows raising the power handling capability of the system in a powerful and systematicway. The advancements in the field of power electronics and microelectronics made it possible to reduce the magnitude of harmonics with multilevel inverters, in which the number of levels of the inverters are increased rather than increasing the size of the filters (Dixon and Moran, 2006). The performance of multilevel inverters enhances as the number of levels of the inverter increases.

This paper has studied three phase cascaded multilevel inverter at 5-level voltage and 11-level voltage then compared the total harmonic distortion (THD) in each of these cases. This paper is divided as follows: Section II presents the background of MI topologies and pulse width modulation. Section III, thereafter, concentrates on the cascaded multilevel inverter and its circuit diagrams at different voltage levels. Section IV simulation results for 5-level and 11-level cascadedinverter. Section V comparison of total harmonic distortion for 5-level and 11-level cascaded inverter. Compiles the simulation results followed by the final conclusions.

II. BACKGROUND

A. Multi-Level Inverter

Multilevel inverters are significantly different from the ordinary inverter where only two levels are generated. The semiconductor devices are not connected in series to for one single high-voltage switch. In which each group of devices contribute to a step in the output voltage waveform. The steps are increased to obtain an almost sinusoidal waveform. The number of switches involved is increased for every level increment.

Multilevel inverters have been broadly classified into three categories namely cascaded H-bridge MI, diode clamped MI [DCMI] and finally, flying

capacitor type MI [FCMI] [1]. DCMI has several advantages and a wide range of application too, but the primary disadvantage of DCMI over the cascaded topology is its switching control complexity and increased switching losses [2]. Since an m – level DCMI has 2(m – 1) main semiconductor switches and diode per phase, when m is sufficiently high, the number of diodes required will make the system impractical to implement. If the inverter runs under PWM, the diode reverse recovery of these clamping diodes becomes the major design challenge in high voltage high power applications [4]. Moreover, DCMI presents bad values for total harmonic distortion [THD], first order distortion [DF1] and second order distortion [DF2] as compared to symmetrical cascaded H – bridge (nine – level) [5]. Other thanthese, one other thing that holds against DCMI is that with higher voltage ratings, the cost of the semiconductor devices increases exponentially. Hence, as compared to DCMI, the cascaded topologies are a much more viable option for high voltage rating applications. Moreover, the cascaded topologies present low distortion output voltage and higher efficiency.

The structure of FCMI is similar to diode clamped MI except that instead of clamping diodes, capacitors are used [1].Moreover, for m – level FCMI, other than the (m – 1) dc link capacitors, FCMI will need auxiliary capacitors equal to [(m – 1)(m – 2)/2] per phase if the voltage rating of the capacitors are identical to that of the main switches. Therefore, the circuitwill have a large number of capacitors which will make the tracking of voltage levels for all the capacitors very difficult. Pre charging all the capacitor to the same voltage level and startup is also complicated. Large number of capacitor also makes the MI more expensive and bulky. Moreover, packaging is also more difficult in FCMI with a high number of levels. Among all the above mentioned comparative study, H bridge type or the cascaded type MI has the advantage of producing output voltage levels more than twice the number ofdc sources.

B. Pulse Width Modulation

In many industrial applications, to control the output voltage of the inverters is necessary for the following reasons,

1) To adjust with variations of dc input voltage, 2) To regulatevoltage of inverters, 3) To satisfy the contain volts and frequency control requirement. There are various techniques tovary the inverter gain. Several modulation control strategieshave been proposed or adopted for multilevel inverters. Themost efficient method of Controlling the gain (and outputvoltage) is to incorporate pulse width modulation (PWM) Control within the inverters.

Instead of, maintaining the width of all pulses of same as in case of multiple pulse width modulation, the width of each pulse is varied in proportion to the amplitude of a sine wave evaluated at the centre of the same pulse. The distortion factor and lower order harmonics are reduced significantly. The gating signals are generated by comparing a sinusoidal reference signal with a triangular carrier wave of frequency Fc [6]. The frequency of reference signal Fr, determines the inverter output frequency and its peak amplitude Ar, controls the modulation index M, and rms output voltage Vo. The number of pulses per half cycle depends on carrier frequency.

