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Critical Analysis on Multilevel Inverter Designs for Renewable Energy Grid

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Abstract

Multilayer Inverter (MLI) technologies have recently gained popularity as a cost-effective option for a number of engineering uses utilizing renewable sources of energy. This arrangement has a few noteworthy properties, including a lower hardware complexity, reduced switching losses, a smaller number of switches, and a better output voltage/current waveform. The reduction of total harmonic distortion is the most important requirement in multilayer inverters. Focus on the benefits; MLI technologies, including industrial equipment depending on a multilayer inverter architecture, have seen great growth. A review of traditional MLI and newly developed MLI is covered in this work. These seem to be the most extensively used power electronic devices in purposes such as motor-drive applications, solar as well as wind power MLIs, (DSTATCOM), and in distribution Grids. With valuable references, this study broadly compares several types of MLIs and their appropriate uses in terms of the number of layers used,the number of switches, and Total Harmonic Distortion (THD).

Keywords: Grid, Multilevel Inverters, Renewable Resources, THD

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Introduction

The growing use of electricity generated and distributed has resulted in the rapid degradation of renewable energy sources. Consequently, there has been a lot of study into Renewable Energy(RE) based electricity production. Rather than its considerable reliance on fluctuating climatic circumstances, solarcells and wind-RE are two significant RE sources attracting increasing attention amongst system research groups. In order to improve energy supply and generate maximum output from RE sources, innovative power conversion devices are needed for optimized reaction conditions. An inverter is indeed an important component of a RE power converter since it transforms Direct Source electricity into Alternating source electricity as needed by the grids and loads.[1] In small-scale businesses or industrial applications, a traditional 2-stage/2-Syage inverter is often employed. The outputs of these inverters contain additional overtones (THD), necessitating the use of costly and large pass band active filters to send the electricity towards the grid system. Furthermore, the use of this in elevated power applications is prohibited due to high supply voltages and considerable switches-loss. As a result, multilayer inverters (MLIs) have emerged as the most effective medium and high-power conversion device alternative. MLI design was initially proposed in mid-1975, with many variants. For its capacity to operate at high voltages, reduced switching inefficiencies, high efficacy, and minimal EM interference, such MLIs are gaining in popularity. MLIs can address the growing need for higher power ratings while improving power quality and lowering THD. MLIs are most often used in the middle-high energy converters from various connections of switching devices and single/multiple DC energies while operating at a low switching frequency. Multilevel Inverters are extensively employed for various purposes, including powerful electric drives, RE conversion, e-mobility, active power filters, direct high-voltage current, and STS-COM. The output waveform of an MLI has reduced distortions and Harmonic contents. The need for a high switching device, either IGBT, MOSFET, etc., however, is a typical drawback. A digital circuits circuit is required for each switching device, which directly increases MLI's complexity and expense. As a result, one of the most significant study questions is how to construct MLIs with a small number of components that yield a larger level of voltage. Monitoring and modulating these MLIs has become more difficult as MLI architectures have progressed.The key

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goal mentioned in the literature is to reduce losses and enhance the harmonic profile.

In addition to these benefits, the multilayer inverter offers a few advantages over the two-level inverter.[2]

- Distortions do have a lower harmonic impact.
- Leading to variations in voltage levels, the sinusoidal waveform is pure.
- Works with PWM at low and high frequency.
- Power loss are decreased.
- Powerful performance.
- Voltage fluctuation is slow.

Unfortunately, multilayer inverters have numerous disadvantages. Among the most significant disadvantages is that they need a large number of switches, despite their lower wattage. The overall system grows increasingly complicated and costly as each switch is linked to its gate driving circuit. As a result, the purpose of this research is to provide an overview of various topologies while keeping the number of switching controls in mind.

