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Development of Dual PV System with Field Programmable Gate Array (FPGA) for Multilevel Inverters

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Abstract: **In this emerging era, the demand and utilization of electrical energy is high. In various ways, electrical power is utilized, and the world is heading towards the renewable energy resources, which is one of the major sources of electrical power. The output of these sources is mostly DC and our most of the loads are AC operating. So, it requires conversion i.e. DC to AC power for consumption. So, the inverters are introduced for this purpose. The multilevel inverters are introduced to reduce the demerits of two level and three level conventional inverters. This thesis introduces a new method of generating five levels using symmetrical cascaded H-bridge topology of multilevel inverters with field programmable gate array (FPGA) for solar energy system. The field programmable gate array is used as a controller for the switching of solid state devices i.e. MOSFETs by using single pulse width modulation technique. The simulation of the controller is done with MODEL SIM PE student version 10.4a and, its programming is done on Quartus-II (64-bit) with the help of Verilog hardware programming language. In this research two H-bridges are connected in cascade to get the required number of levels at the output by designing the prototype. These five levels are analyzed on the Power quality (PQ) analyzer, output voltage and total harmonic distortion is also observed on the power quality analyzer.**

***Index Terms*— Cascaded H-bridge MLI, FPGA, PWM technique, PV system, Total Harmonic Distortions, PQ analyzer.**

I. INTRODUCTION

The employment of Power Electronics has increased swiftly as the world is heading towards more energy efficient transmission and utilization of energy resources. Wind, photovoltaic and fuel cells are the renewable energy resources and can be easily interfaced with multilevel inverters.[1] We require conversion of electricity from one form to another to efficiently transform and exploit Electrical Energy. Hence an electrical circuit called converter is used for better performance and to improve power quality. Energy exists in many forms and the energies can be converted into one another forms as well, and the Power Electronic has solved this huge problem by endowing us with the devices like, INVERTER (To convert the DC electrical power into AC electrical power)[2], RECTIFIER (To convert AC electrical power into DC electrical power) etc. As industries have begun to demand more energy i.e. high power so from the perspective of being easily accessible and plentiful, the solar energy is the suitable option to meet the demand. The purpose of this research is to design a dual PV system with FPGA for multilevel inverters by using single pulse width modulation technique. The prototype-based project is completed, and the designed prototype of inverter uses symmetric configuration of two voltage sources and eight switches to produce five level output voltage. Many industrial systems have now started to demand high power for now a days. However, some branch appliances need medium or low power for their services.[3] Industrial loads when being supplied from high power source that may result in effective for certain high powered motors, whereas other loads may be impaired. Due to many merits of multilevel inverters, voltage-source multilevel inverters have many applications in industry and utility power applications.[4] Some motor drives and utility appliances for low voltage require medium voltage. In single phase as well as in three phase inverters there is a problem of power unbalances and it is proved that the removal DC-DC component doesn't affect the performance.[5] Since 1975, the multilevel inverter has been presented at the place of high power and medium voltages. It is a power electronic system capable of using many lower level DC voltages as input to provide the desired alternating voltage level at the output. By using MLI's we get the output that is free from harmonics, almost distortion free, reduced dv/dt results, high power quality, electromagnetic compatibility will be better and low power losses. There are many multilevel inverter configurations are available but there is little bit difference in the mechanism of their switching and input voltage source to the MLIs. Out of several topologies, there are three topologies which are used all over the world and are diode clamped MLI, flying capacitor and cascaded H-bridge multilevel inverter and the multilevel inverters are the propitious converters in the power electronics.[6] In this research the symmetric cascaded H-bridge is used because of many advantages over diode clamped and flying capacitor topologies because in this topology there is no any issues like capacitor unbalancing, regulation and monitoring of DC voltage discharging, regulation of capacitor voltages and switching efficiency problems, etc. Field programmable gate array is used as controller for the switching purpose of the solid state devices used in this prototype i.e. MOSFETs. EP3C5 model of FPGA of altera wave share company is used and its coding is done on the Quartus-II (64-bit) software by the help of Verilog hardware programming language and simulation of FPGA is made on the Model Sim student version 10.4a. This is used for providing controlling pulses to the MOSFETs for switching

