Survey of Multilevel Inverter Topologies, Control Techniques and Applications

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Abstract: Multilevel inverters (MLI) have become indispensable for most power electronic applications in medium and high voltage ranges. The emergence of new topologies overpowered on the traditional ones which, multiples its ability to produce a higher number of levels with less number of components. Moreover, the recently developed topologies of MLI uses asymmetrical DC sources to obtain the same levels with less number of semiconductor switches resulting in a reduction of capital costs and boosting the system reliability. Practically, the asymmetrical dc sources can be obtained from various types of renewable energy sources including photovoltaic, wind turbine system, fuel cell, etc. Finally, the various recently developed techniques for modulation plays a crucial role to enhance the overall performance of MLI. This paper presents a survey for traditional and recent topologies of MLI along with the advantages offered by the new topologies.

***IndexTerms* - Multilevel, Inverters, Semiconductor, Control.**

I. Introduction

Over the last few decades, multilevel inverter (MLI) topologies have gained popularity in industrial application because of the superior power quality compared to its conventional two-level counterpart. Lower harmonic distortion and better wave quality resembling a sinusoidal wave and lesser voltage stress on the switches have added to its popularity. For low and medium voltage/power applications, 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, etc [1].

They are widely used in drives and other allied areas in industries. MLI's are an assembly of power semiconductor devices along with different dc links to achieve staircase waveform close to sinusoidal at the output. Neutral Point Clamped (NPC), Flying Capacitor (FC) and Cascade H-Bridge (CHB) are the three basic and popular MLI topologies used in commercial application since last few decades. Although there are few issues with the conventional MLI like a higher number of source requirement, voltage balancing of the capacitor and large switch requirement in CHB topology, FC topology and NPC topology respectively. Still, their advantages in terms of power quality supersede the shortcomings. Researchers have been trying to solve and mitigate the issues with MLI and have published a large number of papers over the last few years.

They have mainly focused on reducing the switch count, source count and voltage balancing control of MLI. The design of MLI mainly depends upon the number of levels required at the output, number of semiconductor devices used, number of dc voltage sources and capacitors utilized, modularity of topology and the total standing voltage (TSV) of topology, etc. The features of multilevel inverters (MLIs) have made them a superior candidate for the DC-AC power conversion [2].

The bias towards the distributed generation (DG) is getting increased recently. The renewable energy systems (RES) play a vital role in fulfilling the increased power demand. The power quality is one of the key parameter in this emerging area of power generation. The power quality is improved by adapting the MLI technology for DC-AC power conversion stage [3]. The three basic topologies used for RES are Cascaded H-bridge (CHB) [4], Neutral point clamped (NPC) [6] and Flying capacitor (FC) [7].

The CHB is fed with multiple sources, whereas the other aforementioned are of single source type. The single source topologies lack in modularity and have the tendency to increase the additional components viz., capacitor count, and diode count other than switching devices for higher level generation. The modular multilevel converters (MMCs) [9] are introduced for HVDC power transmission. The MMCs are associated with voltage balancing issues across DC-link capacitors, which are connected to a single source. The RES enabled the use of multiple source topologies like CHB, which are free from capacitor balancing issues. To enhance the efficiency by reducing the switching losses, many topologies with reduced switching device count are presented in [10].

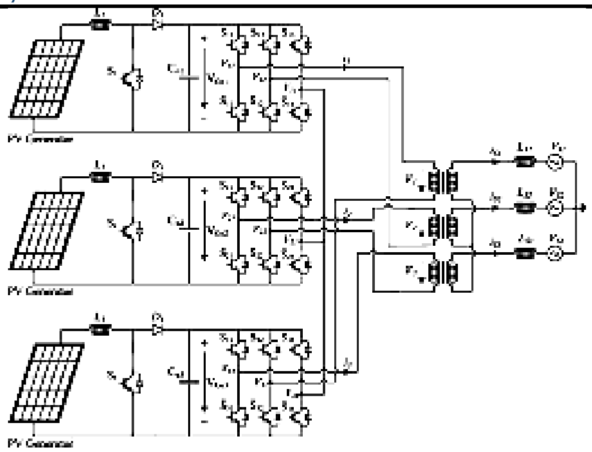

Figure 1: Multilevel inverter [3]

