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Review of Multilevel Inverter Topologies, Control Techniques and Applications

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Abstract : For the vast majority of power electronic applications operating in the medium and high voltage ranges, multilevel inverters (MLI) have become an absolute need. The introduction of new topologies has rendered the conventional ones obsolete, which has resulted in a multiplication of the capacity to build a greater number of levels using a smaller number of components. Also, the newly developed topologies of MLI employ asymmetrical DC sources to produce the same levels with a reduced number of semiconductor switches. This results in a decrease in capital expenditures and an increase in the system's overall dependability. In a practical sense, asymmetrical direct current sources may be derived from a wide variety of renewable energy sources, such as solar, fuel cell, and wind turbine systems, amongst others. In conclusion, the many newly established methods for modulation play an important role in improving the overall performance of MLI and are thus essential to its success. In this study, a survey for classic and current topologies of MLI is presented, along with a discussion of the benefits afforded by the new topologies.

***Index Terms* –Multilevel, Inverters, Semiconductor, Control.**

I. INTRODUCTION

Since multilayer inverter (MLI) topologies provide greater power quality than their typical two-level cousin, they have been more popular in industrial applications over the last several decades. This is one reason for their appeal. The fact that it has a lower harmonic distortion, better wave quality that is similar to a sinusoidal wave, and less voltage stress on the switches has contributed to the rise in popularity of this technique. MLI find their applications in almost every field of electrical engineering, including renewable energy systems, HVDC applications, distributed generation (DG) system, industrial drive applications, uninterruptible power supplies, and so on [1]. These applications are for low and medium voltage/power applications. They find widespread use in drives as well as other associated fields of industry today [2]. In order to generate a staircase waveform that is relatively near to sinusoidal at the output, MLIs are an assemblage of power semiconductor devices that also include a variety of dc connections. The Neutral Point Clamped (NPC), Flying Capacitor (FC), and Cascade H-Bridge (CHB) topologies are the three most fundamental and widely utilized MLI topologies in commercial applications during the last several decades [3]. While there are a few drawbacks to the standard MLI, such as the need for a greater number of source requirements, voltage balancing of the capacitor, and a large number of switch requirements in the CHB, FC, and NPC topologies correspondingly, the MLI is still widely used. Despite this, the benefits they provide in terms of the quality of the electricity they produce outweigh the drawbacks. Researchers have been working on finding solutions to the problems caused by MLI and have published a significant number of articles over the course of the last several years in an effort to do so. They have concentrated their efforts mostly on decreasing the switch count, the source count, and the voltage balancing control of the MLI [4].

The design of an MLI is primarily dependant on a number of factors, including the number of levels that are required at the output, the number of semiconductor devices that are used, the number of dc voltage sources and capacitors that are utilized, the modularity of the topology, and the total standing voltage (TSV) of the topology, among other factors. Multilevel inverters, often known as MLIs, have become a strong contender for the DC-to-AC power conversion due to the qualities that they include [5]. Recently, there has been a shift toward a greater emphasis on distributed generation, sometimes known as DG. The use of renewable energy sources (RES) is becoming more important in meeting the rising demand for electricity. In this relatively new field of power production, one of the most important factors to consider is the electricity's overall quality [6]. The MLI technology is adapted for use in the DC-AC power conversion stage, which results in an improvement in the power quality [7]. The Cascaded H-bridge (CHB) are the three fundamental topologies that are employed for RES. The CHB is funded by a variety of sources, in contrast to the other banks listed, which each have just a single source of funding [8]. The single-source topologies lack flexibility and have a propensity to expand the number of extra components, such as the number of capacitors and the number of diodes, in addition to the switching devices required for higher-level generation. For high-voltage direct current (HVDC) power transmission, the modular multilevel converters (MMCs) [9] are introduced. The MMCs are linked to voltage balance problems across the DC-link capacitors, all of which are connected to the same source. The RES made it possible to employ multiple source topologies like CHB, which don't have any capacitor balance problems and may be used instead [10].

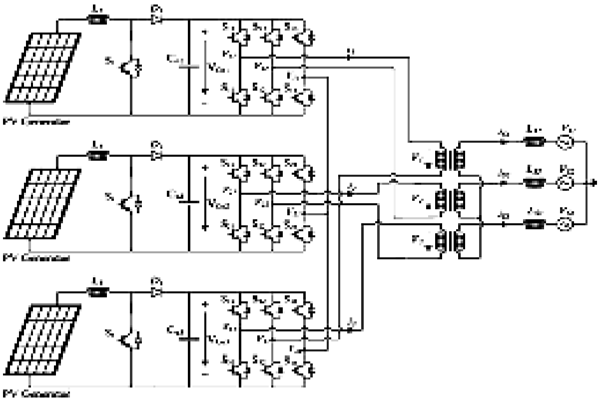

Figure 1: Multilevel inverter [3]

The MLI configurations may either be symmetrical, in which case they have identical sources supplied, or asymmetrical, in which case they have uneven sources fed. In the context of applications using renewable energy, three-phase architecture with a symmetrical structure is presented. In order to improve the modularity and equitable distribution of power across each power cell, the authors suggest three-phase power cells architecture with restructured CHB.

