

# Single-Phase Nine-Level Grid-Connected Inverter for Photo-Voltaic System

Mr.R.V.Ramesh Babu<sup>1</sup>

Dr.S.Satyanarayana<sup>2</sup>

<sup>1</sup> DP.G Student, Department of EEE, VRS & YRN Engineering College, Chirala, Andhrapradesh, India  
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<sup>2</sup> Principal, VRS & YRN Engineering College, Chirala, Andhrapradesh, India

## Abstract

The ever-increasing energy consumption, fossil fuels soaring costs and exhaustible nature, and worsening global environment have created a booming interest in renewable energy generation systems, one of which is photovoltaic. Such a system generates electricity by converting the Sun's energy directly into electricity. Photovoltaic-generated energy can be delivered to power system networks through grid-connected inverters.

A single-phase seven-level inverter for grid-connected photovoltaic systems, with a novel pulse width-modulated (PWM) control scheme is proposed. Three reference signals that are identical to each other with an offset that is equivalent to the amplitude of the triangular carrier signal were used to generate the PWM signals. The inverter is capable of producing seven levels of output-voltage levels ( $V_{dc}$ ,  $2V_{dc}/3$ ,  $V_{dc}/3$ ,  $0$ ,  $-V_{dc}$ ,  $-2V_{dc}/3$ ,  $-V_{dc}/3$ ) from the dc supply voltage. Along with this a novel nine level grid connected inverter with reduced number of switches is also proposed. It generates nine levels of output voltage ( $V_{dc}$ ,  $V_{dc}/4$ ,  $2V_{dc}/4$ ,  $3V_{dc}/4$ ,  $0$ ,  $-V_{dc}/4$ ,  $-2V_{dc}/4$ ,  $-3V_{dc}/4$ ,  $-V_{dc}$ ). The proposed system is verified through simulation and the results were presented.

**Keywords:** Nine level inverter, Photo voltaic, Single phase.

## 1. Introduction

A single-phase grid-connected inverter is usually used for residential or low-power applications of power ranges that are less than 10kW [1]. Types of single-phase grid-connected inverters have been investigated [2]. A common topology of this inverter is full-bridge three-level. The three-level inverter can satisfy specifications through its very high switching, but it could also unfortunately increase switching losses, acoustic noise, and level of interference to other equipment. Improving its output waveform reduces its harmonic content and, hence, also the size of the filter used and the level of electromagnetic interference (EMI) generated by the inverter's switching operation [3].

Multilevel inverters are promising; they have nearly sinusoidal output voltage waveforms, output current with better harmonic profile, less stressing of electronic components owing to decreased voltages, switching losses that are lower than those of conventional two-level inverters, a smaller filter size, and lower EMI, all of which make them cheaper, lighter, and more compact[3],[5].

Various topologies for multilevel inverters have been proposed over the years. Common ones are diode-clamped, flying capacitor or multi cell, cascaded H-bridge, and modified H-bridge multilevel. This project recounts the development of a novel modified H-bridge single-phase multilevel inverter[20]-[25] that has two diode embedded bidirectional switches and a novel pulse width modulated (PWM) technique[11]-[17]. The topology was applied to a grid-connected photovoltaic system with considerations for a maximum-power-point tracker (MPPT) and a current-control algorithm .

## 2. Review Of Inverter Topologies

In this section short reviews of the most common topologies are presented. Figure 1. Shows the topologies considered in this paper.

### 2.1 Diode-Clamped Topology

It was the first widely popular multilevel topology, and it continues to be extensively used in industrial applications. Later, the NPC inverter was generalized for a greater number of levels, using the same concept of diode-clamped voltage levels, which resulted in the current designation of a diode-clamped converter. As it can be seen in Figure 1, the three-level NPC inverter uses capacitors to generate an intermediate voltage level, and the voltages across the switches are only half of the dc input voltage. Due to capacitor voltage balancing issues, practical diode-clamped inverters have been mostly limited to the original three-level structure.

## 2.2 Flying Capacitor

The three-level flying capacitor topology, as shown in Figure 1.(b), can be considered as a good alternative to overcome some of the NPC topology drawbacks. In this topology, additional levels and voltage clamping are achieved by means of capacitors that “float” with respect to the dc source reference. It does not require additional clamping diodes and provides redundant switch states that can be used to control the capacitor charge even under loads with the dc level. Nevertheless, larger structures require a relatively high number of capacitors, and additional circuits are also required to initialize the capacitor charge.