III. CASCADED MULTI-LEVEL INVERTER

Single phase structure of an m- level H – bridge cascaded is as shown in figure 1. The number of voltage levels can be represented by the equation (m = 2s + 1) where m is numberof possible output voltage levels and s is the number of dc sources. Cascaded H-bridge multilevel inverters typically use IGBT or MOSFET switches. These switches have low block

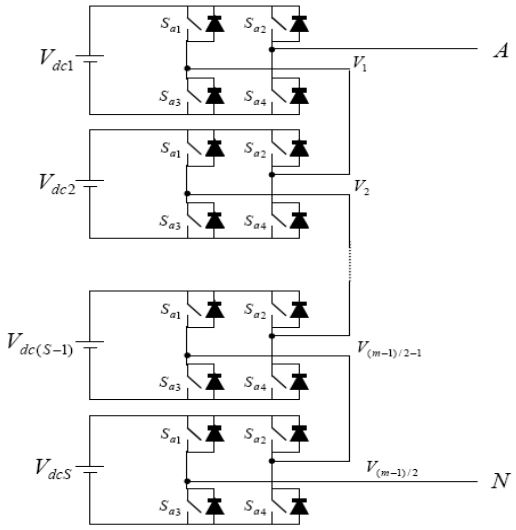

Figure 1. Single Phase Structure of Cascaded Multilevel Inverter

voltage and high switching frequency. Cascaded H-bridge inverters have excellent input current and output voltage waveforms. Output voltage has smooth steps, so the outputvoltage, in case of an H – bridge cascaded MI, is nearly sinusoidal even without filtering [4]. Yet another advantage of cascaded H – bridge inverter is that the series of H – bridges makes for modularized layout and packaging. This will enable the manufacturing process to be done more quickly andcheaply [1]. The field applications of cascaded H – bridgetype include use in laminators, mills, conveyors, pumps, fans,blowers, compressors, etc [3]. They have also been proposed for such applications as static var generation, interface withrenewable energy sources and for battery based applications. Cascaded inverters are ideal for connecting renewable energy sources with an ac grid because of the need for separate dcsources, which is the case in applications such as photovoltaicor fuel cells. The cascaded inverter is also highly popular intraction and electric vehicles [1].

- Advantages of cascaded multilevel inverter

1).The series structure allows a scalable, modularized circuitlayout and packaging since each bridge has the same structure. 2).Switching redundancy for inner voltage level is possible because the phase voltage output sum of each bridges output. 3).Potential of electrical shock is reduced due to separate DCsources. 4).Requires less number of components whencompared to other two types. Some disadvantages 1). Limited to certain applications where separate DC sources are available. 2). Usage of the power semiconductor switchesincreases exponentially whenever the level is to be increased.

Simulation of Cascaded H-bridge 5-level and 11-level inverter

Fig. 2 shows the simulation model of a 5-level cascaded H-bridge inverter. Each separate dc source is 100V and MOSFET power electronic devices are use. In this topology power cells are in series and the number of phase voltage levels that can be obtained at the inverter terminals is proportional to the number of cells. In other words, in this topology the number of phase voltage levels at the inverter

