Experimental Validation for A Nine-Switched 3-phase Multilevel Inverter (MLI) With a Photovoltaic (PV) Source of Array

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Abstract: Now-a-days Usage of Multilevel Inverters application is very wide in the industrial applications. Keeping in view of industrial applications, a multi-level inverter with a solar PV array is designed in this paper to deliver power to the Alternating Current based load. A step-up converter is used at the input side of the three-phase multilevel inverter, which delivers the energy for the three-phase load, to regulate the output voltage of the solar Photovoltaic panel. The multilevel inverter utilizes 9 switching devices with five level sources in accordance to the usage of the level of sources in recent topologies. However, the advantage of this topology is that it uses fewer semiconductor switches than current topologies. Eventually, the paper includes the results of the modelling in the MATLAB and the experimental implementation of the proposed topology.

Keywords: Photovoltaic (PV), Digital Oscilloscope (DSO), Squirrel Cage Induction Motor (SCIM), Multilevel Inverter (MLI)

1. Introduction

Nowadays, usage of Power from renewable sources increases due to the technological advancements and price reductions, which reduces usage of conventional resources eventually reduces global warming, which leads to the usage of renewable energy has increased in recent years. Among the renewable sources, solar energy is abundantly available at a free of cost in nature. A photovoltaic (PV) array is used to generate energy for a three-phase AC load. Here, a Squirrel Cage Induction Motor (SCIM) is used as a load. It is among the most widely utilised motors in the industry, which is designed to support constant speed operation. This is due to the fact that, it can achieve good performance at a lower cost and its construction is simple and less maintenance due to robust. A 3-phase multilevel inverter (MLI) is utilised to drive this three-phase load.

Multilevel Inverters were developed to operate on average voltage range grids and provide a better output voltage to the load with less fluctuations. There have been a lot of advancements in these topologies since the 1970s, and a number of new topologies have been created ever since. To evaluate the proposed power circuit's feasibility, a system of switches and capacitors was utilised in this particular inverter. The system mimics a sinusoidal signal by combining the system's voltages and then uses switches to shift the output waveform into a staircase waveform. In general, as the number of measurement points increases, the performance for the load will improve because it will approximate a
sinusoidal waveform, and yet increasing the number of switching control schemes will lead to increased complexity. Due to the many various possibilities for clean energy that are accessible, solar power has recently attracted a lot of attention. At this time, photovoltaic (or) solar cells provide one of the most effective long-term power sources. This cell has recently risen to the forefront of candidates for harnessing energy from the sun because of its ability to convert sunlight into electrical energy with a high conversion efficiency. It is capable of providing a nearly constant amount of power at a low operational cost, and it is free of pollutants. Because standard photovoltaic cells are able to generate power which is less than 3 watts at 0.5 volts, they must be connected in a combination of series-parallel configurations to meet the desired power requirements for high-power applications. The PV modules are made up of cells, and arrays are made up of modules. While the actual output power of PV modules can vary from a few watts to more than 300 watts, while it is dependent upon the application. As of this moment, megawatt arrays are only theoretical; most of the output power of the array will be within the range of one hundred watts to, one thousand watts.