LITERATURE REVIEW

In an study,[3] researchers created a novel cascaded asymmetric MLI for solar electricity production with fewer switching circuitry. There are three main sources plus 11 switching devices in the circuit. For Photovoltaic use, a framework of the system structure is offered. There has been a proposal for a new single-phase cascaded MLI. The suggested architecture works with both low and high switching frequencies. The suggested topology's main benefits are that it achieves a bigger number of components as well as a superior harmonics characteristic while reducing the device count. The comprehensive review demonstrates this. During controlled circumstances, the cascaded structure is confirmed, and the waveforms quality and harmonically profile for currents and voltages meet harmonic criteria. It is determined that the effectiveness of modeling is 97.8%, although it fluctuates in the experimental environment from 94 to 96%. Twenty-two switches and six DC sources are among the power components utilized to generate 85 levels. Even with greater ratings, the voltage stress on the switches is greatly decreased. The 85 levels of the cascade structure create a high-quality waveform with a THD of less than 5%. The cascaded structure's voltage THD is 0.34%, while the current THD is 0.13%, both of which are within IEEE519 harmonic standards. The arm circuit operates at a frequency of 50 Hz, which reduces switching loss. The MLI's effectiveness fluctuates between 94 and 96%, depending on the testing setup and load circumstances.

In a study,[4] author proposed an advanced MLI circuit with the primary goal of reducing the number of electrical components. The suggested circuit's functioning and sequence of operations are explained and demonstrated. To create the power circuits' controllingpulses, innovative various carrier controlling technique is applied in the elements. The created circuit was studied using MATLAB circuitry in a Simulation environment, and several single-phase Multi inverter analyses were displayed. When opposed to the conventional bridging type or other Multilevel Inverter circuits, the necessary supplies both for the inverter circuits presented and another inverter circuit mentioned to are determined to be minimal. For producing 49 levels, the improved Half - bridge: ACMLI circuit needs the fewest switching devices compared to certain other Multilevel inverter circuits, as well as the THD is likewise the lowest (1.83%) compared to certain other converters, and THD is 1.89% for ACMLI 49 level bridge type multilevel. For ACMLI, 20 switches and 16 switches for the ACCMLI-H bridge were used.

For diverse classifications of Photovoltaic systems,[5] a small three-phase modular multilevel inverter (MMLI) based on asymmetrical input multi-terminal MLI.Decreased element numbers are used in the suggested three-phase MLI. It generates 7-level voltage output by combining the three H-bridge cells for every phase. As a result, the suggested MLI uses fewer switches to save money and simplify control. The suggested inverter is evaluated for the reconfigurable procedure and backed up by a critical comparison analysis that demonstrates the inverter's benefits. MATLAB/Simulink is used to examine and assess the suggested MMLI. The suggested MLI may be utilized for multi-stage applications and modular operations and works extremely efficiently. The suggested MLI's better performance is confirmed by MATLAB simulations and experiments deployment. Furthermore, it demonstrates that the suggested MLI produces voltage with a minimal THD of 3.56% at a switching frequency of 10.0 kHz, decreasing calculation time. This result complies with IEEE 519 requirements. There are 18 IGBT switches in this 7-level MMLI.

Few researchers[6] improved 13-level framework and analysis of PUC-MLI are suggested in this work.This article discusses a packed-U cell MI.To eliminate harmonic, the suggested inverter employs 8 switches device and 3 voltage sources, effectively controlledby SPWM methods. The resultant currents and voltages were examined, revealing that the MI is dependable and performs well. To reduce undesirable harmonic, an LPF filter is built in the MI output. The suggested inverter has a low harmonic distortion, which results in great power quality and a compact frequency response. Due to their many benefits over conventional MI, this is getting prominence attention for usage in a spectrum of uses. In this study, a 13-level smooth waveform is presented as the output of a modified PUC-MI. In comparison to traditional MI. The proposed inverter employs just 8 switching devices and 3 DC sources. To examine the results of the designed MI simulations are run by using MATLAB/Simulink program. The improved output waveform and decreased THD are highlighted, demonstrating the suggested PUC-MI efficiency.The proposed 13-level having 8 switching IGBTs are in operation. The output voltage's THD is 10% without utilizing any harmonics filters. It's 0.05% after filtration.

