

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

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Abstract

Multilevel Inverters are growing technology applicable to power electronics, Electric drive systems and Power systems etc. Even there are many topologies available in real world, here new multilevel topologies are discussed and comparative results are analysed. Neutral point diode clamped inverter is analysed and its total harmonic distortion value is calculated as 81.7%. 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. This topology is tested in Matlab/Simulink environment. Total Harmonic Distortion (T.H.D) value of 7 level voltage is seen as a 30.33%. Which is very low as compared with 3 phase diode clamped five level inverter (81.7%). 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: Multilevel Inverter, Cascaded H- Bridge, Sinusoidal Pulse Width Modulation, Total Harmonic Distortion, FPGA controller.

I. INTRODUCTION

The Inverter is an electrical device which converts direct current (DC) to alternate current (AC). For emergency backup power inverter is used in home. Some aircraft systems uses inverter to convert a portion of the aircraft DC power to AC. The electrical devices like lights, radar, radio, motor and other devices use AC power. Recently industrial applications have begun to require high power. Industries possess certain appliances that require medium or low power for their operation. High power source usage for all industrial loads may prove beneficial to some motors that require high power, while it may lead damage to other loads. Utility applications of some medium voltage motor drives require medium voltage. Multi level inverter has become an alternative in high power and medium voltage situations. The Multi level inverter is used for industrial applications as alternative in situations of high power and medium voltage. There are three types of multilevel inverters. 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 limited amount of voltage is transferred by diodes, reducing the stress on other electrical device. The input DC voltage is twice the maximum output voltage, which becomes the main drawback of the diode clamped multilevel inverter. By increasing the switches, diodes, capacitors the problem can be solved. The capacitor balancing issues limited them to the three voltage 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 usage of capacitors. Capacitor clamped switching cells are arranged seriously. The limited amount of voltage is transferred by capacitors to electrical devices. The switching states of the inverter are like in the diode clamped inverter. Diode clamping is not required in this type of multilevel inverters. The input DC voltage is twice the output voltage, became the drawback of the flying capacitors multi level inverter. The flying capacitors possess switching redundancy within the phase to balance out the capacitors. The active and reactive power flow can be controlled. Switching losses will takes place due to frequency

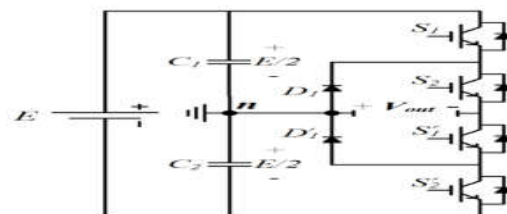


Figure: 1 Basic circuit diagram of Diode clamped Multi Level Inverter

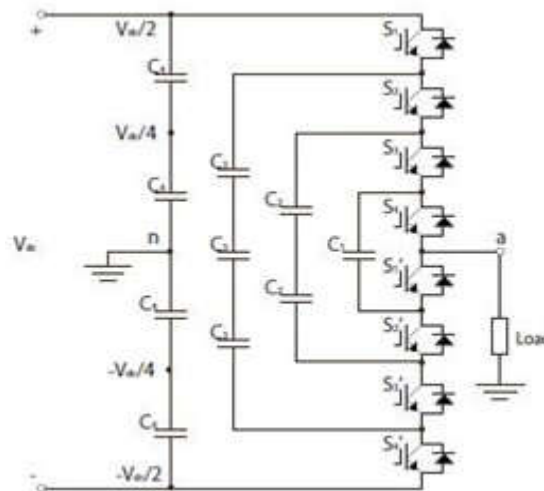


Figure: 2 Basic circuit of flying capacitor Multi Level Inverter.

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-bridge 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. The merits of this type of multi level inverter are its requirement of components in lesser quantity compared with diode clamped and flying capacitor inverters sections. The new alternate switching strategic methods are used for soft switching.

II. 7 LEVEL CASCADED H-BRIDGES MULTI LEVEL INVERTER FED PHOTO VOLTAIC SYSTEM.

1. Photo Voltaic System

The solar light energy is converted to electric energy by photovoltaic approach. It takes place with the enrolment 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 integration of solar cells. The cell connected in series may refer as string and the combination of cell in parallel may called group. This integration of solar cell collectively called as Solar PV Module. The elementary component of solar PV module is Solar PV cell. Series and parallel integration of several solar PV cell which are electrically connected to generate the required current and voltage represented as solar PV array. The Fig. 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 made.

