Comparative Analysis of Harmonic Distortion of a Solar PV Fed Cascaded H-bridge Multilevel Inverter Controlled by FPGA and Diode Clamped Inverter

M. Subhashini1*, P. Latha2 and M. A. Bhagyaveni3

1Department of Applied Electronics, St. Joseph’s College of Engineering, Chennai-600119, Tamil Nadu, India; subhashinikrishnan29@gmail.com
2Department of ECE, St. Joseph’s College of Engineering, Chennai-600119, Tamil Nadu, India; lathagct@yahoo.com
3Department of ECE, Anna University, Chennai-600025, Tamil Nadu, India; bhagya@annauniv.edu

Abstract

Background/Objectives: Multilevel Inverters are growing technology, even there are many topologies available in real world, here new multilevel topologies such as diode clamped multilevel inverter and cascaded-H-bridge inverter are discussed and comparative results for lower total harmonic distortion are analysed. Methods/Statistical Analysis: Neutral point diode clamped inverter is analysed and its total harmonic distortion value is calculated. Cascaded H-Bridge (CHB) 7 level inverter is analysed and then simulated, finally it is verified using FPGA controller. Three H-bridges are seriously connected to produce 7 level output voltage, FPGA controller uses Sinusoidal Pulse Width Modulation (SPWM) to produce pulse pattern for H-bridges. Results: This topology is tested in Matlab/Simulink environment. Total Harmonic Distortion (T.H.D) value of 7 level voltages is seen as a 30.33%. Which is very low as compared with 3 phase diode clamped five level inverter (81.7%). Conclusion/Application: Solar Photo Voltaic system is employed to compete the disadvantages of conventional energy sources and resulted in energy conservation system that reduces power consumption.

Keywords: Cascaded H-Bridge, FPGA Controller, Multilevel Inverter, Sinusoidal Pulse Width Modulation, Total Harmonic Distortion

1. Introduction

The Inverter is an electrical device which converts Direct Current (DC) to Alternate Current (AC). The inverter is used for emergency backup power in a home. The inverter is used in some aircraft systems to convert a portion of the aircraft DC power to AC. The AC power is used mainly for electrical devices like lights, radar, radio, motor, and other devices. Now a day’s many industrial applications have begun to require high power. Some appliances in the industries however require medium or low power for their operation. Using a high power source for all industrial loads may prove beneficial to some motors requiring high power, while it may damage the other loads. Some medium voltage motor drives and utility applications require medium voltage. The Multi Level Inverter has been introduced since 1975 as alternative in high power and medium voltage situations. The Multi Level Inverter is like an inverter and it is used for industrial applications as alternative in high power and medium voltage situations. Multi Level Inverters are three types. Diode clamped multilevel inverter is traditional topology is shown in Figure 1. The main concept of this inverter is to use diodes and provides the multiple voltage levels through the different phases to the capacitor banks which are in series. 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. It is the main drawback of the diode clamped multilevel inverter. This problem can be solved by increasing the switches, diodes, capacitors. Due to the capacitor balancing issues, these are limited to the three levels. Flying capacitors multilevel inverter is also existing method but it has better performance compared with Diode clamped MLI is also shown in Figure 2 the main concept of this inverter is to use capacitors. It is of series connection of capacitor clamped switching cells. The capacitors transfer the limited amount of voltage to electrical devices. In this inverter switching states are like in the diode clamped inverter. Clamping diodes are not required in this type of multilevel inverters. The output is half of the input DC voltage. It is drawback of the flying capacitors multi level inverter. It also has the switching redundancy within phase to balance the flying capacitors. It can control both the active and reactive power flow. But due to the high frequency switching, switching losses will takes place.

The cascaded H-bridge multi level inverter is to use capacitors and switches and requires less number of components in each level. This topology consists of series of power conversion cells and power can be easily scaled. The combination of capacitors and switches pair is called an H-bridges and gives the separate input DC voltage for each H-bridge. It consists of H-bridge cells and each cell can provide the three different voltages like zero, positive DC and negative DC voltages. One of the advantages of this type of multi level inverter is that it needs less number of components compared with diode clamped and flying capacitor inverters. The price and weight of the inverter are less than those of the two inverters. Soft-switching is possible by the some of the new switching methods.

2. 7 Level Cascaded H-Bridges Multi Level Inverter

2.1 Photo Voltaic System

The solar light is converted to electricity by photovoltaic effect. This conversion takes place with the help of PV or solar cell. Though solar cell individually has limited output power, for high power applications the structure must be increased by parallel and series combination of solar cells. The cell connected in series may refer as string and the combination of cell in parallel may called group. This combination of solar cell collectively called as Solar PV Module. The elementary component of solar PV module is Solar PV cell. Series and parallel combination of several solar PV cell which are electrically connected to generate the required current and/or voltage are called as solar PV array. The Figure 3 shows the equivalent circuit of solar PV module the arrangement is done such that if we require the same voltage as of one cell but if we require high current then the parallel connection to be done.
2.2 Proposed Cascaded H-bridge Topology

In proposed system there are three H-bridges are used and all are connected in cascaded manner. The No. of H-bridges is determined from Equation 1

\[ N = (2n+1) \]  

(1)

Where,

- \( N \) = No. of levels in voltage
- \( n \) = No. of H-bridges.

