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# Harmonics mitigation technique for asymmetrical multilevel inverter fed by photovoltaic sources

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**ABSTRACT**

A multilevel inverter is an electrical device that converts a DC voltage into a higher AC voltage by generating a stepped waveform with several voltage levels. Unlike traditional inverters that produce a square wave or a pulse-width modulated (PWM) waveform with only two voltage levels, multilevel inverters can generate waveforms with three or more levels, resulting in reduced harmonic distortion, improved efficiency, and decreased electromagnetic interference. The design and control of multilevel inverters are active research areas that aim to enhance their performance, reliability, and scalability. In this research, a 31-level asymmetric cascaded multilevel inverter is suggested. The proposed multilevel inverter (MLI) system employs four photovoltaic cells as dc sources with structure of (1:2:4:8) Vdc. The system is modeled by MATLAB/Simulink and total harmonic distortion (THD) values of the output voltage and current are 1.106% for resistive load, and 1.35% and 0.403% for inductive load. These outcomes demonstrate the recommended circuit's efficacy and demonstrate its suitability for medium- and high-power applications.



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## 1. INTRODUCTION

The increased need for electrical energy causes the conventional energy sources to quickly run out of fuel. Another result of this is an in-depth examination of the production of electricity utilizing renewable energy sources (RESs). Power electronics and power system researchers are giving more and more interest in solar and wind energies, the two primary renewable sources, in order to replace their heavy dependency on changing environmental circumstances [1]–[3]. To improve the power quality and extract the most power possible from RESs, new power converter technologies are necessary [4]–[6]. These technologies are also necessary for the desired operation, control, and power management. An inverter is a crucial component of a renewable energy power conversion system since it transforms DC electricity into AC as needed by the grid and loads. In most utility applications, a typical two- or three-level inverter is used [7]. Nevertheless, because the output from these inverters has a higher harmonic content, it is desirable to use expensive and considerable low pass passive filters before transmitting the electricity to the utility grid. Also, these inverters are not favored for usage in high power applications due to high voltage stress and severe switching loss [8]. Multilevel inverters (MLIs) are the best alternative power circuits to deal with medium and high power applications. The MLI topology concept was initially introduced in the early part of 1975 [9] before being modified [10], [11]. These MLIs attract more attentions because of their ability to function at high voltages, low switching losses, great efficiency, and little electromagnetic interference. In addition to improving power quality by subsequently reducing harmonic distortion, MLIs are able to meet the growing need for power rating. MLIs are often employed in medium and high power conversion systems because they can supply single or multiple dc voltages through low switching frequency operation and a high-quality staircase ac voltage from different connections of power semiconductor switches [12], [13]. Batteries, fuel cells, super capacitors, renewable energy systems, and other devices are examples of potential input dc sources. Massive electric motors, renewable energy conversion, propulsion, electric automobiles, active power filters, high voltage direct current (HVDC), and flexible AC transmission systems (FACTs) are just a few of the many applications where MLIs are employed extensively [14]–[16]. One of an MLI's important characteristics is its ability to function at both fundamental and high switching frequencies using pulse-width modulated (PWM) approaches, as well as produce waveforms with reduced distortion and total harmonic distortion (THD) content [12]-[15]. Nevertheless, a common disadvantage is the demand for several power semiconductor switches. Each switch needing a gate driver circuit makes the system more complicated and costly. Hence, one of the key research questions is how to create MLIs with fewer components that can offer greater output voltage levels. Controlling and modifying these inverters became more difficult with the development of MLI topologies. There are several substantial lower order harmonics in the stepped output voltage waveform of an MLI. Such harmonics primarily cause voltage changes, an increase in loss, malfunctions, and they also have an effect on the electricity's quality. A MLI with a specific control mechanism can be used to handle the aforementioned issues in an efficient manner [17].

Alishah *et al.* in 2017 [18] proposed a cascaded switch ladder MLI was discussed with ten power switches and six input DC sources to produce 31-level output voltage with THD of 3.26%. Antar in 2018 [19] proposed a cascaded H-bridge used 12-swithes and 3-input DC voltage sources to produce a 27-level output voltage was suggested. The THD of the output voltage was 1.165% and 0.674% for single and three phase three respective. A modified circuit used twelve switches and six input DC sources was suggested and simulated by MATLAB to get 31-level output voltage based on phase shifted multicarrier PWM method and the THD of the output voltage was 2.15% [20]. A power circuit uses 12-switches, 16-diodes and 4-input DC sources was built to obtain 31-level output voltage based on alternate phase opposition disposition PWM (APOD-PWM) switching method [21]. The THD obtained for the output voltage is 1.86%. Choudhury in 2021 [22] proposed a 31-level asymmetrical switch-diode uses 8-switches, 4-diodes and 4-input DC sources was proposed. The THD of output voltage was 2.88%. A MLI with reduced number of switches was proposed in [23]. This circuit built based on 12-switches to provide 13-level output voltage depending on multicarrier PWM method. The THD value of the output voltage was 11.25% and with efficiency of 38.16% for resistive load. The same circuit was modified to provide 31-level output with 14-switches and the THD value was 8.45% with efficiency 93.5%. Shah *et al.* in 2022 [24], proposed a 12-power switches with 4-isolated DC sources was built to produce a 31-level output voltage at modulation index of (m=1) and the THD value was 2.11%. Corresponding to previous studies, the principal purpose of this study is to provide high level output voltage with less switching devices and low THD. In the same year, in [25] a 7-switches, 3-diode and 3-DC sources using modified absolute sine PWM controller was modeled and investigated practically to get different output levels with zero-level state and none zero level state. The THD value of the output voltage was 3.4053% for zero-level state and 3.0252% for none zero state. Design single and three phase inverter to generate 25-level using a 12-switches, and 4-PV sources was built based on MSPWM switching method [26]. a single-phase system's output voltage total harmonic distortion obtained for the output voltage is 1.2% while a three-phase system's values are 1.07%. Figure 1 shows the proposed MLI circuit layout.

