Design a Three Phase 43-level Inverter Fed by Renewable Energy Source

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Abstract

The issue of DC to AC inverters has gained interest due to the growing use and investment in renewable energy sources as a competitive power source. This paper presents efficient technique for producing an AC sinusoidal signal from DC power. The primary objective is to create a highly effective inverter that generates a pure sinusoidal AC signal with the least amount of overall harmonic distortion. MATLAB Simulink was utilized to develop and simulate an inverter for this purpose. Four asymmetric DC voltage sources and sixteen power switches are included in the inverter design in a [1:2:7:11]Vdc ratio to create an inverter with 43 levels (-21 to 21).The value output voltage of the single-phase 43- Level (THD-V)equal 0.70%,while a three-phase system's value are 0.63% .The main contribution is the establishment and demonstration of a sound methodology and model based on multilevel inverter with high power and reduce number of switch.

Keywords- Photovoltaic panel, Harmonics, Multilevel Inverter (MLI), THD.

I. INTRODUCTION

Utilizing limitless natural resources, renewable energy generates electricity. As one of the most significant forms of renewable energy, solar energy It is regarded as free energy and is accessible in most countries year-round at different intensities [1]. Its limitlessness and lack of contribution to global warming and pollution is among its greatest advantages. The PV system's appealing features enable it to provide power that meets peak-load requirements. Due to the fact that up to 20% of systems rely on this effective technology, solar energy systems are among the most widely used in the commercial sector [2]. The primary components of a PV system are dc to ac converters. In recent decades, the rating power of energy production and distribution networks has increased dramatically, making multilevel inverters (MLI) a very essential equipment for converting power in a wide variety of applications. [3]. That being said, a high-power system with a high-power consumption is necessary. (MLI) with the proper architecture to handle a high-power system [4], [5], in order to get around the power switches' voltage rating. A transformer-free construction, superior power quality signals, decreased switching losses, and less strain on power electronic switches are just a few benefits of the MLI. Though this technology has some uses and can be used in renewable energy, several researchers use techniques and upgraded new topologies in their work on MLI to improve THD.

From the start of this century, solar energy has increased exponentially, necessitating the use of high voltage and high-power inverters to capitalize on this massive energy. The industry's utilization of two and three level inverters with medium voltage drivers is therefore insufficient. High voltage semiconductor devices, on the other hand, are highly costly [6]. Using medium voltage drivers, multilevel inverters provide a way to manage high power. Many uses for inverters are beginning to emerge, and each of these uses has unique requirements in addition to the advancements in the semiconductor sector [7].

In recent times, industrial medium-voltage applications have highly focused on Multilevel Inverters (MLI) [8]. While working with medium voltage grids, the MLI has shown to be the most advantageous choice because of the restrictions of 2-Level inverters with regard to semiconductor blockage voltage in this range. The MLI reduces the total harmonic distortion (THD) of the voltage and the dv/dt stress across the semiconductor switches to meet grid regulations. It has also been shown that they can create semiconductor switches with reduced electromagnetic interference (EMI) and power dissipation [9]. Based on its architecture, MLIs are often

classified into three fundamental topologies: Cascaded H-Bridge (CHB), Flying Capacitor (FC), and Neutral Point Clamped (NPC) [16]. Because of its versatility and easy modification to several levels, the CHB is widely used. It is built in a modular manner. Because there are more driving circuits and components in standard multilevel inverters, the design and control circuitry get more complicated as the number of levels rises. Moreover, as the number of discrete components increases, the system's dependability declines. Because of this, novel multilevel inverter topologies have recently been developed with the intention of improving the output voltage waveform and increasing component usage [10]. Current studies on this type of inverter focus on two main areas: first, developing topologies that use fewer dc link sources and power electronic switches; second, developing methods for modifying triggering angles to reduce harmonics generated during the inverter's operation. [11]-[12].

In 2018 [13], Using an inductive load and a modified absolute sinusoidal pulse width modulation (MASPWM) method, MATLAB was used to simulate a 27-level cascaded inverter with single and three phases with input voltages of 1 Vdc, 3 Vdc, and 9 Vdc. The three-phase circuit had THD values of 0.67% and 0.0857%, respectively, but the single-phase circuit's THD values were 0.238% and 1.165% for the same current and voltage. In 2018[14], A solar photovoltaic (PV) module was used as the only DC source in the development and simulation of a nine-level converter. The control strategy maintains excellent power quality while reducing power loss and producing more accurate outcomes. By analyzing the data collected for the inverter and taking off the fundamental element at predetermined switching angles, the recommended approach eliminates specific harmonics. In 2019 [15], It was decided to develop a 13-level inverter using DC voltage sources and low-power electrical gadgets. With a zero-level (ZL) inverter and without a zero-level (NZL) inverter, the output voltage THD was 9.5% and 12.5%, respectively. In same year 2019 [16], At carrier frequencies of 1 kHz and 2 kHz, a 15-level inverter multi-carrier SPWM approach was simulated and compared with traditional versions. In this method, a total of 28 switches are employed. In terms of output waveform distortion, the lowest value is 6.71% at 1 kHz and 6.59% at 2 kHz. In 2021. [17], The phase shifted PWM approach was compared with level shifted multicarrier PWM based on phase disposition and opposition disposition using alternative phase opposition disposition techniques to generate an 11-level output voltage. In 2022 [18], In order to generate a 31-level output voltage at a modulation index of (m=1), a 12-power switch system with four separate DC sources was constructed. The total harmonic distortion value was 2.11%. This study's main goal is to provide high output voltage with few switching components and minimal THD. In 2023 [19], 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. 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%.

II. SOLAR PV SYSTEM

Solar energy is the globally most accessible renewable energy source [20]. 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. PV cells transform radiation energy into electrical energy. 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 MPP tracking (MPPT) techniques [21, 22]. The DC sources used as input voltages of the multilevel inverters are set of photovoltaic systems. The model includes a PV array under the influence of solar radiation (Ir) and cell temperature (T). To ensure that the maximum power is obtained from the PV cell, the IGBT switch of the boost converter was controlled by the Maximum Power Point Tracking (MPPT) method. Figure (1) shows the designed PV cell with the DC /DC boost converter model. The MPPT algorithm is programmed depending on some codes and Simulink block, and this code is written based on Perturbation & Observation (P&O) algorithm which depends on the measured voltage and current of the PVs, The MATLAB Function of the MPPT using (P&O) algorithm.

