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A Multilevel Inverter with Fewer Switches Using Boost Converter for Solar PV Applications

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Abstract
To support medium-voltage and high-power applications in flexible power systems, multilevel inverters, which are commonly referred to as MLIs, are currently being developed. The conventional configuration of a multilevel inverter, which aims to accommodate a wide range of applications, necessitates the use of additional switches and sources and is subject to certain constraints. Through the built-in control of the boost converter and the PWM for each level, this research aims to discover a new method that uses a boost converter to obtain an MLI with a minimum number of switches, maintaining this number constant as the number of levels increases. The research results clearly demonstrate the reduction of THD to small values through the use of the boost converter in the proposed method. MLI is usually used in renewable energy applications to obtain certain voltages, for example, from solar cells, therefore, simulations were conducted within the framework of photovoltaic (PV) cells as an input source. When MLI configuration integration is added to a PV system, a lower number of switching components are used for a defined number of voltage output levels. This is in contrast to typical multilevel inverter topologies, which require a larger number of switching components to manage the gating pulse of PV-based MLI. The MATLAB/SIMULINK program assisted in carrying out this work.

Keywords
Inverter, Multi-level Inverters, THD Reduction, Boost Converter.

I. Introduction

The great expansion in the use of electrical energy in all domestic and industrial uses has led to an urgent need for multiple sources of its production. The use and development of renewable energy in its various forms has become essential in recent years because the use of fossil fuels, which are widely used, causes environmental pollution with the possibility of their exhaustion [1–5]. Solar energy is considered one of the most important forms of renewable energy, the use of which has expanded in recent years to produce electrical energy. The electricity produced from solar cells is usually in the form of direct current, and this requires converting it to alternating current in a way that is compatible with most applications that currently consume electrical energy. MLI is one of the most common types of inverter devices used to convert electrical energy from its direct current form to its alternating form. The most important challenge when using inverters to produce AC voltage is the presence of harmonics in the resulting alternating voltages. Therefore, work is being done to reduce THD in various ways, such as increasing the number of inverter levels as well as using filters and other methods. Increasing the number of levels to reduce THD leads to an increase in the number of semiconductors used as switches, as well as the number of DC sources used, and this inevitably leads to an increase in cost, size, and weight, as well as an increase in losses and somewhat difficult to control . In this research, a boost converter was used to produce the multi-level voltages. Using it enabled us to obtain a greater number of levels with simplified control . requirement, reduce the number of switches, and reduce losses in cost, weight, and others.

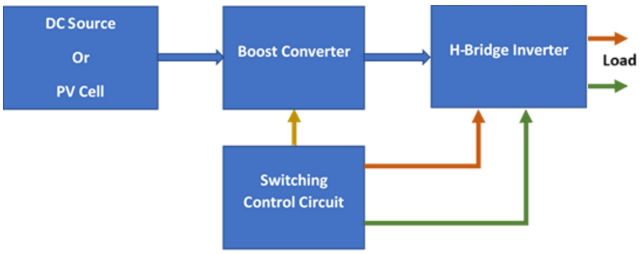

Fig. 1. A Proposed MLI block diagram.

Over the two-level, hard-switched pulse width modulation (PWM), the multi-level inverter (MLI) presents various advantages. These benefits include higher efficiency and a lower dv/dt during high power operations [5–8]. MLI is being implemented in an increasing number of facilities due to its high voltage operation capacity, low electromagnetic interference (EMI) output, high efficiency, and low switching losses. [9]. The increased demands for power quality and power rating linked to lower harmonic distortion and electromagnetic interference have led to an increase in the use of multilevel inverters in power electronic applications. Compared to a conventional two-level inverter, MLI provides numerous benefits for pulse width modulation (PWM) at high switching frequencies [10–13]. Some of the most desirable features of an MLI are as follows: Minimal distortion and dv/dt stress may be utilized in the output voltage generating procedure. It has a low switching frequency, a very low common mode voltage, and very little distortion in the input current. The structural core of MLI consists of capacitor voltage sources and power switching devices. They are appropriate for high-voltage applications and voltage waveforms because of their ability to detect output voltage with larger harmonics, which allows for the achievement of high voltages even with the maximum device rating. In multi-level inverters, three main topologies are used: diode-clamp, capacitor-clamp, and cascade. By far the most popular topology is cascade. A cascade MLI is often assembled via a series of sequentially linked DC sources and switches. [14–16]. To obtain the fundamental voltage and eliminate higher-order harmonics in the output, the switches must be activated and deactivated frequently to generate alternating current voltage with many levels. This is essential to achieve [17]. Several DC sources help to reduce switching losses and voltage supply stress. This research proposes a Boost MLI. The proposed multilevel inverter has simpler controls, fewer switches, better performance, and lower losses. This work describes a specific PWM technique utilized to generate a 7-level output voltage by means of the firing pulses for the switching devices. This process uses one sine waveform source in reference.