For the applicability of distributing generated systems, in a study,[7] proposed a novel single-phase DC-AC MI based on cascaded transformers MLI (CTMLI). Compared to theproposed topology, the suggested MI supplies the demand with 19-level O/P voltage while using fewer components.Low harmonic contents (THD), poor rating switching devices needed, small filtering size, and high standard output power are all possible with the suggested CTMLI inverter. MATLAB/Simulink and empirical testing have been used to verify the correctness of the suggested inverter. 19-level voltage output synthesizing is used to validate the suggested CTMLI procedure. The suggested inverter reduces THD to 5.607% up to 500 kHz without the use of a filter and to 3.08% with the use of a filter. The suggested work uses a 7-level, 19, 37 level output with 8,12, and 16 switches.

Utilizing 9, 13 and 17-level MLI topologies, in, author[8] offered a redesigned MLI architecture. An HRES is constructed that is coupled to a redesigned Cascaded Half-Bridge Multi Level Inverter (CHB-MLI), with switching driven by an ANN model. The suggested hybrid renewable energy method includes ten Metals(MOSFETs) with 17 levels. With minimal components and lower THD, the suggested architecture works well. The suggested system'sCHB-MLI performance is evaluated by creating a methodology in the MATLAB/SIMULINK environment to demonstrate the efficacy of the suggested model, the simulated performance of the suggested CHB-MLI for the renewable energy application is evaluated and the results of current models were discussed. For 17-level MLI has ten MOSFET switching devices. The THD rate is reduced to3.58%.

In author[9] proposed design has a lower number of Dc voltage sources, switches, component count level factor, lower TSV, greater effectiveness, lower THD, and is less expensive than the proposed topology. The suggested MLI is a hybrid of a single-phase T-Type MI and a sub-switch-based H-Bridge module. The modeling and implementation of a multilayer inverter using the staircases PWM approach are covered in this paper. The 9 and 17-level MLIs are also investigated with various cascaded loads. The suggested inverter is robust under non-linear loading conditions and is well suited for grid-connected FACTS and sustainable energy uses. With accurate data and tables, an operating guideline has been provided. Numerical simulation is used to create the output voltage wave. Finally, utilizing the dSPACE controller laboratory, the practical demonstrations were carried out by creating a hardware prototype configuration for both linear and non-linear loads. THD is 8.49% for 9 levels with 7 switches and 4.12% for 17 levels with 12 switches, respectively. The 9th and 7th levels are 95 and 92% efficient, respectively. The laboratory-built testing setup confirms that it is one-of-a-kind, with higher output voltage levels, low harmonic current content, fewer switching device, and increased performance. When contrasted withmany comparable architectures, the suggested MI looks to have some promising qualities.

Table 1: Major contributions of researchers in the field of mli for renewable resource-based grid systems

Ref	*Publishing Year*	*Name*	*No of Switches*	*No. of Level*	*THD*
[3]	2021	Cascaded asymmetrical multilevel inverter	11 switches	85 levels	voltage THD 0.34%,, current THD is 0.13%,
[4]	2020	Modular multilevel inverter	For ACMLI 20 switches, H bridge ACCMLI 16 switches	49 level	1.89% for ACMLI, H bridge ACMLI (1.83 %)
[5]	2020	Three phase modular multilevel inverter-based multi-terminal	18 IGBT	7-level output voltage	3.56%
[6]	2020	Packed U-Cell Multilevel Inverter	8 switches IGBT	13-level	10% without filtering and 0.05% with filtering
[7]	2020	New Cascaded-Transformers Multilevel Inverter	8 for 7 level ,12 for 19 level and 16 for 37 level	7 level, 19, 37level	5.607 without filter and 3.08 % with filter
[8]	2020	Modified Cascaded H-bridge Multilevel Inverter	10 MOSFET switches	17 level	THD is 3.58%.
[9]	2021	Seventeen Level Inverter With Reduced Components	7 for 9 level 12 for 17 level	9 and 17 level	8.49% for 9 level 4.12% for 17 level.
[10]	2020	Hybrid -MLI	12	9,17	8.49%- 9 Level 4.12%- 17 level

