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Cascaded Nine Level Inverter Using Pulse Width Modulation And Hybrid PWM

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ABSTRACT
The multilevel voltage source converters typically synthesize the staircase voltage wave from several levels of dc voltage sources. This paper presents a PWM modulation and hybrid modulation using cascaded topology which allows one to achieve high-quality output voltages and input currents and also outstanding availability due to their intrinsic component redundancy. The simulation results reveal that method can effectively eliminate harmonics in the output waveform of the inverter, and also low THD (Total Harmonics Distortion).
Keywords - Cascade H-bridge inverter, hybrid modulation, phase-shifted PWM, total harmonic distortion

I.   Introduction

Multilevel converters are power-conversion systems composed by an array of power semiconductors and voltage sources. The switches in array are so arranged that by controlling their switching sequence a stepped voltage waveform is produced [1].The stepped output voltage closely approximates an ideal sinusoidal voltage waveform. With increases in level of multilevel inverter the harmonic content of output voltage waveform decreases significantly. The concept of multilevel converters has been introduced since 1975 [2]. Multilevel inverters have emerged as a solution to the problems faced by the conventional square wave and two/three level PWM inverters especially in medium voltage high power applications. The advantages of multilevel inverter include reduced voltage stresses on power semiconductor devices, reduced switching stresses, modulation realization, and improved waveform quality [3] - [4].
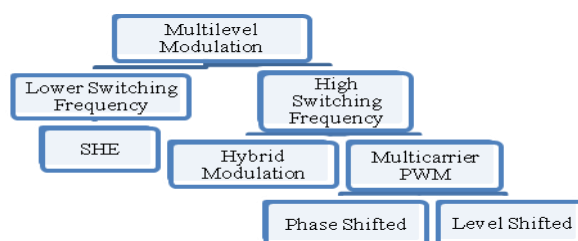

Figure1 Multilevel converter modulation methods.

Several modulation control strategies have been proposed or adopted for multilevel inverters including the following: multilevel sinusoidal pulse width modulation, multilevel selective harmonic elimination, hybrid modulation and space-vector modulation.

PWM is a common control strategy used in many different applications. This technique is the heart of the inverter control signal. Hybrid PWM (H-PWM) is an extension of PWM for CHB with unequal dc source. The main challenge is to reduce the switching losses of the converter by reducing the switching frequency of the higher power cells. Therefore, instead of using high frequency carrier-based PWM methods in all the cells, the high-power cells are operated with square waveform patterns, switched at low frequency, while only the small power cell is controlled with PWM [1].

The problem has been analyzed considering cascaded multilevel which consists of a series of H Bridge inverter units. The general function of this multilevel inverter is to synthesize a desired voltage from several separate dc sources. The number of H-Bridge module (M), depends on the number of levels (N) and can be written as

M = (N-1)/2 [5].

In this paper multilevel sinusoidal three phase pulse width modulation and hybrid modulation for nine level cascaded inverter is developed and the performances relative to inverter for this control strategies is analyzed by calculating Total Harmonic Distortion (THD)
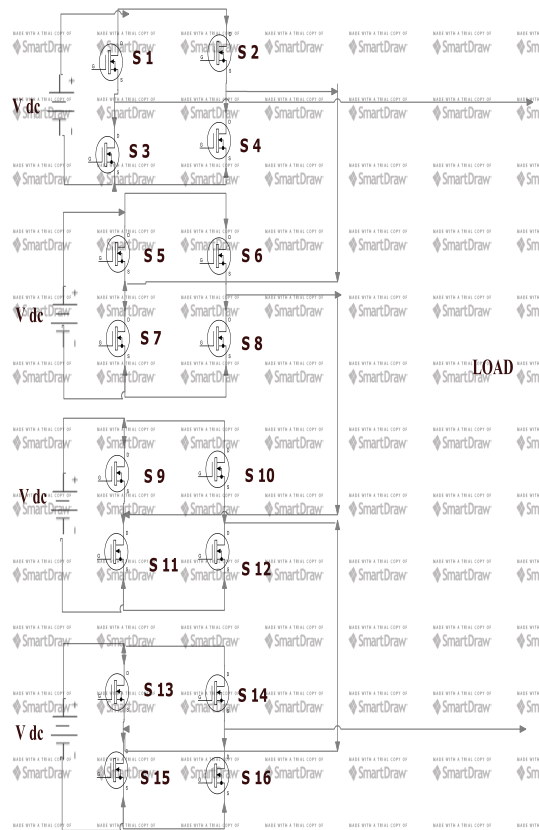
II. Cascaded Multilevel Inverter

