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Switch Ladder Multilevel Inverter Based Grid Connected PV System

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ABSTRACT: In order to tackle the inherent difficulties associated with the design of a multilevel inverter for the purpose of efficient conversion from DC to AC, several modifications are proposed for the conventional H-bridge multilevel inverter. These modifications aim to reduce the number of power electronic components, minimize switching losses, alleviate voltage stress on switches, and maximize the number of output voltage levels. The implementation of this alteration leads to the development of a Switch Ladder Modified H-Bridge Multilevel Inverter (SLMHB-MLI). In addition, this study introduces a novel approach called Pulse Width Modulation (PWM) to effectively reduce the maximum voltage rating on the switches and optimize the switching sequence of the multilevel inverter. Moreover, the incorporation of the innovative Pulse Width Modulation (PWM) approach into the SLMHB-MLI system allows for the manipulation of the magnitude of the output voltage. Simulation and experiments are used to verify the effectiveness of this new topology and PWM approach, respectively.

EYWORDS: Switch ladder Modified H-bridge PV System, Fuzzy Logic Control MPPT, PWM technique.

I. INTRODUCTION

The quick advancement in the investigation of energy generation from alternative sources, including wind, solar, tidal, and others. Among the various sources of energy, photovoltaic systems (PV systems) are of considerable significance. The photovoltaic system produces energy in the form of direct current (DC). The main area of research in renewable energy currently centers around grid-connected photovoltaic systems (GCPS). The increased focus on this matter is driven by various factors, including the declining cost of photovoltaic (PV) panels, environmental benefits, growing energy requirements, smooth integration with current power networks, and developments in power electronics. Key performance measures in GCPS encompass conversion efficiency, maximum power point (MPP) tracking, and total harmonic distortion (THD) of the power supplied to the grid. The performance criteria are substantially influenced by the selection of inverter architecture and the control mechanisms applied.

Indeed, multilevel inverters (MLIs) stand out as a highly promising class of converters. Unlike traditional inverters with only two or three output voltage levels, MLIs offer a greater number of levels. This feature yields several advantages. One significant benefit is the creation of a staircase-like output waveform that closely resembles a sinusoid. This waveform characteristic greatly enhances the quality of the output power, rendering it more suitable for a wide range of applications, especially those demanding low harmonic distortion and high power quality.

The H-bridge topology was designed with the objective of minimizing the quantity of switches in grid-connected photovoltaic systems (GCPS). Nevertheless, the effectiveness of maximum power point (MPP) tracking in GCPS designs utilizing the topology outlined in the aforementioned study, as well as a unique H-bridge, is notably inferior when compared to designs based on the fundamental CHB (Cascaded H-Bridge) topology.

This study presents a novel topology that draws inspiration from the H-bridge and an established Multilevel Inverter (MLI) structure documented in the current literature. Furthermore, it is important to highlight that the selected control technique plays a significant role in determining the performance of Grid connected photovoltaic (PV) systems. Historically, CHB MLI-based GCPS have commonly utilized classical control schemes, such as PID (Proportional-Integral-Derivative), which incorporate diverse modulation techniques and compensations. Nevertheless, a significant limitation of these traditional control systems is their extended transient duration and sluggish reaction time.

This work presents a novel multilevel inverter (MLI) topology, explores its utilization in grid-connected photovoltaic systems (GCPS), and presents a mathematical model for its implementation. By doing simulations and comparing them to previous studies, It evidence that the proposed MLI outperformed then recent converters in terms of performance.

II. LITERATURE SURVEY

Aravind Mittal and Amit Ohuj [1] have explored a novel approach involving a grid-connected system based on a multilevel inverter, utilizing solar photovoltaic technology. The study reveals the implementation of a 3.25 kW P single-stage solar photovoltaic system integrated with a multilevel inverter for grid connection. Khushboo Kothari et.al, [2] Explored a novel concept centered on a Solar-based Multilevel Inverter interfaced with a three-phase grid supply. Multilevel inverters, distinguished from single-level inverters N. Kumar, I. Hussian, et al. [3] conducted a study on a new method for Maximum Power Point Tracking (MPPT) in Solar PV Systems. They used a Reduced Sensor Approach and the PNKLMs Algorithm to integrate the system with the grid. The comparative analysis of three topologies of five-level three-phase multilevel inverters (MLI) was undertaken by Abdelaziz Fria et al. [4] using the MATLAB/Simulink environment. The findings suggest that the total harmonic distortion (THD) is around 32% for both the NPCMLI and PWM H-Bridge topologies.