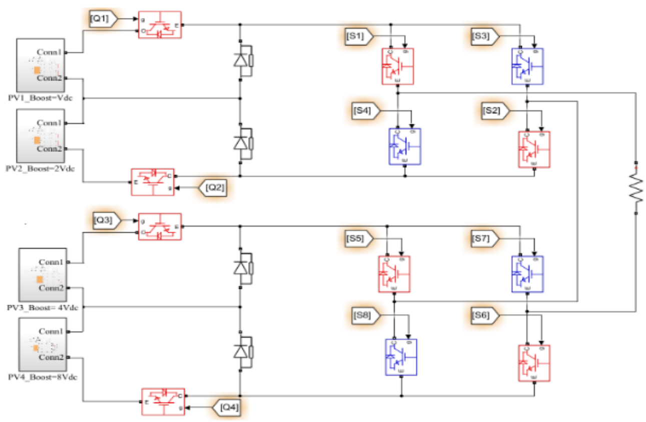


Figure 1. The proposed MLI circuit layout

## 2. PROPOSED 31-LEVEL INVERTER TOPOLOGY
### 2.1. Solar energy

Solar energy is the globally most accessible renewable energy source [27]. The unlimited supply and environmental friendliness of the photovoltaic (PV) system are the reasons why it is becoming more and more popular. PV systems have a long lifetime with a little maintenance. Solar radiation and temperature can affect PV systems since they depend so much on certain atmospheric conditions [28]. PV cells transform radiation energy into electrical energy [29]. There is only one maximum power point (MPP) and tracking this point is very important, so that methods that used to track this point called maximum power point tracking (MPPT) techniques. The MPPT is a technique used in PV systems to optimize the power output from a solar panel by finding and maintaining the point of maximum power transfer. In recent years, researchers have focused on developing new and improved MPPT algorithms to improve the efficiency and performance of PV systems. The most commonly used MPPT algorithms for PV systems are the perturb and observe (P&O), incremental conductance, hill climbing algorithms, global peak searching, modified perturb and observe, adaptive perturb and observe, tip speed ratio (TSR) method, maximum power extraction control (MPEC) method, and the pitch angle control (PAC) method, as well as newer algorithms such as artificial neural networks, fuzzy logic control, and particle swarm optimization [30], [31]. Consequently, the MPPT techniques are very important to minimize the solar array cost by decreasing the number of solar modules required to achieve the desired output power. Since, the PV is not always operating in its maximum power point [32], but with the use of an MPPT it is possible to force the PV to extract the maximum power at the given irradiance level. In this study P&O algorithm is used to track the MPP due to its simplicity and ease of implementation. The four sets of PV power systems employed are shown in Figure 2 as having the attributes shown, where Figure 2(a) shows the voltage and current characteristics as well as the voltage and power of PV1, while Figure 2(b) shows the voltage and current characteristics as well as the voltage and power of PV2, while Figure 2(c) shows the voltage and current characteristics as well as the voltage and power of PV3, and Figure 2(d) shows the voltage and current characteristics as well as the voltage and power of PV4. The specifications of this PV cells are explained in Table 1.