Figure 2 Nine-level cascaded H-bridge

A cascade multilevel inverter consists of a series of H-bridge inverter units. The general function of this multilevel inverter is to synthesize a desired voltage from several separate dc sources, which may be obtained from solar cells, fuel cells, batteries, ultra capacitors, etc. Each separate dc source is connected to a single-phase full-bridge inverter. Each inverter level can generate three different voltage outputs +Vdc,- Vdc and 0 and by connecting the dc source to the ac output side by different combinations of the four switches,S1,S2,S3 and S4 . The ac output of each level's full-bridge inverter is connected in series such that the synthesized voltage waveform is the sum of all of the individual inverter outputs. With enough levels and an appropriate switching algorithm, the multilevel inverter results in an output voltage that is almost sinusoidal [6].

The advantages of cascade multilevel H-bridge inverter with s separate dc source per phase are as follows:

1. The series structure allows a scalable, modularized circuit layout and packaging since each bridge has the same structure.
2. Switching redundancy for inner voltage levels are possible because the phase voltage output is sum of each bridges output.

3. Potential of electrical shock is reduced due to the separate dc sources or voltage balancing capacitors
4. Requires the least number of components considering there are no extra clamping diodes are voltages balancing [6].

III. PWM Control Strategies

The strong evolution known in the multilevel inverter applications was based, on the one hand, on the development of the semiconductor devices, and on the other hand, on the use of the techniques known as of pulse width modulation (PWM). Several multicarrier techniques have been developed to reduce the distortion in multilevel inverters, based on the classical PWM with triangular carriers. Some methods use carrier disposition and others use phase shifting of multiple carrier signals [7]-[8].

For the cascaded inverter, phase-shifted carrier PWM (PSCPWM) is the most common strategy, with an improved harmonic performance being achieved when each single-phase inverter is controlled using three-level modulation. Using this approach, the sinusoidal reference waveforms for the three phase inverter all the phases are in 120 degree phase shift; while each inverter's carrier is phase shifted by 180/n (where n is the number of single-phase inverters in each cascaded inverter phase leg) [9].

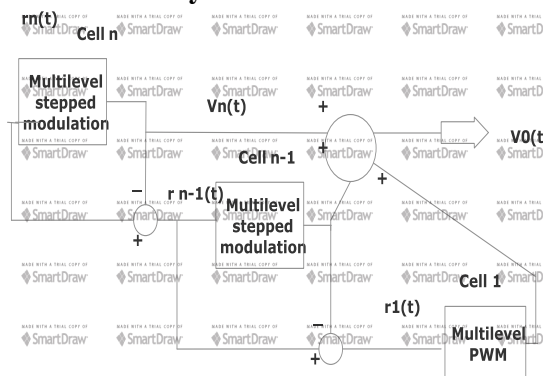## IV. Hybrid PWM Modulation

Figure 3 Hybrid modulation operating principle for CHB with unequal dc sources

A hybrid modulation strategy for asymmetrical multilevel inverters was presented in for three-level series-connected cells, in which only the lowest power cell operates with PWM. Other cells, which operate with higher voltage levels and could employ high-voltage semiconductor devices, operate at low frequency. This strategy can be generalized for multilevel cells, as shown in the simplified block diagram of "Fig. 3" [10].