Janardhan et al. [5] conducted a study whereby they investigated the utilization of MATLAB modeling and simulation techniques for the analysis of a 36W solar photovoltaic module. The study centered on the development of a MATLAB/Simulink software application for the purpose of analyzing the performance of photovoltaic (PV) modules across different levels of solar radiation intensity and temperature. A.R. Beig and R.Y. Udaya Kumar [6] present a new DC to AC inverter specifically designed for photovoltaic power supply systems, emphasizing its cost-effectiveness, reliability, and efficiency for residential applications. The study conducted by Sayli Khadse et al. [7] examined a 5-Level Single Phase Flying Capacitor Multilevel Inverter. The primary objective of the study was to develop a switching strategy that relies on estimated switching angles in order to provide multilevel output voltage waveforms.. Phani Kumar Chamath et al. [8] introduced an innovative inverter architecture that does not require a three-phase transformer. This topology is specifically developed for solar PV systems that are connected to the grid.

The Three-Phase Five-Level Flying Capacitor Multi-Level Inverter was proposed by Ada Olokpo et al. [9]. This inverter was developed and evaluated in four distinct stages, including Solar Energy Harvesting, Current/Voltage Control, Boost Converter, and the FCMII. In their study, Janardhan Kavali et al. [10] conducted a comprehensive analysis of different control systems, focusing on the Total Harmonic Distortion (THD) in the output voltage and utilization factor of power devices. In [11], Muthubalaji et.al discussed the Enhanced Fuzzy logic Controller (EFLC) for boost converter. S Radhika et.al [12] studied various DC-DC converters, benefits and drawbacks, In his work, Hamza B. Al Smadi [13] provides a comprehensive overview of the key considerations involved in the integration of photovoltaic (PV) systems. Additionally, he explores the grid utility standards and codes, as well as forthcoming advancements that would enable grid-connected PV systems to operate as distributed generators. In a study conducted by Ahmed Hossam Eldin et al. [14], a comparative survey was undertaken to examine the three latest generations of solar cells. First-generation solar cells dominate the market due to their exceptional efficiency and the most affordable price compared to other commercially available varieties.

In this research, Harish Kumar Khyani et al. [15] examine the prevalent challenges and obstacles associated with the integration of small-scale solar photovoltaic energy systems into the grid. The response of the system to abnormal voltages is contingent upon the interconnection of its components. In this research, Ali Bughneda et.al [16] examined the categorizations, advancement, and difficulties associated with multilayer inverters. The study also provides valuable recommendations for their application in renewable energy systems. In their study, Shaik Nyamathulla et.al [17] provide a comprehensive examination of MLIs and a categorization of the current MLI configurations, along with their advantages and disadvantages. In their study, Akanksha Sinha et.al [18] conduct a thorough analysis of MLIs and present a hierarchical ranking of the existing MLI topologies, emphasizing their respective benefits and drawbacks. Furthermore, it provides a comprehensive examination of reduced switch count multilevel inverter (RSC-MLI) configurations, encompassing their criteria for selection, common characteristics, designs, and limitations. This article provides a comprehensive overview of multilevel inverters, emphasizing their necessity for grid-connected sustainable solar PV systems.

The modified H-bridge (MHB) module proposed by Karasani Raghavendra Reddy et.al [19] is the foundation for the three-phase hybrid cascaded modular multilevel inverter topology described in this study. This architecture leads to a

reduction in the quantity of power switches, losses, required area for installation, voltage stress, and cost of the converter. Sayed Ahammad, [20.] This study primarily aims to engineer and evaluate a hybrid solar and biomass system for the purpose of decentralized distributed generation and rural power distribution management. The ultimate objective is to provide electricity to a remote region in Bangladesh. In [21], the author discussed the single diode model for PV solar system.

The critical review includes the limitation such as complex circuitry, level of THD, distorted output when integrating the Renewable energy sources. This work proposed a converter topology which is suitable for the solar PV system. This topology not only provide the comfortless also provide non distorted higher output along with optimization based MPPT technique. The THD also remarkably reduced.