II. Proposed Inverter Circuit Description

Fig. 2 shows the proposed inverter circuit. The circuit is composed of the marker part and the H-Bridge. The marker part is composed only from one DC source and a DC-DC boost converter which contain only one switch. by controlling the duty cycle of the boost converter in steps the output level of the inverter can be controlled. The boost DC-DC converter output voltage can be changed by adjusting the duty cycle of the converter using the following equation:

$$V_o = Vi/(1-D) \tag{1}$$

Where,

$$D = t_{on}/(t_{on}+t_{off}) \tag{2}$$

ton and toff are the switching time for the on and off state of the active switch for the boost converter. the boost converter is used instead of the marker parts in the conventional cascade MLI that in which the number of switches in the marker parts increase with the increase number of levels so as the DC sources required. But for the proposed MLI the number of switches is constant and only one source and one switch is required in the marker parts. So any number of levels can be obtained without any increasing in the number of switches and sources and this lead to ease the control circuit. This reduce the number of switch, the dc source required, the cost, the size and the losses. The complete circuit for the proposed MLI is shown in Fig. 2.

To comprehend the circuit's operation, the operation mode for each output level for the 7-level inverter is describe as following for the positive half cycle and they will be repeated for the negative half by changing the switches in the H-bridge.

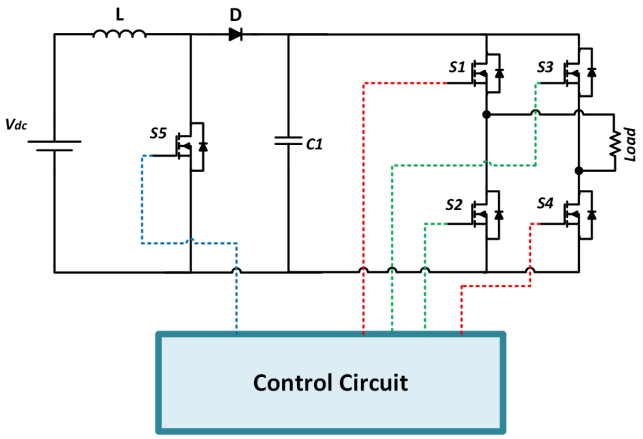

Fig. 2. The circuit diagram of the proposed MLI.

The first third levels of operation will be described for the positive half cycle:

1. **Level 0:** (S_2, S_4 ON; S_5 OFF)
2. **Level 1:** (S_1, S_4, S_5 ON; duty cycle = 25%)
3. **Level 2:** (S_1, S_4, S_5 ON; duty cycle = 50%)
4. **Level 3:** (S_1, S_4, S_5 ON; duty cycle = 70%)
5. **Level 4:** (S_2, S_3, S_5 ON; duty cycle = 25%)
6. **Level 5:** (S_2, S_3, S_5 ON; duty cycle = 50%)
7. **Level 6:** (S_2, S_3, S_5 ON; duty cycle = 70%)

III. The Proposed Inverter Simulation Model & Results

Figures 3 and 4 illustrate the MATLAB-Simulink model of the suggested inverter and the control circuit of the same inverter respectively. Figures 5 illustrate the inverter's switching device timing pulses.

Comprising a range of logical and mathematical MATLAB algorithms, the circuit controller generates the pulses necessary to regulate the proposed inverter.

Figure 6 shows the I-V and P-V output characteristic of the MATLAB PV module (1Soltech 1STH-FRL-4H-245-M60-BLK). The electrical characteristics of the PV module are briefed in Table I. The PV Array block creates an array of photovoltaic (PV) modules. The array is built by connecting each string of modules in series and parallel. This block enables users to model preset MATLAB PV modules. The results in Fig. 6 demonstrate the effect of temperature on both the voltage and current output. The rise of temperature cause PV panel power output to decrease. In this MLI the marker parts which represented by the boost converter has three different DC output level obtained from a series PV array model:

1. The first level for the duty cycle of 25%.
2. The second level for the duty cycle of 50%.
3. The third level for the duty cycle of 70%.

