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An In-Depth Look at Multi-Tier Inverters for Grid-Linked System uses

Shaheena Khanum [1] and Dr. Ravi Prasad D [2]

[1] Research Scholar, Department of Electrical and Electronics Engineering, Sri Siddhartha Institute of Technology
Sri Siddhartha Academy of Higher Education, Tumakuru, India

[2] Research Supervisor, Department of Electrical and Electronics Engineering, Sri Siddhartha Institute of Technology
Sri Siddhartha Academy of Higher Education, Tumakuru, India

Abstract: Multi-level inverters (MLIs) have been increasingly popular in industrial and grid-connected applications in recent years, thanks to their numerous advantages. Nevertheless, the increasing requirement for renewable energy systems (RES) is hindering the effectiveness of these traditional topologies. They are facing challenges in meeting the demand for renewable energy, resulting in issues such as reduced power reliability, inefficiency, and an uneconomical framework. As a result, researchers have been driven to develop new hybrid MLI configurations. This paper offers a thorough analysis of multilayer inverter systems that are connected to the primary power source. The evaluation provides thorough information on the types and configurations of grid-connected inverters. Various multi-level inverter configurations and techniques are categorized and thoroughly examined. In addition, this study presents and analyses multiple control reference frames for inverters. Furthermore, several techniques for controlling inverters are examined, followed by a concise overview of the latest advancements in the literature pertaining to inverters. The most recent grid-connected multi-level inverter systems are also examined, encompassing discoveries and innovations. Ultimately, the research's extent is condensed and potential avenues for future investigations are proposed. The same concept can be expressed by employing an alternative arrangement. Undoubtedly, the Internet has become an indispensable component of our daily existence and has revolutionized the way we interact and communicate. Clearly, it has become a habitual aspect of our social interactions, facilitating immediate connectivity and information sharing.

Keywords: Grid-connected multi-level inverter (GCMLI), renewable energy systems, modulation techniques, control mechanism, topologies.

I. Introduction

Currently, wind and solar power can be integrated into the power grid to enhance the efficiency of alternative and sustainable energy sources [1]. MLIs are employed as intermediaries between different electrical power devices, such as "DC-AC" inverters, and as converters for the utilisation of electricity provided by renewable energy sources, which cannot be directly used. MLIs were initially introduced in 1975 and have subsequently undergone ongoing enhancements to various topologies. For MLIs employed in grid-tied systems, it is possible to transmit a sinusoidal waveform to the grid instead of a current/voltage with a reduced number of harmonics. This serves as an alternative choice. The frequency of this waveform must be identical to that of the grid [2]. An MLI configuration with an LC filter is commonly used to provide a sinusoidal three-phase current and voltage with reduced harmonics.

II. Literature Review

Initially, three-level inverters were the preferred choice for integrating renewable energy sources with the electrical grid. Nevertheless, this particular inverter has other disadvantages, therefore requiring additional enhancements. For example, in order to handle high power applications, they require devices with high power ratings, which increases their cost and leads to greater switching losses. Furthermore, their generated signal oscillates between two voltage levels, specifically 0 V and Vdc, resulting in a waveform that contains numerous harmonics. MLIs have been implemented and extensively employed by the industry [3], since they provide numerous benefits compared to traditional inverters in terms of harmonics, operational efficiency, load stress, and electromagnetic interference (EMI) [4]. The DC input voltage required by MLIs can be supplied by several renewable energy sources, such as solar arrays equipped with DC-DC converters, inductive synchronous generators, windmills powered by generators, rectification designs, and fuel cells with DC-DC converters [1].

Based on a bibliometric analysis using Scopus, a total of 449 research publications focused on MLIs (Microgrid-Linked Inverters) for grid-connected systems were published in different academic journals between 2012 and 2022 (see Figure 1). There was a rise in the quantity of published papers between 2012 and 2019, followed by a minor decline from 2020 to 2022. The primary focus of most MLIs investigations is on gate driver circuits, reducing the number of switches, improving power quality, enhancing fault tolerance, and achieving cost-efficiency for grid-connected systems. Table 1 presents a comparison of the quantity of published articles and citations pertaining to the application of MLI in grid-connected systems across various nations throughout the period from 2012 to 2022. India leads in terms of the biggest number of publications (160) and ranks second in terms of citations (1520). Canada holds the record for the highest number of citations, with a total of 1848, despite having only 31 published publications. China ranks third in terms of both the number of publications (72) and the number of citations (1275). By employing an alternative framework, one can effectively convey the same idea: modifying the arrangement while preserving the essence allows for the avoidance of plagiarism. It is crucial to maintain the formatting of markdown in this context