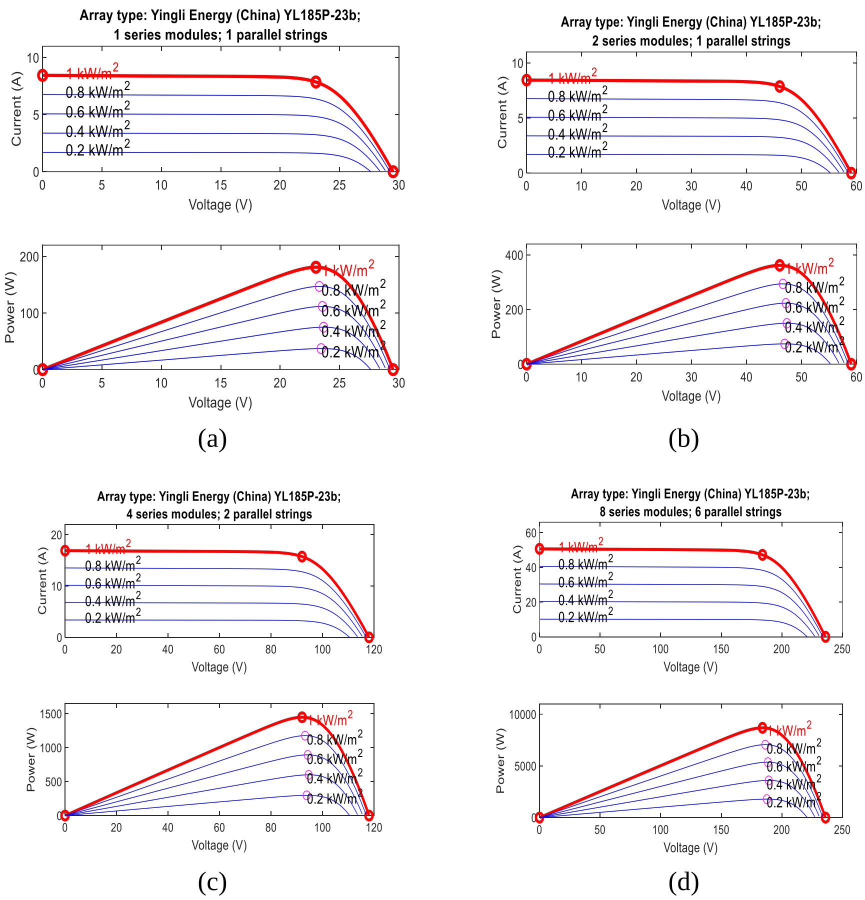


Figure 2. The I-V and P-V characteristics of the used PV cells: (a) PV1, (b) PV2, (c) PV3, and (d) PV4

Table 1. The PV panel specifications and parameters of boost converter

| Components | Symbols | Value |
|---|---|---|
| Yingli energy (China) YL170P-23b | PV1 | 1 series x 1 parallel |
| | PV2 | 2 series x 1 parallel |
| | PV3 | 4 series x 2 parallel |
| | PV4 | 8 series x 6 parallel |
| Maximum power | $P_{Max}$ (W) | 180 |
| Open circuit voltage | Voc (V) | 29.5 |
| Short –circuit current | Isc (A) | 4.45 |
| Voltage at maximum power point | Vmp (V) | 23 |
| Current at maximum power point | Imp (A) | 7.87 |
| Input capacitor | $C_{PV}$ (mF) | 1 |
| Inductor | $L_{Boost}$ (mH) | 1 |
| Output capacitor | $C_{Boost}$ (mF) | 2 |
| Duty ratio | D | 0.75 |
| Input boost converter | Vin (V) | 23 |
| Output boost converter | Vout (V) | 30, 60, 120, 240 |

### 2.2. Boost converter

The boost DC-DC converter circuit is one of the most popular converters that used to raise and regulate the DC output voltage of the PV solar system. Boost converters are commonly used in applications such as battery-powered devices, LED lighting, and power supplies for electronics. They are also used in renewable energy systems such as solar and wind power to boost the voltage of the DC output to match the required input voltage of the grid. Figure 3 illustrates the boost converter's circuit diagram. Designing a boost converter involves selecting components and determining the values of the various components based on the desired output voltage and current.

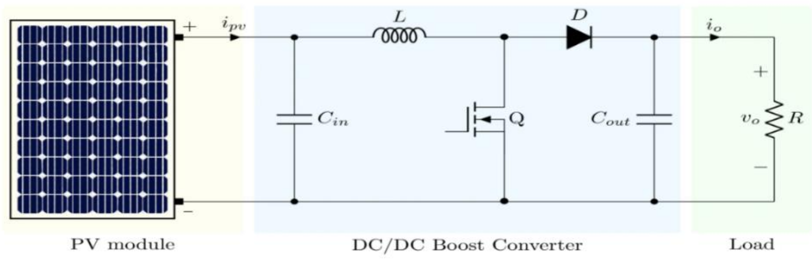


Figure 3. DC-DC boost converter circuit (PV_boost)

The duty cycle ($D$) of the boost converter, the minimum boost inductor ($L_{min}$), and the output capacitor ($C$) of this converter are determined as (1)-(3) [33]:

$$D = 1 - \frac{V_{in}}{V_{out}} \tag{1}$$

$$L_{min} = \frac{D\,(1-D)^2\,R}{2\,f} \tag{2}$$

$$C = \frac{D}{R\left(\frac{\Delta V_O}{V_O}\right)f} \tag{3}$$

Where $\left(\frac{\Delta V_O}{V_O}\right)$ is the outputs voltage ripple and calculated at 1%, ($R$) is output resistance, and ($f$) is the switching frequency.

