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Multilevel Inverters for PV Renewable Energy Systems

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Abstract:

The rise in high-power businesses and the growing number of users have resulted in a notable increase in the power grid's energy demand over the past ten years. Because of this, the production of conventional energy has resulted in a notable increase in world emissions. As a result, there has been a noticeable growth in the integration of renewable energy resources into the electrical grid. Due to its immense potential, photovoltaic systems have become the most popular resource; as a result, installed PV capacity has expanded globally to meet the need for power. Photovoltaic generation relies heavily on power electronics, and there is a growing need for efficient power electronic converters. Because multilayer inverters (MLI) can offer higher efficiency, larger DC connection voltages, and lower electromagnetic interference than two-level inverters, they are currently attracting more attention from researchers. Based on their classifications, development, and challenges, multilevel inverters are reviewed in this research along with useful advice for their use in renewable energy systems. Moreover, this paper has taken a close look at PV systems using several maximum power point tracking (MPPT) techniques.This review also emphasizes the significance of creating a modified multilevel inverter. This work aims to encourage and direct society toward the development of an affordable, efficient multilayer inverter that combines the capabilities of various converters documented in the literature. Specifically, it focuses on the usage of multilevel inverters for PV systems.

Keywords: MultilevelInverter (MLI); Photovoltaic (PV) system; Cascaded H-Bridge Inverter (CHBI): Diode Clamped Multilevel Inverter (DCMLI) :Flying Capacitor Multilevel Inverter (FCMLI).

1. Introduction

The enormous rate at which the world's energy needs are growing has resulted in a strong demand for fossil fuels, which has had a detrimental impact on the environment by increasing greenhouse gas emissions into the atmosphere.As a result, due to its ability to produce nearly pollution-free electricity with high efficiency, renewable energy resources have attracted interest and development [1]. Numerous renewable resources exist, including geothermal, wind, and solar energy [2, 3]. A huge portion of the world's energy comes from solar radiation. Following reflection and absorption, more than 100,000 TW of the sun's total solar radiation reach the Earth's surface [4]. Solar energy could contribute significantly to renewable energy sources because of this quantity of free energy [5]. Even with its availability, solar energy still contributes very little to the global energy network [6, 7]. Over the past three decades, there have been significant advancements in the deployment of PV systems; however, solar technologies continue to face certain obstacles, making them less competitive with other energy sources, like fossil fuels, in the energy market. The high initial cost, erratic nature, and low conversion efficiency of solar technology are a few of these difficulties [8]. In order to facilitate the introduction of solar technologies into the energy market, it is imperative from a technological and scientific standpoint to create new technologies that can deliver higher conversion efficiencies at a lower production cost.The goal of these studies has been to identify solutions that will improve the competitiveness, performance, and dependability of solar-based energy technologies [9–11]. In solar-powered technology, photovoltaic cells are employed to transform solar radiation into electrical energy. PV cells, power converters, and a control unit for controlling the amount of power extracted from the PV cells are the parts of a solar energy conversion system (see Figure 1) [2]. Different control strategies, power converter topologies, and power tracking approaches have been developed for the effective harvesting of electricity from renewable energy sources [12,13]. The majority of large-scale, high-power, grid-connected renewable energy installations use multilevel inverters. Due to their low switching losses, high voltage operating capabilities, low electromagnetic interference (EMI) output, high efficiency, and good power quality performance (low THD output) because of their multiple level output waveform, multilevel inverters are gaining greater attention from academics [16].