One can see that the reference signal of the hybrid multilevel inverter is the reference signal of the nth cell. This signal is compared to a given number of constant levels, which depend on the number of levels synthesized by this cell, as shown in "Fig.3" After determining the desired output voltages of the higher power cells, the reference signal of the nth cell is obtained by subtracting the output voltage of the n + 1 cell from its respective reference signal. This reference, which corresponds to the voltage that higher power cells could not synthesize, is also compared to several constant levels. Finally, the reference signal of the lowest power cell is compared to high-frequency triangle signals with amplitude $V1$ and frequency $f1$, resulting in a high-frequency voltage [10].
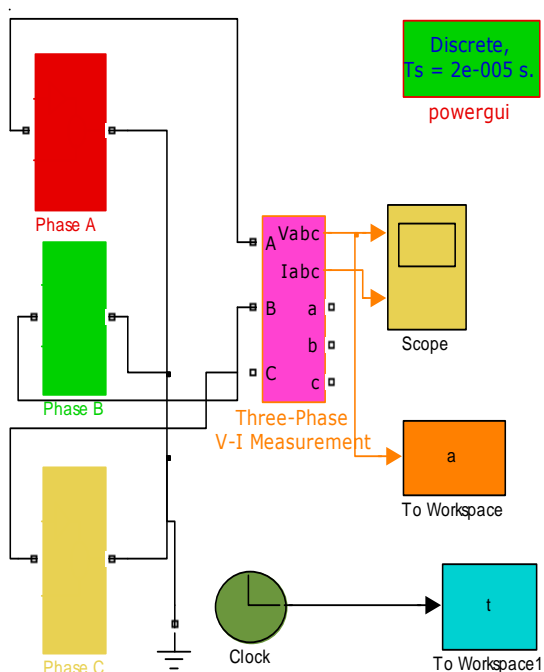
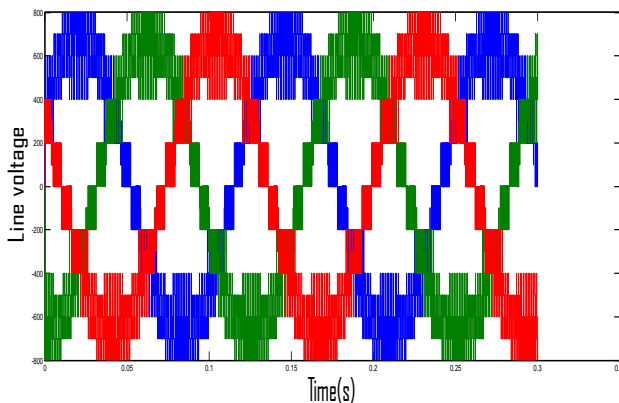## V. Simulation Results

Figure 4 Simulation model

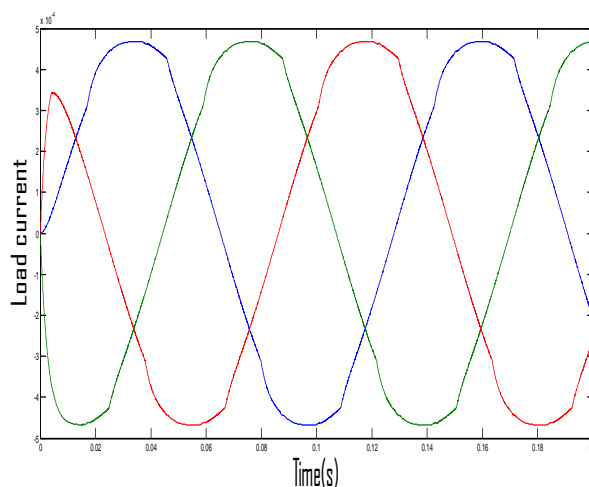Figure 5 Line voltage of three phase nine level Phase shifted PWM inverter.

