Design a 25-level inverter topology with less switching devices fed by PV systems

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ABSTRACT

Multilevel inverter (MLI) technology has lately emerged as one of the most popular solutions for high power and medium voltage energy management. MLIs have many benefits and require more switches for higher levels, which are considered disadvantaged. This could result in large size and extremely expensive cost for the MLI. So, in order to overcome this problem, a new MLI topology is proposed with reduced number of switches. A 25-level inverter fed by isolated unequal photovoltaic panels as DC sources is chosen in this study. The structure of DC voltages is chosen as (1:1:5:5) Vdc. The proposed approach, which is created using twelve switches, is ideally suited for a high-power application. Multi-carrier with a sinusoidal PWM technique is programmed as a controller. According to the simulation findings, a single-phase system's output voltage and current total harmonic distortion (THD) values are 1.2% and 0.462%, respectively, while a three-phase system's values are 1.07% and 0.342%. These findings prove that the power circuit and investigation were successful.

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1. INTRODUCTION

Evidently, significant technological developments with more interesting in renewable energies lead to use photovoltaic (PV) systems as a power source. In addition, there are significant researches using PV systems due to the improved classification of semiconductor switches that encourage researchers to build a multilevel inverter (MLI) based on renewable energies [1]. Power converter dependability, efficiency, and compactness have been significantly improved. Furthermore, they are getting increasingly effective, and the field of their application is expanding. As a result, several MLI topologies have been investigated and developed to replace traditional inverters in medium and high power applications such as energy, grid-connected renewable energy systems, high voltage DC power transmission, electric vehicles, and a wide range of industrial applications [2]. Since using power electronics devices, power quality improvement becomes the big point and takes the attention of researchers. Power distortions caused by MLIs are the drawback point that need to minimize as low as possible to improve power system quality [3]. MLI circuit produce lower THD at the output side and lower voltage stress on power switches compared with the conventional type. Studies about this topic try to produce as sinusoidal output waveform as possible [4]. Symmetrical MLIs need many switches and equal DC sources to produce certain voltage level and these topologies become costly. Also, a very complex and difficult control and modulation approach will need. In the other hand, asymmetrical MLIs need less switches and DC sources with the same voltage level that become lower costly compared with the conventional type. This inventive way gives lower prices, volume, and control complexity. Also the active components can be arranged so that each stage can be linked to unequal DC voltage [5].

Siddique *et al.* [6], introduced a 15-level inverter based on 9-switches and 3-DC sources was developed, as was a 25-level inverter based on 10-switches and 4-DC sources. Apart from having fewer switches, reduction of voltage stresses over the switches is a benefit of both topologies. Prem *et al.* [7], proposed ten switches and four DC sources were combined to produce a 25-level inverter. The recommended design was modulated using the nearest level control (NLC) method, and the total harmonic distortion (THD) values of the output voltage were 3.6%. Sarebanzadeh *et al.* [8], presented 2-DC sources with four capacitors and ten switches were used to create a 25-level inverter. The suggested 25-level inverter has a total loss of 114 w and an efficiency of 97.72% for 5kw output power. Saleh *et al.* [9], suggested it was dependent on a 15-level inverter made up of 11 switches and 3 DC sources. The control circuit used a modified absolute sinusoidal pulse width modulation approach, and the output voltage and current's THD values were 3.6% and 0.84%, respectively. Ouchatti *et al.* [10], developed an 8-PV cell DC source and 27-switches are utilized to create a 9-level three-phase inverter using a modified hybrid multilevel PWM approach. In 2022 [11], a 15-level inverter was created using 3-DC sources and 7-switches with 3-diodes. The output voltage THD was 3%.

According to prior research, the main goal of this article is to deliver higher-level output voltage with fewer switching devices and lower THD. Figure 1 shows an asymmetric MLI topology with 12-switches and 4-DC sources that produces a 25-level output voltage. Section 2 outlines the suggested structure and possible states. Section 3 includes a discussion of control methods. Section 4 presents the simulation findings. Section 5 concludes this study.