III. METHODOLOGY

The circuit diagram in Figure 1 illustrates a SLMHB-MLI system connected to both the load and the grid. When the power generated exceeds the load demand, the grid-tied MLI supplies excess power to the utility grid. Various renewable energy sources can be utilized to generate DC voltage, which is then fed into the SLMHB-MLI system. This MLI operates on a novel PWM technique tailored to the specific load demands and categories. An optional low pass filter LC is employed in the novel PWM technique to minimize Total Harmonic Distortion (THD), although THD without using any filter. On the other hand, the PWM technique necessitates a filter. Thus, the proposed SLMHB-MLI system can function with providing flexibility in implementation.

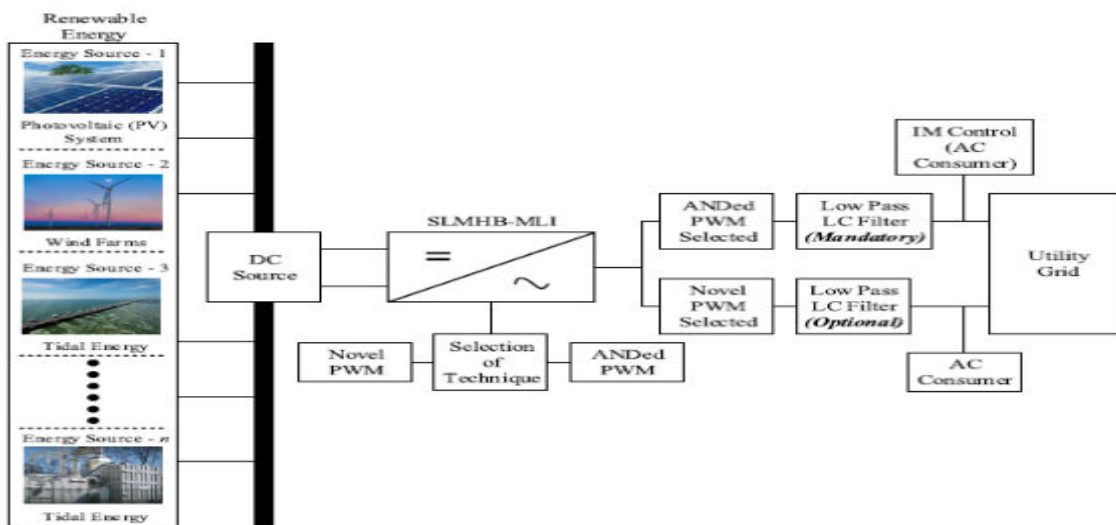


Figure 1: Block diagram of proposed system

3.1 PHOTOVOLTAIC SYSTEM

PV cells, often known as solar panels, are components of photovoltaic (PV) panels, which use solar radiation to generate electricity. These cells are connected to form a module. They are composed of a semiconductor that conducts energy, such as silicon. 30 modules are found in a typical rooftop solar panel. The process of sunlight absorption by the semiconductor in solar panels releases electrons, which are the building blocks of electricity, from their position and allows them to pass through the semiconductor.

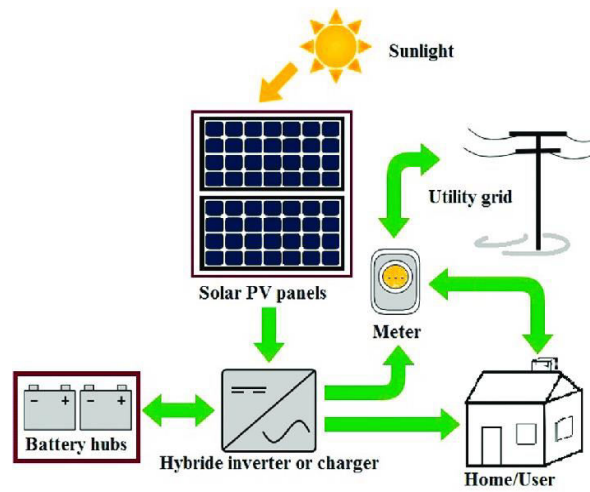


Figure 2: Diagram of PV System

An electric charge disparity arises between the anterior and posterior regions of the cell due to the migration of ejected electrons, each with a negative charge, towards the anterior surface. As a consequence of this disparity, a voltage potential akin to the negative is generated.