The MLI configurations are classified as symmetrical or identical sources fed and asymmetrical or unequal sources fed. A three phase topology in symmetrical configuration is proposed in for renewable energy applications. A three phase power cells topology with restructured CHB is presented in [12] to enhance the even distribution of power across the each power cell and modularity. The high frequency direct grid connected RES with MMCs are presented in. A Three phase five level enhanced structure is reported. The hybrid three phase structures are proposed with improved control technique. A single DC source hybrid seven level three phase topology is presented with hybrid control technique to enhance efficiency. A three phase symmetrical topology with reduced component count is proposed in [9]. As asymmetrical configuration generates more level than symmetrical operating mode but the readily availability of DC sources of different magnitudes is a concern. So single phase topologies are proposed, which can work in both the configurations. An asymmetrical structure with lower source count is presented. These single structures can be extended to three phase operation. A three phase hybrid cascaded modular multilevel inverter (HCMMLI) is presented, which reduced the switch count, gate drive count compared with classical topologies.

II. LITERATURE SURVEY

H. R. Teymour et al., [1] In this paper, a novel configuration of a three-level neutral-point-clamped (NPC) inverter that can integrate solar photovoltaic (PV) with battery storage in a grid-connected system is proposed. The strength of the proposed topology lies in a novel, extended unbalance three-level vector modulation technique that can generate the correct ac voltage under unbalanced dc voltage conditions. This paper presents the design philosophy of the proposed configuration and the theoretical framework of the proposed modulation technique. A new control algorithm for the proposed system is also presented in order to control the power delivery between the solar PV, battery, and grid, which simultaneously provides maximum power point tracking (MPPT) operation for the solar PV. The effectiveness of the proposed methodology is investigated by the simulation of several scenarios, including battery charging and discharging with different levels of solar irradiation. The proposed methodology and topology is further validated using an experimental setup in the laboratory.

B. Sharma et al., [2] The proposed control scheme has the ability of balancing the dc-link capacitors in each H-bridge cell of CHBMLI adopted for this system and during the above-said power generation mismatch conditions in SECS. The proposed system along with maximum and efficient energy conversion, the power quality in the grid-side voltage and injected currents is also monitored and maintained as per standards. In addition, the modelling analysis of the converter has also been derived to define the mathematical model of CHBMLI as PWM converter adopted for this application. The performance of system has been analyzed using MATLAB simulation and validated experimentally on prototype model by using dSPACE-1104.

K. Wang et al., [3] proposed topology; a common dc bus made up of the low-voltage-side ports of IB-FBLLC-based three-port dc-dc converters can completely solve the inherent power imbalance issues. Moreover, the design parameters of dc-dc converters considering the minimization of the input current ripple and optimization of switching frequency range are discussed in detail. Simulation results of the three-phase system and experimental results of the single-phase system clearly verify the effectiveness and feasibility of the proposed topology and control strategies.

A. Ahmed et al., [4] an isolated single sourced multi-output dc/dc converter with a high-frequency link was proposed before to feed different cells of the Asymmetrical Cascaded H-bridge (ACHB) inverter. One of the fundamental advantages of the ACHB is that the main H-bridge is commutated with fundamental frequency, passing the majority of the inverter power. However, the isolated dc/dc converter needs to be connected to the main voltage source with high-voltage/high-frequency switches, which limits the power capability and the efficiency of the converter. In this paper, a switching pattern based on nearest level modulation method is proposed to command all the power to be transferred through the.

A. Kumar et al., [5] This paper proposes a staggered PV connection through cascaded multilevel converter (CMC) for PV-grid tie application utilizing independent maximum power point tracking controller, providing the larger depth of operation under partial shading condition with smaller filter size and electromagnetic interference (EMI). For dynamic and steady-state performance evaluation, a d-q frame-based control algorithm is investigated for the single-phase PV-CMC system. Furthermore, to establish the stability of the proposed controller, a detailed plant model is also investigated along with the detailed comparative analysis for operation of PV under partial shading condition for a conventional PV based centralized and string inverter vis-à-vis proposed PV-CMC approach. The improved performance analysis is demonstrated both through simulation and experimentation.