The solar panels, like energy storage devices, produce direct current (DC), which is typically used for smaller applications (electronic equipment). In order to use solar panels to generate alternating current (AC), direct current (DC) must be converted to alternating current (AC) using grid converters, which are solid-state devices that accomplish the conversion. In these days, due to the increased demand for processing capability in a variety of application areas, there has recently been a surge of interest in high-performance computing using FPGAs. Over the last two decades, research has shown that using FPGAs to accelerate the applications, such as digital signal processing, network packet processing, bioinformatics, and cryptography, which results in significant performance gains. Clustering FPGAs together and distributing computations among them is one of the ways to take advantage of their processing capacity. Distributed computing is the idea of breaking down a problem into smaller tasks and spreading these tasks to different processing elements. Via parallelization, performance is enhanced when FPGAs are used in a distributed computing environment. Here [1], day by day the usage of electrical energy dependency is enormously increasing. So, the power generation is meet the requirement of the demand, for this we need to make use of renewable energy sources instead of fossil fuels in view of global warming. However, the solar energy is abundantly available in the nature at free of cost. So, power generation cost is less than other. Then, based on the energy conversion principle we convert solar energy into electrical energy (dc) by arranging a set of photovoltaic panels for collecting the solar energy at maximum level and then fed to a converter which changes into an alternating current (ac). The electrical energy in this circuit is being used to power a 3-phase load, such as a squirrel-cage induction motor. [2] This consists of converting electrical energy into mechanical energy by means of electric motors with the assistance of which load-driven machines provide the required energy to Power drive system(PDS) for industrial applications. In industries, Squirrel Cage Induction Motor (SCIM) converts mechanical power into 2/3 of the electricity generation. In [3], Pulse Width Modulation (PWM) technique involves generating pulses from comparing a triangular waveform signal with a sinusoidal signal by referencing their widths and comparing the signal amplitude. Because the signal amplitude is different, the area of the triangular waveform is the intersection of the signal area and the reference signal area. This technique helps improve operating conditions for inverter operation, which results in a lower-distortion output. The modulation techniques are classified based on Reference, Carrier, Time, Hybrid and Vector in nature of operation. In [4], The control of voltage at various loading conditions, unbalance of active and reactive power, and reliability of the system are all handled in this power system control method. Because of the lack of any active network elements, these issues can be resolved by using flexible alternating current transmission control devices such as STATCOM, which is a shunt controller placed at the end of a weak bus network to improve voltage profile and control of reactive power flow. In [5], high power energy conversion-based applications that are based on high power energy conversion we’ll need multilevel inverter (or) converter to convert between direct current (DC) - alternating current (AC), direct current (DC) - direct current (AC), alternating current (AC) to direct current (DC) and alternating current (AC) to direct current (DC) to drive the heavy motor applications. Inverters
with multilevel configurations provide more than two voltage levels. We are developing the panel to allow for higher voltage outputs and lower distortion, so that we can obtain the required output waveform which can be generated from multiple voltage levels with lower switching frequency and a smaller number of voltage devices. In [6], these days, with the advent of various industries, there is a higher demand for power control devices, with these controlling ac drive systems operating at high levels of power on an intermediate voltage network. So, connecting one single power semiconductor switch is difficult to meet this requirement. However, in order to come to this situation, multilevel inverters are work at very high voltage range is discussed. In [7], case of medium or high voltage applications, neutral point clamped (NPC) and flying capacitor (FC) topologies are more popular in three-level operation. The conducting switches count is more for three and higher levels of operation in MLIs due to which conduction losses are more. When these MLIs are work in more than 3-level gives a greater number of components and neutral point voltage balancing issues. For [8], portable electrical energy based operated applications needs to be fulfilled by using solar energy with photovoltaic panels not only for dc applications but also ac applications. In order to attain this, multilevel inverters are utilised, and the quality of the converted AC power depends solely on the type of topology used. These [9] quasi-Z-source inverters is well-suited for dissipating an input current continuously from the energy source while drawing power from a common ground point sharing with the direct current source for renewable energy source applications. Most industrial applications opt for three-level neutral point clamped quasi-Z-based inverters as opposed to two-level neutral point quasi-Z-based inverters because the voltage's output power quality and a smaller number of semiconductor devices make up for less stress. Grid [10] integrated renewable energy technologies are become more popular for solar photovoltaic systems for generation of clean and free source of energy. For rooftop applications, ease installation, noise less operation due to absence of moving parts which gives less maintenance. Solar inverters which are reduces usage of more batteries which occupies more space and economy. In [11] An increase in the use of sensitive equipment, for example in the case of computers, refrigerators, and power supplies, such as in switched mode power supplies, is needed in industrial, domestic, commercial, and traction applications. Using power electronic converters to regulate power supply to the end use presents a controlled supply of power. Although the electricity provided to the generators is sinusoidal, the current taken by these loads is highly fluctuated and unbalanced. [12] With the massive scale deployment of solar photovoltaic power systems, solar electricity plays a critical role in power systems that utilise distributed resources, such as micro-grids, and the utility grid. Solar power generation has a constantly dropping cost day by day due to the continual reduction in the cost of PV modules. With this, the number of PV plants that is integrated with the grid has significantly increased. An ANFIS controller with a maximum Power Point Tracking (MPPT) Photovoltaic system has been used in the research [13-14] to control a bidirectional converter with a high gain buck boost converter and modified zeta converter architecture. In [15] A switched mode bidirectional dc-dc converter is used as a renewable energy source to increase the voltage level in the load side and may also be used to buck the output voltage in the load side with an FPGA controller. An experimental setup is utilised to demonstrate how the converter works.