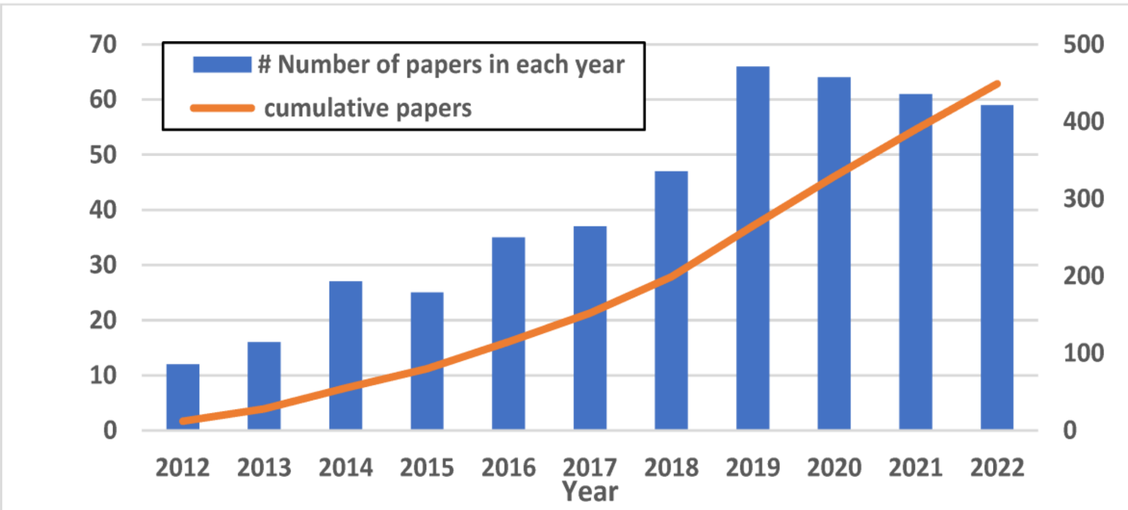

Figure 1. Graph indicating number of articles published on the title (2012–2022)

MLIs are being more commonly integrated into systems that have low levels of electronic radiation and harmonic distortion because they can fulfil specific power rating and electric power quality criteria. This novel method exhibits significant divergence from conventional two-level inverters that employ pulse width modulation (PWM). MLIs exhibit a regular frequency switching pattern, which confers several notable benefits [10]. Consequently, researchers are investigating their potential use in industrial settings that require high performance and power quality, ranging from one to thirty megawatts [11]. MLIs are well-suited for high voltage applications because they can handle greater voltages and provide low Total Harmonic Distortion (THD) output voltage waveforms, even with limited device ratings [12]. Renewable energy sources, such as wind, fuel cells, and PV cells, can be connected to multilayer converters in several ways [13]. The control algorithm utilised determines the regulation of the Pulse Width Modulation (PWM) in Multi-Level Inverters (MLIs), which in turn governs their operational characteristics, power efficiency ratings, and overall functionality [14]. Over the past few years, numerous researchers have proposed various MLI topologies

[15,16]. MLIs are categorised into two primary types based on the quantity of direct current (DC) sources in their topologies. The fly capacitor, neutral-point clamped (NPC), and cascaded H-bridge topologies are currently the most commonly used and widely adopted in the commercial sector [17,18].

The Neutral-point clamped MLI has unequal loss distribution in the switches and voltage balancing of the capacitor for higher voltage level generation. Hence, to overcome these challenges, Meynard et al [17] introduced a new multilevel inverter topology which is named as flying capacitor MLI. This MLI has attracted the industrial application due to its good modularity.

The proposal presented in reference [25] recommended combining a Zero Voltage Transition (ZVT)-PWM converter with a resonant inverter. The existence of parallel and series resonant tanks in the resonant inverter would cause a low-frequency fluctuation in the AC output voltage. Furthermore, [26] presented a novel inverter booster converter incorporating a zero-voltage switching (ZVS) and zero current switching (ZCS) pulse width modulation (PWM) technique. This design comprises three stages: ZVT-PWM boost converters, ZVS-ZCS-PWM buck converters, and ZVT-PWM boost converters. The full-bridge inverter functions as the third stage. A switchable capacitor is an electrical component used in circuits that may be adjusted to different voltage levels.