### 2.3. Multilevel inverter circuit

A multilevel inverter is a power electronic device used in electrical power conversion systems. A multilevel inverter uses multiple levels to synthesize the output waveform. This technique provides several advantages, including enhanced output waveform and power system quality, decreased voltage stress, and higher efficiency [34]. MLIs are widely used in high-power applications such as motor drives, renewable energy systems, and utility applications. In this study, a MLI circuit is modified to produce 31-level output AC voltage using 12-switches, 4-diodes, and 4-DC sources for resistive load (Figure 1). While with inductive load, the four diodes should be replaced with four IGBTs due to charge and discharge cases that causes overshoot during changing form +ve to –ve states (Figure 4). The input DC voltage sources are four asymmetrical isolated DC sources and arranged according to (1:2:4:8) $V_{dc}$, which is supplied from set of solar PV systems with boost converters. The switching patterns that required to achieve 31-level output voltage are shown in Table 2. Figure 5 depicts the current path diagram in various operation modes based on the switching states listed in Table 2, where Figure 5(a) depicts the current path to obtain an output voltage of +12 Vdc, Figure 5(b) depicts the current path to obtain an output voltage of +6 Vdc, Figure 5(c) depicts the current path to obtain an output voltage of -3 Vdc, and Figure 5(d) depicts the current path to obtain an output voltage of -7 Vdc.

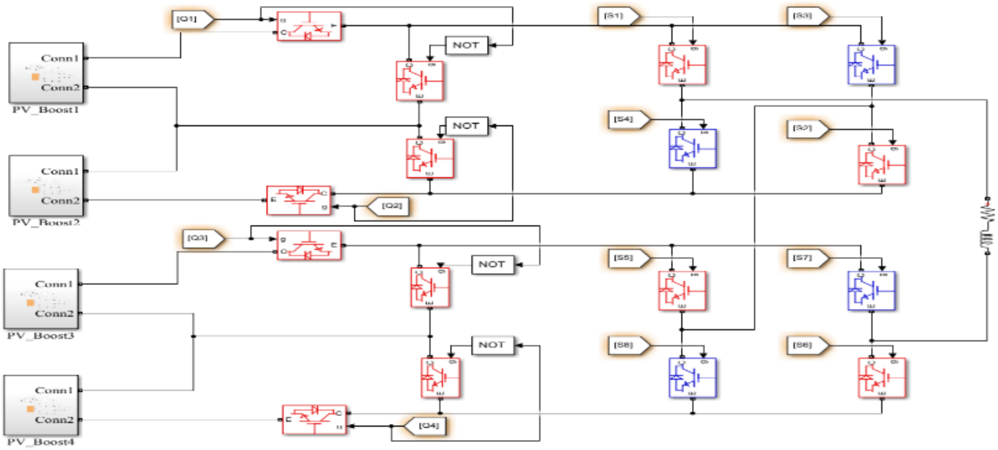


Figure 4. The proposed MLI a 31-level output voltage circuit with inductive load

Table 2. Switches states of 31-level output voltage

| State | Conducting switches: 1=ON; 0=OFF | | | | | | | | | | | | $V_{Out}$ ($V_{dc}$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | $S_6$ | $S_7$ | $S_8$ | $Q_1$ | $Q_2$ | $Q_3$ | $Q_4$ | |
| 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 15 |
| 2 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 14 |
| 3 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 10 | 1 | 1 | 1 | 13 |
| 4 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 12 |
| 5 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 11 |
| 6 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 10 |
| 7 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 9 |
| 8 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 8 |
| 9 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 7 |
| 10 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 6 |
| 11 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 5 |
| 12 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 4 |
| 13 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 3 |
| 14 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 2 |
| 15 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |
| 16 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | -1 |
| 18 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | -2 |
| 19 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | -3 |
| 20 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | -4 |
| 21 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | -5 |
| 22 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | -6 |
| 23 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | -7 |
| 24 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | -8 |
| 25 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | -9 |
| 26 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | -10 |
| 27 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | -11 |
| 28 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | -12 |
| 29 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | -13 |
| 30 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | -14 |
| 31 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 15 |