The boost dc-dc converter generates an output voltage higher than the voltages produced with equation 1. As illustrated in Fig. 4, the PWM signal for every level of the inverter is multiplied by the switching signal for the boost mode through the gate in the control circuit. To operate, the H-bridge circuit's diagonal switches get the switching pulses using a typical sinusoidal pulse width modulation. When one pair of diagonal switches is activated, the other switches are deactivated, and vice versa. The waveform's positive half is turned on by S1 and S4 and its negative half is turned on by S2 and S3. In the control circuit, a 50 Hz sinusoidal reference signal and a 3-phase, 12250 Hz triangular-carrier signal are compared to provide the gate signals for the switches. The pulse width modulated signal is multiplied with the boost signal for each mode with the suitable duty cycle to generate the suitable output signal voltage level.

TABLE I. Solar Module Electrical Specifications

Parameter	Value
$P_{\max}$	245 W
V_m	30.2 V
I_m	8.06 A
V_{oc}	38.3 V
I_{sc}	8.81 A
Efficiency	∼15%

Figure 7 shows the suggested output voltage of the inverter with seven levels. The overall harmonic distortion, or THD, in the output voltage is shown in Fig. 8. Examining the diagram, one discovers that, with a about 0.95 modulation index, the THD equals 7.89%.

IV. Conclusion

In today's applications, multi-level inverters are becoming an increasingly important component, particularly when they are linked with solar applications. The purpose of this study is to present a multilevel inverter that makes use of a dc-dc boost converter as its source and only requires one additional switch in order to attain the required output levels. A high-quality output voltage could be generated by the inverter that has been described, while at the same time reducing the total harmonic distortion (THD). A 7-level output voltage was generated with a lower total harmonic distortion (THD) and fewer components by utilizing the control approach that was provided. The new design is found to be more efficient than the previous used inverters based on the simulation outcomes.

Conflict of interest

The authors have no conflict of relevant interest to this article.

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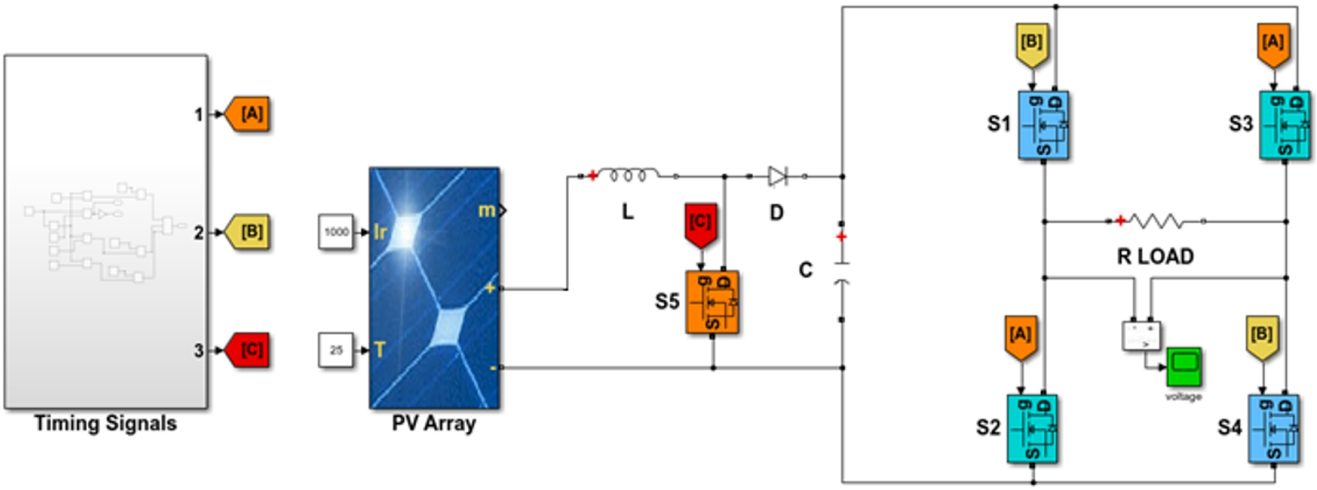

Fig. 3. Simulink representation of the suggested circuit.