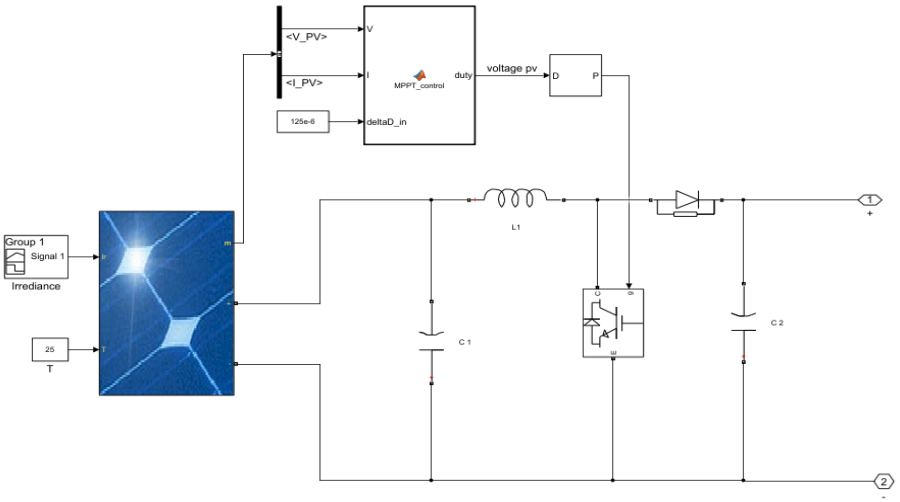


Figure 1. Design PV cell with DC /DC boost converter model.

III. TOPOLOGY 43-LEVEL INVERTER

One type of power electronic equipment utilized in electrical power conversion systems is the multilevel inverter. A multilevel inverter creates the output waveform by combining levels. This method has a number of benefits, such as improved power system quality and output waveform, reduced voltage stress, and increased efficiency [23]. MLIs are extensively utilized in high-power applications, including utility applications, renewable energy systems, and motor drives. In the past few years, a number of authors have investigated and searched for better solutions; some have focused on topologies derived from conventional structures [24]– [26]. Others have assembled multiple basic units to create modular structures, depending on the voltage rating of the semiconductor power switches and the desired output signal quality. There are two types of topologies for these multilevel solutions: those with intrinsically negative voltage levels and those with negative voltage levels using H-bridge. Each has advantages and disadvantages. [27, 28]. In this study, the asymmetric voltage supplies are arranged in Figure (2), as follows (V1 = $1V_{DC}$, V2 = $2V_{DC}$, V3 = $7V_{DC}$, V4 = $11V_{DC}$) for a 16-switch inverter circuit to generate 43-levels from four sources, giving voltage output waves Smoother current and improved Total Harmonic Distortion (THD). Table I shows the switching patterns required to obtain an output voltage of 43-levels. Only the patterns of the positive part are mentioned, and to get the patterns of the negative part we reverse the state of switches S1 to S8 of the positive part. Based on the switching states in Table (1), Figure (3) shows a single-phase current and voltage waveform with 43-levels of level shift at levels (9 to 43). Figure (4) shows the current path diagram in some operating modes at different levels.

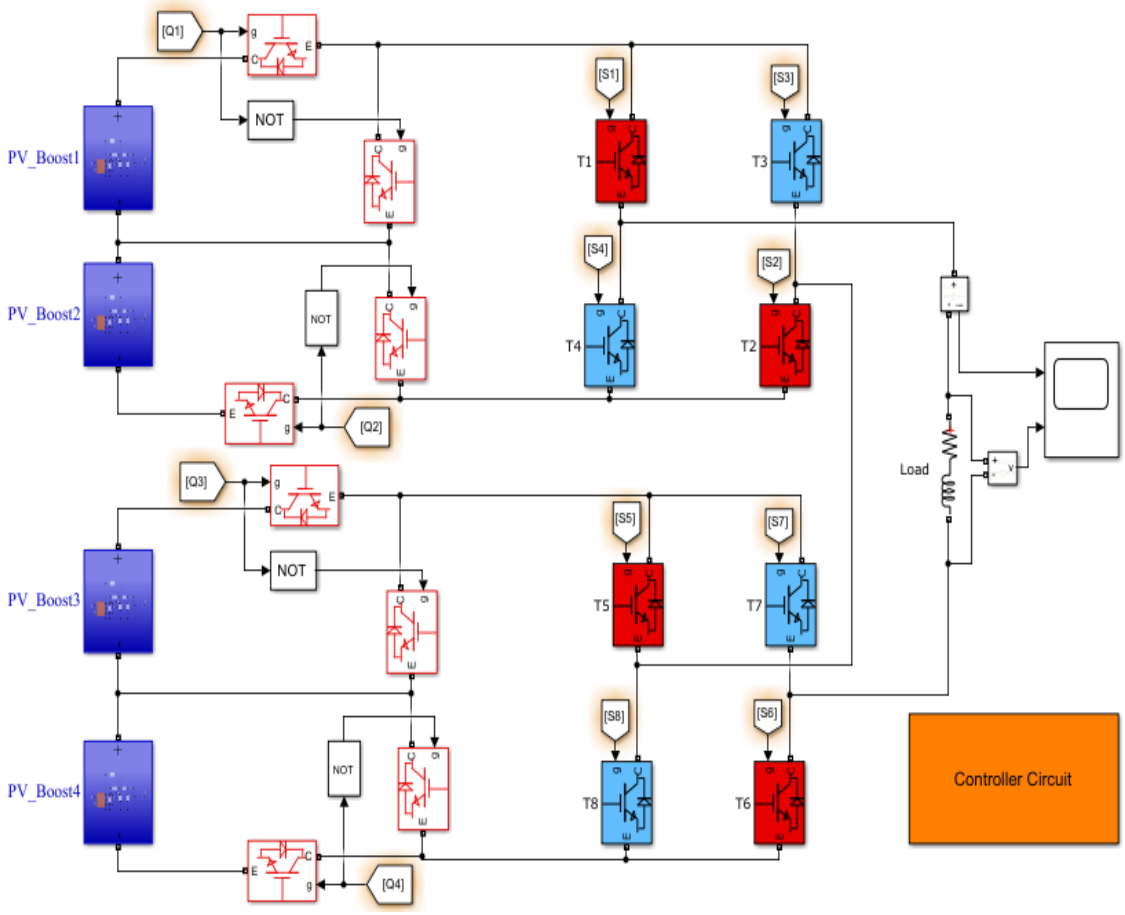


Figure 2. The proposed of the 43-level inverter circuit.

