High Power Multilevel Inverters for Grid-Connected Photovoltaic Applications

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Abstract— **The current topology of multilevel converters, which seem to be perfect for use in high-power solar applications, is investigated in this paper, with the objective of reaching reduced total harmonic distortion and higher efficiency. When compared to conventional converters, multilevel converters have various advantages. Multilevel converters use a low switching frequency to produce high-quality output. It has an impact on switching losses, semiconductor switch size, and harmonic filters. This study examines the THD, efficiency, number of necessary semiconductors, and other significant parameters for various multilevel converter topologies for high-power solar applications. All topologies are simulated in the same operational conditions using MATLAB/Simulink. Finally, based on the simulation findings, the most appropriate multilevel structure is chosen.**

Keywords*— *Photovoltaic; Multilevel Converter; Qualitative Study; High Power Application

I. INTRODUCTION

The use of renewable energy sources to generate electricity has become increasingly popular in recent years [1,2]. Simultaneously, the power rating of wind turbines, photovoltaic power plants, and other renewable energy technology has increased dramatically [3,4]. Multilevel converters have become a topical and intriguing topic in the field of power electronics as a result of the increased demand for medium and high-power converters [3,4,5]. New multilayer topologies with lower THD and improved efficiency are being proposed by researchers, especially at high power levels [5].

A traditional PV plant consists of a large number of PV modules that are connected in series and parallel to generate strings and sub-arrays that feed the inverters. A low-frequency (LF) transformer connects the inverters to the medium-voltage (MV) electric grid [5,6,7,8]. The industry trend is to develop and use greater inverter ratings since price analysis shows that increasing the inverter power rating lowers the inverter cost per watt. As a result, inverters with power ratings of up to a few megawatts are currently available [5,6,7]. Designers also prefer to employ greater nominal voltages for both the DC and AC sides of the inverter, resulting in lower wire costs and power losses.These design decisions also result in smaller cross-section cables, fewer generator connection boxes, and less DC cabling, all of which save money in the long run [5,9]. As a result, multilevel architectures are becoming more common in topologies for medium-voltage grid integration of megawatt-scale PV inverters.

Many various multilevel topologies for PV applications have lately been presented by researchers [2,5,9,11-14]. Important topologies proposed for usage with PV modules include the neutral point Clamped converter (NPC) [1], cascaded H-bridge [10], Y-Connected Hybrid Cascaded [15], Capacitor Clamped [2], Z-source [16], and quasiZ-source [17]. These topologies can be investigated from a variety of perspectives. In order to determine the most appropriate structure for PV modules, we divided our analysis into two sections, each dealing with a quantitative and qualitative examination. The output specification of the converter is investigated in a quantitative analysis using Matlab/Simulink. Line voltage and current, THD, losses, and efficiency are all critical elements to consider.The features that are important to implement the converter

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 08 Issue: 05 | May - 2024 SJIF Rating: 8.448 ISSN: 2582-3930

are verified by a qualitative study. In a qualitative analysis, however, converter reliability, modularity, scalability, and functionality are the most critical factors.

II. MULTILEVELTOPOLOGYREVIEW

This section provides a brief overview of the most prevalent topologies. Figure 1 depicts the topologies considered in this paper.

A. Diode-Clamped Topology (NPC)

According to records, the first multi-level inverter was just a cascaded one developed in 1975 with diodes blocking the source [12], which was then morphed into the diode-clad multilevel inverter suggested in [1. Figure 1 illustrates the topology (a). Each of the inverter's three-phase outputs is wired to a common DC bus voltage that is split into three levels by two DC bus capacitors. Existing For high-voltage level applications, a large number of clamping diodes results in high costs and various constraints [18]. Furthermore, balancing the capacitor voltages necessitates the use of a unique control. As a result, most diode clamped multilevel inverter applications are confined to levels less than five [12,19].

B. Capacitor Clamped Topology

The capacitor clamped multilevel inverter or flying capacitor multilevel inverter [2,14,18], as shown in Fig.1(b), is another type of multi-level inverter that has a topology similar to the NPCMLI structure. Rather than clamping diodes, capacitors are used to maintain the voltages at the desired levels. [18] According to [20] and [21], it is a good replacement for NPC topology in terms of overcoming some of its flaws.