ON and OFF purpose with the help of opto-couplers. It consists of many input and output pins which relate to different circuits. The input to the two H-bridges is supplied from the PV panels of 18V, 30W, whose supply first given to the buck converter which maintains the output voltage to 8V and then it is supplied to the boost converter which boost up the voltage up to 12V and that is supplied to the two half bridges that are connected in cascaded. As it is symmetrical CHB so both H-bridges have the same input voltage, and their output is the algebraic sum of both these supplied voltages. The input current has low distortions, it works at both fundamental switching frequencies, stress is reduced because it generates common mode voltage and without using filters its output carries less total harmonic distortions, these are the attractive features of CHB MLI.

II. Cascaded H-bridge multilevel inverter

Cascaded H-bridge multilevel inverters (CHB-MLI) has been used for DC to AC conversions.[7] It is one of the well-known and widely used topology of multilevel inverters and it is used for both single and three phase power conversions.[8] It employs two or more half bridges connected in series using solid state devices and diodes etc. The single H-bridge comprises of four switches as in given figure.1 in which switches along with diodes are shown.

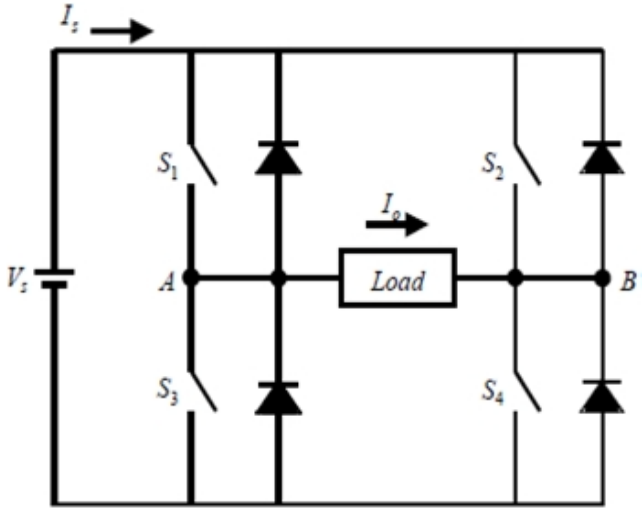


Figure.1 Single H-bridge

When such two or more H-bridges are connected in series then they comprise cascade half bridge. The output voltage level from each H-Bridge cell is the sum of all the voltages produced. The number of output voltage levels will be 2m+1, If "m" levels are required. If we cascade two H-bridge then we will get 5 levels at the output side and it uses 8 switches to control the levels, but when we cascade 4 H-bridges then 9 levels can be achieved and 16 switching devices are to be used. Compared to other two types of MLIs, this type of inverter has advantage over the other two since it needs a smaller number of components and thus its total size and price is also lower. The Five level cascaded H-bridge configuration is shown in figure.2 which shows the eight switches are connected, four in each H-bridge.

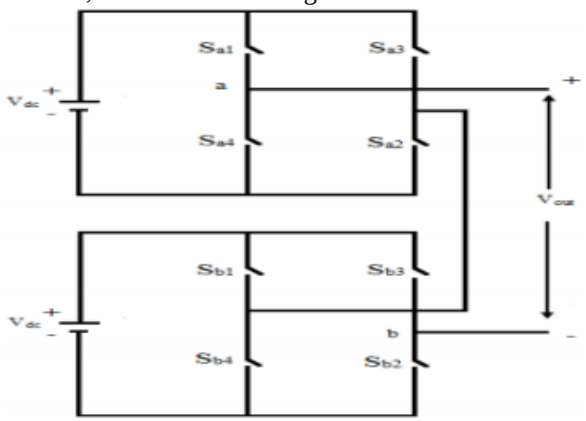


Figure.2 Cascaded H-bridge MLI

The cascaded H-bridge can be classified into two categories and they are shown in given figure.3