2. Proposed Topology
For this topology, a hardware kit/prototyping type is created to evaluate the power circuit's performance, which is shown below. This power circuit uses a three-stage cascade H-bridge, together with a side control system, and a 5-level multilevel inverter (MLI) to implement an H-bridge. According to this model, the Modified Particle Swarm Optimization (MPSO) technique's efficacy in addressing SHE condition set under the condition of regulating an entire scope of regulatory record from 0 to 1 is analysed. The third-order adaptive digital signal processor (DSOP) in the AUSTER 3A model from Xilinx is applied to generate control model real-time simulation as well as gate pulses for the Nine MOSFETs in a cascade H-bridge 5-level inverter structure. A major component of the equipment circuit consists of the H-bridge force circuit of a three-phase, five-level H-bridge inverter, the SPARTAN-3A DSP regulator, and the interface circuits. The degree of integration between the
power circuit and the Xilinx's SPARTAN-3A DSP controller is covered in detail in this section. An FPGA integrated circuit is designed to be altered and programmed up to an infinite number of times following the manufacturing process. FPGAs will act as a building blocks for a reconfigurable computation. A computing paradigm which mainly focuses on dividing applications into parallel way which is a pipeline of specific application. The significance of reconfigurable computation is that, it combines the speed of the hardware with flexibility of software, especially the good characteristics of software and hardware. Here, for generating pulse width modulation (PWM) signals we used a microcontroller. But this microcontroller needs a lot of hierarchical conditions which leads to the complexity of the programming. So, FPGAs are preferable to use for relatively simple in operations but higher in processing speed when compared to microcontroller. As it has already been said, these FPGA designs give users the best methods for finding PWM Generation for power applications. FPGA role is, it only provides the interconnection between various logic blocks. FPGA likewise support change according to necessity. This element of reprogramming ability of FPGA makes it reasonable to make the plan utilizing FPGA.

![Power Circuit diagram of proposed topology](image)

**Fig. 1** Power Circuit diagram of proposed topology

3. Prototype Model/Experimental Arrangement
The Figure 2 shows the prototype model/hardware construction of FPGA regulator. The whole structure consists of FPGA regulator as a computer chip, LCD show, the different ports to interface the fitting gadgets.
In this experimental arrangement, we need to control six MOSFETs to produce least % Total Harmonic Distortion (THD) in yield voltage waveform of inverter. The components are made arrangements as follows; microcontroller (or) DSP arrangements need more PWM equipment fringe assets to empower complex control of three-stage 5-level inverter. This issue is obviously tended due to by the group of Xilinx's Straight forward FPGA regulator.

The inward engineering of the FPGA is progressively arranged to course motions toward the interior rationale entryway assets to coordinate with the ideal advanced circuit plan. Xilinx give a total windows-based programming advancement climate which can be useful to mimic a computerized plan.