C. Cascade H-Bridge Topology

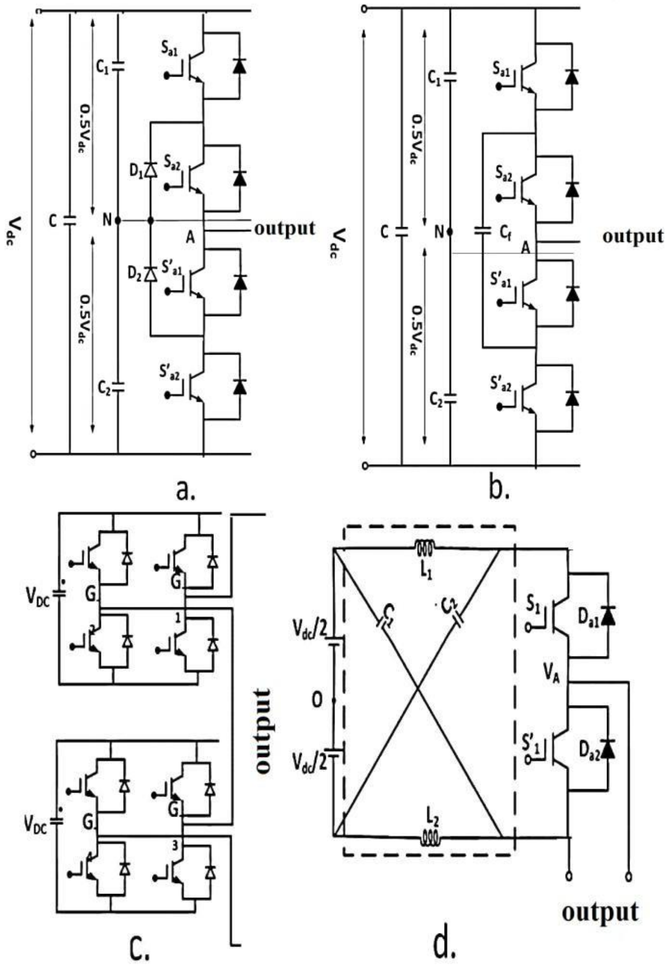
The Cascaded Multi-Cell Inverter (CMCI) suggested in [10] differs from NPCMLI and CCMLI in various ways, most notably in how the multilevel voltage waveform is built. As illustrated in Fig.1(c) [22], it generates the step waveform by cascading full-bridge inverters with different DC sources. The cascade topology enables for the use of dc sources with different voltage levels and the creation of high-resolution multilevel waveforms with a small number of components [23,24].

D. Z-source Topology

[16] introduced the impedance source or Z-source inverter for the first time, as shown in Fig.1 (d). By providing voltage boost capability in typical inverters, Z-source inverters set themselves apart from other types of inverters. Because the output voltage is lower than the DC input voltage, traditional inverters are always buck converters [18]. Furthermore, the upper and lower power switches must conduct simultaneously; otherwise, the DC source would short-circuit. As a result, a dead band is purposely given between the switching on and switching off of the complementary power switches of the identical leg, causing some deformations in the output current. The Z-source inverter [18] addresses these shortcomings.[25,26,28] provide comprehensive discussions on Z-source inverters.

E. Quasi Impedance Source or QZSI Topology

The QZSI topology, which was introduced in [17] as a derivative of the original Z-source inverter and so contains all of the ZSI's benefits, is shown in Fig.1(e). During boost mode, the impedance source or Z-source inverter has the disadvantages of discontinuous input (DC) current, high voltages across the capacitors, and increased stress on power switches [18, 26]. QZSI [26,27] overcomes these constraints. The main advantages of a QZSI are drawing continuous current from a DC source, lowering the voltage across the capacitor C2, having fewer elements and hence higher dependability, and putting lesser voltage stress on the power switches [18].