Y. Shi et al., [6] proposed to suppress the grid voltage disturbance. The closed form equations for control parameters are derived. The effects of the proposed feed forward methods are also compared with that of conventional IGVF. Finally, the grid-connected experimental results of a 60-kW SiC-based 5-level photovoltaic inverter are provided to verify and compare the proposed control methods.

C. A. Rojas et al., [7] the enhanced performance is obtained by reducing the carrier frequency component of the converter voltage, generating an improved voltage ripple. Finally, experimental validation during steady-state and dynamic operation is presented to illustrate the behavior of the dc-dc MMC converter managed by the proposed modulation and control scheme.

C. M. Nirmal Mukundan et al., [8] in this work a two stage Solar Energy Grid Connected System (SEGCS) with DC-DC and Cascaded H-bridge Multilevel Inverter (CHB-MLI) for DCAC conversions are proposed. The shunt connected SEGCS is demonstrated with a non linear unbalance reactive local load. The active power generated in the Photo Voltaic (PV) system with respect to the irradiations is shared to the load and the grid.

N. Shah et al., [9] in the recent trend of using green energy, grid connected Photovoltaic (PV) systems are getting more popular. In this work, the modeling and control of multilevel inverter based single-stage grid connected photovoltaic system based on cascaded two-level inverter (CTLI) is carried out using MATLAB/Simulink. The multilevel inverter topology is developed by the cascade connection of two conventional voltage source inverters (VSI)) using open winding transformer. The inverters are controlled using hysteresis current controller for which the synchronizing reference currents are generated using p-q theory.

G. Ranjith Kumar et al., [10] The loss and thermal distributions of the different power devices in the MLPVI system are investigated and illustrated for various pulse-width modulation (PWM) controllers. The junction temperature and power losses of the components in the MLPVI are simulated by MATLAB/Simulink and Piecewise Linear Electrical Circuit Simulation (PLECS) block set, which validate the theoretical analysis. The reliability of the MLPVI is evaluated using parts stress method. It shows that the MLPVI has a good reliability when phase shift PWM control technique is used.

M. A. Morales Caporal et al., [11] in this paper a grid connected photovoltaic system is presented. The presented system has two stages, the first is the MPPT strategy based on variable-step with predictive current control. In the second stage an active/reactive power control is uses to control a multilevel inverter for grid connection. All the system is developed in MATLAB and simulated on simulink for validation.

C. A. Rojas et al., [12] the main contribution of this paper is the avoidance of the potential leakage current due to parasitic capacitance of the PV modules by using a predictive model based control technique instead of modulated schemes and eliminating high-frequency common-mode voltage components. Experimental results during steady state and dynamic operation are presented to illustrate the behavior of the H-NPC converter commanded by the proposed control scheme.

Table 1: Summary of literature survey

Sr No.	Author Name & Year	Proposed Work	Outcome
1	M. B. Satti, IEEE 2019	Direct model predictive control (DMPC)	Less costly, and simpler in design.
2	B. Sharma IEEE 2018	Grid-connected cascaded H-bridge multilevel inverter (CHBMLI)	Maximum and efficient energy conversion
3	G. Ranjith Kumar IEEE 2017	Five-level modular cascaded H-bridge MLI	Good reliability
4	M. A. Morales Caporal IEEE 2017	Grid connected photovoltaic system	Good efficiency and improved performance.
5	C. A. Rojas IEEE 2017	H-bridge neutral-point-clamped	Avoidance of the potential leakage current

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. A cascade multilevel inverter by Corzine et al (1999) Liu et al (2006) consists of a series of H-bridge inverter units. 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.