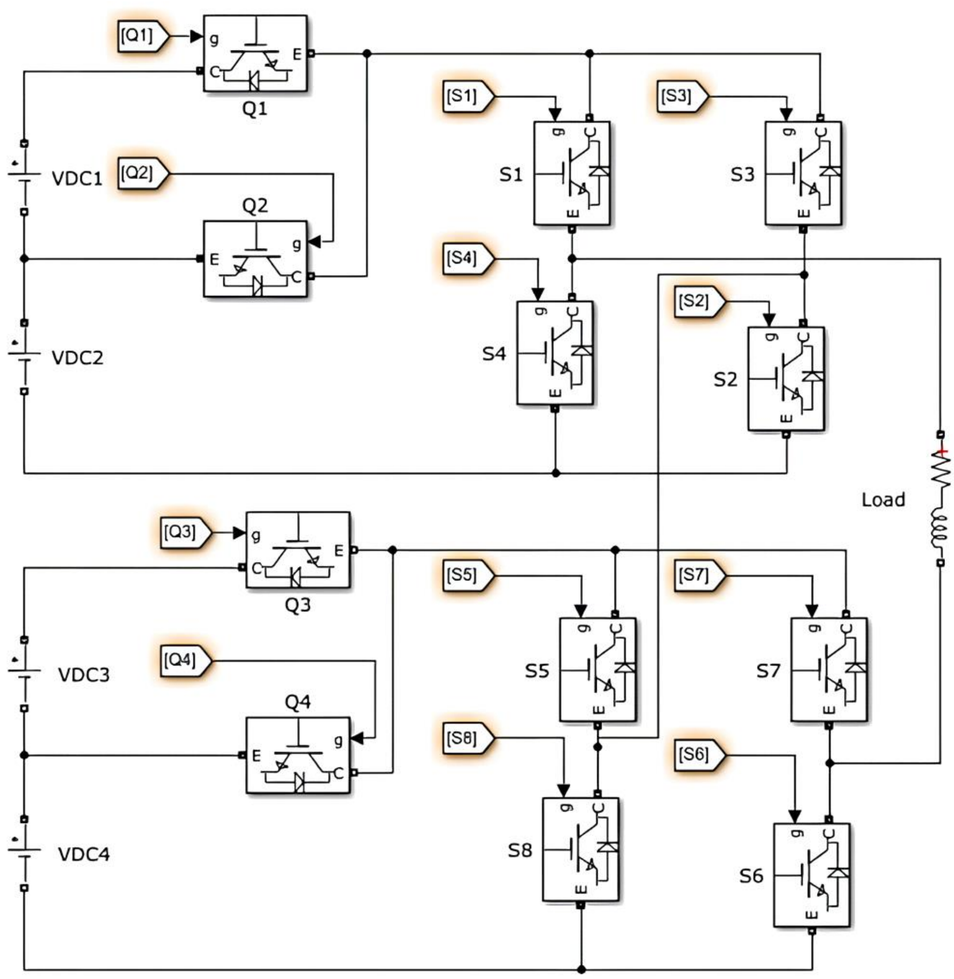


Figure 1. Circuit diagram of the proposed MLI

2. PROPOSED MLI TOPOLOGY

Recently, industrial medium-voltage applications have shown a lot of interest in multilevel inverters [12]. Due to the growing number of driving circuits and components, typical MLIs' power and control circuits become more complicated as the number of levels rises. Additionally, the system's dependability decreases as the number of discrete components rises. In order to increase component consumption while enhancing the output voltage waveform, various MLI topologies have recently been developed [13]–[16]. Recent research on this kind of MLI employs techniques for adjusting triggering angles to reduce harmonics produced by the inverter's operation, as well as less power electronic switches and DC sources [14]–[18]. The typical cascaded MLI circuit's switching device and DC source count is calculated as follows:

$$\text{Switch count} = 2(\text{Level}-1) \tag{1}$$

$$\text{DC source count} = (\text{Level}-1)/2 \tag{2}$$

While in the suggested circuit, number of switching devices and DC sources are selected as:

$$\text{Switch count} = (\text{Level}-1)/2 \tag{3}$$

$$\text{DC source count} = (\text{Level}-1)/6 \tag{4}$$

The recommended design makes use of four separate unequal DC sources, 12 switches, and a 25-level output voltage (+12 Vdc to -12 Vdc). As a result, there are 75% fewer switches and 67% fewer DC sources, respectively. The configuration of the DC voltage sources is (1:1:5:5) Vdc overall.