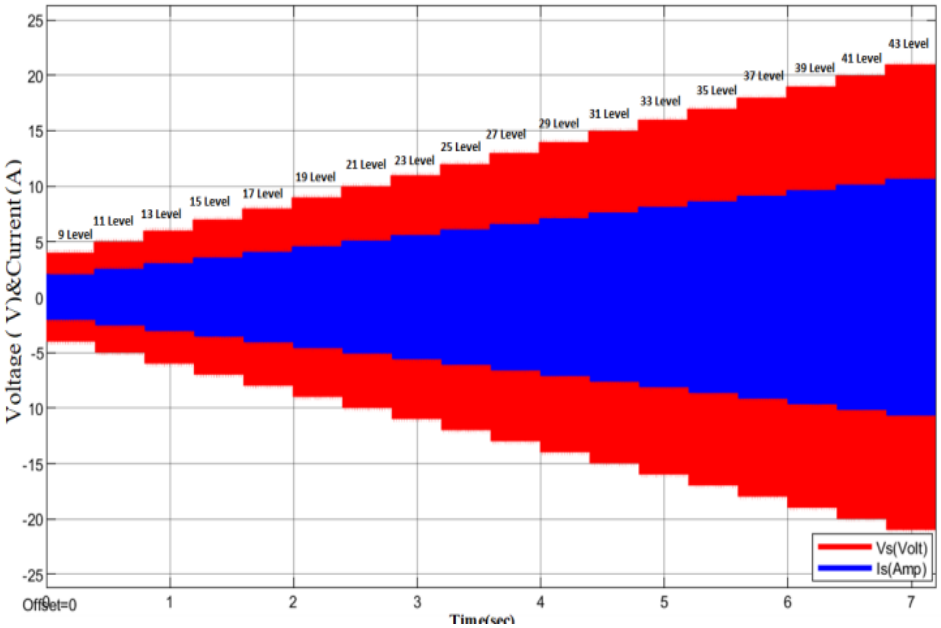


Figure 3. The single-phase current and voltage waveform with 43-levels of level change at levels from 9 to 43 levels.

Table □. Switches states of the 43-level output voltage

Mode	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	0	0	0	0	1	0	1	0	1	0	1	0	0 V_{dc}
2	1	0	0	0	1	1	0	0	1	0	1	0	1 V_{dc}
3	0	1	0	0	1	1	0	0	1	0	1	0	2 V_{dc}
4	1	1	0	0	1	1	0	0	1	0	1	0	3 V_{dc}
5	1	1	1	0	0	0	1	1	1	1	0	0	4 V_{dc}
6	0	1	1	0	0	0	1	1	1	1	0	0	5 V_{dc}
7	1	0	1	0	0	0	1	1	1	1	0	0	6 V_{dc}
8	0	0	1	0	1	0	1	0	1	1	0	0	7 V_{dc}
9	1	0	1	0	1	1	0	0	1	1	0	0	8 V_{dc}
10	0	1	1	0	1	1	0	0	1	1	0	0	9 V_{dc}
11	1	1	1	0	1	1	0	0	1	1	0	0	10 V_{dc}
12	0	0	0	1	1	0	1	0	1	1	0	0	11 V_{dc}
13	1	0	0	1	1	1	0	0	1	1	0	0	12V_{dc}
14	0	1	0	1	1	1	0	0	1	1	0	0	13Vdc
15	1	1	0	1	1	1	0	0	1	1	0	0	14Vdc
16	1	1	1	1	0	0	1	1	1	1	0	0	15 V_{dc}
17	0	1	1	1	0	0	1	1	1	1	0	0	16 V_{dc}
18	1	0	1	1	0	0	1	1	1	1	0	0	17 V_{dc}
19	0	0	1	1	1	0	1	0	1	1	0	0	18 V_{dc}
20	1	0	1	1	1	1	0	0	1	1	0	0	19V_{dc}
21	0	1	1	1	1	1	0	0	1	1	0	0	20Vdc
22	1	1	1	1	1	1	0	0	1	1	0	0	21Vdc