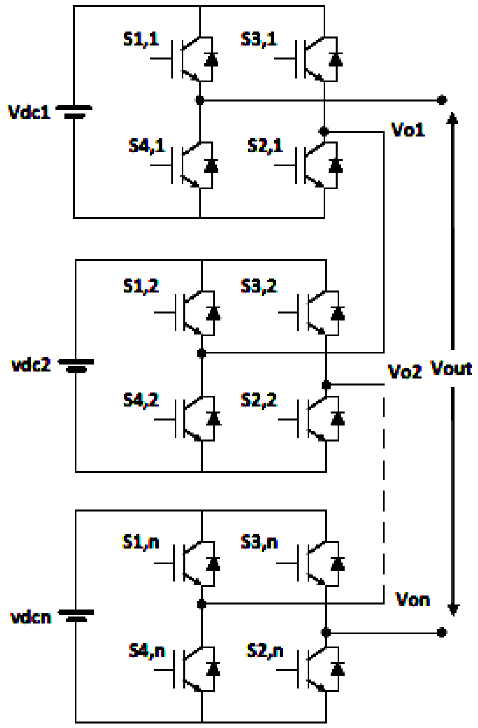

Figure 2: Cascaded H-Bridge MLI Topology

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

The CHB with multiple levels DC Link (MLDCL) inverter is introduced by C. Hochgraf. An MLDCL inverter with two input dc source is shown in Fig. 2. 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 [13].

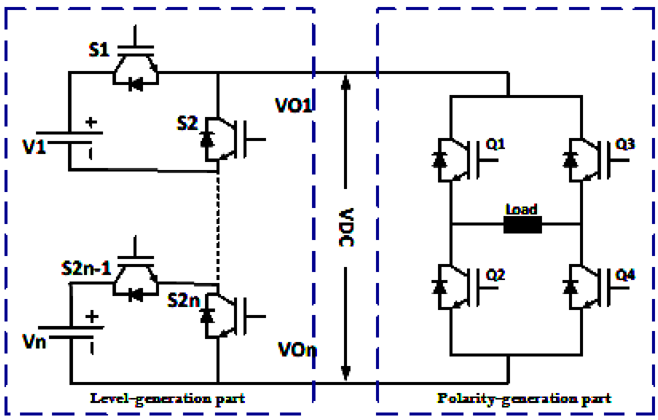

Figure 3: Circuit configuration of the MLDCL inverter

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 [15].

V. CONCLUSION

The multilevel inverters are the optimum solution for the DC/AC conversion applications in medium and high voltage ranges. In this paper, an overview of traditional and recent topologies of MLI is presented. The basic unit of MLI and its Applications are discussed in details. The new topologies to optimize the number of components are introduced which have an enormous impact on the inverter size, cost reliability, and efficiency. The advantage of design such topologies with asymmetric dc source has escalated its application in medium and high voltage ranges. As a result, the MLI topologies are preferred in grid connected applications, such as renewable energy sources. Finally, numerous modulation methods can offer inherent advantages to most of MLI topologies.

