Detailed Review on Multilevel Inverters Driving Renewable Energy Systems with PWM Modulation Technique

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Abstract: *As the number of solar PV installation sites grows every year and solar PV systems become a more viable and affordable source of sustainable energy, efforts are being made to discover technological and economic solutions to the issues arising from various PV usage strategies. In order to ensure effective usage and commercial potential in terms of cost, security, and durability of PV and hybrid PV-wind-storage systems, state-of-the-art research is ongoing in all areas, from material sciences to industrial production and interface. In this article, Multilevel Inverters, their classification, and the modulation techniques being used in MLIs, such as PWM, are briefly discussed.*
Keywords: Solar photovoltaic systems, MLI, Pulse Width Modulation,

I. Introduction

Due to price reductions of up to 50% for PV arrays and interface systems over the past five years, the use of solar photovoltaic (PV) systems has accelerated significantly. The use of PV systems as an emerging type of renewable/alternative energy source is growing thanks to improvements in electric utility grid interface systems, the use of PV arrays in standalone local power production, and building automation with storage batteries and back-up hybrid systems. To support and promote producers, consumers, and new investments in solar PV energy use in various sectors, governments in many countries have established special incentives, tax credits, feed-in tariffs, and energy purchase back legislation programs.

As the number of solar PV installation sites grows every year and solar PV systems become a more feasible and affordable source of green energy, efforts are being made to find technical and economic solutions to the issues arising from different PV utilization strategies. In order to implement efficient utilization and commercial viability in terms of price, protection, and durability of PV and hybrid PV-wind-storage systems, state-of-the-art research is ongoing in all areas, from material sciences to manufacturing and interface. To ensure dynamic matching of energy to load prerequisites with minimal impact on the host utility grid, particular locations concentrate on PV array topologies, vibrant sun tracking, maximum power point control, storage devices, and efficient decoupled interface with smart grid and smart buildings. In additament, research on energy management in distributed generation and smart grids has grown into another area of market based management as well as energy-efficient hybrid utility renewable energy.

Whenever the implemented solar power capacity increased from 1.2 GW in 1992 to 227 GW in 2016, photovoltaic (PV) electricity implementations have seen significant growth in recent decades. Solar energy systems produce about 1% of the overall energy utilised globally. The latter makes up more than 99 percent of all Photovoltaic systems among standalone and connected to the grid systems. This is because grid-connected networks, as opposed to standalone systems, are more stable and have lower significant growth expenses, expandability, and downtime. Leading to a smaller amount of output voltage levels and consequently higher harmonics in the infused grid current, traditional two-level inverters have been found to be inappropriate for the medium and high-voltage power grid [1]. Multilevel Inverters (MLIs), which were created in 1975, are ideally suited for connecting to the medium and high voltage utility grid.

From a technical perspective, power electronic converters are accountable for efficiently completing these tasks. For example, a DC–to–AC converter (inverter) creates a square wave with only odd harmonics. In order to get rid of these harmonics and enhance waveform quality, low pass filters are therefore necessary. Furthermore, in a traditional two-level inverter for high power implementations, a single switch cannot withstand a higher voltage. MLIs have been proposed as a suitable solution for high power and medium voltage applications under these conditions. Fig. 1 depicts the essential output voltage waveform for both the conventional two-level inverter and the MLI arrangement.

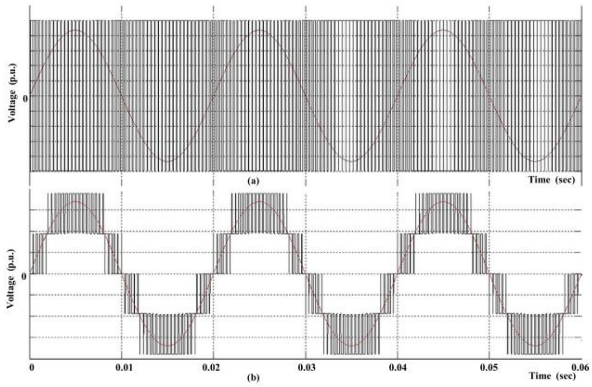

Figure 1 Typical inverter waveforms: (a) Traditional Two-level Inverter waveform, (b) Multilevel Inverter waveform [2]

Here, each fundamental MLI can present distinct features and even some difficulties. In reality, the output waveform quality of any MLI will improve as the number of levels rises. Possible switching techniques will also enhance their potentiality in terms of charge balancing, balancing, reducing energy waste, improving efficiency, having a good power factor, using much less filter, and more. In enhancing organisational performance of MLI, various modulation techniques are tried to introduce. MRI devices, industrial drives, traction, renewable energy use, automotive, energy transmission, uninterruptible power supplies, and other implementations are just a few of the industries that currently use MLIs extensively.