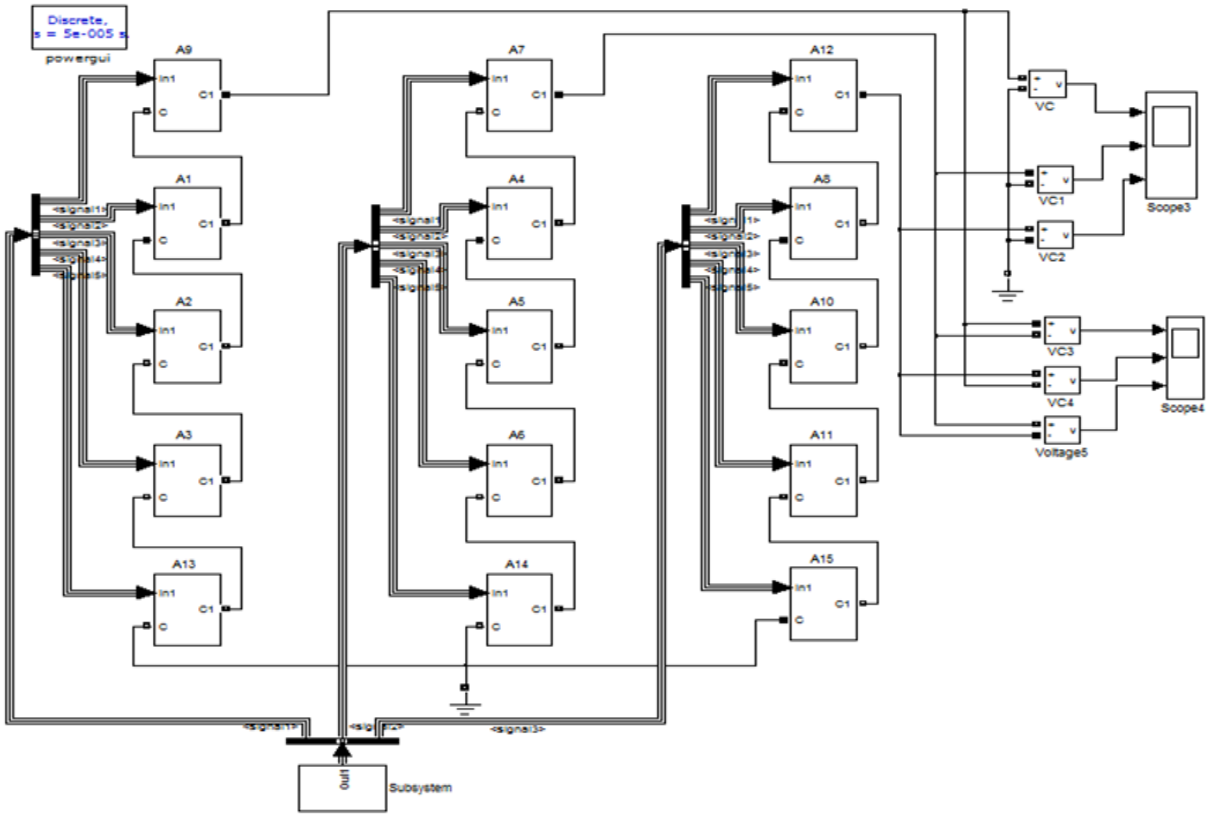

Fig.2 Simulation model for three phase 5-level cascaded inverter

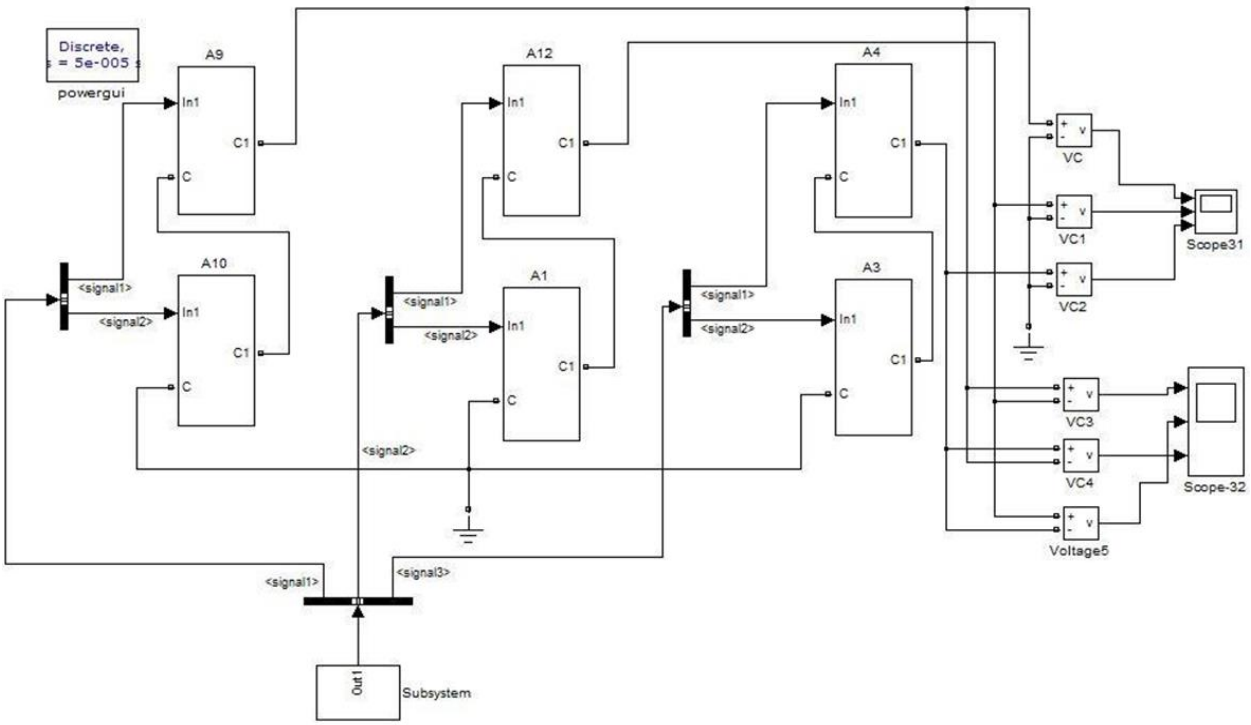

Fig: 3. Simulation model of 3-phase 11- level cascaded inverter

terminal is 2N+1, where N is the number of cells or dc link voltages. In fig.2 two H-bridges are connect in series on single leg. Output of fig. 2 is 5-level phase voltage waveform. In Fig.3 five separate dc source are connect in series on single leg. Both simulation model use sinusoidal pulse width modulation technique.

In this simulation, each cell has separate dc battery and the voltage across the capacitor might differ among the cells. So, each power circuit needs just one dc voltage source. The number of dc link capacitors is proportional to the number of phase voltage levels. The ground point shown in Fig.2 is a common reference point and all