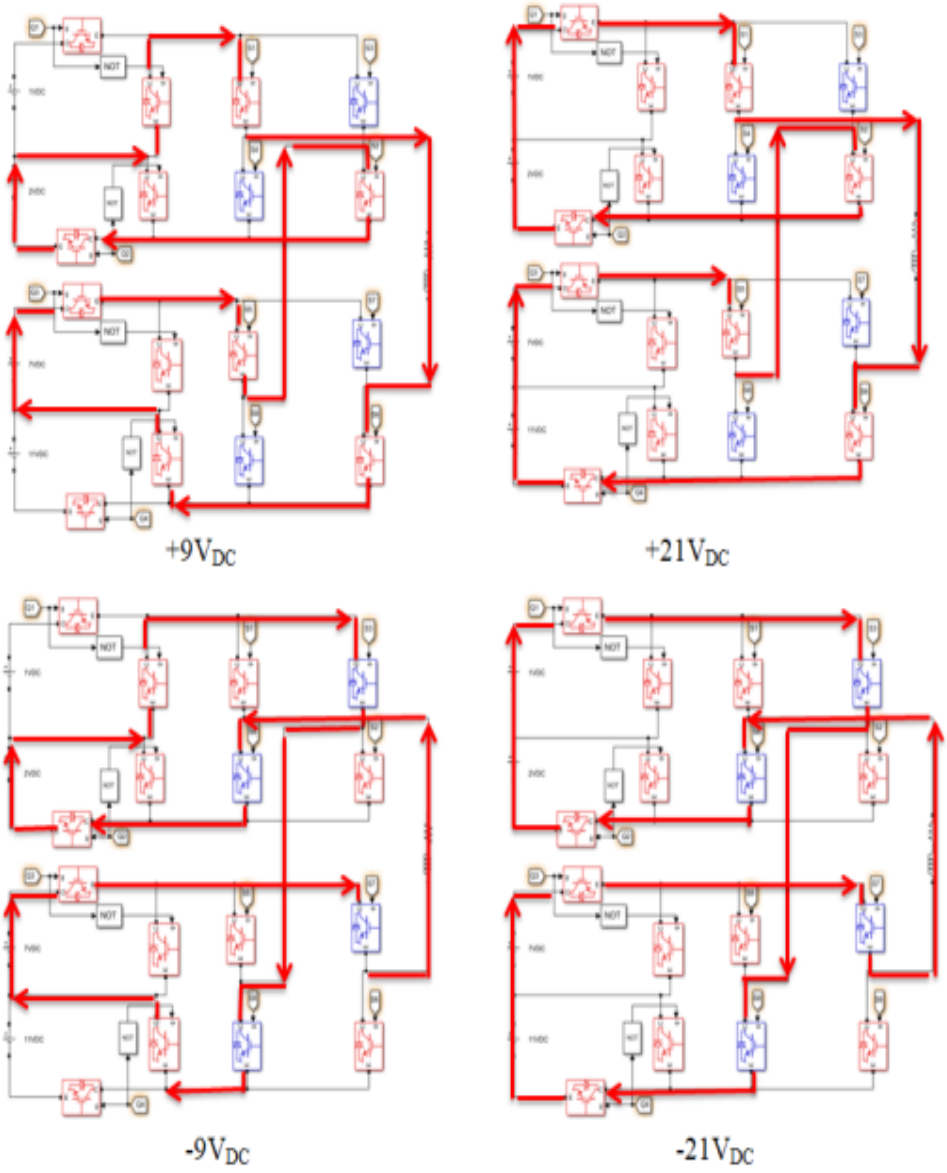


Figure 4. The current path diagram Topology in some operating modes at different levels.

IV. MULTICARRIER SINUSOIDAL PULSE WIDTH MODULATION (MCSPWM) TECHNIQUE

The SPWM is a technique used to produce a sinusoidal waveform by varying the width of series pulses [29]. One of the advantages of SPWM is generating 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 (MCSPWM) is a combination of these two modulation techniques. An m-level inverter needs (m-1) triangle carrier signal. Based on the arrangement of the carrier signals, the MCSPWM control technique can be split into level-shifted and phase-shifted [30]. In this study, the control circuit is designed and modeling according MCSPWM algorithm based on phase disposition technique (PDMCSPWM) as explained in Figure (5). The generation of pulses has been made by comparing every carrier wave with the sine wave and the resultant pulses has been given to the appropriate switches to produce the 43-level staircase waveform. The basic logic gates (AND, OR, NOT) are used to compare these carrier signals to trig switches and produce the desired output levels.

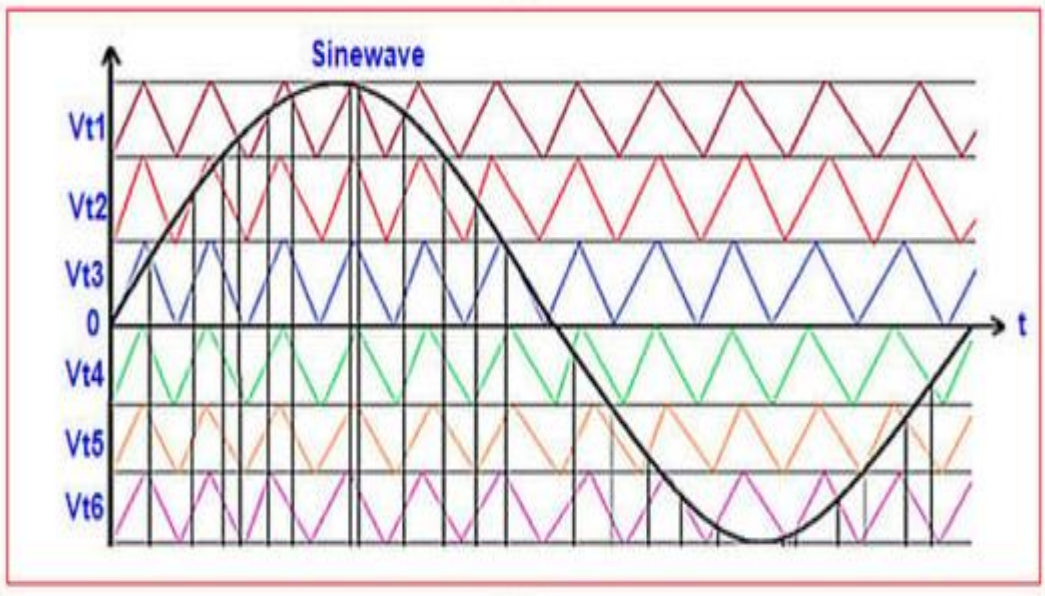
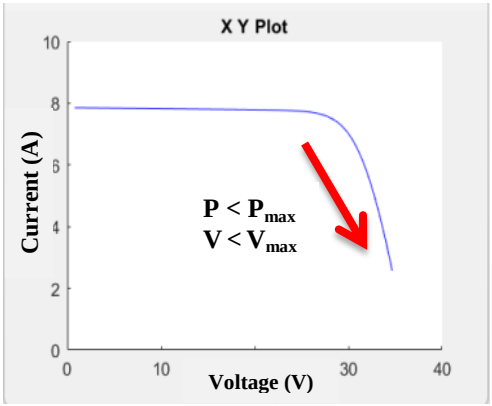


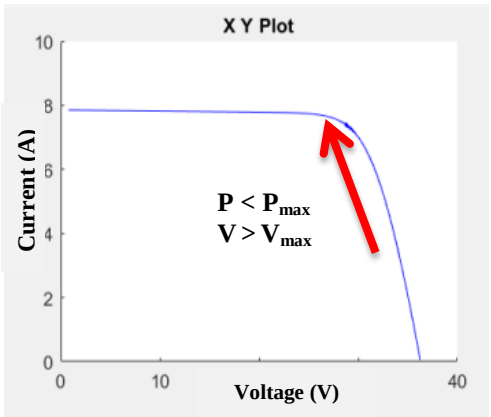
Figure 5. PDMCSPWM algorithm.