Presently, most AC voltages are produced from DC voltages using conventional two-level inverters, as shown in Figure 2. Although it might not always be an issue, low output voltage distortion may be required for some applications. Rather than, numerous voltage levels are combined to produce a smoother stepped waveform with less harmonic distortion and dv dt, as shown in Figure 1 (b). The waveform an inverter generates becomes smoother as it has more voltage levels, but as levels increase, the design is becoming more complex, requiring more elements, and an inverter controller requires more complexity [3].

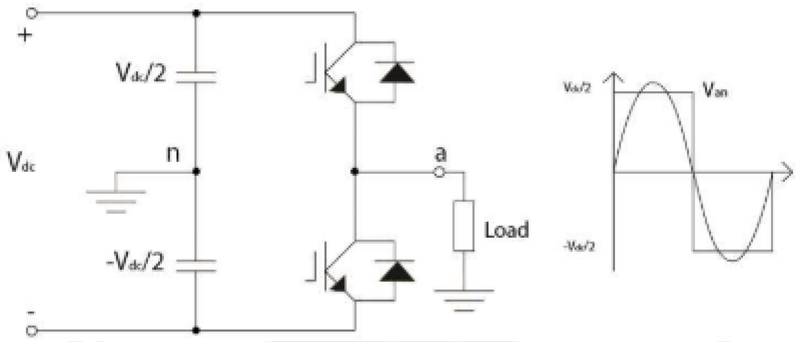

Figure 2 Conventional 2-level Inverter without PWM

II. CLASSIFICATION OF MULTILEVEL INVERTERS

PV cells, that also transform solar energy to electrical energy, can be used to start generating power from solar energy in this renewable energy source. DC voltage is produced by PV cells. This DC is transformed to AC and used for AC implementations by using an inverter. Traditional inverters were at first used for this conversion reason, but they had a number of drawbacks, including high switching stress, EMI issues, high THD in output voltage, and a lack of suitability for demanding applications a lot of power. MLI were created as a result of inverter research. This MLI will generate AC output at various levels, which reduces THD. The THD decreases with an increase in output levels. The H-bridge type of inverter is the most popular MLI. Due to switching losses, MLI can be used with lower switching frequencies.

A variety of power semiconductors as well as capacitive voltage sources combine to form a nearly sinusoidal waveform in multi - level inverter. The three most common multilevel inverter architectures described in the literature are the cascade H-bridge, flying capacitor, and neutral point clamped multilevel inverters [4]. Due to their modular design, the Flying Capacitor and Cascade H-bridge are also referred to as multi-cell converters. The categorization of multilevel inverters is shown in Fig. 2.

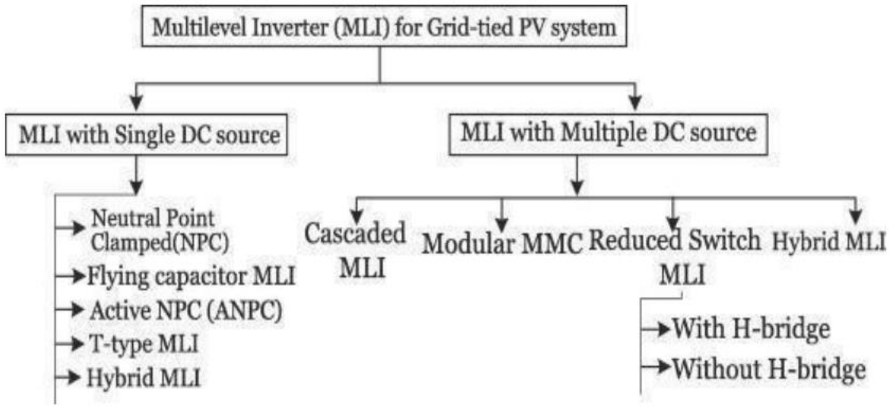

Figure 3 Classification of MLI [4]