In author[10] designed and tested a grid-connected solar energy conversion system based on a binary hybrid MLI. Ten semiconductor switches and three binary weighted isolated DCsources make up the 15-level BHMLI. The benefits of a reduced number of switches, a smaller element count, and a lower device rating are all proven in this study. The applicability of damped SOGI control in BHMLI for reducing overshoots and oscillations during load side variations has been shown. As a result, under poor operating circumstances, low-rated components are made safer. Balanced power transmission to the grid is achieved by using single input multiple output SEPICs in each phase that are coupled to a common PV field. It also supplied segregated DC sources for BHMLI operation and stabilized DC-link voltages during PV output fluctuations. It also uses an incremental conductance technique to achieve quick maximum power point monitoring during dynamic insolation fluctuations. The detailed study performed in the experimental setting demonstrates that SECS integration to the grid is acceptable even under unfavorable operating circumstances. It reduces the load's THD and active power, as well as validates the shunt gain filter's performance during the process. At dynamic load and PV changes, balanced, sinusoidal, and in-phase grid currents are obtained. As a result, SECS operation maintains grid power quality within IEEE-519 guidelines. 1.35% is the computed THD.

Some of the contributions of the author are presented in Table 1.

MULTILEVEL INVERTER AND ITS CLASSIFICATION

We create and over multiple voltage levels (MVL) in an MLI, resulting in a nearly pure sine resultant waveform. Due to the numerous MLV in the outcome, the wave gets increasingly smooth; however, as the levels increase, the network becomes more complicated owing to the introduction of the gates. In addition, the sophisticated control circuitry is necessary. The difference between a standard and a multilayer inverter is seen in Table 2.

Table 2: Difference between conventional and multilevel inverters

Point of difference	*Conventional*	*MLI's*
Rate of change of voltage	High	Less
Switching Losses	High	Low
Application	Low Voltage Applications	High Voltage Application
Voltage Stress	High	Less
Switching Frequencies	High	Less
Voltage Levels	Multiple Levels Can not be produced	Multiple Levels Can be produced
Harmonics	High	Less
Device Count	Less	High

The classification of the LI's is given in Figure 1. The multilevel converter is divided into two parts. MLI with a single source and multiple sources.The Neutral Point ClampedMLI has diodes for the clamping voltage, but the flying capacitor has a capacitor instead of the dides as the name suggests, as shown in Figure 2(a),having 12 switches and Figure 2(b).[11,12] The active NPC was given in[13] is an improvement of the NPC and Flying capacitor, which provides additional voltage level by adding a pase capacitor in a circuit having 10 switches. Another single source MLI is T-type MLI which has less number of switching devices and more active voltage levels as proposed by.[14] Hybrid MLI is the integration of one or more topologies together, having 8 switches.[15] The Multiple sources MLI proposed by[3] is a Cascaded asymmetrical multilevel inverter. Modular MLI,[16] H-Bridge MLI,[5] Cascaded H-Bridge MLI[8] are multiple sourcesof MLI having high levels compared to single levels and low switching count.

Reduced Switch MLI Topologies and Their Performance

Even though the above typical topologies have a wide spectrum of uses, they all need a large number of electrical elements. As a result, the goal of MLI development in the past few of years has been to minimize the number of devices. Lowering the overall switching devices, diodes, capacitors, and voltages may increase dependability while lowering overall costs, losses, and other factors. Several novel RS MLI designs have lately been suggested in this area, and ongoing efforts are underway to reduce the number of required components further. This study gives a concise overview of newly created topologies best suited for varied uses, including industrial drivers, STAT-COM, and RS systems. These designs are suitable for both grid-connected and stand-alone operations.