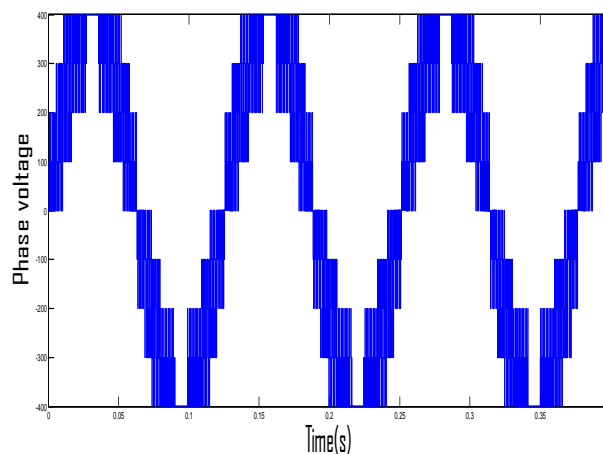Figure 6 Load current of three phase nine level Phase shifted PWM inverter

Figure 7 Phase voltage of three phase nine level Phase shifted PWM inverter.

5.1 THD Calculation

THD contents in the output voltage have been obtained by using FFT analysis. The THD calculated for three phase nine level phase shifted PWM modulation technique for CHB inverter has been calculated 17.44% and for three phase nine level hybrid PWM for CHB inverter THD is 9.92%.
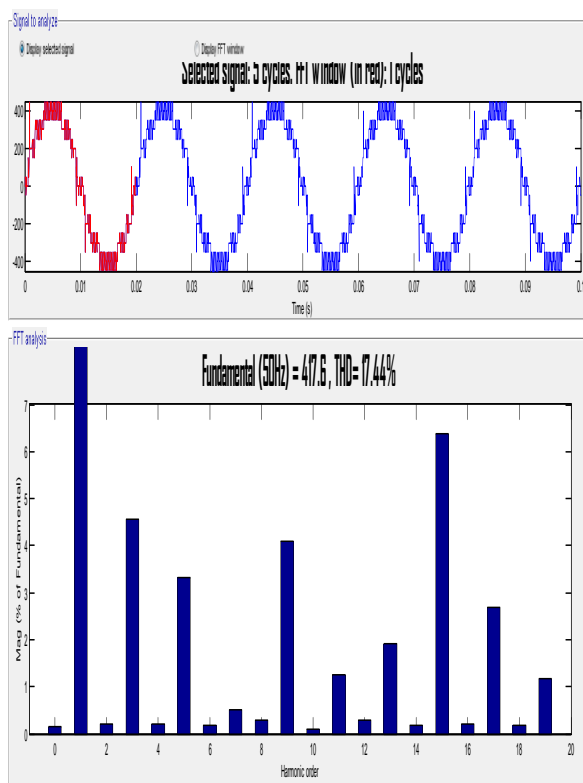
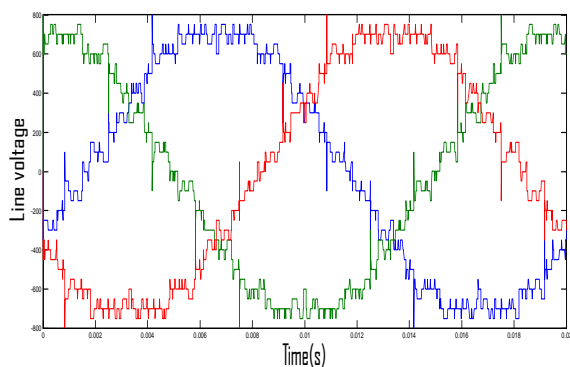Figure 8 THD contents in the output voltage of phase shifted PWM has been obtained by using FFT analysis.
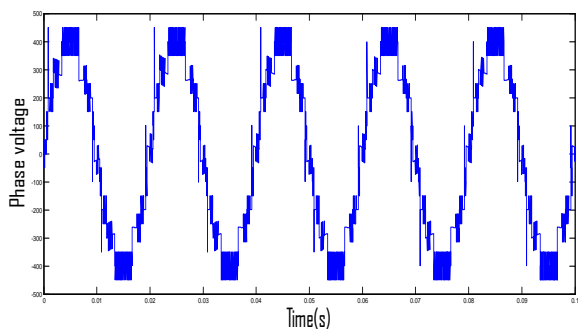