Various kinds and different versions of multilevel converter topologies have been investigated in recent years in the literature. They have been divided into two groups in Fig. 3 according to the number of independent DC sources used. The flying capacitor (FC) or capacitor clamped, the neutral point clamped (NPC) or diode clamped, and the cascaded H-bridge are the three fundamental topologies (CHB). For every phase leg has twice that many valves in a 3-level inverter design. As shown in Figure 4, there have been clamping diodes linked to a neutral midpoint somewhere between two capacitors between it upper and lower two valves.

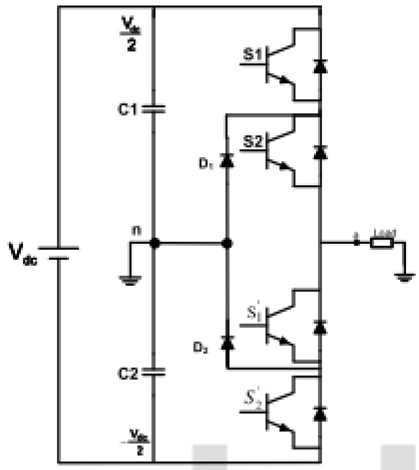

Figure 4 One phase leg of a 3-level inverter

In contrast, current source converters (CSCs) have proven to be a superior choice in a number of applications. Despite having a slow dynamic response, CSC has discovered that implementations like high power drives for fans don't require a fast dynamic response. It offers benefits of inherent four quadrant operation for high power drives. The regeneration mode of operation, whereby the polarity of the voltage at the converter is reversed to return power to the source, is particularly crucial. There is no additional circuit needed for CSC to operate in this mode [5]. Additionally, the inductors in the CSC have a longer lifespan than the capacitors in the VSC.

In order to achieve current multilevel with the aid of power semiconductor devices, current-fed MLC topologies combine a number of inductors to divide input current into equal parts. Thyristor-based paralleled CSI introduced current-fed MLC use in the late 1970s. For SMES applications, a higher level current-fed MLC with pulse width modulation (PWM) support has been found. The term "single-rated inductor current- fed MLC" has since been used to describe this topology. Following this, a generalized current-fed MLC topology known as embedded current-fed MLC has been suggested. On the basis of the duality concept, current-fed MLCs have recently been developed from traditional voltage-fed MLCs like the CHB, FC, and NPC topologies [5]. Fig. 5 classifies the different current-fed MLC topologies, and the following section will provide more information on each topology.

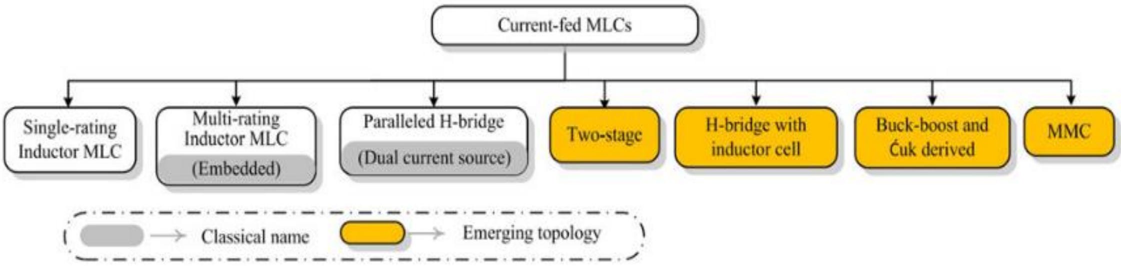

Figure 5 Classification of current-fed MLC topologies. [5]

Either a single source or a number of sources are used to power the current-fed MLC topologies. By following the theory of duality, the configurations of single-rating inductor, multi-rating inductor, and paralleled H-bridge current-fed MLCs are created from traditional voltage-fed MLCs. Uses like active filters, grid-connected PV panel power converters, fuel-cell power grid integration, wind energy conversion, SMES, AC motor drives, and HVDC implementations can use these structures.