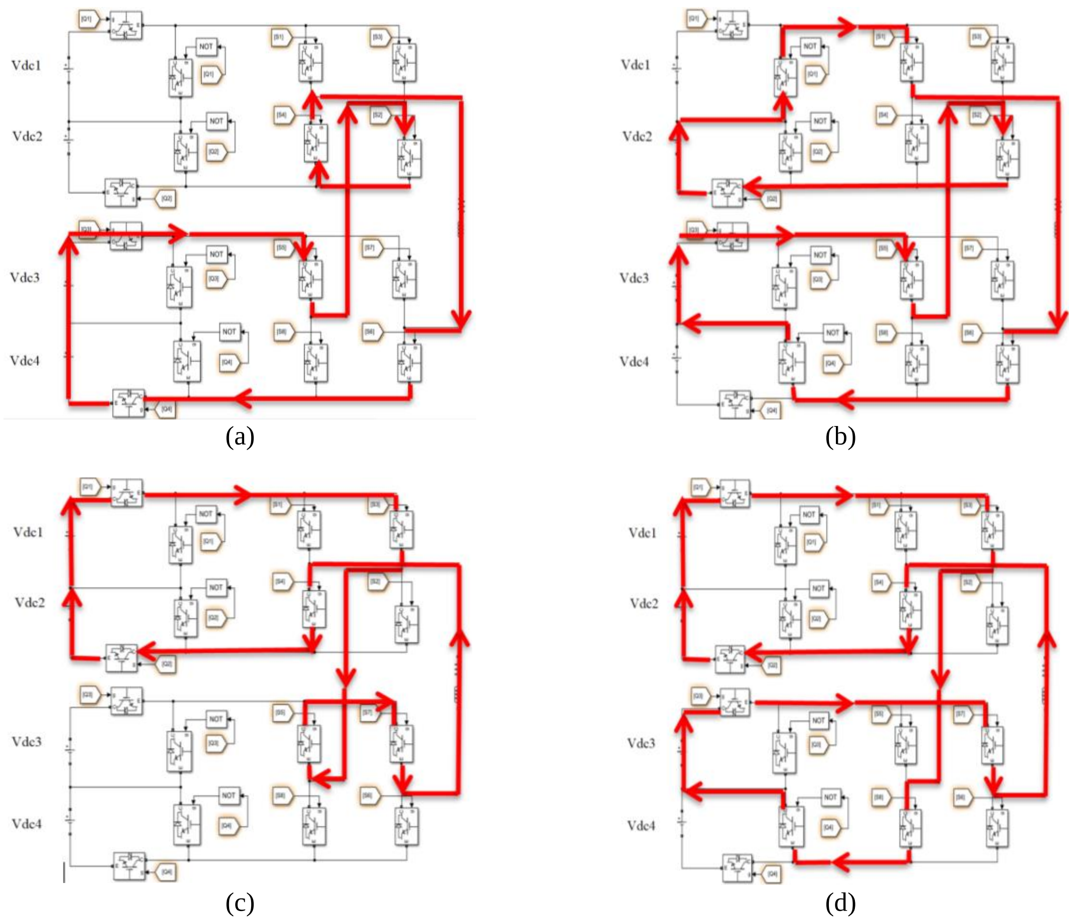

Figure 5. Current path with output voltage of; (a) +12 Vdc, (b) +6 Vdc, (c) -3 Vdc, and (d) -7 Vdc

### 2.4. Control strategy

Sinusoidal pulse width modulation (SPWM) is a technique for producing a sinusoidal waveform by varying the width of a series of pulses. SPWM is a popular technique in power electronics and control applications. One of the advantages of SPWM is that it generates a nearly sinusoidal output waveform, which reduces harmonic distortion and produces a cleaner signal. Multicarrier PWM is a technique used to modulate multiple carrier signals to control the output voltage of an inverter. In multicarrier modulation, the data is split into several subcarriers, and each subcarrier is modulated independently. Sinusoidal pulse width modulation based on multicarrier (MC-SPWM) is a combination of these two modulation techniques. An m-level inverter needs (m-1) triangle carriers. Based on the arrangement of the carrier signals, the MC-SPWM control technique can be split into level-shifted and phase-shifted [35]. In this study, MC-SPWM algorithm based on phase disposition (PD-PWM) technique is adopted to get the 31-level voltage.

## 3. SIMULATION RESULTS

The modified cascade H-bridge 31-level inverter is developed and reformed to achieve the needed levels. MATLAB/Simulink is used to examine the performance of the proposed power circuit depicted in Figure 4. The selected solar PV set provides DC voltage of 23 V and current of 7.87 A and the step-up converter circuits boosted the output voltages to 30 V, 60 V, 120 V, and 240 V according to the structure (1:2:4:8) Vdc as explained in Table 1. Figure 6 presents the results of PV and boost converter. Figure 7 show the voltage and current waves of the 31-level inverter Figure 7(a) for R and Figure 7(b) for RL-load at 25 °C and 1000 w/m$^{2,}$ respectively. The FFT analysis of the voltage and current waveforms are explained in Figure 8 for (a) R-load and (b) RL-load, respectively. The THD value for the output voltage and current of the 31-level inverter for R load is 1.106% while for RL-load are 1.35% and 0.403%, respectively. Table 3 illustrates the comparison results between the two suggested types. These findings demonstrate the efficacy of the proposed circuit.