Table 1 displays the MLI switching patterns required to obtain the requisite 25-level output voltage. Based on the switching states given in Table 1, Figure 2 shows the current path diagram in various operating modes. Where Figure 2(a) depicts the current path to obtain an output voltage of +2Vdc, Figure 2(b) depicts the current path to obtain an output voltage of -6 Vdc, Figure 2(c) depicts the current path to obtain an output voltage of +5 Vdc, and Figure 2(d) depicts the current path to obtain an output voltage of -12 Vdc. Numerous PWM techniques have been employed with multilayer inverters to decrease THD. There are several multicarrier PWM systems as well [5], [19]. In this work, a multicarrier PWM (MCPWM) with phase disposition (PD) approach is employed to lower the THD of the output voltage and current.

Table 1. Switches states of 25-level output voltage

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

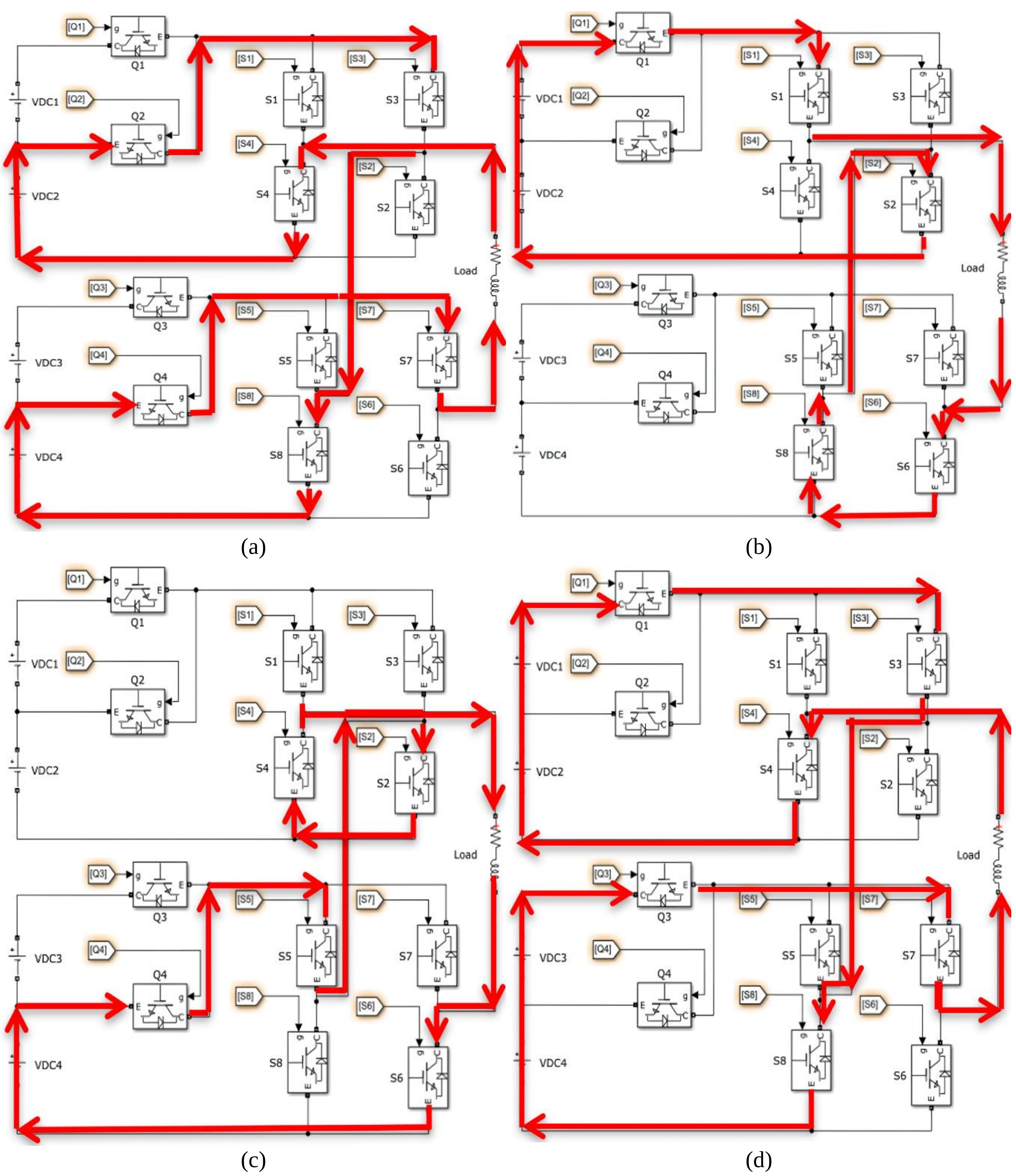
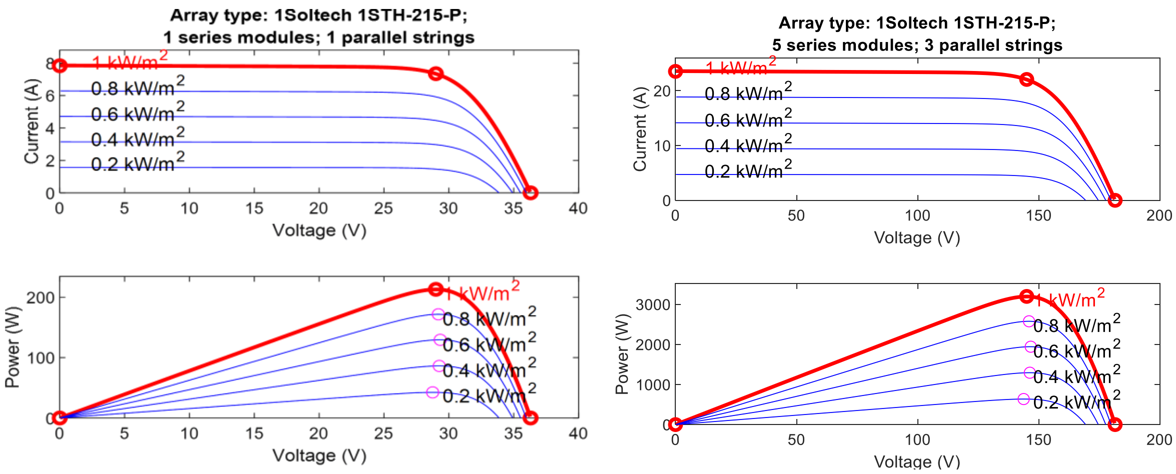