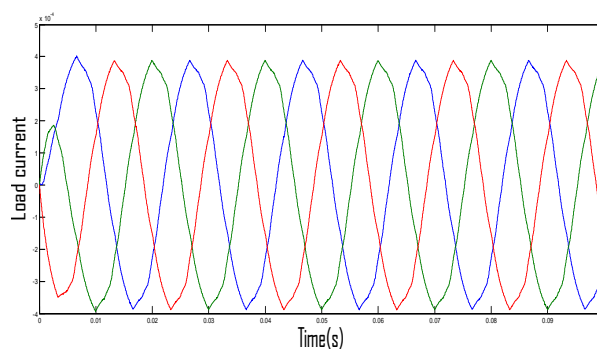Figure 11 Load current of three phase nine level Phase shifted PWM inverter.

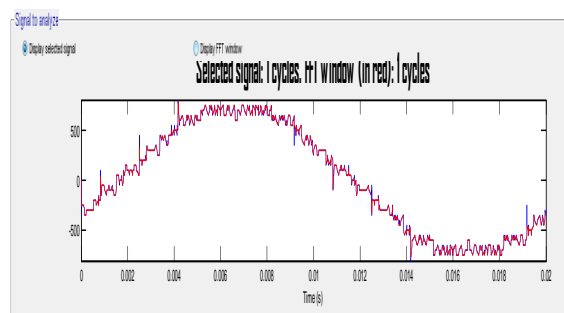Figure 9 Line voltage of three phase nine level Hybrid PWM

Figure 12 THD contents in the output voltage of Hybrid PWM has been obtained by using FFT analysis

VI. Conclusion

The objective of this study is to develop three phase nine level Cascaded H-Bridge voltage inverter using PWM and hybrid control strategies. The obtained results show that the control strategies are able to eliminate the most undesirable harmonics while ensuring a good amplitude control of the fundamental harmonic. The THD calculated is 17.44 %for three phase nine level phase shifted PWM and 9.92 %.for three phase nine level hybrid modulation. Multilevel inverter are potentially useful for a wide range of applications: transport (train traction, ship propulsion, and automotive applications), energy

Figure 10 Phase voltage of three phase nine level Hybrid PWM.

conversion, manufacturing, mining, and petrochemical, to name a few.

References

[1] Rodriguez,J. Franquelo,L.G., Kouro, S. Leon, J.I. Portillo, R.C. Prats and M.A.M. , Multilevel Converters: An Enabling Technology for High- Power Applications*, IEEE Conf,* Vol. 97, No. 11, November 2009 , 1786 - 1817

[2] R. H. Baker and L. H. Bannister, "Electric Power Converter," U.S. Patent 3 867 643, Feb. 1975.

[3] Madhusudan Singh, Arpit Agarwal and Namrata Kaira, Performance Evaluation of Multilevel Inverter with Advance PWMControlTechniques,*PowerElectronics(IICPE), 5thIndiaInternationalConferenceon DigitalObject*,2012 IEEE ,1 – 6.

[4] Imarazene Khoukha, Chekireb Hachemi and Berkouk El Madjid, Multilevel Selective Harmonic Elimination PWM Technique in the Nine Level Voltage Inverter, Computer Engineering & Systems, ICCES *'07. International Conference on Digital Object*, 2007., 387-392 .