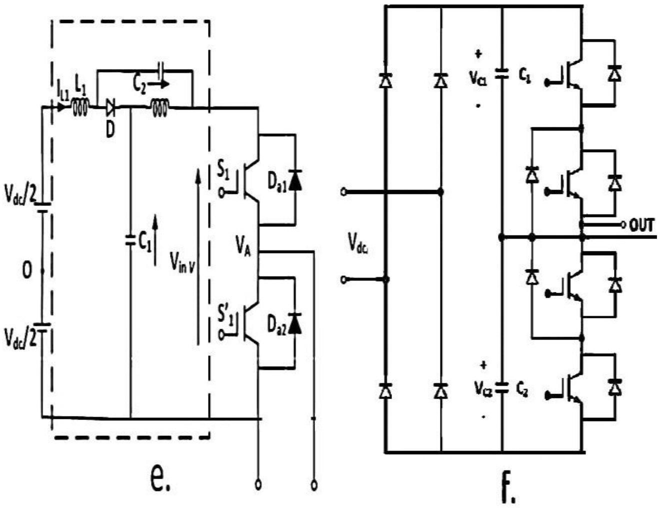


Fig1:a) NPC, b) Capacitor clamped, c)Cascade, d)Z-source, e)Quasi Z source f)Hybrid

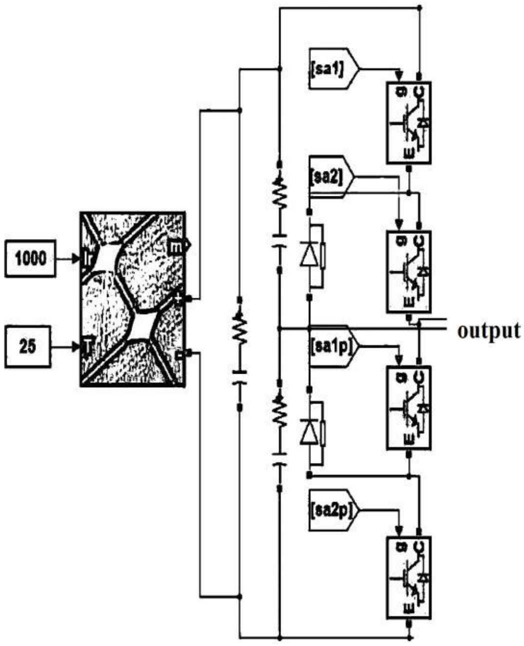


Fig.2:.Threelevel NPC, PV source model in MATLAB/Simulink.

F. Y-Connected Hybrid Cascaded Topology

This architecture is achieved by replacing the traditional two-level leg in the CMI's H-bridge module with a diode clamped or capacitor clamped multilevel leg to reduce the number of distinct DC sources. Each phase of this topology has a cascaded NPC-based H-bridge module that can produce three levels of voltage [15, 19]. Using hybrid topologies, the number of switching devices in the conversion system will be minimised.

III. RESULTS DISCUSSION

In this section, six case studies examine the most typical topologies of multilevel converters that are coupled to PV arrays. The best suited inverter configuration is discovered by comparing their output waveforms and features. All scenarios were carried out in the same way, with the same PV array source and loads, and all switches modelled as IGBTs. Canadian solar load CS5C90M is a PV array module with 40 parallel strings and 10 series linked modules per string, irradiation rate 1000, temperature of 25oC, and a three-phase resistive load of R=10(Ω).

A. Three level NPC PV source inverter

In MATLAB, a three-level NPC PV source inverter model is shown in Fig.2. The PV array and load are both connected to the inverter. Figure 3 depicts the voltage and current waveforms of this simulation.