Figure 2. Current path with output voltage of (a) +2 Vdc, (b) -6 Vdc, (c) +5 Vdc, and (d) -12 Vdc

3. PHOTOVOLTAIC SYSTEM

PV system-based power generation has received a lot of attention due to its numerous benefits, which include ease of allocation, longer life, lack of noise and pollution, faster installation, high mobility and component portability, and the ability to produce power output that can meet peak load requirements. PV systems are therefore employed in a wide range of industrial applications, including battery charging systems, solar-powered hybrid vehicles, satellite power systems, solar-powered water pumps, and so on [20].The job of the DC-DC voltage converters is to match the properties of the load with those of the solar panels. The four sets of PV power systems employed are shown in Figure 3 as having the attributes shown, where Figure 3(a) shows the voltage and current characteristics as well as the voltage and power of PV1 & PV2, while Figure 3(b) shows the voltage and current characteristics as well as the voltage and power of PV3 & PV4.



(a) (b)

Figure 3. I-V and P-V characteristics of used PV systems (a) PV1 & PV2, and (b) PV3 & PV4.

The PV systems are coupled to provide voltages in a (1:1:5:5) Vdc configuration. One PV series and one PV in parallel were employed in the first set (1Vdc). Five PV are connected in series and three are connected in parallel in the second set (5Vdc). The output power and voltage (P-V) waveform are shown in this picture with the open-circuit voltage (Voc) and short-circuit current (I-V) waveforms. A step-up converter is used to obtain the required DC output voltage. To determine the maximum power of the PVs, the maximum power point tracking (MPPT) method can be utilized. The perturb and observe (P&O) approach was employed in this study [21]. The PV parameters are explained in Table 2. Figure 4 depicts the whole MATLAB circuit utilized in this investigation.