3.2 SOLAR CELL CHARACTERISTICS

The current-to-voltage (I-V) characteristic and power-to-voltage (P-V) characteristic of a solar cell are non-linear, making it challenging to identify the maximum power point (MPP). Unlike linear curves, where the MPP occurs at the midpoint, determining the MPP on a non-linear curve requires specialized techniques. A typical V-I characteristic of a solar cell, illustrating the non-linear relationship between current and voltage under varying operating conditions. Identifying the MPP involves finding the point where the product of current and voltage (power) is maximized. Single diode model shown in figure 4 is used in this study.

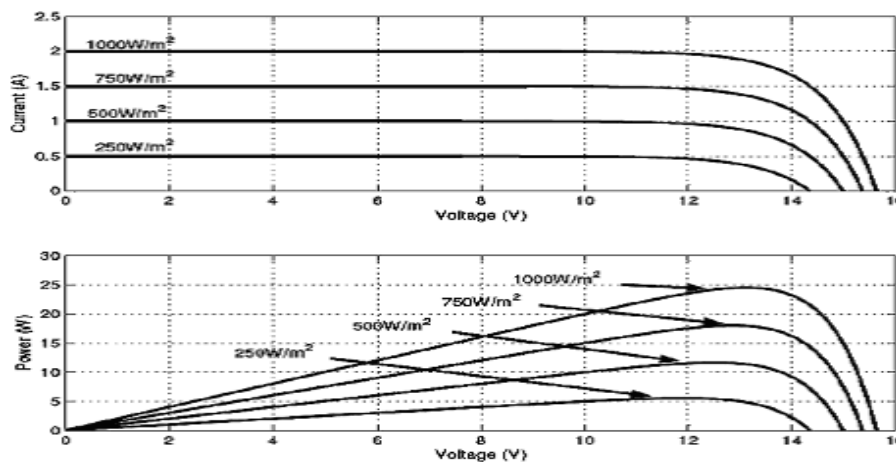


Figure 3: Characteristics of solar cell

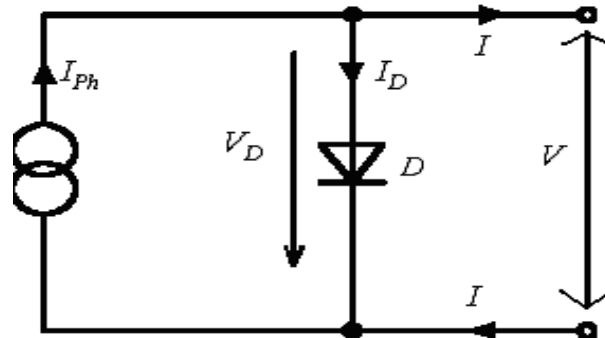


Figure 4: Equivalent circuit of a solar cell

3.2 SWITCH LADDER

The switch ladder multilevel inverter (SLMLI) is a specific configuration of a multilevel inverter that utilizes a linear arrangement of switches to produce various voltage levels at its output. The aforementioned design facilitates the production of stepped waveforms, which exhibit a high degree of similarity to sinusoidal waveforms while exhibiting lower Total Harmonic Distortion (THD) in comparison to conventional two-level inverters. The switch ladder multilevel inverter is characterized by the arrangement of switches in many stages or levels, wherein each level is responsible for generating a portion of the overall output voltage. The required output voltage waveform can be produced by effectively regulating the switching states of the switches at each level. The switch ladder multilevel inverter topologies that are frequently employed encompass the diode-clamped (neutral-point-clamped), capacitor-clamped, and cascaded H-bridge arrangements.