V. SIMULATION AND RESULTS

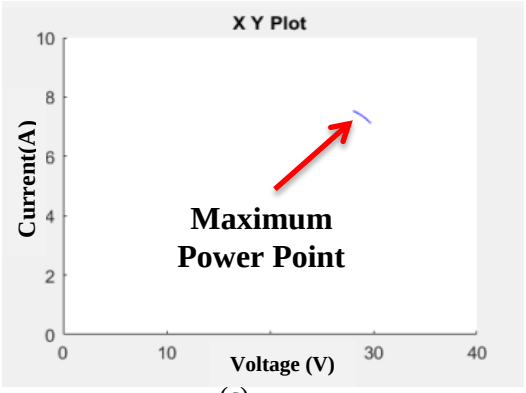
Figure (6) shows the result of the PV voltage and current characteristics. Also, it shows the way the energy follows around the extreme point until it reaches that point. Figure (7) shows the value of the maximum voltage, current, and power of the PV. Figure (8) shows the I-V and P-V characteristics of the four PVs that used in this study. While Figure (4) shows the output voltage and current waveforms with single-phase FFT analysis at different levels. While Figure (9) shows the THD for single-phase output voltages 43-levels of topology with respect to voltage levels. This system was built as a three-phase system. Figure (10) shows the three-phase voltages and currents of 43- level with their FFT analysis. While Figure (11) shows the THD of the Topology with 43-level three-phase output voltages with respect to the voltage levels.



(a)



(b)



(c)

Figure 6. Characteristics of PV at MPPT controller.

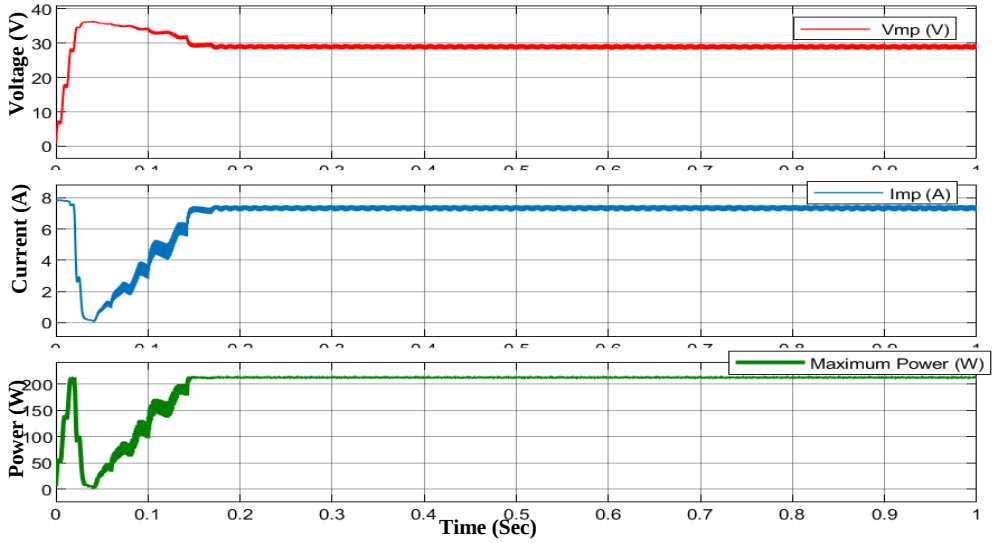
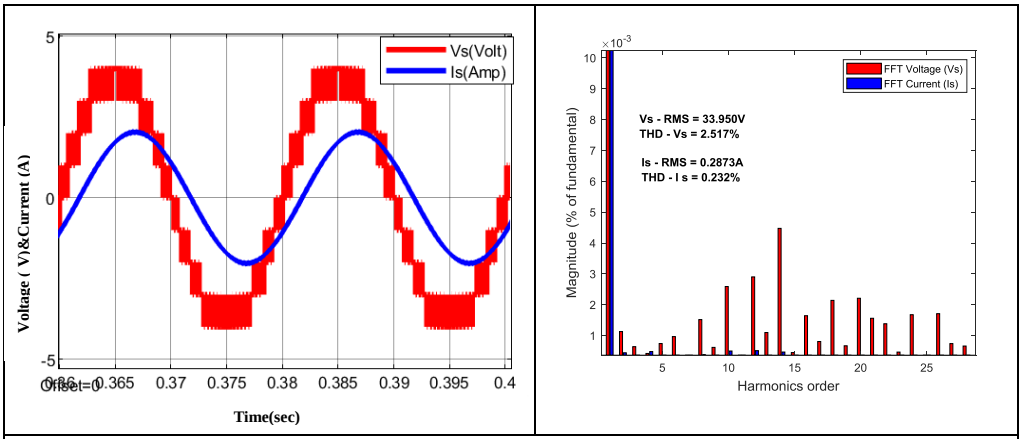
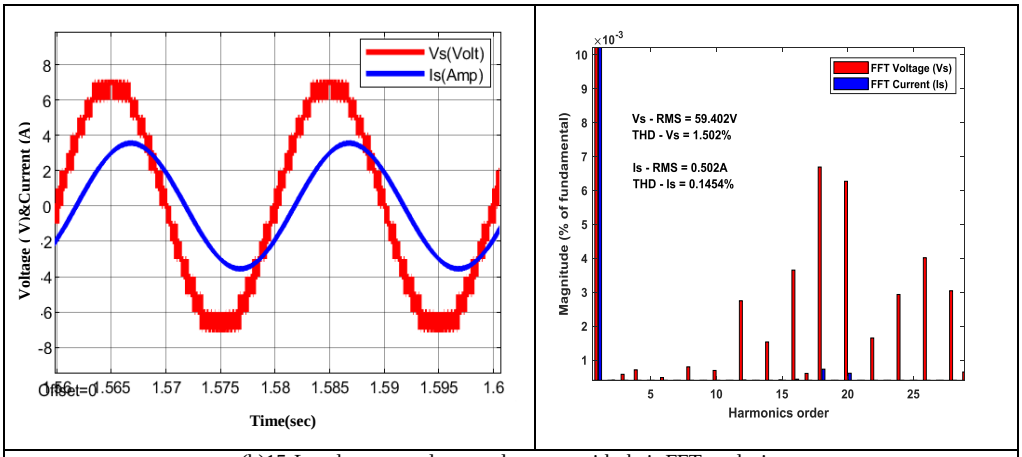