II. BACKGROUND

M. B. Satti et al., [1] For the unique H-Bridge multilevel inverter topology-based grid-connected photovoltaic system (GCPS), a direct model predictive control (DMPC) is given. In comparison to traditional control methods, the DMPC offers a number of benefits, including as optimality, the capacity to handle multiple control objectives, and direct manipulation of semiconductor switches rather than the modulator. The primary control objectives of the GCPS are to maximize the energy produced by the photovoltaic (PV) system and inject current into the grid with a power factor that is near to unity and with the least amount of total harmonic distortion (THD). When it comes to these control objectives, the DMPC does well. Simulink MATLAB is used to simulate the full GCPS using the suggested controller, and the results are then compared to those of other GCPSs that have already been published. The suggested GCPS was more effective, less expensive, and easier to construct since fewer semiconductor switches were used while maintaining the same number of output voltage levels. Also, compared to other systems described in the literature, its voltage and current THD are similar.

C. Boonmee et al.[2], a novel control approach for grid-connected two-cell cascaded H-bridge multilevel solar systems was created from conventional control techniques in order to enhance the system's performance. This was done by monitoring the highest power point that could be injected into the grid and keeping the power factor at unity even when a solar string had low power. The creation of this novel control approach was also based on conventional control methods. The outcomes of the MATLAB/Simulink simulation were contrasted with those of the traditional methodologies in order to show that the system operated precisely as predicted.

C. Dinakaran et al., [3] a single-phase five-level inverter for the SPV configuration is introduced using a brand-new pulse width modulation (PWM) supervisory method. More power switches, poor power quality, and increased switching losses are characteristics of traditional inverters. The suggested technique consists of a single bidirectional control and a typical single-phase, single bridge. Effectively producing five production voltages (V dc /2, V dc, 0, -V dc /2, and -Vdc), the inverter creates input voltage. Using the use of a fuzzy controller, Maximum Power Point Tracking (MPPT) was attained in SPV. The recommended method may be verified by simulation using the PROTEUS model and MATLAB/SIMULINK.

T. Bertin et al., [4] Due to its modular multilevel structure, the solar Cascaded H-Bridge Multilevel Inverter (CHBMLI) is regarded in the photovoltaic (PV) area as an intriguing contender for a grid-tied converter. The elimination of passive components, flexibility, and local Maximum Power Point Tracking (MPPT), which guarantee maximum energy extraction, are this topology's key benefits. Nevertheless, demonstration units often run at low frequencies (less than 5 kHz) with a small number of PV panels because of the complexity of multi-level systems (between 3 and 5). In order to enhance the switching frequency (20 kHz) and the quantity of PV panels employed, this study suggests using distributed real-time hardware architecture with a comprehensive control system (up to 20). The hardware design is built on a fieldbus for real-time communication between a master controller and local controllers that are linked to each PV panel through a common insulated data bus. Modularity and scalability are benefits that this distributed system offers. To guarantee the independent management of each DC (Direct Current) voltage and the output grid current, an adjusted control system is proposed. Results from the experiments show that using 6 modules to achieve a 20 kHz frequency is possible using the given design.

S. Boontua et al., [5] For managing real power and reactive power (PQ) of a single-phase five-level H-bridge multilevel inverter for a PV grid-connected system (FHB-MLI for PVGCS) under poor irradiation conditions, the P&O MPPT control approach is utilized in this study. In this system, the maximum power is maintained for each module by using the maximum power point tracking (MPPT) method of Perturb and Observe (P&O). During uneven power irradiation from each PV, the suggested controller controls the actual dc-link voltage independently of one another and varies real power and reactive power with grid-current magnitude and power angle. A promising experiment and simulation utilizing the MATLAB/SIMULINK tool are used to validate the suggested technique. Results from simulations using a configuration of two PV modules, real power and reactive power processing under weak irradiation conditions, show that the overall system can function satisfactorily even under circumstances where the modules' irradiation varies while still injecting the maximum amount of power into the grid.