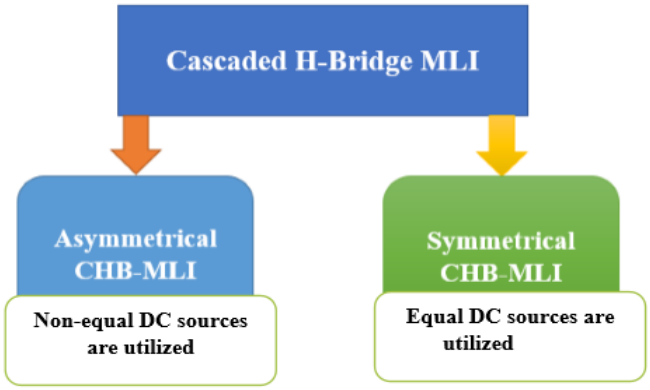


Figure.3 Types of CHB MLI

II.1 Asymmetric Cascaded H-bridge MLI

It is a type of cascaded half bridge multilevel inverter having two half bridges connected in series having different input voltages in each cell.[9]

II.2 Symmetric Cascaded H-bridge MLI

All DC sources have equal voltage level because the word symmetric shows equality, that's why generated output is sum of the DC supplies.[9] The voltage magnitude of the DC supply is given as in eq: 1

$$Vp = Vdc \quad \text{..... 1}$$

Whereas p = 1, 2, 3,....., m

$$V1 = V2 = ... = Vm = Vdc$$

The output voltage levels could be found by using $K = 2x + 1$ where x is power cells number required and the peak voltage generated as in eq: 2

$$VP = x * Vdc \quad \text{..... 2}$$

If x= 2 then five levels can be generated with peak voltage of 2Vdc.

III. Field Programmable Gate Array (FPGA)

FPGAs are the "field programmable" in comparison to the conventional CPUs, which implies that the consumer may customize them after development.[10] More than three decades ago, field programmable gate arrays(FPGAs) were introduced and have since evolved, giving way to new generations of FPGAs with improved performance and logic density that can be used in wider variety of applications. Ross Freeman (cofounder of Xilinx) invented the first FPGA in 1985, and since then their logic ability has greatly improved and they have become a common option because FPGA systems can be reprogrammed to implement the final desired application of the consumer after manufacturing. Infinite periods and some restricted periods can be reprogrammed for some FPGAs. FPGAs contain blocks of programmable logic; these blocks build a physical collection of gates of logic that can be used to perform various operations. This offers the ability for FPGAs to conduct tasks many times faster than a hard-wired processor. By using a hardware description programming language, or HDL, field programmable gate arrays are usually customized. To configure the gate interconnections(how the gates connect to each other) as well as the gate themselves, a programmer may use HDL commands. For example, a Boolean operator, such as AND,OR, or XOR, can be assigned to gate. It is feasible perform advanced logic operations by linking many gates together.

FPGA is used as a micro-controller. FPGA is used for advanced modulating techniques to the multilevel inverters for switching because of high flexibility.[11] The model of FPGA is EP3C5 of altera wave share company. This is used for providing controlling pulses to the MOSFETs with the help of opto-couplers. It consists of many input and output pins which relate to different circuits. Its programming is done with the help of its software Quartus-II (64-bit) web edition by using Verilog hardware programming language and its simulation is done with the help of Model Sim software. To compile any type of design in Quartus-II the following steps must be remembered

- Analysis and synthesis
- Filter (place and route)
- Assembler (generate programming files)
- Time Quest Timing Analyzer
- EDA Netlist Writer

Figure.4 Field Programmable Gate Array Pictorial View

IV. Block Diagram

The block diagram of the development of dual PV system with FPGA for multilevel inverters is shown in the figure.5 given