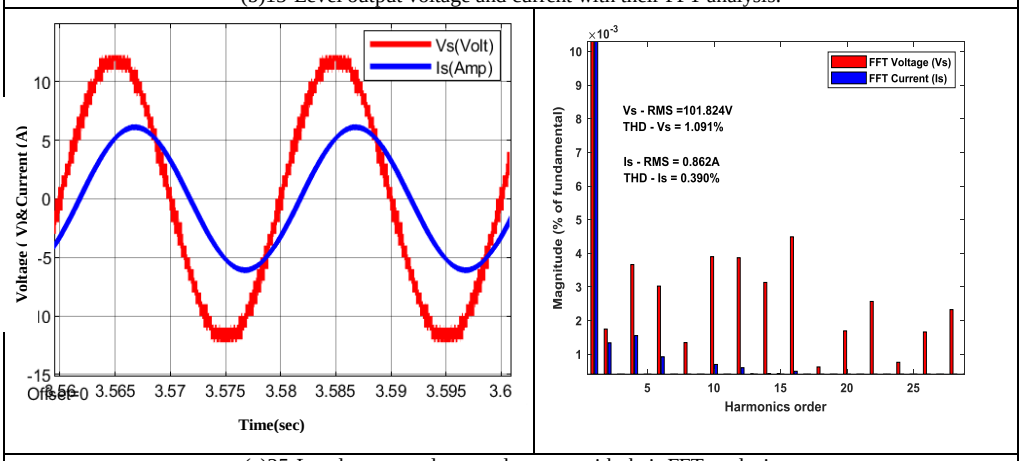
Figure 7. Voltage, current, and power of the selected PV.



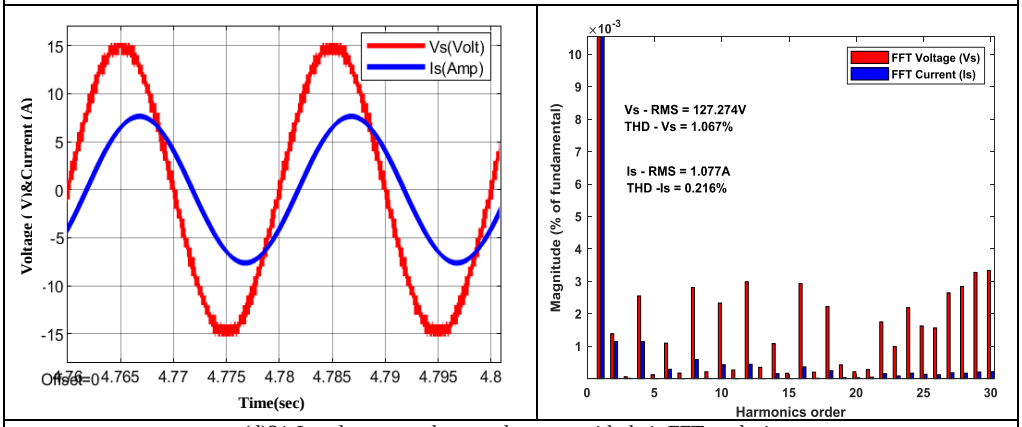
(a) 9-Level output voltage and current with their FFT analysis.



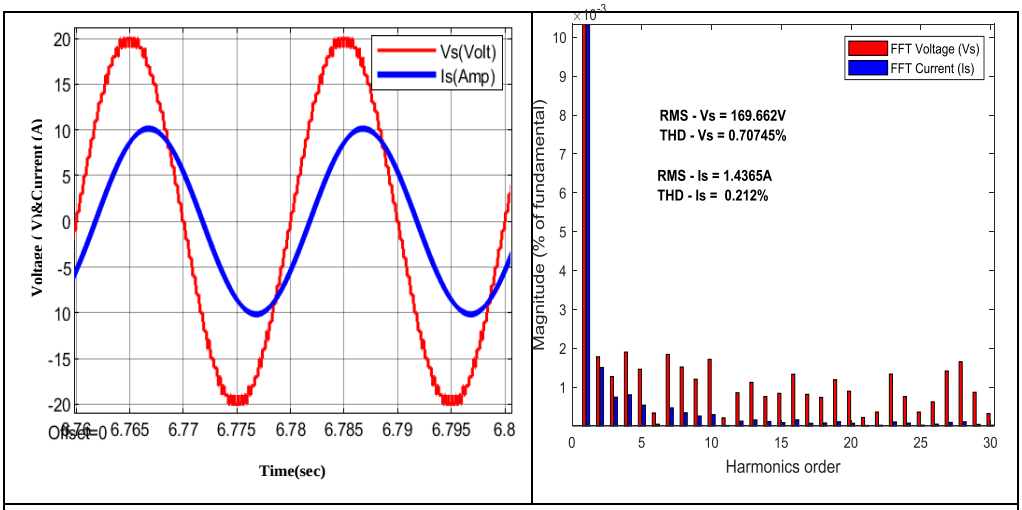
(b)15-Level output voltage and current with their FFT analysis.