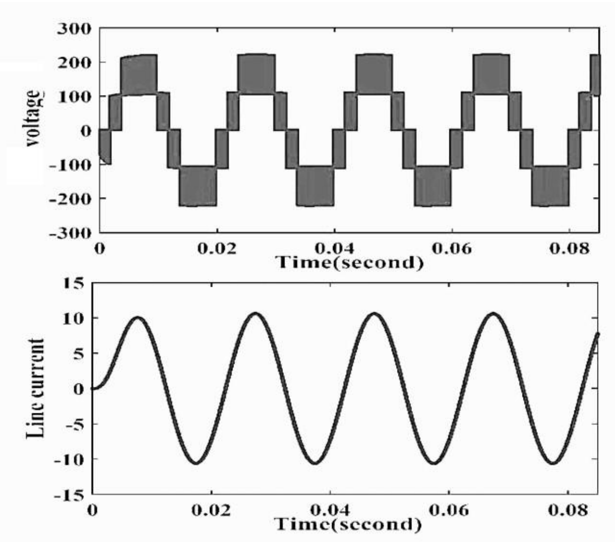


Fig.3. Three level NPC inverter voltage and current waveforms.

MATLAB/Simulink calculates the total harmonic distortion (THD) value of each waveform. For this case study, the capacitor values are 2200F, and the THD of line voltage is 36.22 percent; additionally, the inverter efficiency is computed as = 98.93 percent.

B. Capacitor clamped three level PV source inverter

Figure 4 shows a three-level capacitor clamped PV source inverter architecture. Capacitor values are in the 1000F range. Figure 5 depicts the voltage and current waveforms of this simulation. For this inverter topology,

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 08 Issue: 05 | May - 2024 SJIF Rating: 8.448 ISSN: 2582-3930

the THD line voltage is 49.89 percent, and the efficiency is computed as = 98.65 percent.

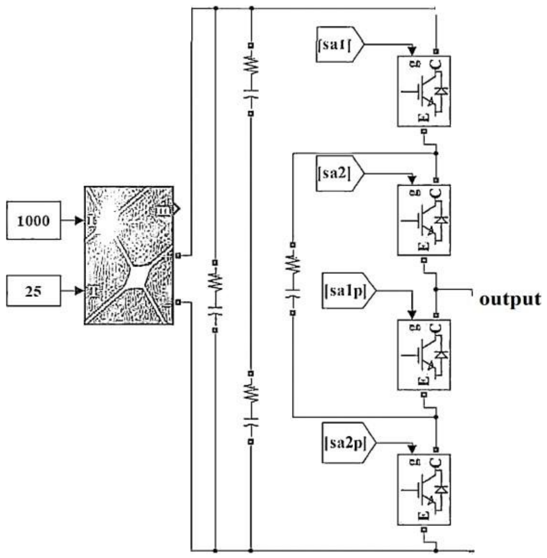


Fig. 4. Three level Capacitor clamped, PV source model in MATLAB/Simulink.

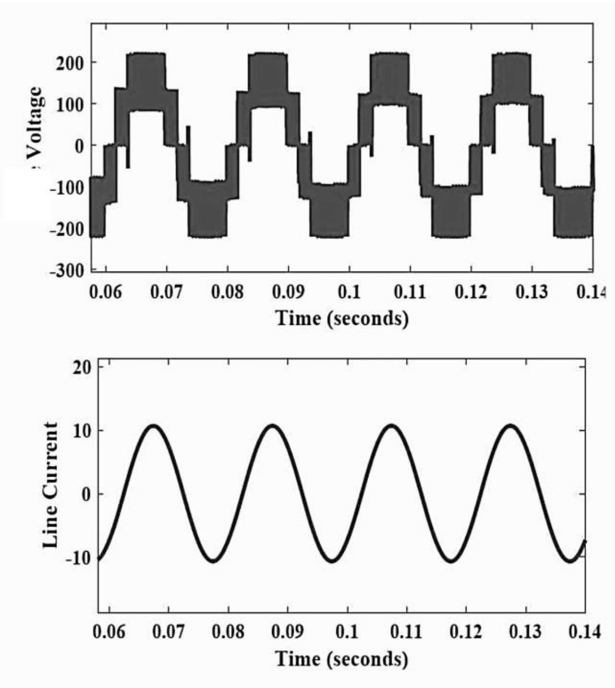


Fig. 5. Three level Capacitor clamped voltage and current waveforms.

C. Three Level Cascaded PVSource Inverter

In MATLAB, Fig.6 shows a three-level cascaded PV source inverter model, while Fig.7 shows the voltage and current waveforms. For this model, the THD line voltage is 47.18 percent, and the efficiency is computed as = 83.33 percent.