Table 2. PV Parameters

Components	Specifications
Number of panels	1
Number of cells in series	1
Cell	4
Short circuit current	7.84
Operating temperature	25°
Maximum system voltage	29
C_{PV}	2mF

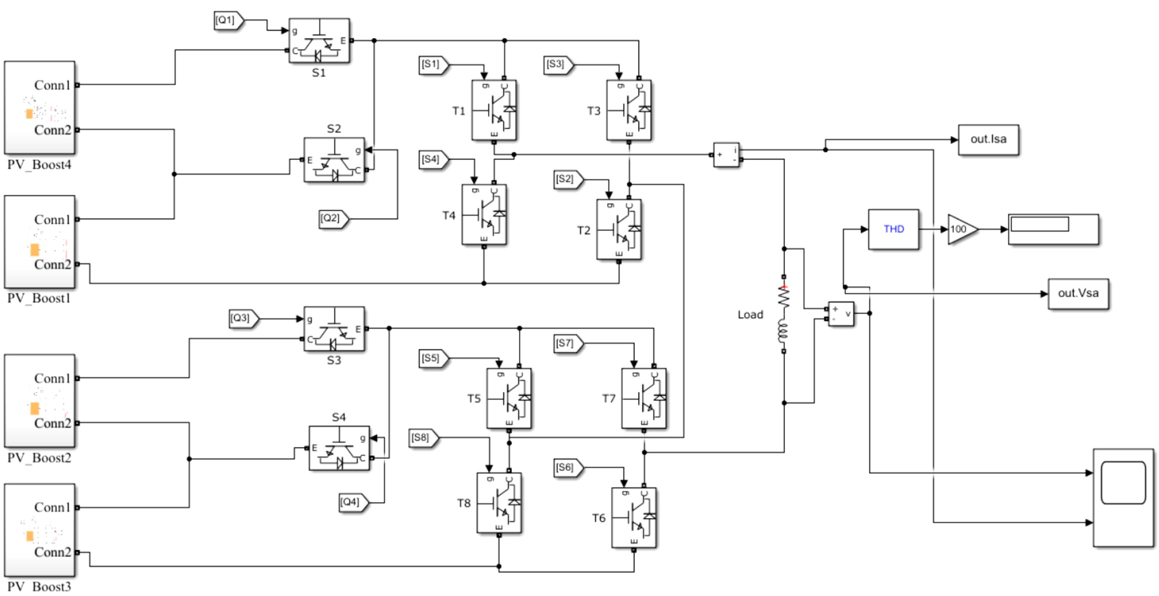


Figure 4. Model circuit of the 25-level inverter

4. SIMULATION AND RESULTS

The suggested system shown in Figure 4 is represented by a MATLAB programmer model that comprises of four PV systems to produce four power DC set voltages of 35 V, 35 V, 175 V, and 175 V, respectively, according to the (1:1:5:5) Vdc structure. R=100 and L=200 mH are chosen for the load, while 3 kHz is selected as the switching frequency. PV1 and PV2 have a 200 w output whereas PV3 and PV4 have a 3 kw output. In order to obtain the 25-level voltage, Figure 5 depicts a multicarrier PWM algorithm using the PD approach by comparing the sine wave reference with the carriers to generate the inverter trigger signals. Despite the fact that the sun radiation varies at random between 200 and 1000 w/m^2 as seen in Figure 6, the temperatures for all PV systems are considered to be constant at 25 °C and 1000 w/m^2, Figures 7 and 8 depict the single-phase and three-phase 25-level voltage and current waveforms, respectively. These waveforms FFT analysis is shown in Figures 9 and 10. The THD values for the output voltage and current of a single-phase system are 1.2% and 0.462%, respectively, whereas they are 1.07% and 0.342% for a three-phase system. These numbers demonstrate the system's adaptability to many environmental factors. In order to highlight the suggested MLI circuit's benefits and strong points, it is crucial to contrast it with other structures. The comparisons between the proposed circuit and various topologies were explained in Table 3.