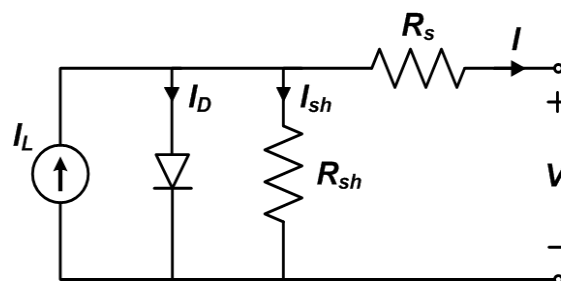


Figure: 3 Equivalent circuit diagram PV system

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)

$$N = (2n + 1) \tag{1}$$

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.

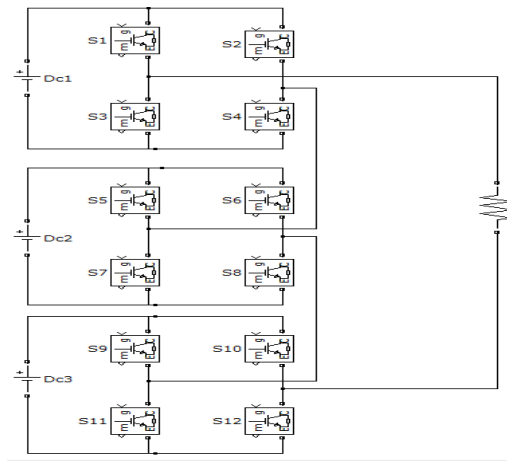


Figure: 4 Proposed 7 level cascaded H-bridge multilevel inverter

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

Table: 1
Switching device On/OFF status for 7 level Voltage

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.

III. 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 output of an inverter sections. The output voltage is controlled by incorporating pulse width modulation control (PWM control) within the inverters. In this method, a d.c. input voltage which is fixed is supplied to the inverter and a output voltage which is an controlled a.c. is evolved by making adjustments at the on and-off periods . PWM inverters which are voltage type are incorporated in to such fields as power supplies and motor drivers. The advantages of PWM control are:

- Without any additional components the output voltage control can be evolved.
- The output voltage control eliminates lower order harmonics. The higher order harmonics can be eliminated by filters.

In the Sinusoidal pulse width modulation scheme, the inverter switch is turned on and turned off for stipulated times during every half-cycle, the pulse width is varied to change the output voltage. Harmonics which are lower 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 increases, they can be eliminated easily by filters. It aims at generating a low- order harmonics eliminated output voltage of inverter. It is acquired when the sampling frequency is high where the fundamental output frequency of the inverter is low.

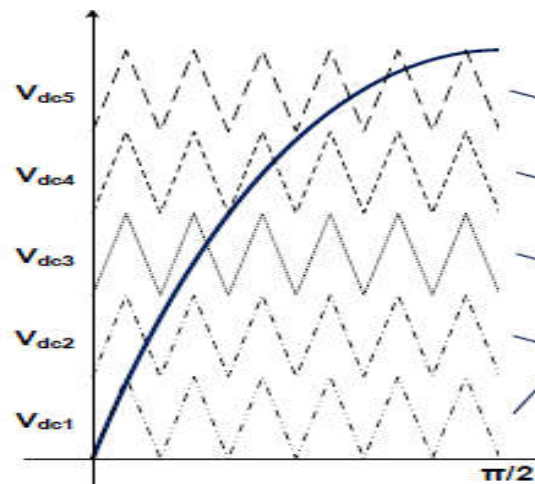


Figure: 5 SPWM techniques.

IV. 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 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 condition is slow speed of execution. 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 computing performance. The numerical computation on workstations for non-experts is MATLAB niche. This is one way that tell us to look at the number of MATLAB-related books on mathworks.com. MATLAB remain as an environment which is valuable even for super computer users to explore and fine-tune algorithms before more laborious coding in various languages. Computing languages and environments acquire a distinctive character or culture. In MATLAB, that culture contains several elements: an experimental bias, interactive environment and compression of the write-compile-link-execute analyze cycle; an emphasis on syntax that is compact and friendly to the mode which is interactive, also tightly 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. Solar module is created by connecting number of solar cells in series and parallel in order to boost the current and voltage respectively.