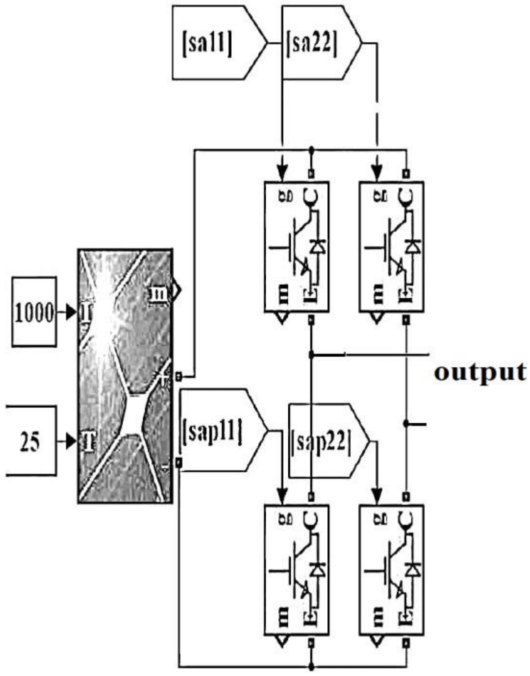


Fig. 6. Three level Cascaded PV source model in MATLAB/simulink.

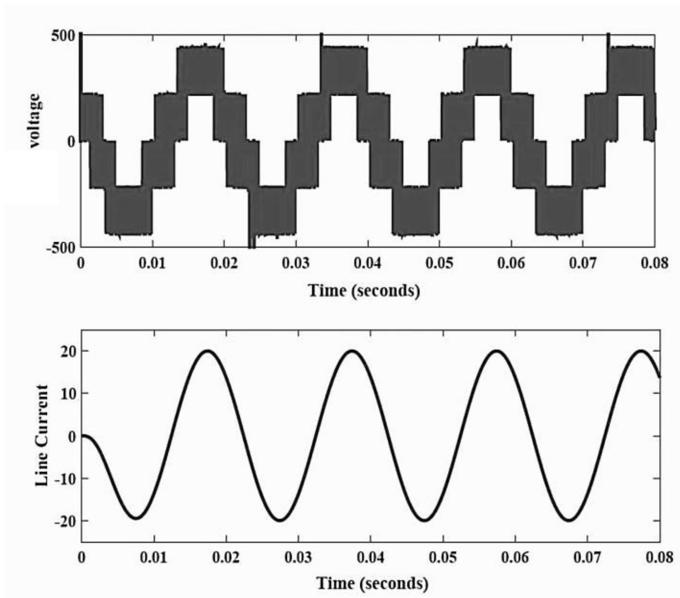


Fig. 7. Voltage and current waveforms of three level cascaded inverter.

D. Three Level Z-source PVConnected Inverters

Three level Z-source PV connected inverter as well as its output wave forms are shown in Fig.8 and 9. The inductance values are assumed to be the same equal to 0.5mH as are the capacitor values 0.4mF. THD of this modelled is measured 42.19% and its efficiency is calculated as η=99.48%.

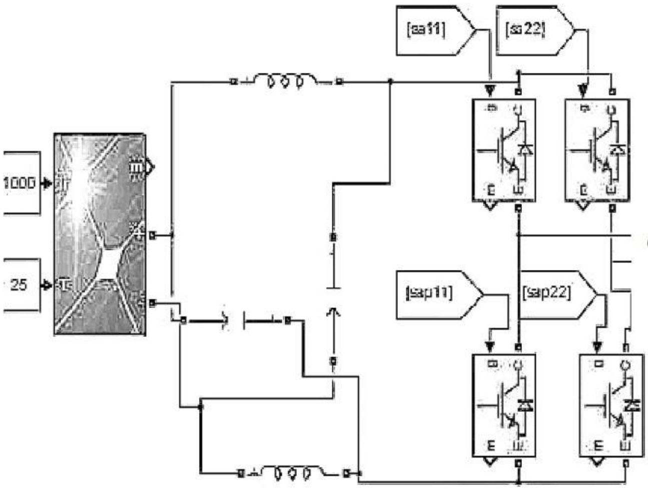


Fig. 8. Three level Z-source PV connected inverter in MATLAB/simulink.