[5] V .Manimala, Mrs.N.Geetha and M.E Dr.P.Renuga, Design and Simulation of Five Level Cascaded Inverter using Multilevel Sinusoidal Pulse Width Modulation Strategies, *Electronics Computer Technology (ICECT), 3rd International Conference* ,Vol. 2 ,2011 , 280 – 283

[6] John N. Chiasson, Leon M. Tolbert, Keith J. McKenzie, and Zhong Du, Elimination of Harmonics in a Multilevel Converter Using the Theory of Symmetric Polynomials and Resultants, Transactions on control systems technology, Control Systems Technology, IEEE Transactions on Vol13,NO.2, 2005 , 216 - 223 .

[7] Mariaraja P ,Brindha Sakthi B ,Saranya A V ,Prabha Rani S J and Sathyapriya M, Reduction of Harmonics using Seven Level Cascaded Multilevel Inverter, *International Journal of Engineering Research & Technology* Vol. 3 Issue 3, March 2014.

[8] José Rodríguez, Jih-Sheng Lai, andFang Zheng Peng, Multilevel Inverters: A Survey of Topologies,Controls, and Applications IEEE Transactions on industrial electronics, vol.49, August 2002,724-738 .

[9] [10] Brendan Peter McGrath and Donald Grahame Holmes, Multicarrier PWM Strategies for Multilevel Inverters IEEE, VOL. 49, No. 4, August 2002

[10] Cassiano Rech and José Renes Pinheiro, Hybrid Multilevel Converters: Unified Analysis and Design Considerations, Vol. 54, No. 2, April 2007.

[11] Cassiano Rech and Jost Renes Pinheiro, Impact of Hybrid Multilevel Modulation Strategy on Input and Output Harmonic Performances in Power Electronics and Control Research Group Federal University of Santa Maria Santa Maria, RS, Brazil, 2010.

[12] Mariusz Malinowski, K. Gopakumar, Jose Rodriguez and Marcelo A. Pérez, Member, A Survey on Cascaded Multilevel, IEEE vol. 57, no. 7, July 2010

[13] Siva Sankari M.S, Sasurie Vijayamangalam, Kumar K.K, Hybrid modulation technique for cascaded multilevel inverter for high power and high quality application,*International Journal of Communications and Engineering*, Volume 02 no.2, 04 March2012.

[14] Poh Chiang Loh, Donald Grahame Holmes, Yusuke Fukuta, and Thomas A. Lipo, "Reduced Common-Mode Modulation Strategies for Cascaded Multilevel Inverters", IEEE vol. 39, no. 5, September 2013.

[15] M S. Sivagamasundari and dr P.Melba Mary,Analysis of cascaded five level multilevel inverter using hybrid pulse width modulation, *International Journal of Emerging Technology and Advanced Engineering,* Vol. 3, Issue 4, April 2013

[16] M. Murugesan, R. Pari, T. Bharani Prakash, R. Sakthivel and D. Pushpalatha ,Analysis and Implementation of Modified Hybrid Multilevel Inverter for Induction Motor Drive, JEPE 2014

[17] Makoto Hagiwara, and Hirofumi Akagi, Fellow Control and Experiment of Pulse width-Modulated Modular Multilevel Converters, IEEE vol. 24, no. 7, July 2009.

[18] José´ Rodrı´ guez, Leopoldo G. Franquelo, Samir Kouro, Jose´ I. Leo´n, Ramo´n C. Portillo,Ma angeles Martı´n Prats andMarcelo A. Pe´rez, , Recent Advances and Industrial Applications of Multilevel Converters, IEEE vol. 57, no. 8, August 2010

[19] M. Kiran kumar, A. Madhu Sainath, V. Pavan Kumar,,Selective Harmonic Elimination by Programmable Pulse Width Modulation in Inverters"2011.

[20] Hirofumi Akagi, "Classification, Terminology, and Application of the Modular Multilevel Cascade Converter", IEEE, vol. 26, no. 11, November 2011.