The construction of the Flying Capacitor MLI and the Diode Clamped MLI is analogous, with the exception that the FCMLI used floating capacitors instead of clamping diodes [3]. The output waveform of the FCMLI demonstrates that the amplitudes of the current phase are directly correlated to the voltage fluctuations of the capacitors adjacent to it [27]. The FCMLI at the "m" level utilises a three-tiered structure with a DC link capacitor range of 0m-10. To generate a positive polarity output voltage, switches S1 and S2 are activated, whereas switches S3 and S4 are triggered to produce a negative polarity output voltage. In order to produce an output of zero volts, it is necessary to activate either S1 and S3, or S2 and S4. The FCMLI provides greater voltage synthesis freedom in comparison to the DCMLI. By carefully choosing the appropriate switching combinations, it is possible to achieve more than five unique levels [9]. The system offers various advantages, such as the capability to manage both reactive and actual power. Nevertheless, this architectural design incurs significant expenses and presents difficulties in its construction due to the requirement for a considerable quantity of capacitors. Moreover, it is susceptible to a substantial decrease in switching frequency while transferring real power [27,28].

Inverters can be categorised according to the specific switching technique they utilise. Soft-switching and hard-switching inverters are the two primary classifications, each with the ability to incorporate one or many power stages. Grid-connected DC inverters often employ soft switching technology to attain exceptional efficiency, superior performance, and high-power density.

Abrupt swings in switch currents and voltages, especially in high-frequency switching inverters, can lead to significant electromagnetic interference (EMI) challenges and switching losses [19,20]. The rapid and unpredictable cycling of device power, often known as hard swapping, might present several difficulties during the switching process. The stray inductances and parasitic capacitances of power electronic devices produce substantial current or voltage spikes when changing states. The soft-switching design incorporates a combination of traditional hard-switching PWM circuits with additional diodes, passive components, and power-switching devices that depend on high resonant networks, such as the capacitor-inductor tank, to decrease the rates of voltage change (dv/dt) and current change (di/dt). Conventional buck-boost inverter designs have several drawbacks, such as: (a) generating high-frequency harmonics that can lead to electromagnetic interference (EMI), (b) having substantial leakage current due to the common mode voltage of the emitters, (c) decreased efficiency at high switching frequencies, and (d) larger and heavier converter configurations required for high efficiency at low switching frequencies. By utilising an alternative structure, it is possible to communicate the same information without resorting to plagiarism. An illustration might be provided: Rather than committing plagiarism, one can maintain the authentic context and semantic significance of the text by altering its structure. Soft-switching techniques reduce power losses in a switching circuit by guaranteeing that the voltage and power remain at zero during the switching process. Extensive research has been conducted on several soft-switching inverter topologies in the literature. An advanced multi-input inverter with high step-up capability, soft-switching, and low circulating current is described in references [21] and [22]. Furthermore, reference [23] describes a soft-switching inverter that operates at high frequencies and is controlled by zero current switching (ZCS). On the other hand, reference [24] provides a flyback inverter with smooth switching based on capacitive idling, which operates in a single stage.

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The NPC inverter type was developed by the authors in [29]. This topology consists of two capacitors, rectifiers, and four unidirectional power switches. The diodes are connected in series to distribute the blocking voltage [30]. When switches S1 and S2 are activated and S4 is deactivated, two equal voltages of Vdc/2 are produced. To achieve a value of Vdc/2, it is necessary to activate both S3 and S4. Additionally, S2 and S3 should be active while the voltage is 0 volts. When transferring the same voltage between the DC link capacitors, it is anticipated that each active switching mechanism will undergo voltage strain. In order to reduce the strain on the diodes, the voltage of each capacitor is controlled using diode clamps, as seen in reference [28].

III. CONCLUSION

This paper offered an in-depth exploration of grid-connected multi-node inverters. It provided an introduction to the principles and issues related to multi-level inverters, as well as the different types of topologies of MLIs. these were classified based on the number of stages and the inclusion of transformers, and the paper further detailed the commutation, switching methods, and topologies of MLIs, such as half-bridge and full-bridge clamped inverters, cascaded inverters, and flying inverters. Moreover, the paper discussed the control approaches for grid-connected MLIs, including strategies for voltage sources GCMLI, voltage source fed symmetric GCMLI, asymmetrical cascaded GCMLI, and hybrid GCMLI. lastly, the paper addressed some newly suggested GCMLIS, along with the author's inventions, research findings, and possible challenges that can be considered in future studies.