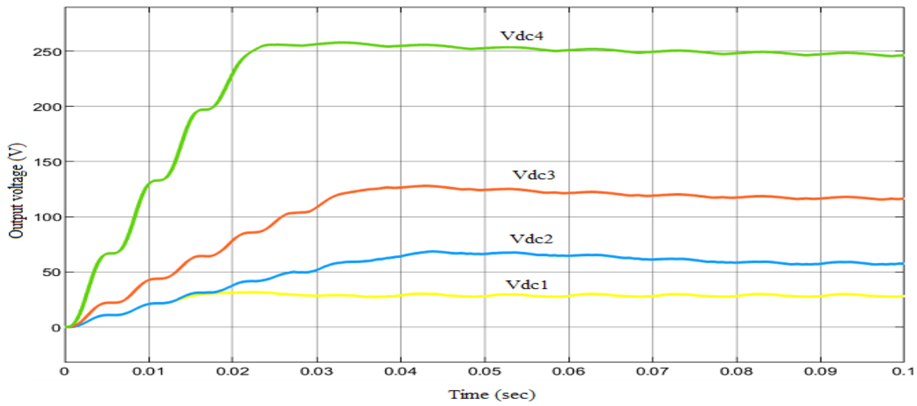


Figure 6. Simulated output of the boost converters

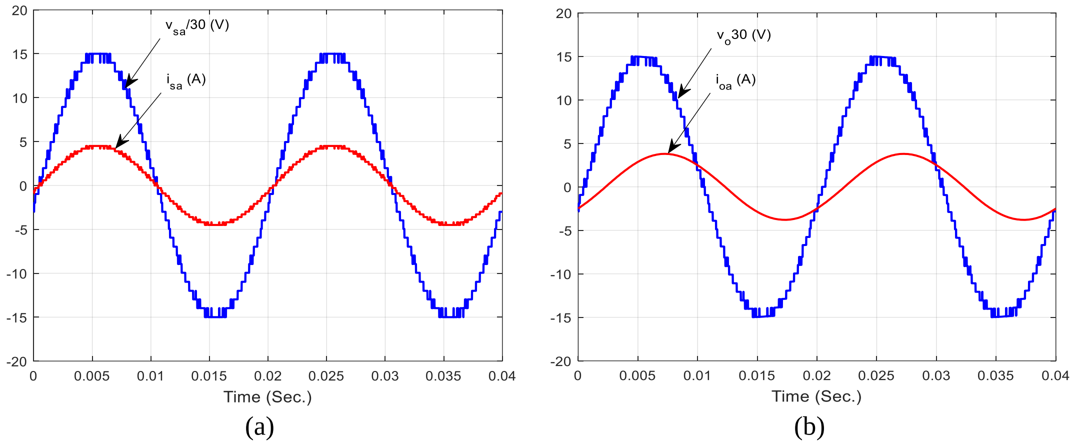


Figure 7. Voltage and current waves of the 31-level inverter for; (a) R-load and (b) RL-load

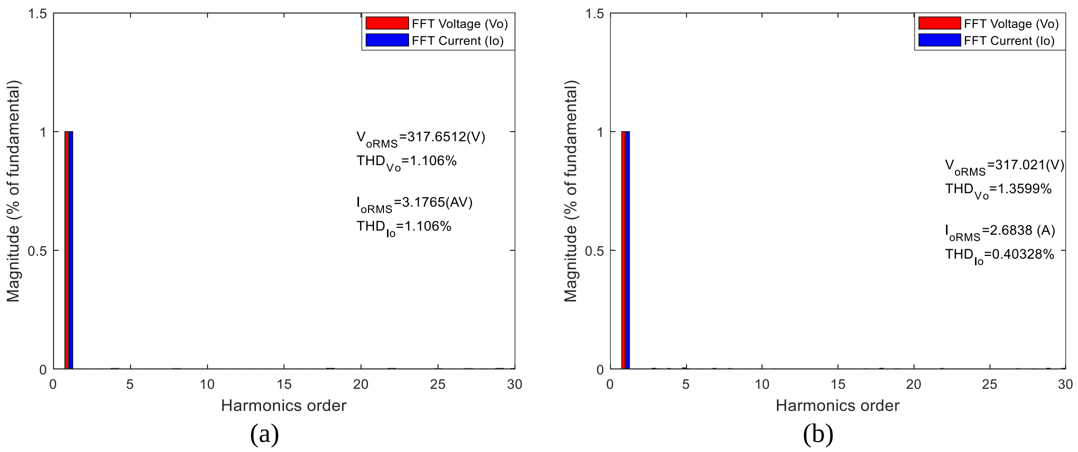


Figure 8. The FFT analysis of the 31-level output voltage and current for; (a) R-load and (b) RL-load

Table 3. Compares between the two suggested types

| Parameters | Sources | No of switches | Diodes | THD-V (%) | THD-I (%) |
|---|---|---|---|---|---|
| 31-Level inverter (R-load) | 4 | 12 | 4 | 1.106 | 1.106 |
| 31-Level inverter (RL-load) | 4 | 16 | 0 | 1.35 | 0.403 |

## 4. CONCLUSION

Based on asymmetrical structure of the PV cells sources, this study has been built to get 31-level inverter. From several perspectives, the suggested generic topology was compared to various types of published topologies in the literature. The suggested topology requires fewer IGBTs, power diodes, driver circuits, and dc voltage sources, according to the comparative findings. Furthermore, the magnitude of the switches' blocking voltage is less than that of traditional topologies. According to IEEE-519 standard, the THD values of the output voltage and current at resistive and inductive loads without any filters are within standards. These results verify that these circuits can be used safely with medium and high power applications due to good power quality.

## REFERENCES


[1] O. Ellabban, H. A-Rub, and F. Blaabjerg, "Renewable energy resources: Current status, future prospects and their enabling technology," *Renewable and Sustainable Energy Reviews*, vol. 39, pp. 748–764, Nov. 2014, doi: 10.1016/j.rser.2014.07.113.