(c)25-Level output voltage and current with their FFT analysis



(d)31-Level output voltage and current with their FFT analysis



(e)43-Level output voltage and current with their FFT analysis.

Figure 8. The output voltage and current waveforms with FFT analysis at different levels.

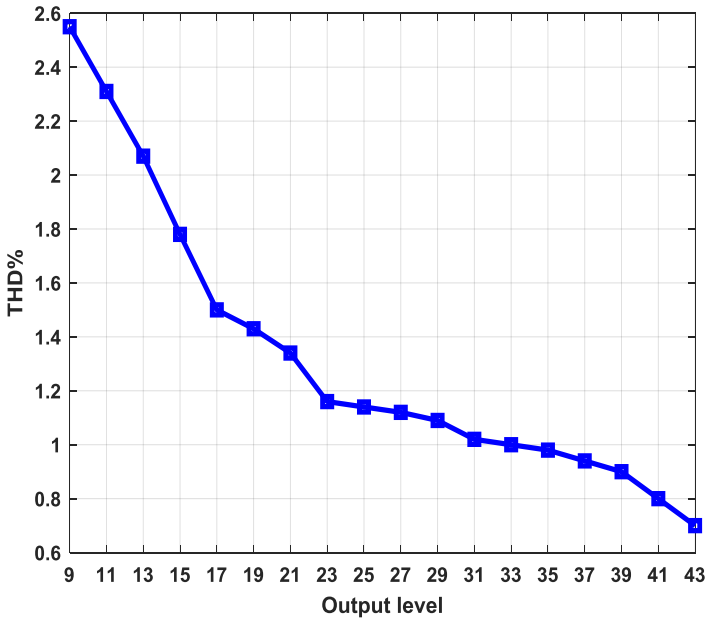
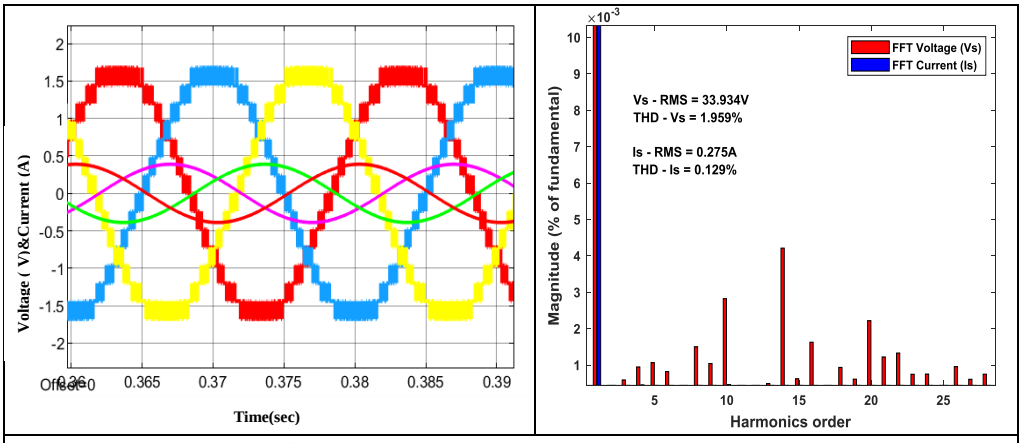
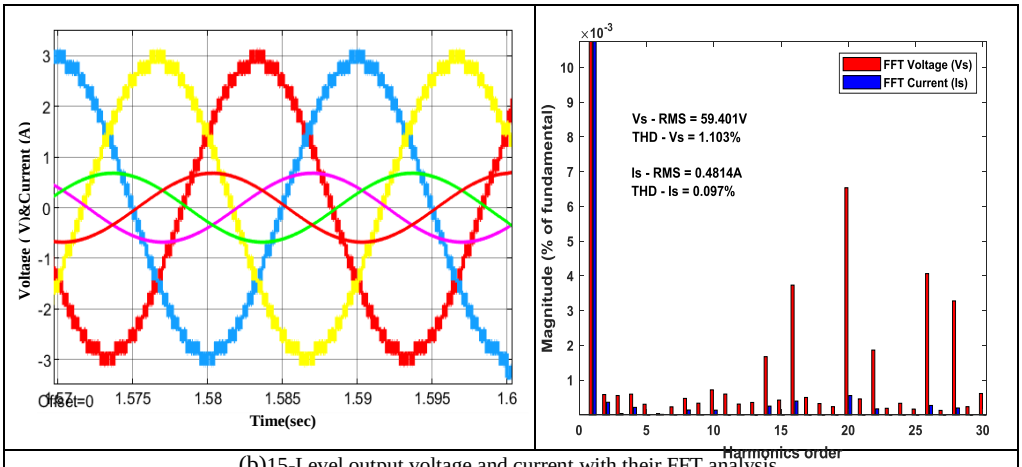


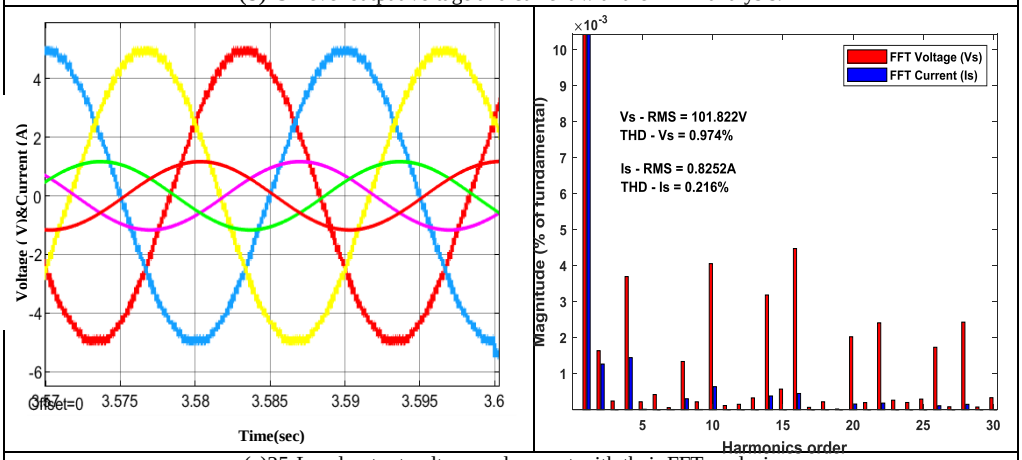
Figure 9.THD of the single phase 43-level output voltages with respect to voltage levels.