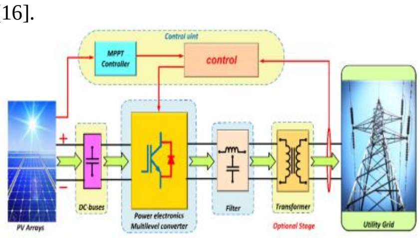


Figure .1.PV Powered Renewable Energy System

Three-level converters were the first multilevel converters to be attempted, and later on, various multilevel converter topologies were tried. This was done in 1975. To achieve higher power generation levels, the MLI is predicated on the idea of synthesizing a stepped voltage waveform using several DC sources and numerous low-power rated semiconductor switches. Multiple-input DC sources can be derived from a variety of energy sources, including fuel cells, batteries, solar PV panels, and capacitors. The power switches are then controlled by algorithms when these various DC sources are combined to provide a high output voltage. MLI topologies have a wide range of industrial uses, including enhanced power converter topologies in grid-connected renewable energy systems (RES). These days, MLI trends mostly center on reducing the number of switches, gate driver circuits, and DC supplies in order to increase fault tolerance and power quality and, consequently, lowerthesystem'cost. MPPT controllers have advanced in a number of ways, including tracking speed, precision, simplicity, efficiency, and dependability. The best MPPT algorithm typically runs quickly and oscillates less around the PPP, keeping up with the output power's quick variations. ..There are now many uses for MPPT control systems [24], however tracking a PV system with MMPP or tracking the MPP under uniform irradiance are the two main uses for these controllers. The MPP for every PV system must be distinct and not depend on a convoluted tracking technique. It should be noted that in certain instances, anomalous occurrences may occur, such as partial shadowing (PS), which is one of the most frequent elements that has a steric effect on the power collected from photovoltaic systems. It is related to global maximum power point (GMPP) and multipeak points that produce MMPP [26]. An old-fashioned MPPT algorithm under PS typically has poor efficiency. The literature offers multiple classifications for MPPT controller indexing. These divisions are predicated on various factors, including modernism, tracking methods, and sensing use. MPPT is often divided into three categories: advanced (soft computing), hybrid, and traditional. The traditional approaches are often straightforward, but they are unable to distinguish between local and global peaks during PS, which is one of the reasons for their poor efficiency. They need to be tracked using sophisticated tracking techniques because of their increased efficiency.Studies have suggested hybrid approaches as a blend of both traditional and advanced methods to address the constraints associated with using each approach alone. Finding the optimal MPPT technique to employ is still a problem, though. Therefore, research on MPPT approaches is still being done in order to develop a system that performs better in terms of system cost, installation convenience, tracking efficiency, and adapt abilitytovariousPVsystems.
The classification of MLIs used for PV systems is presented in this paper, along with a discussion of the design and operation of three main MLI topologies, each with pros and cons. Because of MLIs' decreased levels of electromagnetic interference and harmonic distortion, as well as their capacity to meet power quality and power rating requirements, they are being used in power systems. An MLI has a number of benefits over conventional two-level inverters that employ high switching frequency PWM. Across a power range of 1 to 30 MW, MLIs are currently being explored as an industrial solution for systems that require dynamic performance and good power quality. Because MLIs can produce lower THD output voltage waveforms and higher voltages with a limited device rating, they are therefore perfect for use in high voltage applications.Sustainable energy sources, including wind, fuel cells, and photovoltaic cells, can interact in a wide range with a multilayer converter system. The PWM of MLIs is primarily determined by the type of control algorithm used, which also affects the devices' application, efficiency, and power ratings. In recent decades, several studies have proposed several MLI topologies.Figure 2 illustrates how the MLIs were divided into two major groups according to how many DC sources were used in each group's design. The flying capacitor (FC), the cascaded H-bridge (CHB), and the neutral point clamped (NPC) or diode clamped topologies are the most often utilized in the industries.

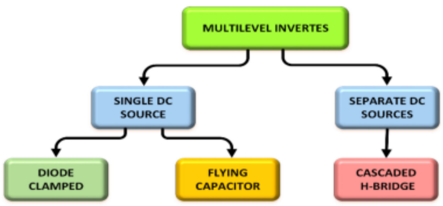


Figure.2. Classification of Multi Level Inverters

2. Multilevel Invertersfor PV Systems

Recently, there has been a lot of interest in the use of multilayer inverters (MLI) in PV systems to increase power quality and efficiency. One of the difficulties in photovoltaic (PV) applications is choosing the right converter, as this affects how the PV system behaves. It is possible for the developed MLC to supply uninterrupted electricity regardless of the weather. The suggested MLC demonstrated a seamless changeover between the charging and discharging modes. The cascaded H-bridge (CHB) converter's modular features, ability to connect to medium voltage grids, and high-quality output waveforms make it suitable for use in grid interconnections. For large-scale PV systems, a CHB-MLC with DC-DC stage isolation has been presented.With minimal distortion, the suggested CHB converter provided high-quality currents. Because of its modular architecture, it was able to run at high voltages and increase power quality. It also lowered conduction and switching losses, which allowed it to function at high switching frequencies and reduced current leakages in transformerless PV systems.