Total harmonic distortion

Integer multiples of the fundamental frequency are referred to as "harmonics." Because it includes harmonics, the inverter output voltage is not pure sinusoidal. As a result, the output voltage waveform's quality deteriorates. THD is used to determine how well a PWM voltage matches its sinusoidal reference or how a waveform appears when seen from its fundamental.[17] The RMS value of the fundamental is divided by the root of the sum of squares of all harmonics above the fundamental. The following is the formula for computing THD:

$$THD=\frac{\sqrt{\sum_{n=2}^{\infty} Vn^2}}{V1} \text{------------------(i)}$$

Where,

The fundamental component's RMS value is V1, and the nth harmonic component's RMS value is Vn. According to the IEEE 519 standard,

The maximum acceptable THD for low voltage applications is 5%, whereas the maximum permissible for individual voltage harmonics is 3%.

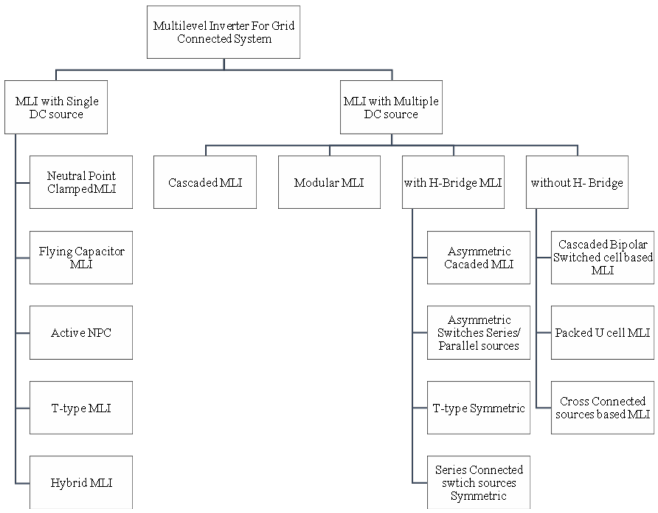
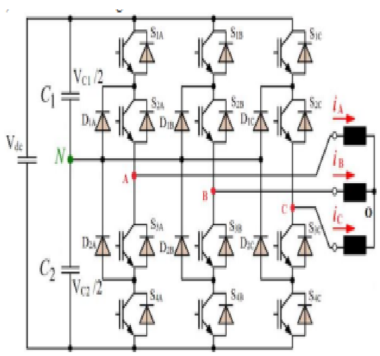
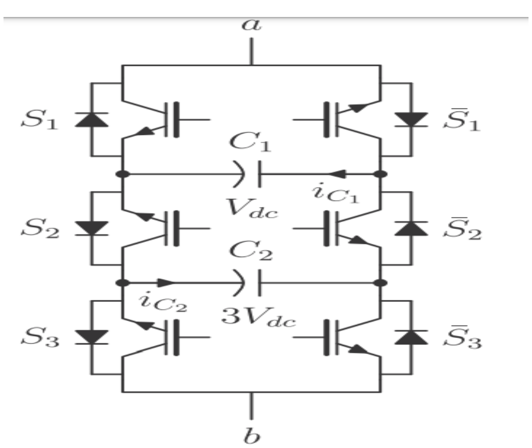


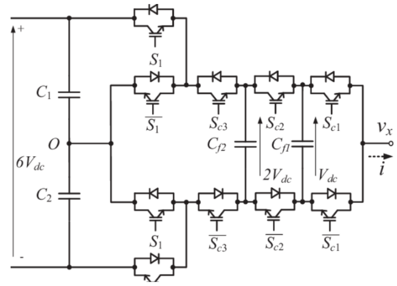
Figure 1: Classification of Multilevel Inverter Based Grid Connected Systems