Each H bridges are single phase inverter circuit having 4 switching devices which may be SCR, MOSFET or IGBT. According to Bridge rule same leg switching devices shouldn’t turned ON same time. There are three different DC sources are used to produce 3 level in positive half cycle.

The CHB-MLI is simple arrangement of numbers of two-level bridges, whose terminals are connected in series to yield synthesized output waveforms. CHB-MLI requires several independent DC sources. The combinations of the four switches of each cell can able to generate three output voltage level, \(+V_{dc}/2\), \(0\) and \(-V_{dc}/2\) if the input voltage is \(V_{dc}\). The overall output is the sum of the individual bridge outputs. Such a proposed system circuit is shown in Figure 4.

| S.no | Voltage | ON Status |
|------|---------|-----------|
| 1    | V1      | S1,S4,S7,S8,S11,S12 |
| 2    | V2      | S1,S4,S5,S8,S11,S12 |
| 3    | V3      | S1,S4,S5,S8,S9,S12 |
| 4    | 0       | S3,S4,S7,S8,S11,S12 |
| 5    | -V1     | S2,S3,S5,S6,S9,S10 |
| 6    | -V2     | S2,S3,S6,S7,S9,S10 |
| 7    | -V3     | S2,S3,S5,S7,S10,S11 |

The above Table describes the pulse pattern for 7 level voltages.

3. Controlling Method

The advent of the multilevel inverter topology has brought forth various Pulse Width Modulation (PWM) schemes as a means to control the switching of the active devices in each of the multiple voltage levels in the inverter. The most efficient method of controlling the output voltage is to incorporate Pulse Width Modulation control (PWM control) within the inverters. In this method, a fixed d.c. input voltage is supplied to the inverter and a controlled a.c. output voltage is obtained by adjusting the on and off periods of the inverter devices.

The PWM control has the following advantages:
• The output voltage control can be obtained without any additional components.
• With this type of control, lower order harmonics can be eliminated or minimized along with its output voltage control. The filtering requirements are minimized as higher order harmonics can be filtered easily.

In the Sinusoidal Pulse Width Modulation scheme, as the switch is turned on and off several times during each half-cycle, the width of the pulses is varied to change the output voltage. Lower order harmonics can be eliminated or reduced by selecting the type of modulation for the pulse widths and the number of pulses per half-cycle. Higher order harmonics may increase, but these are of concern because they can be eliminated easily by filters. The SPWM aims at generating a sinusoidal inverter output voltage without low-order harmonics. This is possible if the sampling frequency is high compared to the fundamental output frequency of the inverter as shown in Figure 5 where multicarrier pulses are used for SPWM technique.

MATLAB is on computation, not mathematics: Symbolic expressions and manipulations are not possible (except through the optional Symbolic Toolbox, a clever interface to maple). All results are not only numerical but inexact, thanks to the rounding errors inherent in computer arithmetic. The limitation to numerical computation can be seen as a drawback, but it’s a source of strength too: MATLAB is much preferred to Maple, Mathematical, and the like when it comes to numerics. On the other hand, compared to other numerically oriented languages like C++ and FORTRAN, MATLAB is much easier to use and comes with a huge standard library. The unfavourable comparison here is a gap in execution speed. This gap is not always as dramatic as popular lore has it, and it can often be narrowed or closed with good MATLAB programming. Moreover, one can link other codes into MATLAB, or vice versa, and MATLAB now optionally supports parallel computing. Still, MATLAB is usually not the tool of choice for maximum-performance Computing. The MATLAB niche is numerical computation on workstations for non-experts in computation. This is a huge niche—one way to tell is to look at the number of MATLAB-related books on mathworks.com. Even for supercomputer users, MATLAB can be a valuable environment in which to explore and fine-tune algorithms before more laborious coding in another language. Most successful computing languages and environments acquire a distinctive character or culture. In MATLAB, that culture contains several elements: an experimental and graphical bias, resulting from the interactive environment and compression of the write-compile-link-execute analyze cycle; an emphasis on syntax that is compact and friendly to the interactive mode, rather than tightly

**Figure 5.** SPWM techniques.

### 4. Simulation Design and Result Analysis

MATLAB is a software package for computation in engineering, science, and applied mathematics. It offers a powerful programming language, excellent graphics, and a wide range of expert knowledge. MATLAB is published by and a trademark of The Math Works, Inc. The focus in

**Figure 6.** Simulation diagram of PV module.
constrained and verbose; a kitchen-sink mentality for providing functionality; and a high degree of openness and transparency (though not to the extent of being open source software). Figure 6 show the Simulation diagram of PV module and Figure 7 shows the Simulation diagram of PV sub module. Solar module is created by connecting number of solar cells in series and parallel in order to boost the current and voltage respectively.