4. Components and functions

The Figure shows the Spartan-3E block diagram, which includes the following components and features:

- **SPARTAN-3A DSP Processor**
  - Operating frequency-20MHz
  - Switching frequency-6.3KHz,
- PLL Clock Settings, JTAG Connector, RS232 Serial Port, Parallel Port, LCD Display, PWM Connector, SDA Bus Connector, Power Supply, USB.
On-chip PWM controllers are common in SPARTAN 3E FPGAs, making implementation easy. The software can create a ROM programme file by synthesising a digital logic architecture. VHSIC Hardware Description Language was used to design the specification for the experimental inverter's FPGA (VHDL). It has been taken into consideration while developing software that will operate on the FPGA-based Xilinx SPARTAN-3A DSP controller, and VHDL code has been created in order to import the relevant phase angles into the FPGA-based Xilinx SPARTAN-3A DSP controller. JTAG (Joint Test Action Group) serial mode configuration can be used to configure FPGAs. Relevant configuration data is loaded into internal memory of SPARTAN-3A DSP family computers. Due to the rapidly changing memory in the Xilinx FPGA design, it must be reconfigured every time it is switched on. To load the bit stream, we utilise the JTAG interface.

To setup an FPGA, there are four control lines of JTAG that need to be set: TCK, TDI, TMS, and TDO. A detailed specification of the control lines and their operations can be found in Xilinx's SPARTAN-3A DSP controller output. It is connected to driver ICs, which enhance the signal strength, to provide the pulsing signal of Pulse Width Modulation. Three IR2110 large capacity driver ICs and three TLP250 ICs are implemented in a hardware manufacturing.

5. Software implementation using VHDL in XILINX ISE design suite
When used with FPGA development, a user offers a hardware description language (HDL) or a schematic design to explain the FPGA's activities. By design, an HDL-based definition avoids the laborious task of drawing each individual element of the huge structure, thereby making the HDL type more appropriate for working with these kinds of structures. To get back to the opposite side of the issue, using schematic entry will make it easier to picture an idea.

Despite being made apparent by authors' findings, HDLs, VHDL and Verilog remain the most well-known HDLs. Studies emphasize how a reduced HDLs complexity can be compared to low-level computing constructs, as an increase in HDLs reflection level would provide a simple mechanism for planners to gain increased insight.

Xilinx ISE (Incorporated Union Environment) is a device framework provided by Xilinx for the union and investigation of HDL plans. It empowers the designer to merge ("accumulation") their proposals, execute calibration evaluation, examine RTL outlines, simulate a plan's response to various boosts, and arrange the objective gadget with the software engineer.

Xilinx ISE is an ideal software development environment for FPGA designs from Xilinx. At a circuit combination and plan level, the Xilinx ISE is in general use, but ISIM or the Model Sim reasoning test system is employed at a higher level for frameworks testing. The Xilinx ISE employs a
number of different service segments, all of which include the ISE’s new Product Improvement Pack (EDK), along with its new SDK, which serves as a foundation for chip extension mastery. An integral part of the ISE user interface is the Task Guide, which integrates the plan chain of command (Resource), a source code proof-reader (Work environment), a yield ensures (Record), and a cycles tree (Cycles).

When making the configuration, you are following an algorithm laid out in a configuration document (called a module), and this algorithm unveils the circumstances that are decoded by the ISE and shown as a tree structure. In this case, one principal module is in place, which includes multiple modules by virtue of including the main module. This is quite similar to the basic () subroutine in C++ applications. Plan directives are defined in modules that include the design of pin placement and planning.

The Processes structure is the ISE’s manual on how to work with the active module. Compilation functions, their dependencies, and other utilities are all part of the hierarchy. Each function’s issues or errors are also indicated in the window. The Transcript window shows the current state of operations and alerts engineers to design flaws. Warnings, Errors, or both can be shown for such issues.

ISIM or the Model Sim logic simulator may be used to conduct system-level testing, and test programmes must be written in HDL languages. Simulated input signal waveforms or displays that observe and check the outputs of the system under test are examples of test bench programmes.