[2] P. R. Kareem and A. M. T. I. Alnaib, "PEM Fuel Cell Powered Multilevel Converter," *Anbar Journal of Engineering Sciences*, vol. 9, no. 1, pp. 300–307, Nov. 2018, doi: 10.37649/aengs.2018.147746.

[3] K. Kumar, N. R. Babu, and K. R. Prabhu, "Design and Analysis of RBFN-Based Single MPPT Controller for Hybrid Solar and Wind Energy System," in *IEEE Access*, vol. 5, pp. 15308-15317, 2017, doi: 10.1109/ACCESS.2017.2733555.

[4] K. K. Gupta and S. Jain, "Comprehensive review of a recently proposed multilevel inverter," *IET Power Electronics*, vol. 7, no. 3, pp. 467–479, Mar. 2014, doi: 10.1049/iet-pel.2012.0438.

[5] S. S. Lee, "A Single-Phase Single-Source 7-Level Inverter With Triple Voltage Boosting Gain," in *IEEE Access*, vol. 6, pp. 30005-30011, 2018, doi: 10.1109/ACCESS.2018.2842182.

[6] R. R. Karasani, V. B. Borghate, P. M. Meshram, H. M. Suryawanshi, and S. Sabyasachi, "A Three-Phase Hybrid Cascaded Modular Multilevel Inverter for Renewable Energy Environment," in *IEEE Transactions on Power Electronics*, vol. 32, no. 2, pp. 1070-1087, Feb. 2017, doi: 10.1109/TPEL.2016.2542519.

[7] A. M. T. I. AL-Naib, "Speed Control of Three-Phase Induction Motor Based on V/F Technique," *Al-Kitab Journal for Pure Sciences*, vol. 1, no. 1, pp. 1–10, Dec. 2017, doi: 10.32441/kjps.v1i1.85.

[8] H. Vadizadeh, N. Farokhniah, H. Toodeji, and A. Kavousi, "Formulation of line-to-line voltage total harmonic distortion of two-level inverter with low switching frequency," *IET Power Electronics*, vol. 6, no. 3, pp. 561–571, Mar. 2013, doi: 10.1049/iet-pel.2012.0019.

[9] R. H. Baker and L. H. Bannister, ''Electric power converter,'' U.S. Patent 3,867,643A, Feb. 18, 1975.

[10] A. M. T. Ibraheem, L. A. Mohammed, and Q. H. Ali, "Implementation of Phase Shifted Carrier Modulation Technique for Cascaded Five-Level Inverter Using FPGA," *IOP Conference Series: Materials Science and Engineering*, vol. 881, Baghdad, Iraq, 2020, doi: 10.1088/1757-899X/881/1/012127.

[11] M. D. Manjrekar, P. K. Steimer, and T. A. Lipo, "Hybrid multilevel power conversion system: a competitive solution for high-power applications," in *IEEE Transactions on Industry Applications*, vol. 36, no. 3, pp. 834-841, May-June 2000, doi: 10.1109/28.845059.

[12] L. G. Franquelo, J. Rodriguez, J. I. Leon, S. Kouro, R. Portillo, and M. A. M. Prats, "The age of multilevel converters arrives," in *IEEE Industrial Electronics Magazine*, vol. 2, no. 2, pp. 28-39, Jun. 2008, doi: 10.1109/MIE.2008.923519.

[13] VJ. Rodriguez *et al.*, "Multilevel Converters: An Enabling Technology for High-Power Applications," in *Proceedings of the IEEE*, vol. 97, no. 11, pp. 1786-1817, Nov. 2009, doi: 10.1109/JPROC.2009.2030235.

[14] S. De, D. Banerjee, K. S. Kumar, K. Gopakumar, R. Ramchand, and C. Patel, "Multilevel inverters for low-power application," *IET Power Electronics*, vol. 4, no. 4, p. 384, 2011, doi: 10.1049/iet-pel.2010.0027.

[15] A. M. T. I. Al-Naib and A. G. Abdullah, "Practical implementation of modified converter," *Al-kadhum 2nd international Conference on Modern Applications of Information and Communication Technology*, 2023, doi: 10.1063/5.0119301.

[16] Z. Zheng, K. Wang, L. Xu, and Y. Li, "A Hybrid Cascaded Multilevel Converter for Battery Energy Management Applied in Electric Vehicles," *in IEEE Transactions on Power Electronics*, vol. 29, no. 7, pp. 3537-3546, Jul. 2014, doi: 10.1109/TPEL.2013.2279185.

[17] S. Schulz, M. Becker, M. R. Groseclose, S. Schadt, and C. Hopf, "Advanced MALDI mass spectrometry imaging in pharmaceutical research and drug development," *Current Opinion in Biotechnology*, vol. 55, pp. 51–59, 2019, doi: 10.1016/j.copbio.2018.08.003.