phases are connected in this point. Each H-bridge cell may have positive, negative or zero voltage. Final output voltage is thesum of all H-bridge cell voltages and is symmetric with respect to neutral point, so the number of voltage levels is odd.

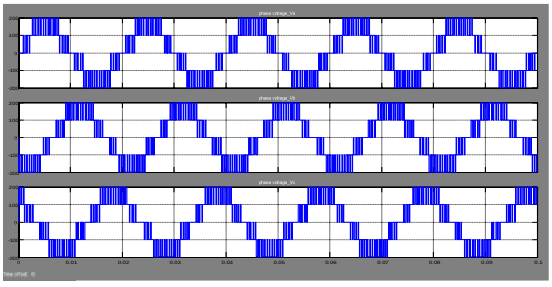

Fig.4 phase voltage waveform of 3-phase 5-level cascaded inverter.

IV.SIMULATION RESULTS

A. Simulation result of 5-level and 11-level cascaded inverter for phase voltage waveform

Fig.4 shows the phase voltage waveform of 3-phase 5- level cascaded inverter with 5-step in full cycle time[T] in sec. Fig.5 Fast Fourier Transform [FFT] analysis shows the harmonic content in each of the voltage level as percentage of the fundamental component in 5-level cascaded inverter. Total harmonic distorction [THD] is 37.96% in 3-phase 5-level cascaded inverter for phase voltage waveform.