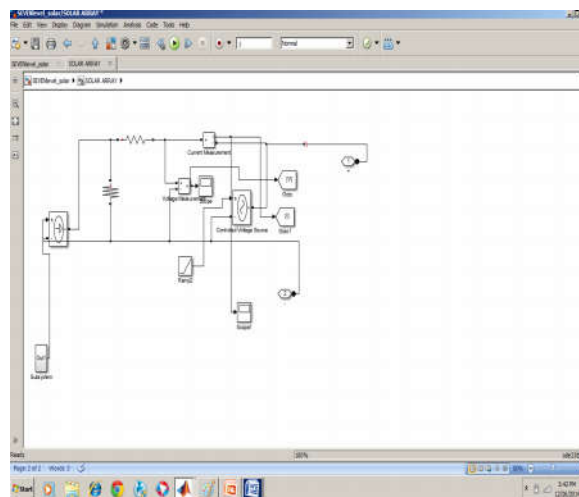


Figure: 6 Simulation diagram of PV module

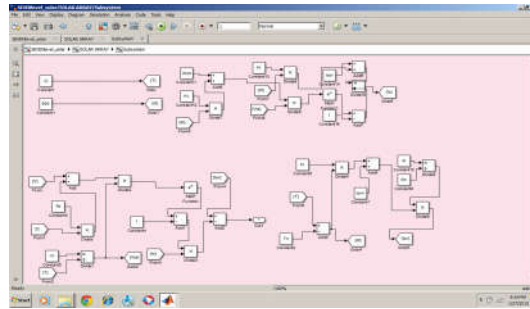


Figure: 7 Simulation diagram of PV sub module

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% which is very less compared with 3 level inverter where T.H.D will be 46%. It will result in even more sensors and switches being integrated into vehicle and will further increase the complexity of wiring, cost factor and weight analysis of the complex wiring structure. The harness via wiring is the heaviest, complex, bulky and expensive electrical component in a vehicle and it can contribute up to 50 kg. Given the weight, complexity and cost of the complex wiring harness, it is desirable that other alternatives has to be investigated , 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

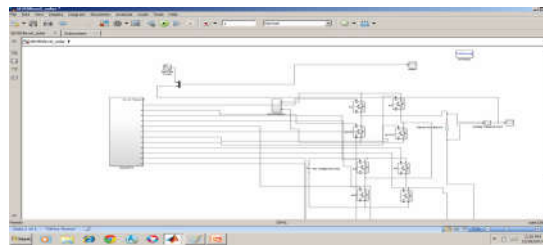


Figure: 8 Simulation diagram of Proposed C.H-B. 7 level inverter

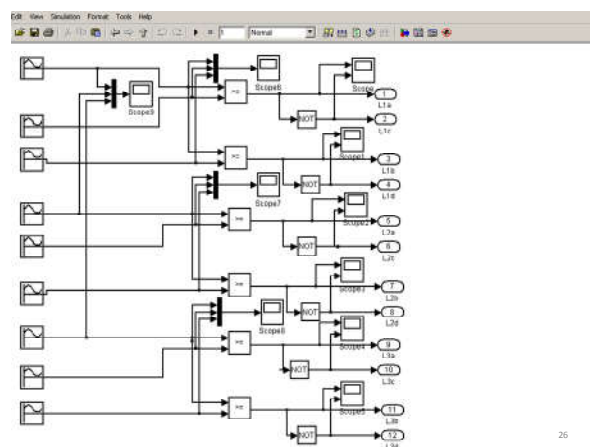


Figure: 9 Schematic of Pulse Width Modulation Scheme

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 need of any extra hardware requirements. The Figure 11: depicts the stepped voltage waveform of seven level multilevel inverter resembles near sinusoidal waveform.