M. T. Islam et al., [6] A multilayer inverter is essential for converting dc electricity from various renewable energy sources into ac power. Many different strategies may be tested on an existing multilayer inverter in order to increase its effectiveness. The output voltage of the power inverter exhibits total harmonic distortion due to the modulation algorithm, modulation frequency, voltage drops between the switches, and modulation of the dc bus voltage, which causes overheating of devices and shortens their lifespan. The output voltage quality and total harmonic distortion are improved in this study with the help of a level-shifted pulse width modulation approach. In order to compare this innovative control strategy to the more traditional level-shifted pulse width modulation (LSPWM) with Phase Opposition Disposition (LSPWM-POD) approach, it is applied to an eleven-level conventional cascaded H-bridge multilevel inverter. The performance of the suggested LSPWM has been simulated for verification, and it was discovered that there are two optimum locations where the approach works well.

N. Mukundan et al. [7] for use in photovoltaic power conversion systems (PPCS) systems that are linked to distribution grids. At more levels, the power quality becomes better, and it's possible to achieve balanced active power sharing across the sources. The power flow is accomplished in both directions. By controlling the DC-DC converter using an incremental conductance (IC) method, the two-stage SPVS draws the most power possible from the solar panels. Together with the active power penetration into the grid, the system is developed with multi-functional goals including reactive power support and load harmonic reduction. With the MATLAB/Simulink platform, the system is modelled and simulated. A laboratory prototype is created, and test results are generated for result validation.

X. Pan et al.,[8] For large-scale photovoltaic (PV) systems, one of the most appropriate topologies is the cascaded H-bridge (CHB) multilevel inverter. Yet, when solar irradiation is unequal, a power mismatch issue is likely to occur. Voltage control is the main focus of current efforts to eliminate power mismatches, however this approach is inadequate for situations when there is a significant power imbalance. In order to solve this issue, a parallel control technique that eliminates power mismatch through power sharing across inverters is presented in this study. The power mismatch elimination approach can handle the majority of imbalance scenarios without voltage over modulation because it switches from circulating current management to voltage regulation. The efficiency of the suggested technique was verified by the simulation results.

B. Sharma et al., [9] In order to address the issue of different temperatures and irradiations that lead to partial shading and panel mismatch conditions in large-scale photovoltaic (PV) generation, this study presents a control scheme for a grid-connected cascaded H-bridge multilevel inverter (CHBMLI) based solar energy conversion system (SECS). Along with being practical in high-voltage systems, the main benefit of isolated dc connections in CHBMLI is sacrificed when used as a pulse-width modulated (PWM) converter to control uneven dc sources or loads because of changing power output or consumption, respectively. When SECS experiences the aforementioned power generation mismatch situations, the suggested control strategy has the capability of balancing the dc-link capacitors in each H-bridge cell of the CHBMLI used for this system. The proposed system is monitored and maintained in accordance with criteria for maximum and efficient energy conversion, grid-side voltage, and injected current quality. The mathematical model of CHBMLI as the PWM converter used for this application has also been defined by the modeling study of the converter. MATLAB simulation was used to analyze the system's performance, and the dSPACE-1104 was used to verify the results experimentally on a prototype model.

K. Wang et al.,[10] Large-scale grid-connected solar systems are a viable application for cascaded H-bridge (CHB) multilevel converters (megawatt to gigawatt). Unfortunately, the inter-module and inter-phase power balance cannot be guaranteed by the typical CHB multilevel converter, leading to unbalanced grid currents. Hence, a novel architecture with three-port DC-DC isolation converters based on interleaved-boost full-bridge LLC (IB-FBLLC) and CHB multilevel converters is suggested in this study. The inherent power imbalance problems may be totally resolved in this suggested topology by using a common dc bus made up of the low-voltage-side ports of three-port dc-dc converters based on the IB-FBLLC architecture. Also, a thorough discussion of the dc-dc converter design parameters is provided, taking into account the minimizing of input current ripple and optimization of switching frequency range. The efficacy and viability of the suggested topology and control techniques are amply supported by simulation results for the three-phase system and experimental findings for the single-phase system.

III. CASCADED MULTILEVEL INVERTERS

There is a growing interest in multilevel topologies since they can extend the application of power electronics systems to higher voltages and power ratios. The multilevel inverters, for medium to high voltage range and which also includes AC motor drives, distribution of power, power quality and power conditioning applications. The general function of multilevel inverter is to synthesize a desired voltage level from several separate DC voltage sources, which may be obtained from batteries, or renewable energy sources. Main advantages of this topology are control and protection requirements of each H-bridge. The cascaded multilevel inverter has been studied and used in drives, transmission system and power conditioning; the CMLI has been utilized in a wide range of relevance. With its modularity and flexibility, the CMLI shows superiority in high power applications, especially parallel and series connected facts controller.