E. Three level Quasi-Z source PV source inverter

The output waveforms of the Quasi-Z source model are displayed in Fig.11, and the output waveforms of the Quasi-Z source model are shown in Fig.10. The inductance values are expected to be the same as the capacitor values, which are 0.4mF. This model's line voltage THD and efficiency are 41.49 percent and 98.95 percent, respectively.

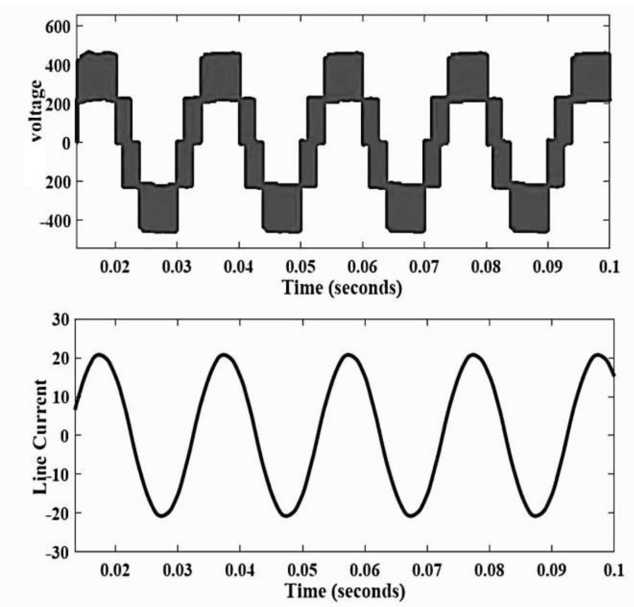


Fig. 9. Voltage and current waveforms of three level Z source inverter.

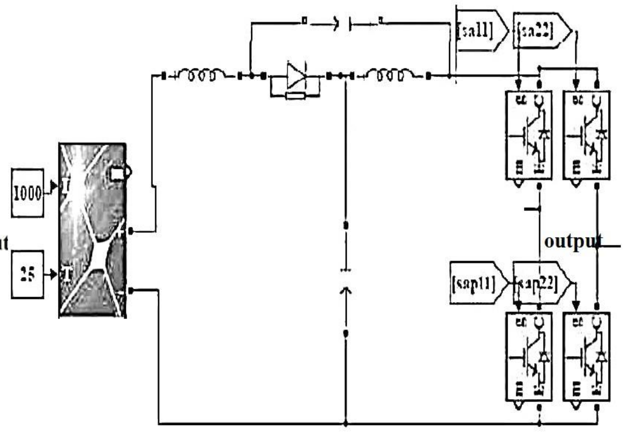


Fig. 10. Three level Quasi Z source PV connected model in MATLAB/simulink.

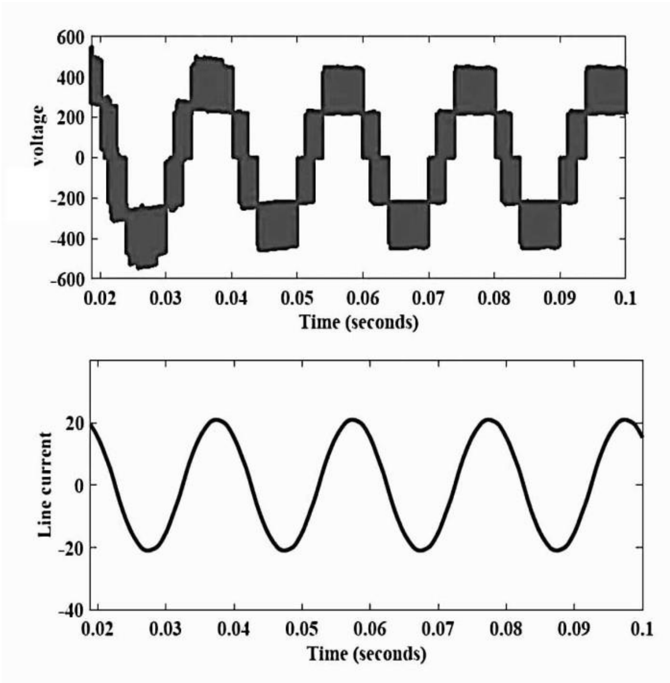


Fig. 11. Voltage and current waveforms of three level Quasi Z source.