III. MODULATION TECHNIQUES (PWM)

The effectiveness of the suggested topology as a whole is greatly influenced by modulation schemes. Fundamental switching frequency and high switching frequency are two categories for the modulation techniques that are frequently used for these configurations. Selective harmonic elimination, switching angle computation, space vector control, as well as closest level control are the four subtypes of the fundamental switching frequency, which can have one or two commutations per cycle. Whereas space vector modulation and PWM are two subsets of the high switching frequency, which has many commutations per cycle. It is used to compute switching losses and total harmonic distortion, two crucial specifications for multilevel inverters (THD).

In order to drive multilevel converters, a variety of modulation strategies have been developed, including those for Neutral Point Clamped (NPC), Flying Capacitor (FC), Cascaded H-Bridge (CHB), and, more recently, modular multilevel converters. To balance the energy storage of their dc-bus capacitors without the need for extra devices, the first three VSC structures need the appropriate PWM-controlled strategies.
PWM techniques reduce THD, switching losses, and the need for filtering. We've presented a closed-loop current control strategy and a PWM control scheme. Figure 6 displays PWM technologies and control strategies.

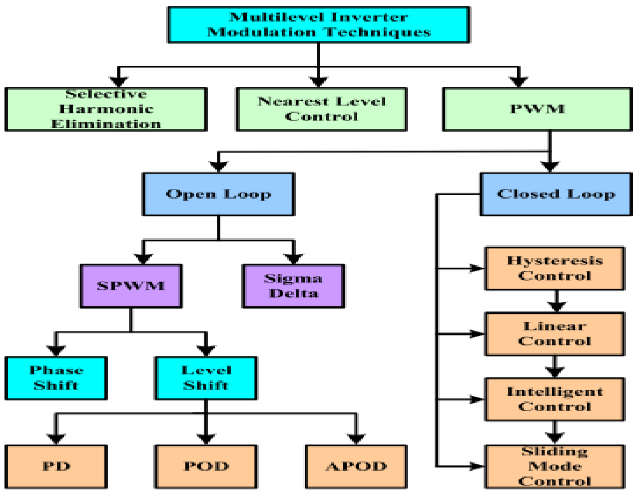

Figure 6 PWM techniques and control methods [6]

All carrier waveforms using the phase disposition method have the same frequency and amplitude and are in phase. The carrier sets' zero reference is positioned in the center. Considerable harmonic energy is concentrated at the carrier frequency for this methodology. In this APOD technique, each carrier waveform has an alternate 180° phase offset. According to this method, the five level inverter output waveform's four carrier waveforms must alternately be 180° out of phase with one another.

IV. LITERATURE REVIEW

For dc voltage transmission systems, the inherent features of modular multilevel converters (MMC) are attracting increasing interest. The voltage modulation of the converter is one of the main research areas for understanding converter performance. It is important to research how voltage modulation techniques affect MMC performance, especially for medium voltage applications with a limited number of submodules. An in-depth analysis of the carrier-based pulse with modulation (CB-PWM) methods that were suggested to be used with earlier multilevel inverter iterations. To ensure equal energy distribution on the arm cells, the CB-PWM methods were modified to be compatible with a different cell ranking and selection algorithm. A review of the most recent zero sequence signals (ZSS) technology used with three-phase inverters can be found in [7].

Multilevel inverters (MLI) are becoming a viable technology for a number of applications, which has recently drawn more attention to them in research and industry. High power and high/medium voltage applications were the first to use the MLI concept because they can effectively interface with renewable energy sources. Since the past ten years, the development of reduced switch MLI topology has been a quickly developing research area that has not yet been reviewed. As a result, [8] focuses on the various reduced switch MLI topologies in the context of three different configuration types: symmetric, asymmetric, and hybrid. To comprehend the crucial parameters of the MLI topologies, the relevant information on these topologies is carefully tabulated composed of three classifications in the comparison tables. These configurations produce higher voltage levels to enhance power quality as well as to lessen the need for passive filters. This review also offers a thorough analysis of various modulation methods and MLI topology control schemes. Additionally, with suitable mathematical expression, the various MLI performance characteristics and its computation techniques are discussed. The classification of the proper MLI topology for FACTS, motor drives, and renewable energy applications will be aided by this review.