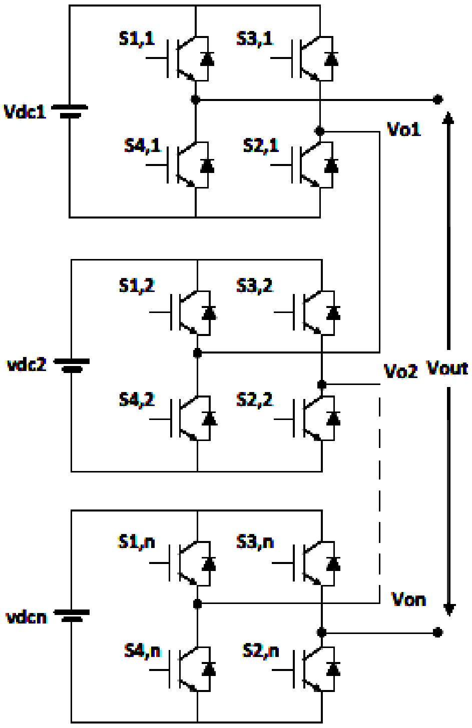

Figure 2: Cascaded H-Bridge MLI Topology

The CMLI synthesizes its output nearly sinusoidal voltage waveforms by combining many isolated voltage levels. By adding more H-bridge inverters, the amount of V_{an} can simply increased without redesign the power stage, and build-in redundancy against individual H-bridge inverter failure can be realized. A series of single-phase full bridges makes up a phase for the inverter. A three phase CMLI topology is essentially composed of three identical phase legs of the series-chain of H-bridge inverters, which can possibly generate different output voltage waveforms and offers the potential for AC system phase-balancing. This feature is impossible in other VSC topologies utilizing a common DC link. Since this topology consists of series power conversion cells, the voltage and power level may be easily scaled.

IV. TOPOLOGIES WITH H-BRIDGE

An MLDCL inverter with two input dc source is shown in Fig. 3. It consists of ‘n’ cascaded half-bridge units; each has a single dc source with two series switches. These cascaded units are considered the "level generation" part of the inverter which produces a stepped dc voltage waveform. The H-Bridge is used to change the output voltage polarity to generate a complete multi level ac waveform. Compared to the traditional MLIs, the MLDCL Contains less number of switches for the same output voltage Levels.

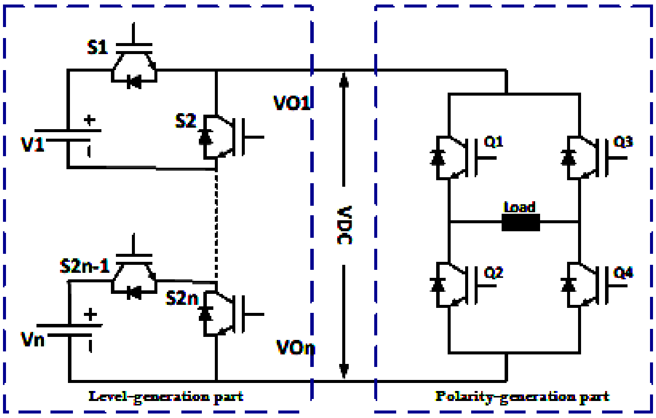

Figure 3: Circuit configuration of the MLDCL inverter

The advantage of this topology is that it operates with asymmetric source configuration. One application area in the low-power range (< 100 kW) is the permanent-magnet (PM) motor drives. A fast switching semiconductor can be deployed for the leveler scheme such as Metal Oxide Semi-Conductor Field Effect Transistor (MOSFETs) while the polarity generation part can use Insulated-Gate Bipolar Transistor (IGBTs). Moreover, the MLDCL scheme implementation includes the photovoltaic and fuel cells.

V. CONCLUSION

The multilevel inverters are the optimum solution for the DC/AC conversion applications in medium and high voltage ranges. An overview of the classic and modern topologies of MLI is provided in this study. The fundamental component of MLI and its applications are thoroughly addressed. The introduction of novel topologies to optimize the number of components has a significant influence on the size, cost, reliability, and efficiency of inverters. The benefit of using asymmetric dc sources in such topologies has increased their use in medium and high voltage ranges. As a consequence, grid-connected applications like those using renewable energy sources favor MLI topologies. Lastly, the majority of MLI topologies may benefit naturally from a variety of modulation techniques.

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