2.1.Cascaded H-Bridges MLI

The CHB-MLIs are created by connecting multiple single-phase H-bridge inverters with independent DC sources in serial (SDCS). As illustrated in Figure 3, every H-bridge is comprised of one DC supply and four unidirectional power switches. By connecting the DC source to the AC output, each inverter level is programmed to create three voltage outputs: +Vdc, 0Vdc, and −Vdc. The required output is obtained by connecting the four switches

(S1–S4) in various ways. When the S1 and S4 switches are turned on, the output is +Vdc; however, when the S2 and S3 switches are turned on, the output is −Vdc. Either S1 and S2 or S3 and S4 must be in the ON state in order to generate the 0 output voltageThe full-bridge inverter's AC outputs are connected serially such that the voltage waveform that is produced is a representation of the total of all the inverters' outputs. The number of output phase voltage levels in a cascade inverter is denoted by m = 2s + 1, where s is the number of distinct DC sources. Because this architecture does not include clamping diodes and clamping capacitors, it requires less components than DCMLI and FCMLI. Furthermore, as it is devoid of DC link capacitors, it is not affected by the voltage balancing issue. However, if voltage balancing is the main concern, the various DC sources can be replaced by either a single renewable energy source with multioutput converters or a separate renewable energy source with separate converters.

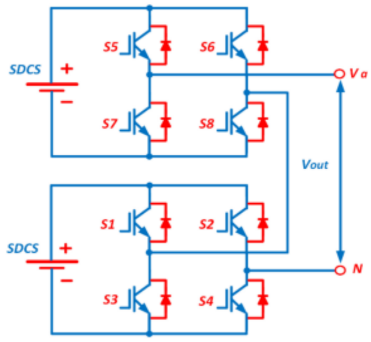
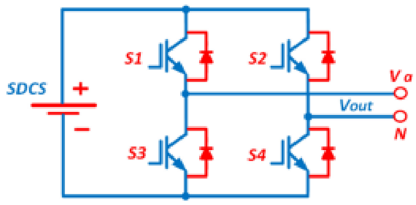


Figure.3. CHBMLI Cascaded H-Bridge Multi Level Inverter



Multilevel cascaded inverters have been suggested for use in battery-powered applications, as well as in applications for static variable generation and as an interface with RES. By connecting a cascade inverter directly in series with the electrical system, it is also possible to use it for static variation compensation. Since they require independent DC sources when utilized in fuel cells and solar systems, they are appropriate for connecting RES to the AC grid [50]. Additionally, as many batteries or ultracapacitors function as SDCSs in such situations, they have been suggested for usage as the primary traction drive in electric cars. This topology's structure is adaptable and can be applied to a variety of inverter levels. By applying varying ratios of DC sources and lowering the switching redundancy associated to inner voltage levels, it is possible to generate diverse output voltages. Transformer-dependent CHBMLIs, which are similar to CHBMLI structures but differ in that the isolation transformer's output voltage is connected serially, are designed to lessen the requirement for separate DC sources.

Advantages

The CHB-MLI has a straightforward, modular design. • Simple to expand to new heights. Only requires switches that are one-way. Fit for applications requiring fault tolerance. The independent DC sources lessen the risk of electric shock. It is possible to use an asymmetric source arrangement. Easily configured as a configuration with a single DC source

Disadvantages

The CHB-MLI provides fewer levels of output voltage. Needs a greater quantity of gate driver circuits. In order to raise the output voltage, multiple DC sources are needed. Restricted to specific uses where independent DC sources are available. The blocking voltage that switches must withstand must match the input voltage. Loss of modularity due to an uneven source arrangement. The cost of implementation (asymmetric source configuration) is significant. Asymmetric switches have varying voltage ratings. source configuration).

2.2 Flying Capacitor MLI

The topologies of the DCMLI and FCMLI are quite similar; the only difference is that the FCMLI uses floating capacitors instead of clamping diodes. The voltage variation in the nearby capacitors directly affects the size of the voltage steps in the output waveform for the FCMLI. The'm' level inverter's FCMLI structure consists of 0m − 1 0 DC link capacitor countThe schematic of the three-level FCMLI topology is shown in Figure 4. It includes a DC supply with two capacitors for obtaining voltage levels (Vdc/2, 0, −Vdc/2) along with four unidirectional power switches and a flying capacitor. While S3 and S4 are switched ON for the negative polarity output voltage, switches S1 and S2 must be in the ON position to generate the positive polarity output voltage. Turning on switches S1 and S3 or S2 and S4 produces the 0 level output voltage. The voltage synthesis in an FCMLI is more versatile than in a DCMLI. When there are more than five levels, choosing the right switching combination can help solve the voltage balance issue.The ability to manage both reactive and active power is a significant benefit of this architecture; nevertheless, the usage of many capacitors increases system cost and complicates assembly. Furthermore, when it comes to practical power transmission, these systems have significant switching frequency losses.