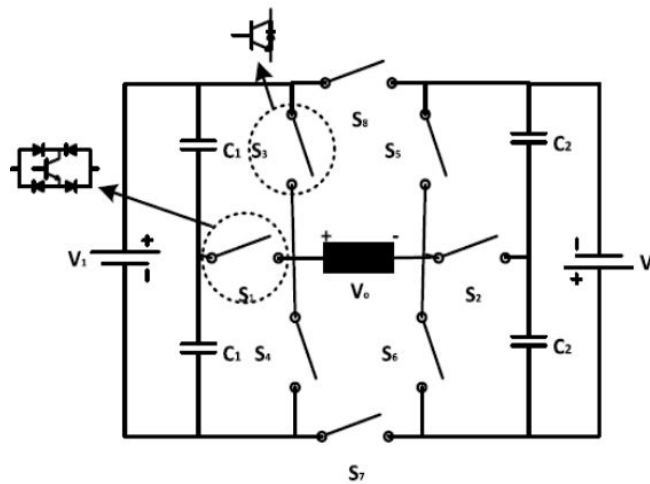


Figure 5: Schematic of the SLMHB-MLI

The structure of the system depicted in Figure 5 consists of two direct current (DC) sources (V_1 , V_2), four capacitors (2 of C_1 , 2 of C_2), eight unidirectional switches (S_1 , S_2 , ..., S_8), and 14 freewheeling diodes interconnected across each switch. Furthermore, the proposed topology involves the conversion of bidirectional switches (S_1 , S_2) into unidirectional switches, referred to as "converted unidirectional switches," as depicted in Figure 1. In order to mitigate the appearance of random voltage across the connected load, it is crucial to establish a closed-loop configuration during each switching sequence, thereby preventing simultaneous activation of all switches of the SLMHB-MLI. The capacitors located on the left side (C_1) and the capacitors located on the right side (C_2) are indistinguishable and serve the purpose of voltage division. In order to achieve efficient capacitive voltage division, it is necessary to satisfy certain characteristics. Firstly, both pairs of capacitors (C_1 , C_2) must possess identical values and originate from the same manufacturer. Additionally, their voltage ratings must satisfy the minimum expectations set by the DC voltage source to which they are attached. In addition, in order to attain effective capacitive voltage division, it is necessary to

link resistors of significant value (Megaohms) in parallel with each capacitor, thereby guaranteeing equitable voltage distribution across them. Capacitors are of utmost importance in the generation of several voltage levels at the output.

3.3 FUZZY LOGIC CONTROLLER (FLC)

Fuzzy logic is an effective method for managing nonlinearity, particularly in creating Maximum Power Point Tracking (MPPT) controllers. These controllers excel in quickly and accurately tracking the maximum power point (MPP) in various scenarios. The fuzzy logic controller process can be classified into three criteria:

1. Fuzzification: This is the initial stage where clear inputs, such as changes in input voltage levels, are transformed into fuzzy inputs using stored membership functions. Fuzzification is the starting point of the Fuzzy Logic Controller (FLC) process, and it involves designing fuzzy values based on input characteristics.
2. Rule Evaluation: In this stage, the fuzzy processor evaluates rules based on the fuzzy inputs to determine the controlling action in response to the set of input values. Linguistic rules are utilized to determine the appropriate action, resulting in a fuzzy output from the rule evaluation process.

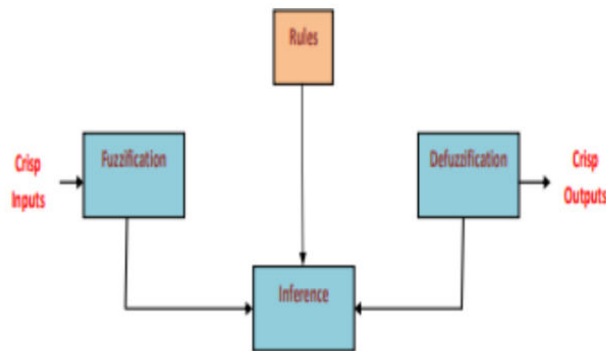


Figure 6: Fuzzy logic controller

3. The final category involves transforming the fuzzy output into a crisp value. Defuzzification techniques are employed to convert the fuzzy value into a precise output value consistent with the intended output. Each fuzzy output variable undergoes transformation based on the output membership function for every input set.
4. The fuzzy logic controller process involves fuzzification to convert clear inputs into fuzzy inputs, rule evaluation to determine control actions based on linguistic rules, and defuzzification to transform fuzzy outputs into crisp values consistent with the desired output.

During the Rule Evaluation stage of the FLC design for the MPPT block, the input and output variables are classified into several levels: NB (negative large), NS (negative small), ZE (zero), PB (positive big), and PS (positive small). The variables in question are allocated to the Sampling Sequence in accordance with the sampling time. During the Fuzzification process, numerical inputs are converted into linguistic variables using membership functions. The design of rules for MPPT focuses on the relationship between changes in voltage and power increase. The rules are structured such that changes in voltage causing power increase are consistently followed in the same direction. If there's a decrease in power, the subsequent change is in the opposite direction. Following theoretical design, adjustments are made to the membership functions and rules based on errors to optimize performance. This iterative process ensures that the FLC achieves maximum effectiveness in tracking the maximum power point.