F. Y-Connected three level Hybrid Cascaded PV source inverter (CMI)

Figures 12 and 13 depict a three-level hybrid cascaded NPC PV source inverter model, as well as its voltage and current waveforms. The capacitors have a temperature of 2200F, a THD of 37.57 percent, and an efficiency of 81.8 percent. Hybrid topologies are commonly employed to provide high-level output voltage. This concept was first presented in [19], with 17-level CMI being the best fit for PV power generation. The low THD rate of this topology is confirmed by its simulation result.

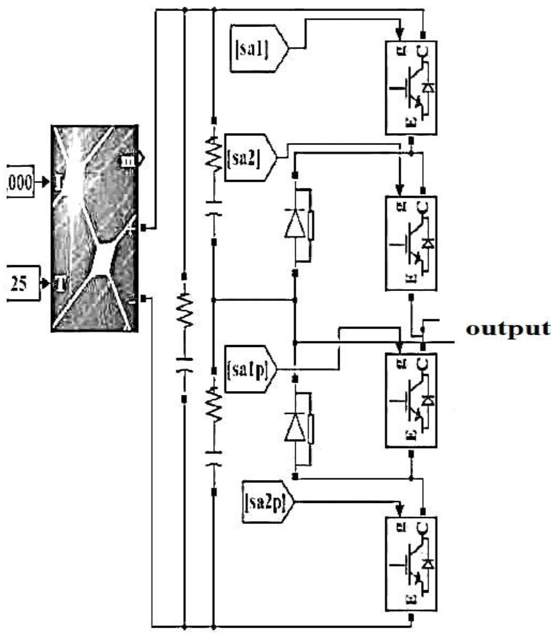


Fig. 12. Three level Hybrid PV source inverter in MATLAB/simulink.

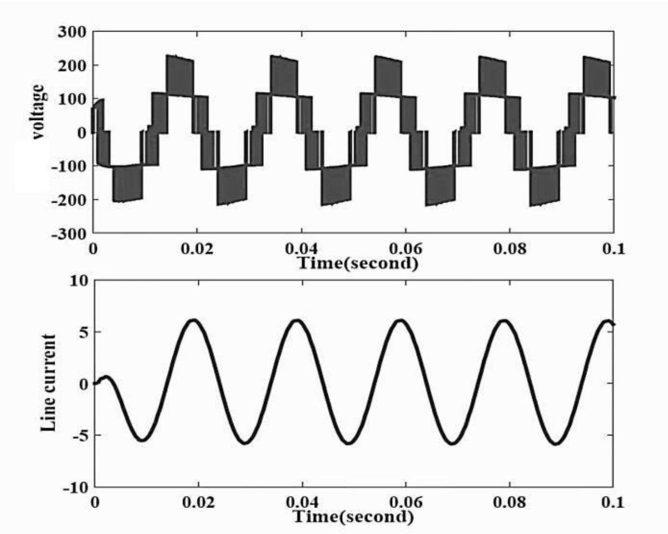


Fig. 13. Voltage and current waveforms of three level hybrid model.

IV. CONCLUSION

In the case of high - power applications, the price analysis of a converter reveals that multilayer converters are more cost effective than conventional versions. Different multilevel converter topologies were researched and compared in this study in order to discover the most acceptable topology for use in PV applications. Six multilevel topologies that have been proposed in the literature were studied. The investigation was carried out using both quantitative and qualitative methods. Important output parameters of suggested multilevel topologies were examined using a quantitative approach.At the same time, MATLAB and Simulink are being used. In addition, a qualitative analysis was conducted to evaluate some of the pros and disadvantages of each topology that were not taken into account in the simulation. In compared to other types of converters, the results show that quasi-Z-source converters work better.

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