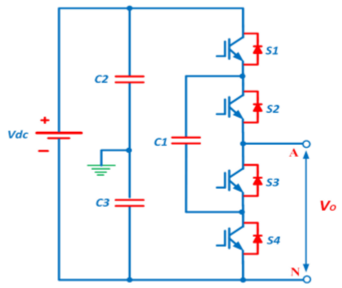


Figure.4. Flying Capacitor Multi Level Inverter

Advantages

FCMLI minimizes the quantity of DC sources needed. Phase redundancies are offered to maintain the capacitors' voltage levels in balance. Fit for applications requiring fault tolerance. The flow of both reactive and real power is controllable Filters are not required to lower harmonics.

Disadvantages

The voltage balancing circuit's complexity. For high levels, more capacitors are needed. High switching frequency and losses when transmitting real power. High cost of installation.

2.3.Diode Clamped MLI

The neutral point clamped inverter (NPC), which is another name for this kind of inverter, was created in 1981 by Nabae et al. The DCMLI structure, which produces an output voltage with three levels, is shown in Figure 5.5. This topology's structure consists of two diodes, two capacitors, and four unidirectional power switches. The blocking voltage is shared by the clamping diodes through a series connection. Three levels make up the output voltage in this topology: Vdc/2, 0, and −Vdc/2. Vdc/2 is produced by leaving the switches on S1 and S2, while −Vdc/2 is produced by turning on S3 and S4. Turning on switches S2 and S3 creates the 0 level voltage. It is anticipated that each active switching device will experience voltage stress during the equivalent voltage passing through the DC link capacitors, which will be clamped to each capacitor's voltage via diode clamping. In an actual application, the clamping diodes are connected serially to share the blocking voltage. Then, each active device just needs to block a voltage level of V /(m − 1) dc. The clamping diodes' voltage ratings need to differ in order to prohibit reverse voltage. The primary design flaw in high voltage situations when using the PWM approach to operate the DCMLI is the clamping diodes' diode reverse recovery.

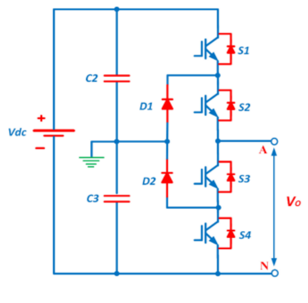


Figure.5. Diode Clamped Multi Level Inverter

considering its high-power delivery capability, simplicity, and efficiency, the DCMLI has a wider industrial use than the other multilevel converter topologies. It has been used in variable speed motor drives, high voltage system interconnections, and static VAR compensators (SVC). Since all of the parts of the DCMLI converter share a DC bus, a capacitor is not necessary. As a result, it can be applied to additional back-to-back topologies, changeable speed drives, and high voltage back-to-back connections. However, this converter has issues with balancing and stabilizing the capacitor DC voltage in the DC link, as well as difficulty with single inverter real power flow due to discharging or overcharging of the DC level without sufficient management.

Advantages

For industrial applications, the DCMLI is a good choice. Shows a high efficiency of switching at fundamental frequencies. Capacitors can be precharged collectively. The control scheme is easy to understand. Decreases the amount of DC sources needed. Fit for applications that must withstand faults. Voltage balancing and unequal loss sharing across switching devices in neutral point clamped (NPC) converters can be resolved with the usage of neutral clamping switches.

Disadvantages

The voltage balancing circuit's complexity. The difference in the losses incurred by the inner and outside switches. As the level rose, more clamping diodes were used.

3. Conclusions

The purpose of this paper's brief overview of multilevel inverters is to draw attention to the necessity of developing new inverters or altered inverter combinations for grid-connected and photovoltaic systems. MLIs have been described in detail in a number of areas, including classifications, benefits, drawbacks, and how well they can improve energy conversion in contemporary energy systems. In light of this assessment, standard MLIs should be used in a modified strategy that uses MLIs for various levels in order to minimize the number of switches. In terms of size, affordability, reduced THD, and high efficiency energy conversion, modified MLIs are a potential option for PV and other renewable energy systems.

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