Tbale 1. Rule Table for Fuzzy Logic Controller (FLC)

$\Delta V \backslash \Delta P$	NB	NS	Z	PS	PB
NB	PB	PS	NB	NS	NS
NS	PS	PS	NB	NS	NS
Z	NS	NS	NS	PB	PB
PS	NS	PB	PS	NB	PB
PB	NB	NB	PB	PS	PB

IV. RESULTS AND DISCUSSION

The proposed system undergoes testing and validation within the Matlab/Simulink environment, employing a Switch Ladder Multilevel Inverter alongside a Fuzzy Logic MPPT (FLC) controller for optimizing the inverter's performance. The design specifications for the photovoltaic (PV) system are presented in Table 2, outlining the necessary parameters and requirements.

Table -2: PV System Parameters

At Temperature T = 25°C, Insulation G=1000W/m ²		
Open circuit voltage	V _{oc}	21.0 V
Short circuit current	I _{sc}	3.74A
Voltage at max.power	V _m	17.1V
Current at max power	I _m	3.5A
Maximum power	P _m	60.0W

The generation of 17-levels at the output is achieved by picking DC sources with equal values (V1 = V2 = 100V). The term "symmetric MLI" is used since the DC voltage sources have the same magnitudes. The resistive-inductive (RL) load is set up in a configuration where R is equal to 260 and L is equal to 100mH.

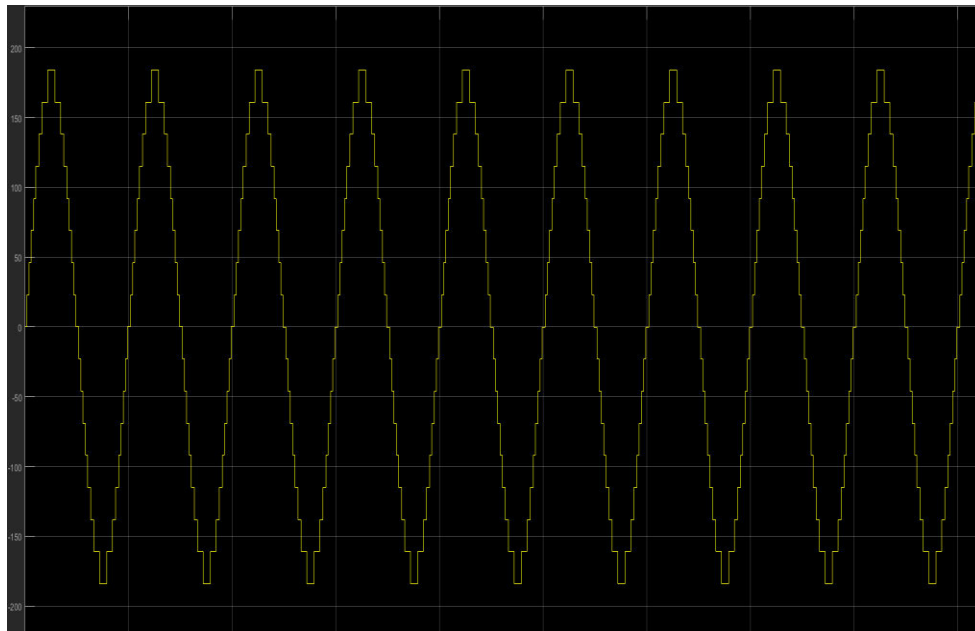


Figure 7: Voltage of 17 Level MLI

Figure 7 illustrates the generation of 17 distinctive voltage levels at the output, with a positive peak at 200V and a negative peak at -200V. In the context of 17 level MLI, the magnitude of DC voltage sources is modified to ensure that V1 is set to 25V and V2 is set to 75V.