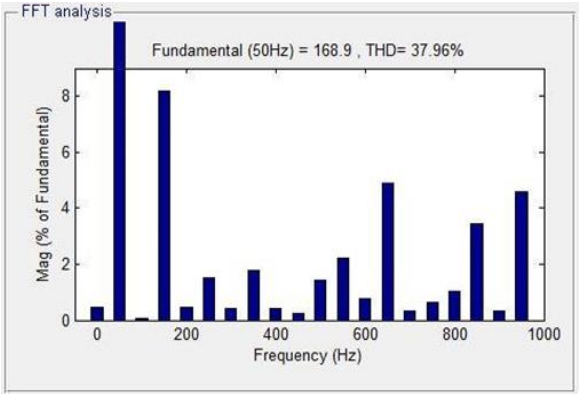

Fig.5 FFT analysis of phase voltage of 5-level cascaded inverter

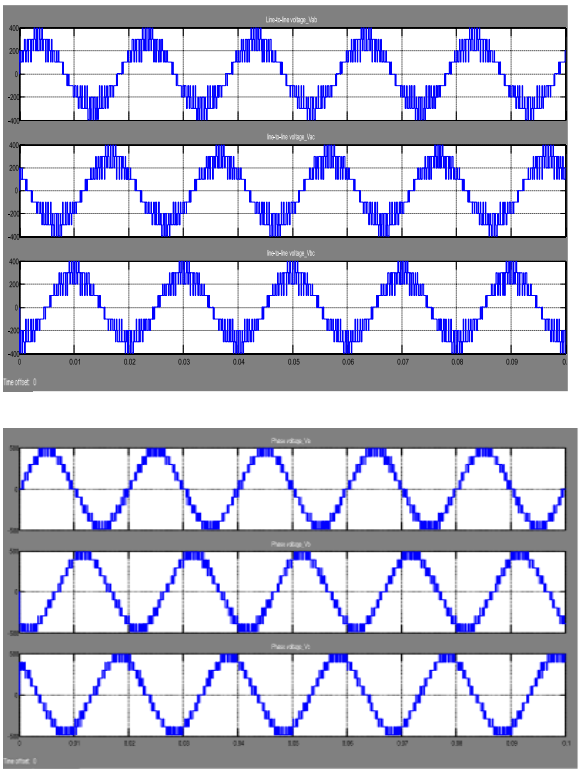

Fig.6 phase voltage waveform of 3-phase 11-level cascaded inverter.

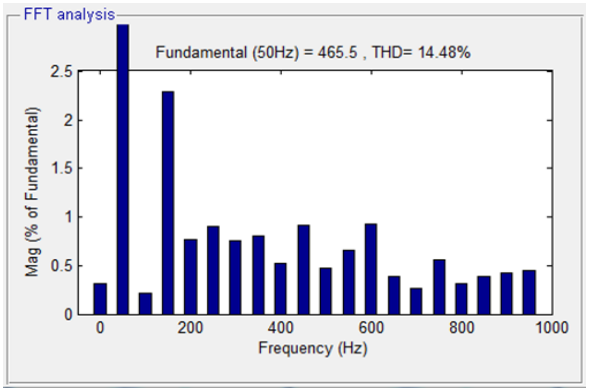

Fig.7 FFT analysis of phase voltage of 5-level cascaded inverter.

Fig.6 shows the phase voltage waveform of 3-phase 11- level cascaded inverter with 11-step in full cycle time[T] in sec. Fig.7 Fast Fourier Transform [FFT] analysis shows the harmonic content in each of the voltage level as percentage of the fundamental component in 11-level cascaded inverter. Total harmonic distorction [THD] is 14.48% in 3-phase 11-level cascaded inverter for phase voltage waveform.

B. Simulation result of 5-level and 11-level cascaded inverter for line-to-line voltage waveform

Fig.8 shows the line-to-line voltage waveform of 3-phase 5-level cascaded inverter. Fig.9 Fast Fourier Transform [FFT] analysis shows the harmonic content in each of the voltage level as percentage of the fundamental component in 5-level cascaded inverter. Total harmonic distorction [THD] is 32.31% in 3-phase 5-level cascaded inverter for line-to-line voltage waveform of one cycle.

Fig.8 line-to-line voltage waveform of 3-phase 5-level cascaded inverter.

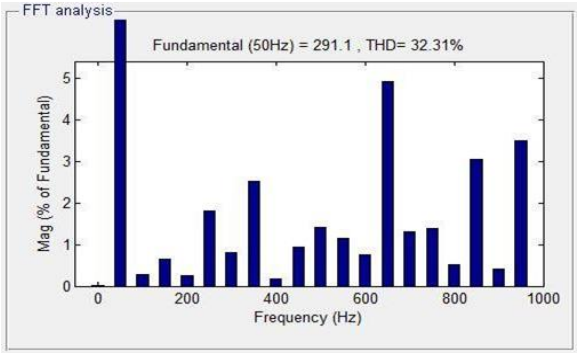

Fig.9 FFT analysis of line-to-line voltage of 5-level cascaded inverter.

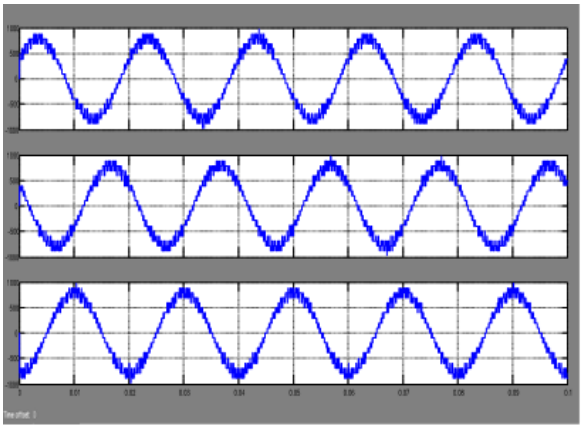

Fig.10 line-to-line voltage waveform of 3-phase 11-level cascaded inverter

Fig.10 shows the phase voltage waveform of 3-phase 11- level cascaded inverter with 11-step in full cycle time[T] in sec. Fig.11 Fast Fourier Transform [FFT] analysis shows theharmonic content in each of the voltage level as percentage of the fundamental component in 11-level cascaded inverter. Total harmonic distorction [THD] is 12.45% in 3-phase 11- level cascaded inverter for phase voltage waveform.