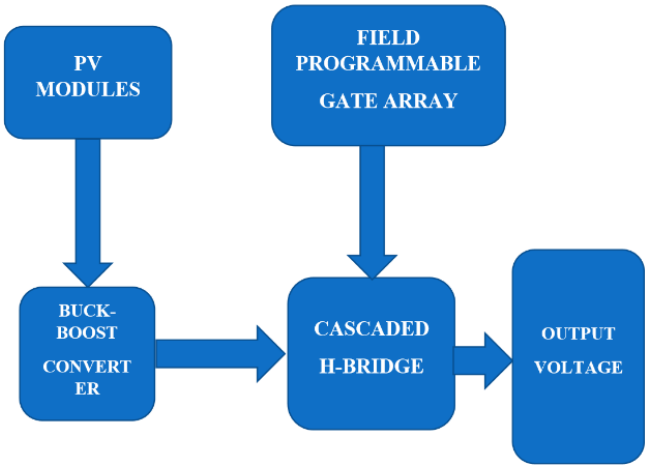
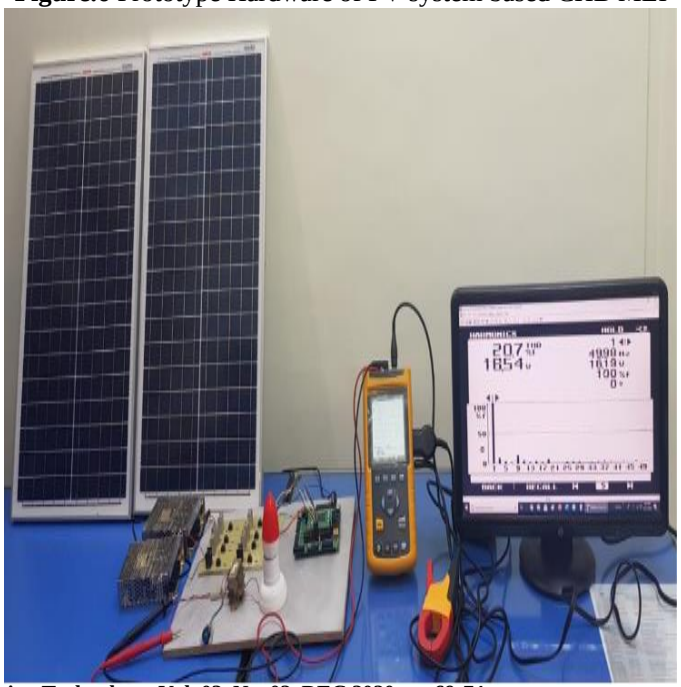


Figure.5 Experimental Setup

V. Brief Review of the Hardware

Two 18V, 30W PV panels are used to supply the two half bridges which are cascaded with each other. Buck-boost converter is used to set the voltage at 12V. Field programmable gate array is used as a micro-controller for the switching of MOSFETs, both n-channel IRF Z44N and p-channel IRF9540 were used for the required output voltage. Optocouplers 4N35 are also used to provide signals to the MOSFETs and 10KΩ resistors are used in between optocouplers and MOSFETs and 220Ω resistors are used for the protection of LED of the optocoupler and at the output of the inverter a step-up transformer is used and the load is connected with its secondary as given in figure.6

Figure.6 Prototype Hardware of PV system based CHB MLI



VI. Experimental Circuit of CHB MLI

The given below circuit shown in figure.7 reveals the cascaded H-bridge circuit in which two H-bridges are connected in series, each H-bridge comprised of four MOSFETs that can be connected with optocouplers which provides signals from controller to the MOSFETs for switching ON and OFF.