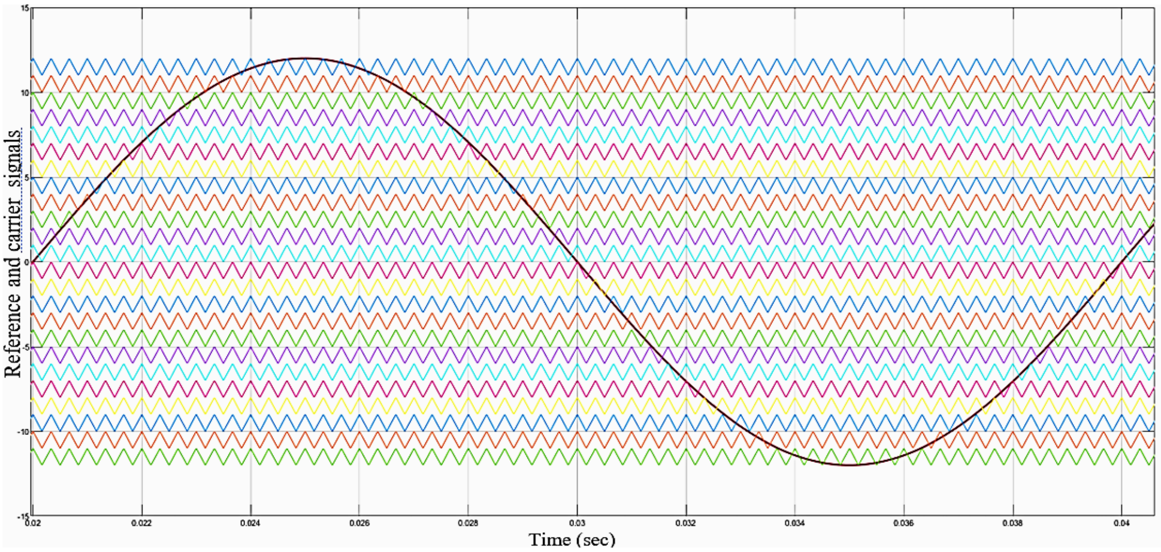


Figure 5. Multicarrier PWM algorithm using PD technique

Table 3. Compares the system volumes of our suggested type and other types.

References	[22]	[23]	[24]	[25]	Proposed
Actives switches	10	10	10	10	12
Sources	4	4	4	2	4
THD-V (%)	4.98	5.57	3.25	3.1	1.20
Diodes	8	4	0	4	0
Flying capacitors	0	0	4	4	0

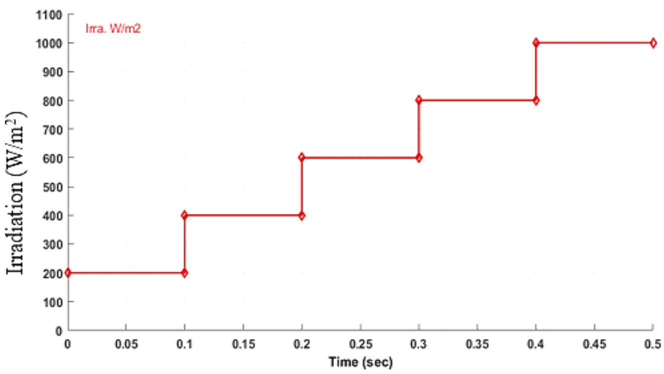


Figure 6. The proposed irradiation

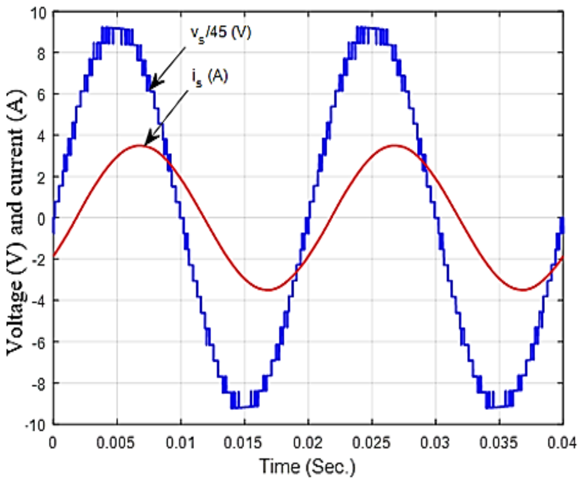


Figure 7. Single-phase 25-level voltage and current at T=25 ˚C and 1000 w/m^2

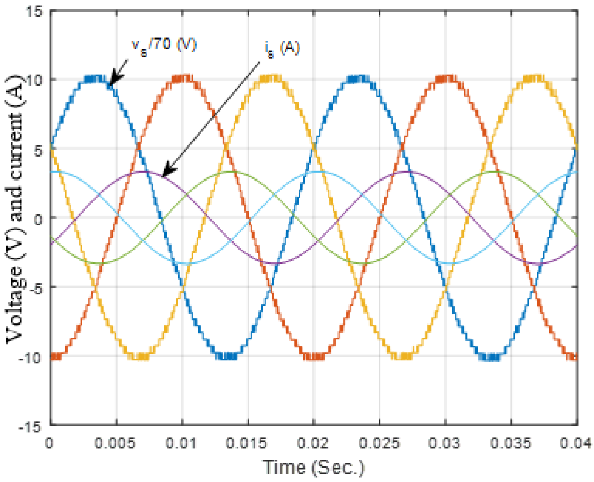


Figure 8. Three-phase 25-level line voltages and currents at T=25 ˚C and 1000 w/m^2