VI.CONCLUSION

This paper has carried out a comparative study of cascaded multilevel inverters having five and eleven voltagelevel. The results from the simulations shows that the harmonics reduce as voltage level increases from 5-level to 11-level cascaded inverter.11-level

cascaded inverter is synthesis the sine wave. This paper can be used as a ground work for further research in the forming of a new topology orin the implementation of cascaded topology in a specific application

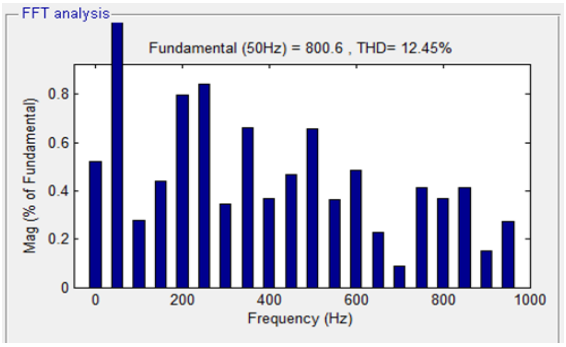

Fig.11 FFT analysis of line-to-line voltage of 11-level cascaded inverter.

V.COMPARISON OF THD

Table I. shows the comparison of total harmonic distortion for 5-level cascaded inverter and 11-level cascaded inverter with phase voltage and line-to-line voltage. Fig.12 shows the graphical representation of table I. depicting the fall in the total harmonic distortion [THD] with respect to voltage level.

TABLE I. COMPARISON OF THD FOR 5-LEVEL AND 11-LEVEL INVERTER

Voltage level	Phase / line-to-line voltage	THD
5-level	Phase voltage	37.96%
5-level	Line-to-line voltage	32.31%
11-level	Phase voltage	14.48%
11-level	Line-to-line voltage	12.45%

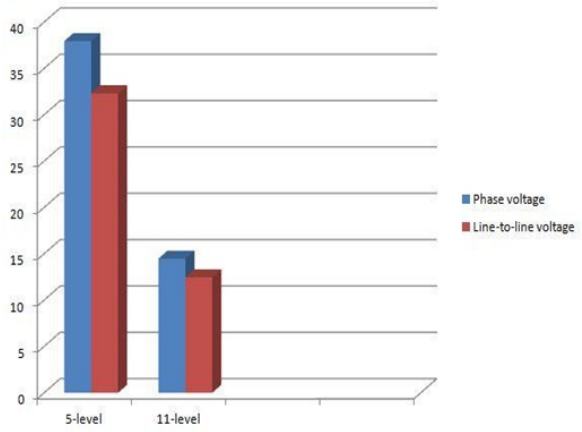

Figure 12: Grapical reperesentation of the decreasing harmonic content with the increase in the voltage level of the cascaded multilevel inverter.

REFERENCE

[1] S. Khomfoi, L. M. Tolbert, "Multilevel Power Converters," Power Electronics Handbook, Elsevier, 2006, pp. 451-482

[2] Y. Cheng, C. Qian, M. L. Crow, S. Pakarek and S. Atcitty, "A comparison of diode clamped and cascaded multilevel converters fora STATCOM with energy storage", in IEEE transactions on Industrial Electronics, in October 2006.

[3] L. Tolbert, F. Z. Peng and T. Habetler, "Multilevel converters for large electric drives", in IEEE transactions Industrial Applications, in January 1999.

[4] J. Rodriguez, J. Lai and F. Z. Peng, "Multilevel Inverters: A survey of topologies, controls and applications", in IEEE transactions on Industrial Electronics, in August 2002.

[5] D. A. Zambra, C. Rech and J. R. Pinheiro, "Comparison of neutral point clamped, symmetrical and hybrid asymmetrical multilevel inverters", in IEEE Transactions on Industrial Electronics, in July 2010.

[6] B. P. McGrath, D.G. Holmes, "A Comparison of Multicarrier PWM Strategies for Cascaded and Neutral Point Clamped Multilevel Inverters" in IEEE 2000.