REFERENCES

[1] Mahalakshmi, R.; Thampatty, K.S. Grid connected multilevel inverter for renewable energy applications. Procedia Technol. **2015**, 21, 636–642. [**Google Scholar**] [**CrossRef**]

[2] Li, W.; Ruan, X.; Bao, C.; Pan, D.; Wang, X. Grid synchronization systems of three-phase grid-connected power converters: A complex-vector-filter perspective. IEEE Trans. Ind. Electron. **2013**, 61, 1855–1870. [**Google Scholar**] [**CrossRef**]

[3] Bughneda, A.; Salem, M.; Richelli, A.; Ishak, D.; Alatai, S. Review of multilevel inverters for PV energy system applications. Energies **2021**, 14, 1585. [**Google Scholar**] [**CrossRef**]

[4] Daher, S.; Schmid, J.; Antunes, F.L. Multilevel inverter topologies for stand-alone PV systems. IEEE Trans. Ind. Electron. **2008**, 55, 2703–2712. [**Google Scholar**] [**CrossRef**]

[5] Vahedi, H.; Sharifzadeh, M.; Al-Haddad, K. Modified seven-level pack U-cell inverter for photovoltaic applications. IEEE J. Emerg. Sel. Top. Power Electron. **2018**, 6, 1508–1516. [**Google Scholar**] [**CrossRef**]

[6] Abdoli, H.; Khorsandi, A.; Eskandari, B.; Moghani, J.S. A new reduced switch multilevel inverter for pv applications. In Proceedings of the 2020 11th Power Electronics, Drive Systems, and Technologies Conference (PEDSTC), Tehran, Iran, 4–6 February 2020; IEEE: Piscataway, NJ, USA, 2020. [**Google Scholar**]

[7] Agrawal, R.; Jain, S. Comparison of reduced part count multilevel inverters (RPC-MLIs) for integration to the grid. Int. J. Electr. Power Energy Syst. **2017**, 84, 214–224. [**Google Scholar**] [**CrossRef**]

[8] Xiao, B.; Tolbert, L.M. Efficiency improved and current balanced three-phase modular cascaded H-bridge multilevel PV inverter for grid-connected applications. In Proceedings of the 2014 IEEE Energy Conversion Congress and Exposition (ECCE), Pittsburgh, PA, USA, 14–18 September 2014; IEEE: Piscataway, NJ, USA, 2014. [**Google Scholar**]

[9] Bana, P.R.; Panda, K.P.; Naayagi, R.; Siano, P.; Panda, G. Recently developed reduced switch multilevel inverter for renewable energy integration and drives application: Topologies, comprehensive analysis and comparative evaluation. IEEE Access **2019**, 7, 54888–54909. [**Google Scholar**] [**CrossRef**]

[10] Balal, A.; Dinkhah, S.; Shahabi, F.; Herrera, M.; Chuang, Y.L. A Review on Multilevel Inverter Topologies. Emerg. Sci. J. **2022**, 6, 185–200. [**Google Scholar**] [**CrossRef**]

[11] Pharne, I.; Bhosale, Y. A review on multilevel inverter topology. In Proceedings of the 2013 International Conference on Power, Energy and Control (ICPEC), Dindigul, India, 6–8 February 2013; IEEE: Piscataway, NJ, USA, 2013. [**Google Scholar**]

[12] Rodríguez, J.; Bernet, S.; Wu, B.; Pontt, J.O.; Kouro, S. Multilevel voltage-source-converter topologies for industrial medium-voltage drives. IEEE Trans. Ind. Electron. **2007**, 54, 2930–2945. [**Google Scholar**] [**CrossRef**]

[13] Rodriguez, J.; Franquelo, L.G.; Kouro, S.; Leon, J.I.; Portillo, R.C.; Prats, M.A.M.; Perez, M.A. Multilevel converters: An enabling technology for high-power applications. Proc. IEEE **2009**, 97, 1786–1817. [**Google Scholar**] [**CrossRef**][**Green Version**]

[14] Kouro, S.; Malinowski, M.; Gopakumar, K.; Pou, J.; Franquelo, L.G.; Wu, B.; Rodriguez, J.; Pérez, M.A.; Leon, J.I. Recent advances and industrial applications of multilevel converters. IEEE Trans. Ind. Electron. **2010**, 57, 2553–2580. [**Google Scholar**] [**CrossRef**]

[15] Hasan, N.S.; Rosmin, N.; Osman, D.A.A.; Musta'amal, A.H. Reviews on multilevel converter and modulation techniques. Renew. Sustain. Energy Rev. **2017**, 80, 163–174. [**Google Scholar**] [**CrossRef**]

[16] Shehu, G.S.; Kunya, A.B.; Shanono, I.H.; Yalçınöz, T. A review of multilevel inverter topology and control techniques. In Proceedings of the 2017 Nineteenth International Middle East Power Systems Conference (MEPCON), Cairo, Egypt, 19–21 December 2017. [**Google Scholar**]