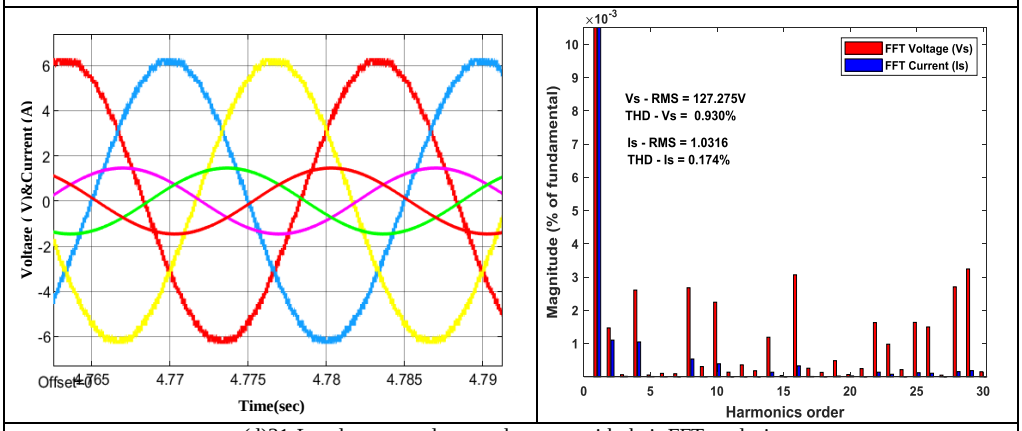
(a) 9-Level output voltage and current with their FFT analysis.



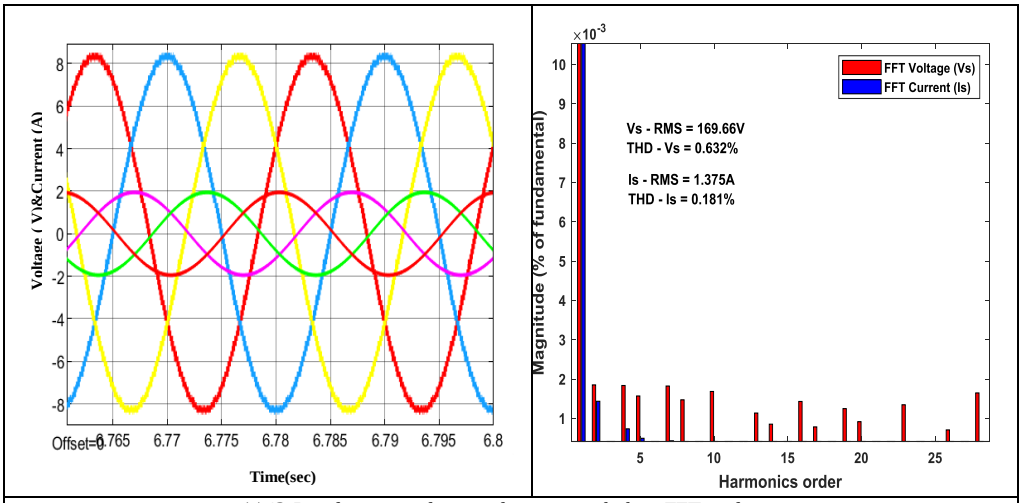
(b)15-Level output voltage and current with their FFT analysis.



(c)25-Level output voltage and current with their FFT analysis



(d)31-Level output voltage and current with their FFT analysis



(e)43-Level output voltage and current with their FFT analysis.

Figure 10. Line voltage and current of the three-phase 43-Level with their FFT analysis.

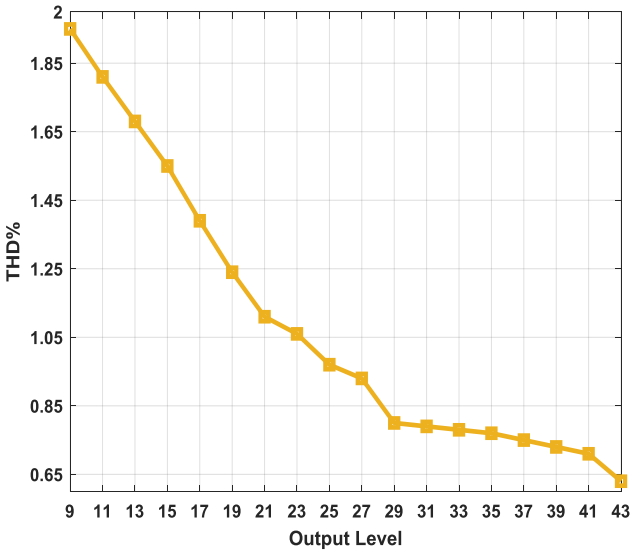


Figure 11.THD of the three phase 43-level output voltages with respect to voltage levels.

VI. CONCLUSION

Based on the simulation results obtained for all cases, it appears that the MC-SPWM algorithm based on the phase-disposition (PD-PWM) technique and improving the power quality by enhancing the voltage and current THD% has proven its efficiency. THD has been attained at levels that are appropriate by world standards. In order to get a high output voltage, lower the THD, and boost reliability, a multilevel inverter is required. Table Ⅱ shows the results of the single-phase and three-phase inverter. can suggest for Future Work used reducing harmonics in output voltage when using hybrid renewable energy as supply such as wind and solar energy.

Table Ⅱ the results of the single-phase and three-phase inverter.

N .of Level	THD-V(%) 1ϕ	THD-V(%) 3ϕ
9- Level	2.51	1.95
15- Level	1.50	1.10
25- Level	1.09	1.97
31- Level	1.06	0.93

43- Level	0.70	0.63

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