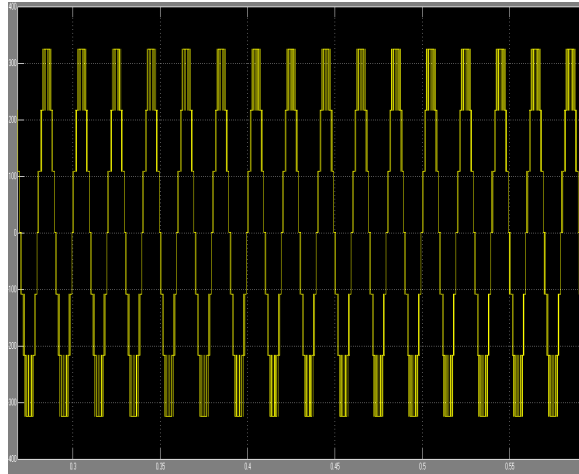


Figure: 10 final output voltage of 7 levels MLI

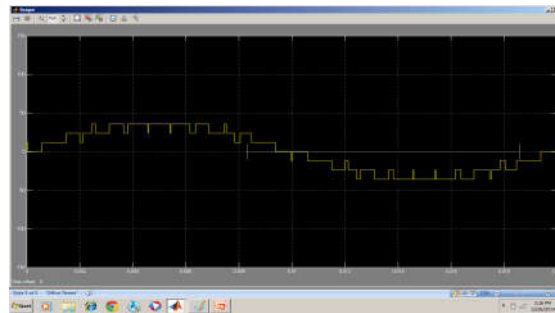


Figure: 11 Stepped voltage waveform of 7 levels MLI

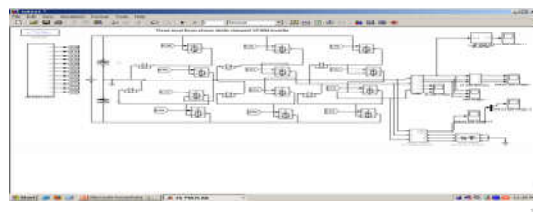


Figure: 12 Schematic diagram of the Diode Clamped Multilevel Inverter

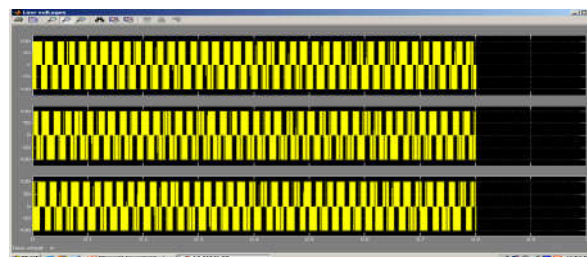


Figure: 13 Line Voltage Output of NPC Inverter

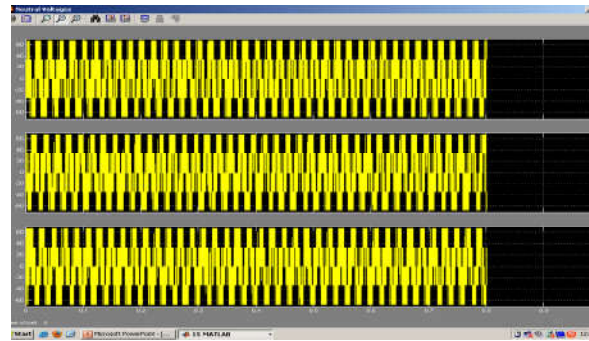


Figure: 14 Phase Voltage Output of NPC Inverter

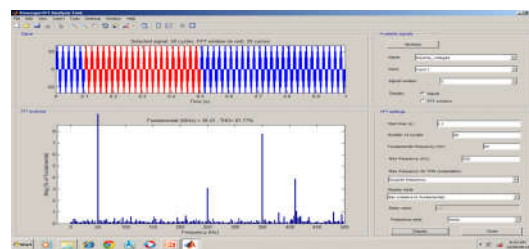


Figure: 15 Harmonic Distortion of NPC inverter

The figure: 15 depict 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.

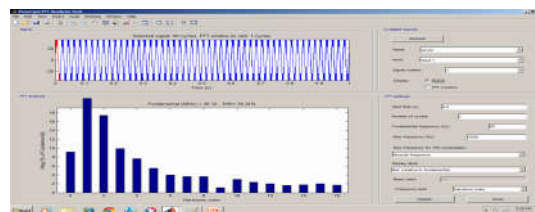


Figure: 16 Harmonic Distortion of CHB inverter

The figure: 16 depict the Harmonic distortion of CHB inverter. The figure: 13 depict 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.

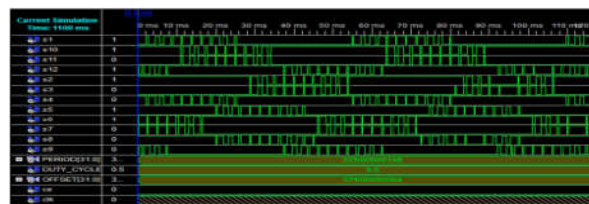


Figure: 17 Gate pulse generated from FPGA for 7 level inverter voltages.

Table: 2
 T.H.D comparison of different MLI topology

S.no	Type of MLI	T.H.D
1	Diode clamped MLI	81.77%
2	Flying capacitor MLI	88.33%
3	Proposed MLI	30.33%

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.

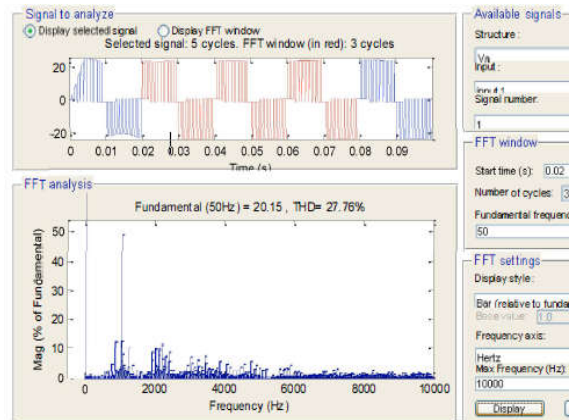


Figure: 18 FFT analysis of Line voltage of proposed MLI topology

V. 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. Moreover use of FPGA controller in hardware development makes works simpler. The simulated results are listed.

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