Figure 8 shows the complete simulation diagram of Cascaded H-bridge 7 level multilevel inverter circuit. Actually these three H-bridges are developed in Sub system block in order to reduce the complexity of understand. IGBT are used as switching devices, but in hardware MOSFET IRF840 is used because of fewer prices as compared to IGBT. Figure 10 shows 7 level output voltage waveform which looks like a near sinusoidal voltage. The harmonics content in the proposed system is 19 percent which is very less compared with 3 level inverter where T.H.D. will be 46 percent. Expected to grow as additional features are added to vehicles. The new features will result in even more sensors and switches being integrated into vehicle and will further increase the complexity, cost and weight of the wiring harness. The wiring harness is the heaviest, most complex, bulky and expensive electrical component in a vehicle and it can contribute up to 50 kg to the vehicle mass6. Given the weight, complexity and cost of the wiring harness, it is desirable to investigate other alternatives, such as WSNs. Intra-Vehicle WSNs have the potential to solve this problem but can deliver the same level of performance and reliability offered by wired.

The Figure 9 depicts the schematic representing pulse width modulation scheme employed to generate triggering signals to control the operations of IGBT switches thus enable us to control the output voltage without the
Comparative Analysis of Harmonic Distortion of a Solar PV fed Cascaded H-Bridge Multilevel Inverter Controlled by FPGA and Diode Clamped Inverter

need of any extra hardware requirements. The Figure 11 depicts the stepped voltage waveform of seven level multilevel inverter resembles near sinusoidal waveform. The Figure 12 depicts the Schematic diagram of Diode Clamped Multilevel Inverter.

The Figure 15 depicts the Harmonic Distortion of Neutral Point Diode Clamped Inverter. Thus the total Harmonic Distortion of Cascaded-H-Bridge multilevel inverter and the Total Harmonic Distortion value of Neutral point diode clamped inverter are analysed and the results are tabulated. Thus the results depict that cascaded-h-bridge configuration results in reduced total harmonic distortion compared to the neutral point diode clamped multilevel inverter.

The Figure 16 depict the Harmonic distortion of CHB inverter. The Figure 13 depicts the Line Voltage output of NPC inverter. The Figure 14 depicts the phase voltage output of neutral point diode clamped inverter.

The Figure 17 depicts that the waveform of the gate pulses which are generated from FPGA for the solar PV system fed 3-level multilevel inverter. To generate these pulses sinusoidal pulse width modulation technique was implemented in FPGA. The Figure 18 depict the FFT analysis of Line voltage of proposed MLI topology.

From Table No 2 we can analyse the various MLI topologies and their T.H.D. minimization percentage. Among three methods proposed MLI has much reduced T.H.D.

5. Conclusion

Thus the new multilevel topology of Cascaded H-Bridge is designed and results are verified in both simulation
and FPGA controller. Various MLI topologies are given detailed manner and T.H.D. comparison shows proposed MLI topology gives better results. Total Harmonic Distortion (T.H.D.) value of 7 level voltages is seen as a 30.33% in Figure 15. Which is very low as compared with 3 phase diode clamped five level inverter (81.7%) in Figure 16.

6. References

1. Rodriguez J, Bernet S, Wu Bin, Pontt JO, Kouro S. Multilevel voltage-source-converter topologies for industrial medium-voltage drives. IEEE Transactions on Industrial Electronics. 2007 Dec; 54(6):2930–45.
2. Morrison AJ. Global demand projections for renewable energy resources. IEEE Canada Electrical Power Conference; 2007 Oct 25-26. p. 537.
3. Carrasco JM, Franquelo LG, Bialasiewicz JT, Galvan E, Guisado RCP, Prats MaAM, Leon JI, Moreno-Alfonso N. Power-electronic systems for the grid integration of renewable energy sources: a survey. IEEE Transactions on Industrial Electronics. 2006 Jun; 53(4):1002–16.
4. Tolbert LM, Peng FZ. Multilevel converters as a utility interface for renewable energy systems. IEEE Power Engineering Society Summer Meeting; 2000 Jul 15-20; Seattle, Washington.
5. Busquets-Monge S, Rocabet J, Rodriguez P, Alepuz S, Bordonau J. Multilevel diode-clamped converter for photovoltaic generators with independent voltage control of each solar array. IEEE Transactions on Industrial Electronics. 2008 Jul; 55:2713–23.
6. Khomfoi S, Tolbert LM. Multilevel power converters. Power Electronics Handbook. 2nd ed. Elsevier; 2007. p. 451–82.