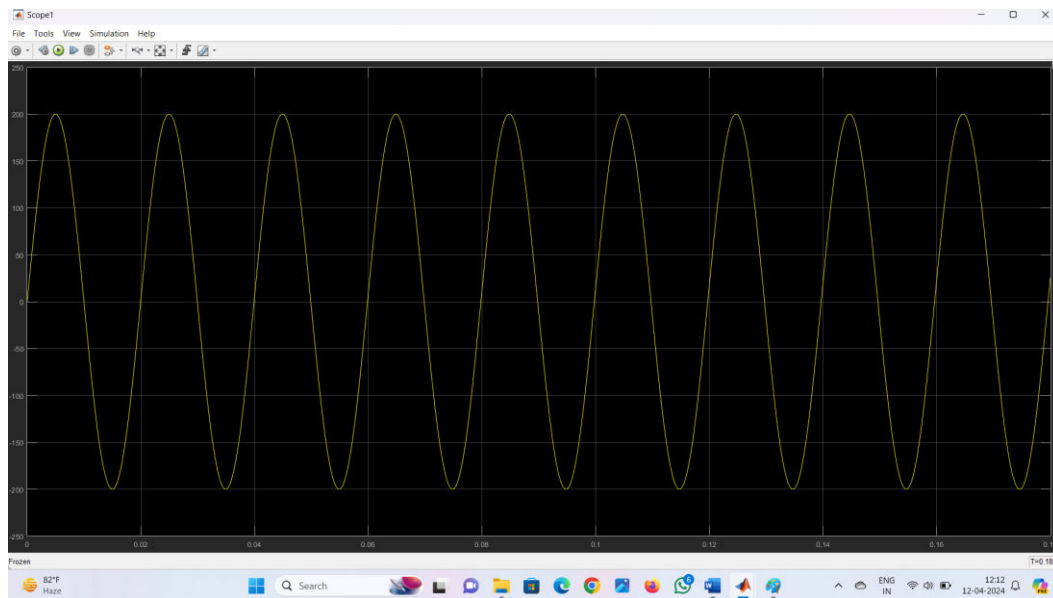


Figure 8: Output voltage of the SLMLI

Figure 8 illustrates the output AC voltage generated by the switch ladder multilevel inverter. Despite the dynamic nature of the inputs from the solar PV system, the profile of the MLI output voltage remains relatively constant.

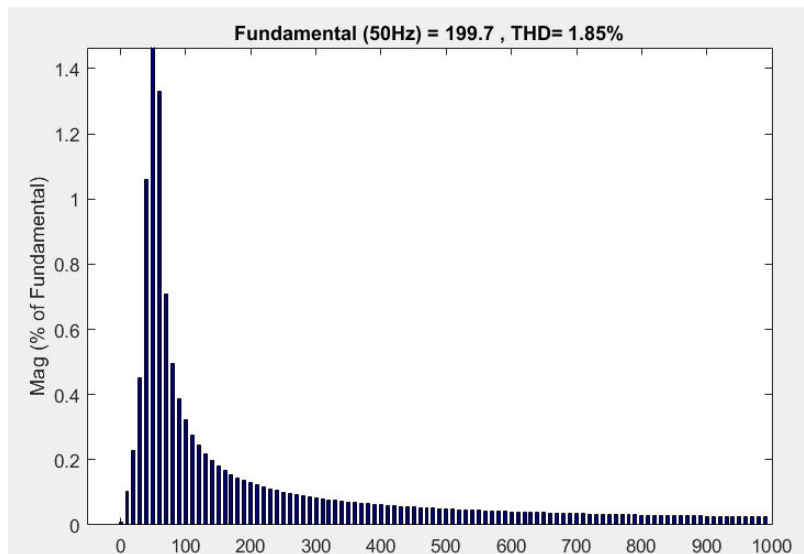


Figure 9: THD of MLI Output voltage profile

The total harmonic distortion (THD) of the output voltage profile of the MLI is depicted in Figure 9. The THD spectrum obtained from the measurements demonstrates a remarkably low value of about 0.02%, suggesting a negligible level of distortion. In general, lower order harmonics exhibit a tendency to prevail; nevertheless, within the framework of our proposed system, they are efficiently eradicated.

Table 3 Comparison & Validation

	MPPT Technique	Output voltage (V)	THD %
5 Level Inverter	P&O	64.4	2.27
Switched Ladder MLI	P&O	185	2.18
Switched Ladder MLI	FLC	200	1.86

V. CONCLUSION

This paper introduces a switch-ladder modified H-bridge multilevel inverter (SLMHB-MLI). The primary objective of this topology is to maximize the output voltage levels while minimizing voltage ratings on switches, Total Harmonic Distortion (THD), and requirements on power electronic components. Additionally, the SLMHB-MLI employs a PWM technique to adjust the Root Mean Square (RMS) of the output voltage by varying the duty cycle of the associated pulse train signal. These advantages stem from rigorous research efforts. The theoretical concepts presented in this paper are validated by achieving the THD 0.02% and output voltage of 200V.

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