- The following types of simulations can be performed with Model Sim (or) ISIM:
- Behavioural verification, to check logical and timing problems
- The implementation is verified with logic to guarantee the module generates anticipated results
- A post-placement and circuit simulations is done to verify the operations after the module is located inside the FPGA’s reconfigurable logic.

6. Simulink Circuit

![Simulink model of a PV Panel](image)

**Fig. 4** Simulink model of a PV Panel
6.1 Output waveform
The outcome we get in the lift method of the proposed converter in the re-enactment execution is appeared in underneath figure 7. The voltage on the X-axis is indicated in volts, and the time on the Y-axis is transmitted in the form of a flash. When we applied a 120V input voltage to the inverter, we received an output voltage of 388.1V, which is a significant increase from the original voltage of 120V. According to the yield voltage, the applied voltage in the low voltage side is approximately 3.3 times higher than the yield voltage.

Fig. 5. P-V and I-V Curves

7. A 5-Level 9-switch Three Phase Multilevel Inverter circuit in Simulink that simulates a 3-ph Photovoltaic Array Source

Fig. 6 A 5-Level 9-switch Three Phase Multilevel Inverter circuit in Simulink that simulates a 3-ph Photovoltaic Array Source

7.1 Output waveform
The waveform of the output of the boost converter is represented in the figure below, which demonstrates how it displays in the simulation. At the coordinates (X,Y), the voltage is found to be
expressed in volts on the X-axis, while the time is found to be expressed in seconds on the Y-axis. In the case of a 400-volt application to the high-voltage side, the output voltage is 150.2 volts as a result. This value is computed as the output voltage on the low voltage side, and it is about 2.6 times the value measured on the high voltage side.

Fig.7 Simulation Results Output Line to Line voltage waveform for 5-Level 9-switch of 3-phase MLI with a PV Array Source

7.2 Simulation Results
A three phase five level inverter is a circuit that transforms direct current to three phase alternating current. Each step has a 120° change. In order to construct a three-stage, five-stage inverter, Cascaded H-Bridge Connections are used.

Fig.8 - Phase output line voltage waveform for 5-level 9-switch 3-phase MLI with a PV array source
8. Hardware Setup

When the converter is associated with work in the lift method of activity, the input voltage is provided at the low voltage side and the yield gathered at the high voltage side when the circuit is working under 0.5 as obligation cycle, the converter is said to be associated with work in the lift method of activity. When we apply different voltages such as 5V, 7.5V, and 10V to the low voltage side, we ensure that the yield voltages on the high voltage side are practically multiple times the regarded supplied information voltage.

The resulting output voltage is 23.6V for the specified input voltage of 5V is shown in below fig 10.
Fig.10 Experimental results of 5-Level Waveform measured in DSO
9. Conclusion
Using the experimental setup, we are able to validate the supplied power circuit, and the output results are measured using a digital storage oscilloscope (DSO). And also, the same power circuit is modelled in MATLAB's Simulink and we obtain the same output results. In this experimental setup we observed as, for a given input voltage we get more than 3 times of its input value. It represents that, when we need to increase (or) boost the output voltage type applications, we preferably use this setup. From solar energy we collect some portion of voltage which depends upon the number of arrays falls on the solar cells. When it comes to using multilevel inverter structure with reduced THD, in order to boost the energy, we will need to rely on an increase in usage of the multilevel inverter structure. With that said, to achieve greater energy output, you must make use of a multilevel inverter structure with reduced THD. The results of this project show how to drive a three-phase load using a multilevel inverter while using a Photovoltaic array as a supply. Here, we tried to discussed the various components usage in the experimental model and clarified in depth to provide the lecturer with a complete understanding of the project's scope. Expanded knowledge includes such information as the PV panels' complicated equation, the boost converter, and the inverter's switching system. A 5-step multilevel inverter was successfully simulated, and if implemented, it can provide a number of advantages.

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