Due to their capacity to offer lower electromagnetic interference, higher efficiency, and greater DC link voltages, multilevel inverters (MLI) are currently more appealing to researchers than two-level inverters. In this paper, multilevel inverters are reviewed in terms of their classifications, developments, and difficulties, along with useful suggestions for implementing them in renewable energy systems. Additionally, this paper has given careful consideration to PV systems using various maximum power point tracking (MPPT) techniques. In this review, the significance and creation of a modified multilevel inverter are also highlighted. This article concentrates on the use of multilevel inverters for PV systems in general to encourage and direct society to concentrate on developing an effective and affordable multilevel inverter that possesses the combined capabilities of these converters reported in the literature [9].

The control of multilevel inverters using traditional and cutting-edge carrier-based PWM techniques was examined in [10]. Phase disposition (PD) PWM, Opposite Phase disposition (POD) PWM, Alternative Phase disposition (APOD) PWM, Phase Shifted PWM, and Asymmetrical PWM are a few of the methods discussed. The study compares these techniques and displays the simulation results.

The multilevel inverters and applications for their use are the main topics of the papers in this special section. There will be at least two parts to this section. A new module for a cascaded multilevel inverter is explored in the first section. This module can generate 13 levels with fewer components and goes by the name of Envelope Type (E-Type) module. With fewer switching components, DC voltage sources, and blocked voltage by switches, a new general multilevel inverter topology based on cascaded connection of sub-multilevel units is proposed in[11]. The suggested topology is designed to generate any level with the fewest possible components and switch peak voltage..

[12] provides an overview of modulation techniques for hybrid multilevel inverters. Modulation techniques take into account the modulation index in relation to the defined amplitude and frequency. Different multilevel inverters can be used with these modulation techniques. While some techniques can be applied directly to multilevel inverters, others need to be modified for different multilevel inverters. As a result, a particular modulation technique can synthesize multiple multilevel configurations, greatly enhancing flexibility and lowering total harmonic distortion (THD). The modulation techniques presented here are intended to observe the impact of various techniques on various multilevel inverter topologies.

Multilevel Inverters (MLI) have gained significant importance recently as a result of the introduction of high power and medium power appliances. The MLI is frequently used to drive AC loads that must be operated at low harmonic levels. The different MLI topologies and the modulation methods used on MLIs are reviewed in this paper. The various MLI topologies are divided into symmetrical type and asymmetrical type while being reviewed. Both currently developed and upcoming MLI topologies can be categorized into one of these two categories. These topologies are thoroughly reviewed in order to look at the various performance metrics. Additionally, the modulation methods are divided into fundamental switching frequency (FSF) and high switching frequency (HSF) modulation methods. The concepts that MLI communicates are easily understood thanks to this classification. Additionally, this article provides a thorough understanding of the various characteristics of each modulation technique [13].

A more popular multilevel inverter topology today, particularly for transformerless grid-connected photovoltaic systems, is the three-level neutral point clamped (3L-NPC) inverter. The creation and enhancement of such a topology were significant research topics in recent years due to the imbalance between the two DC load-side capacitor voltages. In order to improve efficiency, reduce switching device and conduction losses, and better distribute losses, new structures were developed. For this reason, seven derived topologies are discussed and contrasted with the traditional inverter in this paper. This study also includes a section on adapting modulation methods to address the neutral point fluctuation issue. In [14], a number of carrier-based PWM and space vector modulation techniques are taken into consideration, discussed, and contrasted.

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V. CONCLUSION

Due to their ability to operate at extremely high frequency variations while emitting lower-order harmonic content, multilevel inverters have recently attracted more attention for high-power applications. A multilayer inverter not only offers high power ratings, but also enables the use of renewable energy. The three main topologies of conventional MLIs are diode clamped MLIs (DCMLIs), flying capacitors MLIs (FCMLIs), and cascaded H-bridge MLIs (CHBMLIs). We talked about MLI and its categorization in this essay. Additionally, voltage-fed and current-fed systems have been covered. Multilevel converters (MLC) with PWM control and modulation techniques.

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