[17] Peng, F.; McKeever, J.; Adams, D. Cascade multilevel inverters for utility applications. In Proceedings of the IECON'97 23rd International Conference on Industrial Electronics, Control, and Instrumentation (Cat. No. 97CH36066), New Orleans, LA, USA, 14 November 1997; IEEE: Piscataway, NJ, USA, 1997. [**Google Scholar**]

[18] Escalante, M.F.; Vannier, J.-C.; Arzandé, A. Flying capacitor multilevel inverters and DTC motor drive applications. IEEE Trans. Ind. Electron. **2002**, 49, 809–815. [**Google Scholar**] [**CrossRef**]

[19] Peng, F.Z.; Lai, J.-S.; McKeever, J.W.; VanCoevering, J. A multilevel voltage-source inverter with separate DC sources for static var generation. IEEE Trans. Ind. Appl. **1996**, 32, 1130–1138. [**Google Scholar**] [**CrossRef**]

[20] Joos, G.; Huang, X.; Ooi, B.-T. Direct-coupled multilevel cascaded series VAR compensators. IEEE Trans. Ind. Appl. **1998**, 34, 1156–1163. [**Google Scholar**] [**CrossRef**]

[21] Mahdavi, J.; Tabandeh, M.; Shahriari, A. Comparison of conducted RFI emission from different unity power factor AC/DC converters. In Proceedings of the PESC Record, 27th Annual IEEE Power Electronics Specialists Conference, Baveno, Italy, 23–27 June 1996; IEEE: Piscataway, NJ, USA, 1996. [**Google Scholar**]

[22] Mahdavi, J.; Roudet, J.; Scheich, R.; Rognon, J. Conducted RFI emission from an AC-DC converter with sinusoidal line current. In Proceedings of the Conference Record of the 1993 IEEE Industry Applications Conference Twenty-Eighth IAS Annual Meeting, Toronto, ON, Canada, 2–8 October 1993; IEEE: Piscataway, NJ, USA, 1993. [**Google Scholar**]

[23] Mohammed, S.A.Q.; Jung, J.-W. A State-of-the-Art Review on Soft-Switching Techniques for DC–DC, DC–AC, AC–DC, and AC–AC Power Converters. IEEE Trans. Ind. Inform. **2021**, 17, 6569–6582. [**Google Scholar**] [**CrossRef**]

[24] Babaei, E.; Tarzamni, H.; Tahami, F.; Jahan, H.K.; Sharifian, M.B.B. Multi-input high step-up inverter with soft-switching capability, applicable in photovoltaic systems. IET Power Electron. **2020**, 13, 133–143. [**Google Scholar**] [**CrossRef**]

[25] Huang, Y.-F.; Konishi, Y.; Ho, W.-J. Series resonant type soft-switching grid-connected single-phase inverter employing discontinuous-resonant control applied to photovoltaic AC module. In Proceedings of the 2011 Twenty-Sixth Annual IEEE Applied Power Electronics Conference and Exposition (APEC), Fort Worth, TX, USA, 6–11 March 2011; IEEE: Piscataway, NJ, USA, 2011. [**Google Scholar**]

[26] Tan, G.; Tang, Y.; Gao, B.; Fu, X.; Ji, Y. Soft-switching AC module inverter with flyback transformer for photovoltaic power system. Przegląd Elektrotechniczny **2012**, 88, 180–184. [**Google Scholar**]

[27] Amorndechaphon, D.; Premrudeepreechacharn, S.; Higuchi, K. An improved soft-switching single-phase inverter for small grid-connected PV-system. In Proceedings of the 2008 34th Annual Conference of IEEE Industrial Electronics, Orlando, FL, USA, 10–13 November 2008; IEEE: Piscataway, NJ, USA, 2008. [**Google Scholar**]

[28] Chen, M.; Lee, X.; Tsutomu, Y. A novel soft-switching grid-connected PV inverter and its implementation. In Proceedings of the 2011 IEEE Ninth International Conference on Power Electronics and Drive Systems, Singapore, 5–8 December 2011; IEEE: Piscataway, NJ, USA, 2011. [**Google Scholar**]

[29] Meynard, T.A.; Foch, H. Multi-level conversion: High voltage choppers and voltage-source inverters. In Proceedings of the PESC'92 Record, 23rd Annual IEEE Power Electronics Specialists Conference, Toledo, Spain, 29 June–3 July 1992; IEEE: Piscataway, NJ, USA, 1992. [**Google Scholar**]

[30] Chen, A.; He, X. Research on hybrid-clamped multilevel-inverter topologies. IEEE Trans. Ind. Electron. **2006**, 53, 1898–1907. [**Google Scholar**] [**CrossRef**]