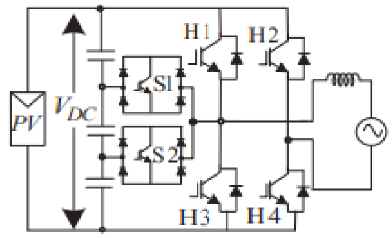
(a) Neutral Clamped MLI[18]



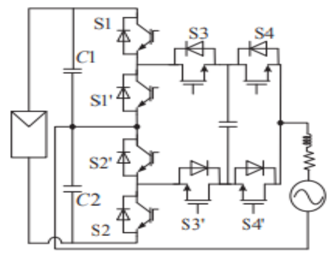
(b) Flying Capacitor MLI[19]



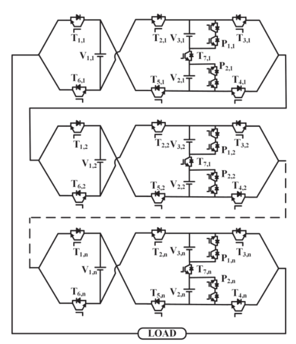
(c) Active NPC MLI[20]



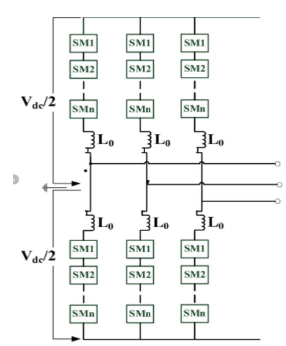
(d) T-Type MLI[21]



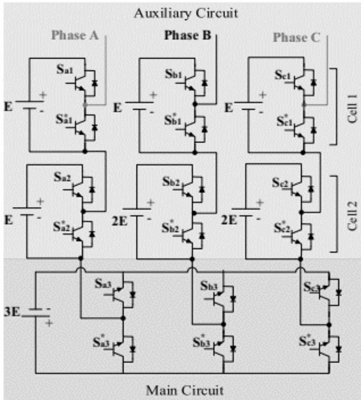
(e) Hybrid MLI[22]



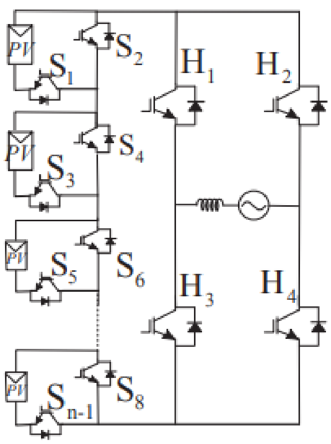
(f) Cascaded MLI[3]



(g) Modular MLI[23]



(h) H-Bridge MLI[5]



(i)Modular MLI[23]

Figure 2(a-i): Types of the MLIs

CONCLUSION

MLI has become very common in educational research and commercial applications for higher and lower electrical applications due to their many inherent benefits. A review of many innovative multilayer designs with lower device counts is offered in this work. A few of these topologies are designed for a particular purpose, whereas others are designed to lessen the amount of components and/or inputs while increasing output levels are associated to other MLIs with fewer switches. Based on literature evaluation, this can be suggested that in order to reduce device and/or source count, numerous negotiations are managed to make with the key benefits of MLI framework, including loss of modifiability structure, multiple increases in operating voltage of a switching devices, sophisticated control techniques, issue of capacitance and harmonic distortions. In this study, a qualitative and quantitative overview of many novel MLI topologies is given, as well as a comparison. New topologies are developed to decrease the quantity of elements, which has a significant influence on circuit size, expense, and performance. The benefits of using an integrated MLI with Machine Learning in such configurations have increased their use in middle - high power levels. As a consequence, in grid-connected applications such as renewable energy sources, MLI topologies are chosen.

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