[18] R. S. Alishah, S. H. Hosseini, E. Babaei, and M. Sabahi, "Optimal Design of New Cascaded Switch-Ladder Multilevel Inverter Structure," *in IEEE Transactions on Industrial Electronics*, vol. 64, no. 3, pp. 2072-2080, March 2017, doi: 10.1109/TIE.2016.2627019.

[19] R. K. Antar, "Multilevel inverter with unequal and selected DC voltage sources using modified absolute sinusoidal PWM technique," *2018 1st International Scientific Conference of Engineering Sciences - 3rd Scientific Conference of Engineering Science (ISCES)*, Diyala, Iraq, 2018, pp. 62-67, doi: 10.1109/ISCES.2018.8340529.

[20] K. Thakre, K. B. Mohanty, A. Chatterjee, and V. S. Kommukuri, "A modified circuit for symmetric and asymmetric multilevel inverter with reduced components count," *International Transactions on Electrical Energy Systems,* vol. 29, no. 6, Mar. 2019, doi: 10.1002/2050-7038.1201.

[21] M. H. Mondol, M. R. Tür, S. P. Biswas, M. K. Hosain, S. Shuvo, and E. Hossain, "Compact Three Phase Multilevel Inverter for Low and Medium Power Photovoltaic Systems," in *IEEE Access*, vol. 8, pp. 60824-60837, 2020, doi: 10.1109/ACCESS.2020.2983131.

[22] S. Choudhury *et al.*, "Harmonic Profile Enhancement of Grid Connected Fuel Cell through Cascaded H-Bridge Multi-Level Inverter and Improved Squirrel Search Optimization Technique," *Energies,* vol. 14, no. 23, p. 7947, Nov. 2021, doi: 10.3390/en14237947.

[23] N. S. Solanki and A. K. Jha, ''Reduced Number of Switches of 31-Level Cascades Multilevel Inverter,'' *Article, GSJ*, vol. 10, no 6, June, 2022.

[24] M. J. Shah, K. S. Pandya, and P. Chauhan, "An MPPT-based 31-Level ADC Controlled Micro-Inverter," *Engineering, Technology & Applied Science Research*, vol. 12, no. 5, pp. 9149–9154, Oct. 2022, doi: 10.48084/etasr.5199.

[25] R. K. Antar, T. A. Hussein, and A. M. Abdullah, "Design and implementation of reduced number of switches for new multilevel

inverter topology without zero-level state," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 13, no. 1, p. 401, Mar. 2022, doi: 10.11591/ijpeds.v13.i1.pp401-410.
[26] A. R. Ali, A. A. Abdulghafoor, and R. K. Antar, "Design a 25-level inverter topology with less switching devices fed by PV systems," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 14, no. 3, p. 1816, Sep. 2023, doi: 10.11591/ijpeds.v14.i3.pp1816-1824.
[27] J. Mohtasham, "Review Article-Renewable Energies," *Energy Procedia*, vol. 74, pp. 1289–1297, Aug. 2015, doi: 10.1016/j.egypro.2015.07.774.
[28] J.-S. Ko, J.-H. Huh, and J.-C. Kim, "Overview of Maximum Power Point Tracking Methods for PV System in Micro Grid," *Electronics*, vol. 9, no. 5, p. 816, May 2020, doi: 10.3390/electronics9050816.
[29] B. Subudhi and R. Pradhan, "A Comparative Study on Maximum Power Point Tracking Techniques for Photovoltaic Power Systems," in *IEEE Transactions on Sustainable Energy*, vol. 4, no. 1, pp. 89-98, Jan. 2013, doi: 10.1109/TSTE.2012.2202294.
[30] T. Esram and P. L. Chapman, "Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques," in *IEEE Transactions on Energy Conversion*, vol. 22, no. 2, pp. 439-449, June 2007, doi: 10.1109/TEC.2006.874230.
[31] M. A. Eltawil and Z. Zhao, "MPPT techniques for photovoltaic applications," *Renewable and Sustainable Energy Reviews*, vol. 25, pp. 793–813, Sep. 2013, doi: 10.1016/j.rser.2013.05.022.
[32] O. Diouri, N. Es-Sbai, F. Errahimi, A. Gaga, and C. Alaoui, "Modeling and Design of Single-Phase PV Inverter with MPPT Algorithm Applied to the Boost Converter Using Back-Stepping Control in Standalone Mode," *International Journal of Photoenergy*, vol. 2019, pp. 1–16, Nov. 2019, doi: 10.1155/2019/7021578
[33] M. H. Rashid, "Power Electronics Devices, Circuits, and Applications," Fourth Edition, Pearson Education Limited, p. 277, 2014.
[34] K. K. Gupta and P. Bhatnagar, "Multilevel Inverters conventional and emerging topologies and their control," pp 40, 2017, *Elsevier Inc.*
[35] L. M. A. Alsaqal, A. M. T. I. Alnaib, and O. T. Mahmood, "Comparison of multiple modulation techniques for various topologies of multilevel converters for single phase AC motor drive," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 10, no. 2, p. 662, Jun. 2019, doi: 10.11591/ijpeds.v10.i2.pp662-671.

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