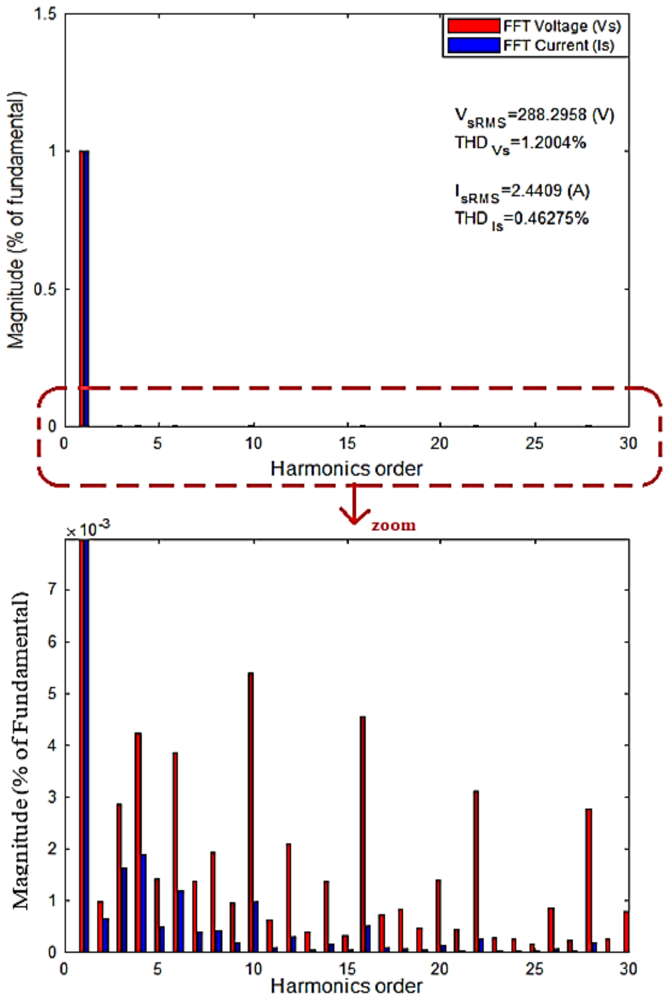


Figure 9. The FFT analysis of the single-phase 25-level output voltage and current

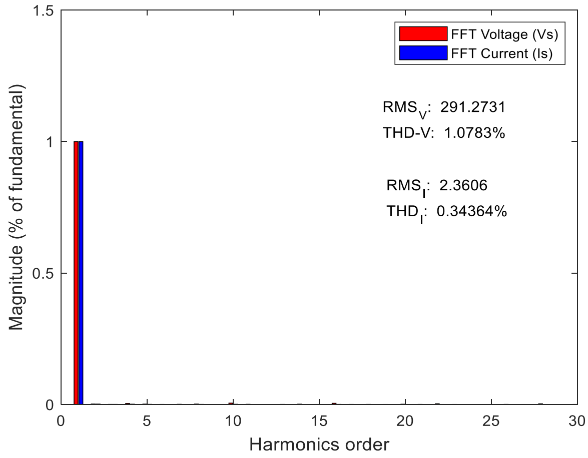


Figure 10. The FFT analysis of the three-phase 25-level output voltage and current

5. CONCLUSION

This study proposes and models a novel 25-Level inverter design with multicarrier PWM, 12 switches, and 4 PV Systems as DC sources. The effectiveness and benefits of the suggested topology are shown by the simulation results. The control circuit is straightforward and does not become more complicated as the number of levels rises. Therefore, the suggested method is appropriate and usable as a solution for ON and OFF grid applications. The THD values are quite low and acceptable.

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