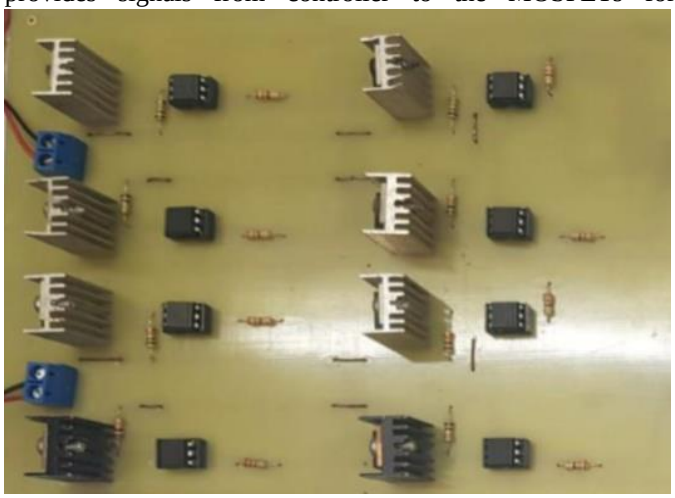


Figure.7 Hardware circuit of CHB MLI

VII. Working of the hardware design

When the input of two PV panels is given to buck-boost converters, the output of each PV panel is approximately 18V volts that is given to the buck converter it will control the voltage up-to 8V and that 8V is given to the boost converter that will boost up the given voltages up-to 12V. These 12V of each H-bridge, remember there are two H-bridges connected in series with each other. When the controlling signals from FPGA are given to the MOSFETs with the help of opto-couplers then they are triggered alternatively as 1-3, 2-4, 5-7 and 6-8. The resistors of 10K Ω are connected to pull down the n-channel MOSFETs because when they are triggered their base has positive voltage. Diagonally switches are triggered and in this way five levels at the output are obtained.

VIII. Experimental Results

The control signals from the field programmable are given to the semi-conductor switches for switching ON and OFF purpose. The pulse of 50MHz is given to each pin of the FPGA with 20ns time of the clock pulse and from which the pulse of 50KHz frequency is given to the circuit of CHBs with 20ms time of pulse with 10ms on time period there is offset of 2ms between the pulses to the MOSFETs as in figure and these are generated with the help of simulation using MODEL SIM SOFTWARE as shown below in figure.8 and in this graph of control pulses of the individual pin is expressed and each pin is shown in line to each pulse as visualized in the diagram and these pulses are given to the opto-couplers which sends it to the semi-conductor switches and they will switch ON and OFF according to the given commands and for particular time interval.

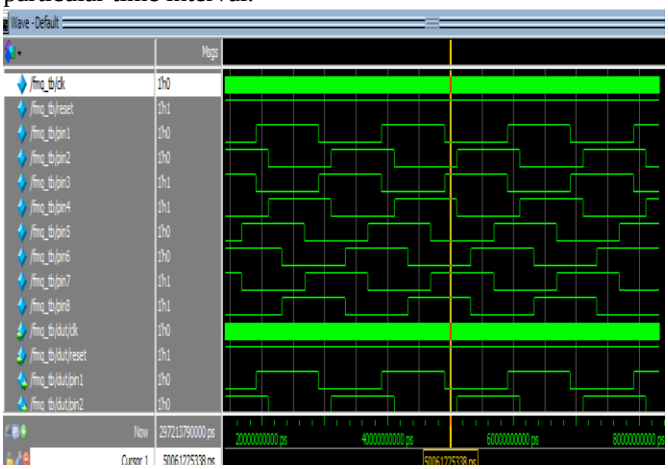


Figure.8 Waveforms of control signals

And results are taken on the power quality analyzer, which demonstrates the five level output voltage with peak voltage of 16.59V at output side is obtained which is the sum of the two voltage sources as in given figure9.