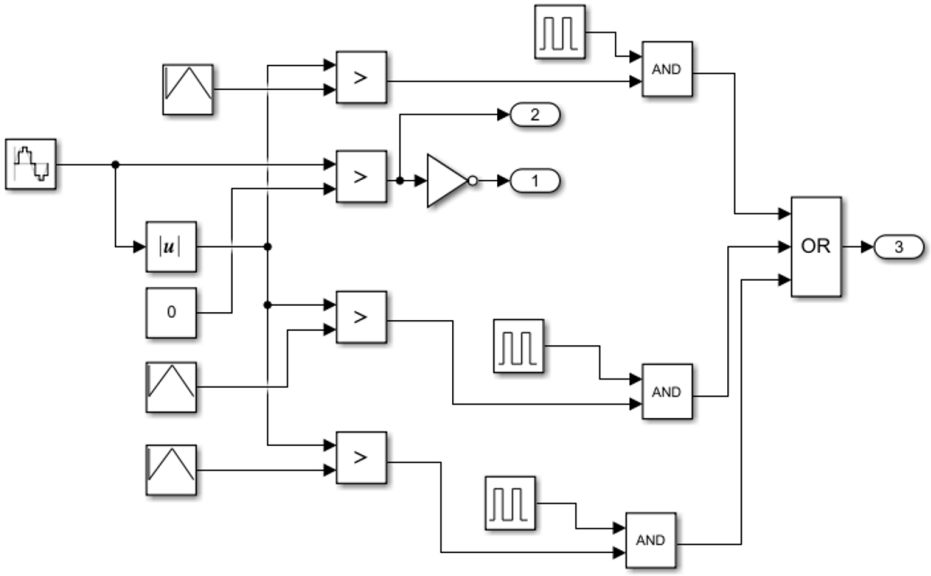

Fig. 4. The timing signals control circuit.

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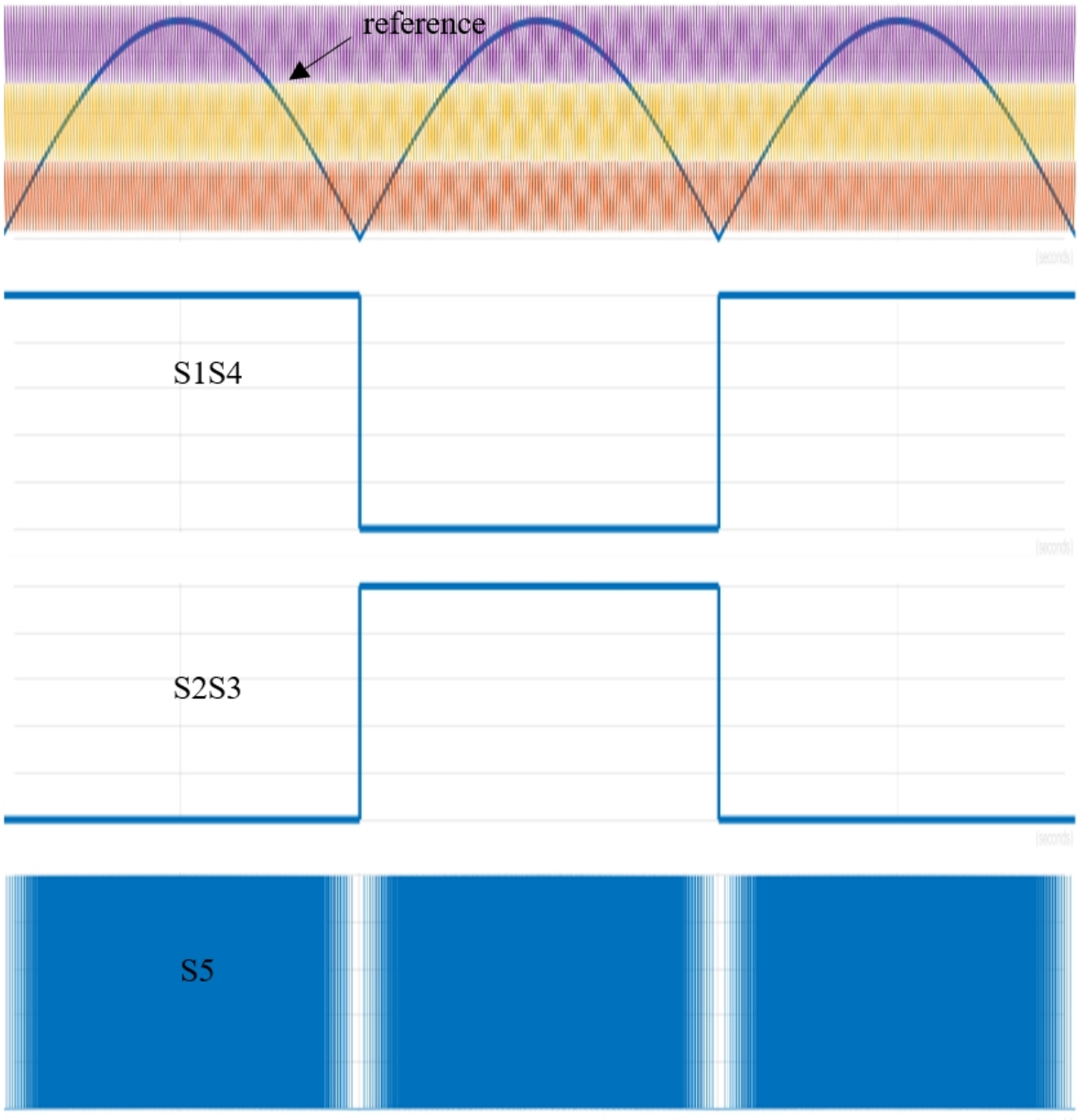