REFERENCES

1. H. R. Teymour, D. Sutanto, K. M. Muttaqi and P. Ciufo, "Solar PV and Battery Storage Integration using a New Configuration of a Three-Level NPC Inverter With Advanced Control Strategy," in IEEE Transactions on Energy Conversion, vol. 29, no. 2, pp. 354-365, June 2014, doi: 10.1109/TEC.2014.2309698.
2. B. Sharma and J. Nakka, "Single-phase cascaded multilevel inverter topology addressed with the problem of unequal photovoltaic power distribution in isolated dc links," in IET Power Electronics, vol. 12, no. 2, pp. 284-294, 20 2 2019, doi: 10.1049/iet-pel.2018.5640.
3. K. Wang, R. Zhu, C. Wei, F. Liu, X. Wu and M. Liserre, "Cascaded Multilevel Converter Topology for Large-Scale Photovoltaic System With Balanced Operation," in IEEE Transactions on Industrial Electronics, vol. 66, no. 10, pp. 7694-7705, Oct. 2019, doi: 10.1109/TIE.2018.2885739.
4. A. Ahmed, M. Sundar Manoharan and J. Park, "An Efficient Single-Sourced Asymmetrical Cascaded Multilevel Inverter With Reduced Leakage Current Suitable for Single-Stage PV Systems," in IEEE Transactions on Energy Conversion, vol. 34, no. 1, pp. 211-220, March 2019, doi: 10.1109/TEC.2018.2874076.
5. A. Kumar and V. Verma, "Performance Enhancement of Single-Phase Grid-Connected PV System Under Partial Shading Using Cascaded Multilevel Converter," in IEEE Transactions on Industry Applications, vol. 54, no. 3, pp. 2665-2676, May-June 2018, doi: 10.1109/TIA.2017.2789238.
6. Y. Shi, L. Wang and H. Li, "Stability Analysis and Grid Disturbance Rejection for a 60-kW SiC-Based Filterless Grid-Connected PV Inverter," in IEEE Transactions on Industry Applications, vol. 54, no. 5, pp. 5025-5038, Sept.-Oct. 2018, doi: 10.1109/TIA.2017.2779873.
7. C. A. Rojas, S. Kouro, M. A. Perez and J. Echeverria, "DC–DC MMC for HVdc Grid Interface of Utility-Scale Photovoltaic Conversion Systems," in IEEE Transactions on Industrial Electronics, vol. 65, no. 1, pp. 352-362, Jan. 2018, doi: 10.1109/TIE.2017.2714120.
8. C. M. Nirmal Mukundan and P. Jayaprakash, "Cascaded H-Bridge Multilevel Inverter Based Grid Integration of Solar Power with PQ Improvement," 2018 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES), Chennai, India, 2018, pp. 1-6, doi: 10.1109/PEDES.2018.8707467.
9. N. Shah, "Multilevel Inverter Based Single-Stage Grid Connected Photovoltaic System using Cascaded Two-Level Inverter," 2018 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES), Chennai, India, 2018, pp. 1-6, doi: 10.1109/PEDES.2018.8707445.
10. G. Ranjith Kumar, G. R. Zhu, J. Lu, W. Chen and B. Li, "Thermal analysis and reliability evaluation of cascaded H-bridge MLPVI for grid-connected applications," in The Journal of Engineering, vol. 2017, no. 13, pp. 1595-1599, 2017, doi: 10.1049/joe.2017.0601.
11. M. A. Morales Caporal, J. d. J. Rangel Magdaleno, I. Cruz Vega and R. Morales Caporal, "Improved grid-photovoltaic system based on variable-step MPPT, predictive control, and active/reactive control," in IEEE Latin America Transactions, vol. 15, no. 11, pp. 2064-2070, Nov. 2017, doi: 10.1109/TLA.2017.8070409.
12. C. A. Rojas, M. Aguirre, S. Kouro, T. Geyer and E. Gutierrez, "Leakage Current Mitigation in Photovoltaic String Inverter Using Predictive Control With Fixed Average Switching Frequency," in IEEE Transactions on Industrial Electronics, vol. 64, no. 12, pp. 9344-9354, Dec. 2017, doi: 10.1109/TIE.2017.2708003.
13. M. R. Islam, A. M. Mahfuz-Ur-Rahman, M. M. Islam, Y. G. Guo and J. G. Zhu, "Modular Medium-Voltage Grid-Connected Converter With Improved Switching Techniques for Solar Photovoltaic Systems," in IEEE Transactions on Industrial Electronics, vol. 64, no. 11, pp. 8887-8896, Nov. 2017, doi: 10.1109/TIE.2017.2652402.
14. M. S. Manoharan, A. Ahmed and J. Park, "A PV Power Conditioning System Using Nonregenerative Single-Sourced Trinary Asymmetric Multilevel Inverter With Hybrid Control Scheme and Reduced Leakage Current," in IEEE Transactions on Power Electronics, vol. 32, no. 10, pp. 7602-7614, Oct. 2017, doi: 10.1109/TPEL.2016.2632864.
15. V. Sonti, S. Jain and S. Bhattacharya, "Analysis of the Modulation Strategy for the Minimization of the Leakage Current in the PV Grid-Connected Cascaded Multilevel Inverter," in IEEE Transactions on Power Electronics, vol. 32, no. 2, pp. 1156-1169, Feb. 2017, doi: 10.1109/TPEL.2016.2550206.