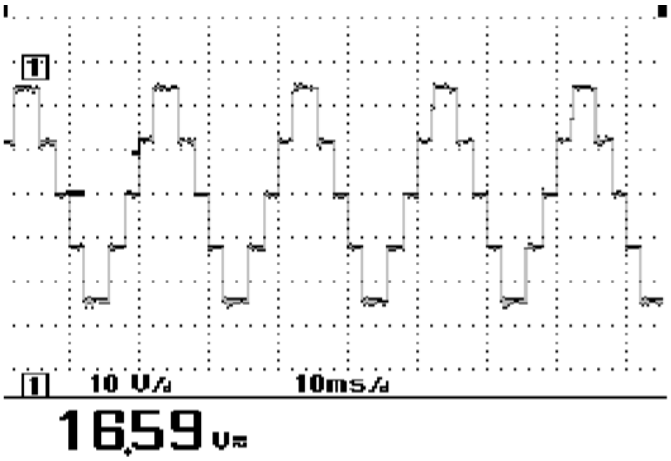


Figure.9 Waveforms of output voltage

IX. Harmonic Spectrum Analysis

Problems with power quality are apparent in voltage, current or frequency differences that cause sensitive devices to malfunction. The integration of inverter-connected PV and wind power plants and the widespread growth in nonlinear loads have resulted in a harmonic power system crisis.[12] Harmonics are the multiple components of the fundamental frequency and it is the major problem in the power electronic converters. But inspite of this problem the output of the converters have high efficiency and they have proved their importance in the field of power electronics converters. Harmonics are present in every complex waveform other than periodic sinusoidal waveforms and these waveforms have higher order harmonics i.e. second, third and so on.

The determination of these harmonics can be done by using

general formula of Fourier series as shown in eq. 3.

$$f(t) = a_o + \sum_{n=1,2,3.....}^{\infty} (a_n Cos\, n\omega t + b_n Sin\, n\omega t) \quad (3)$$

Where a_o = DC component of actual waveform
$a_n Cos\ nwt + b_n Sin\ nwt$ = n^{th} harmonic of the function
So, a_o , a_n , and b_n can be calculated by using these equations

$$a_o = \frac{1}{2\pi}\int_0^{2\pi} V_L(\omega t)\, d\omega t \quad (4)$$

$$a_n = \frac{1}{\pi}\int_0^{\pi} V_L(\omega t)\, Cos\, n\omega t\, d\omega t \quad (5)$$

$$b_n = \frac{1}{\pi}\int_0^{\pi} V_L(\omega t)\, Sin\, n\omega t\, d\omega t \quad (6)$$

All the electrical machines are designed to operate at some fundamental frequency and when these harmonic (multiple components of frequency) passing through these machines will cause serious issues of power quality and equipment damage. The output of the inverters contains these harmonic components because their output is not pure sinusoidal but square and quasi square waves. If the waveform is not pure sinusoidal but if it is nearer to the sinusoidal then number of harmonics will be lesser. So, the multilevel inverters have powerful applications in power electronic converters and to obtain a minimum THD in output of inverter, the switching technique is optimized, and the inverter is effectively modulated.[13] The total harmonic distortions in the output voltage of this five level cascaded H-bridge multilevel inverter is found to be 20.7% which is analyzed on the power quality (PQ) analyzer as shown in given figure.10

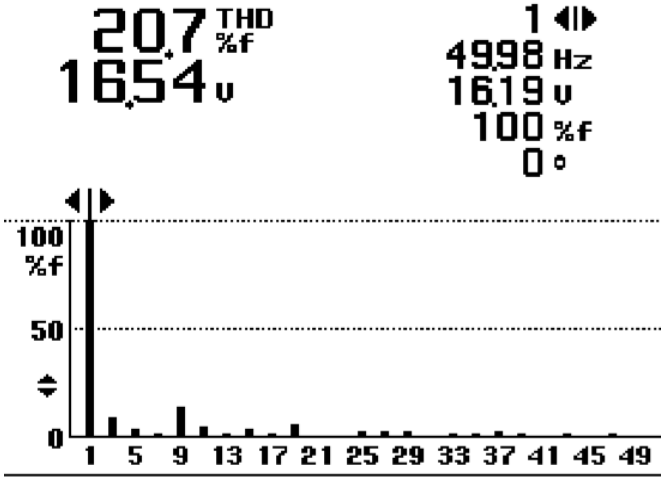


Figure.10 Harmonic spectrum of output voltage

X. Conclusion

The Five-level symmetrical cascaded H-bridge multilevel inverter for dual PV system with FPGA is designed experimentally. The simulation of FPGA is done with the help of MODEL SIM PE student edition 10.4a, which is used as a controller for the switching purpose of the MOSFETs. Single Pulse width modulation technique is applied to trigger the transistors. The 12V is input supplied to each H-bridge and the output voltage is obtained to be 16.59V with total harmonic distortions of 20.7% which is observed on the power quality (PQ) analyzer experimentally.

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