Fig. 5. The suggested inverter Timing signals.

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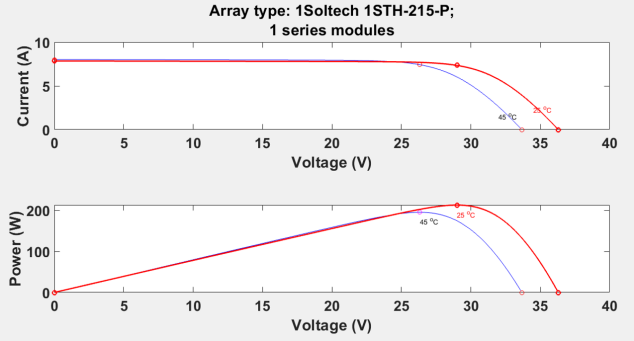

Fig. 6. I-V characteristic varying irradiation, fixed temperature.

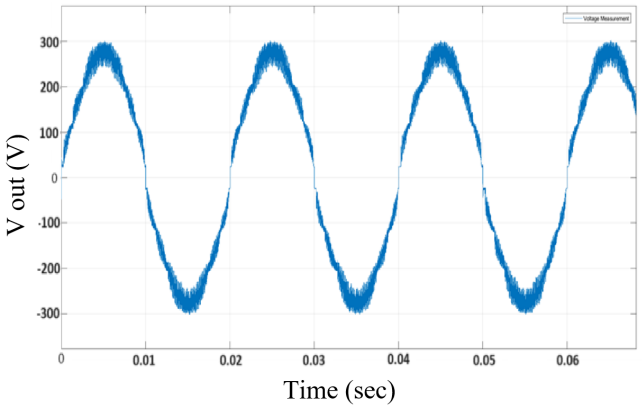

Fig. 7. The 7-level inverter output voltage.

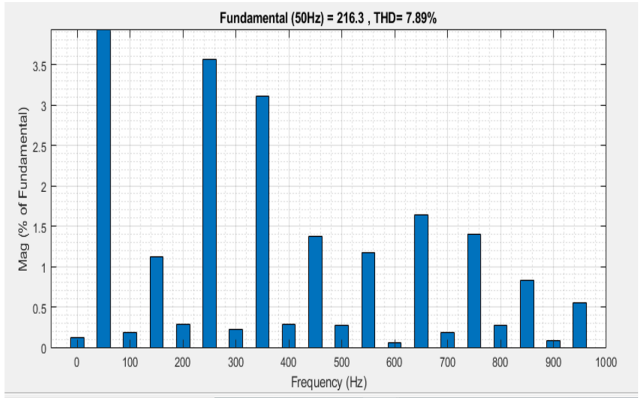

Fig. 8. The proposed inverter's total harmonic distortion (THD).

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