## 2.3 Cascade H-Bridge

This topology is composed of several H-bridge converters in cascade connection. Figure 1.(c) shows a two-cell inverter. The cascade topology allows the use of dc sources with different voltage values, and high-resolution multilevel waveforms can be achieved with a relatively low number of components. In addition, dc sources can be added or subtracted, which can increase the number of output levels. Although the original cascaded topology requires several isolated dc sources, in some systems, they may be available through batteries or PV panels; thus, it has been used to implement high-efficiency transformer less inverters.

## 2.4 Multiple Transformer

Figure 1.(d) shows a multiple-transformer topology composed of two cells. It is similar to the cascaded H-bridge topology, but the outputs of the isolation transformers are cascaded instead of directly cascading the H-bridge outputs. As a result, only one dc source is required. Currently, there are commercial inverters (for SARES applications) in the market that are based on this topology. In practice, these inverters have been proved to be robust and reliable. One disadvantage of this topology is the fact that it requires several low-frequency transformers.

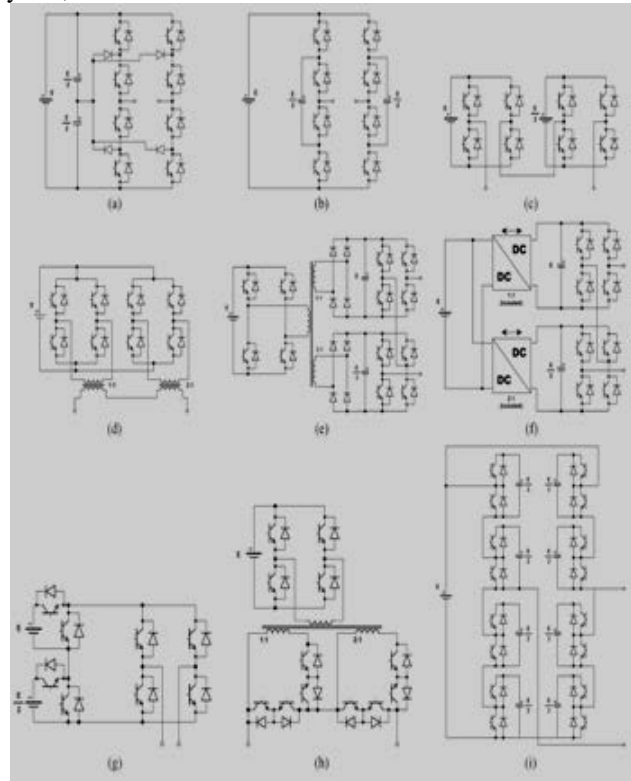
## 2.5 Other Variations of the Cascade H-Bridge

If only one dc source is available, then it is possible to use the topology shown in Figure 1.(e). This topology is simple, but losses in additional rectifier diodes can be significant, and it does not support a bidirectional power flow. On the other hand, this topology is based on high-frequency switching, and inherent benefits of low-frequency switching are lost.

## 2.6 Multiple Source

The multiple-source topology, as shown in Figure 1.(g), uses several isolated dc sources to produce a rectified multilevel waveform, which is then converted into an ac voltage. In practice, the multiple-source topology is

one of the most efficient multilevel topologies currently available. It has been tested in some RES for more than ten years, and it .



**Figure 1.** Multilevel inverter topologies (a) NPC. (b) Flying capacitors. (c) Cascade H-bridge. (d) Multiple transformer. (e) and (f) Variations of the cascade H-bridge. (g) Multiple source. (h) Multi winding transformer. (i) Modular topology.

has proved to be very efficient, robust, and reliable]. The disadvantage of this topology is the fact that it requires several isolated dc sources and does not provide input–output isolation.

## 2.7. Multilinking Transformer

The multiwinding-transformer topology can be considered as a variation of the multiple-source topology. A three-cell multiwinding inverter is shown in Figure 1.(h). Unlike the multiple-source topology, the multiwinding topology requires only a single dc input, which is achieved using a multiwinding line-frequency transformer. It provides input– output isolation, and because it employs only one transformer, high efficiency can be achieved. The major disadvantage is the relatively high number of switches presented in the output stage. Additional information about this topology can be found in.

## H. Modular Topology

Figure 1.(i) shows an eight-module modular topology that has been recently proposed for high-power applications.

### 3. Proposed H-BRIDGE converter

The different topologies presented as multilevel converters show a number of characteristics in common, giving them some clear advantages over bi-level converters, such as:

- Reduction in the commutation frequency applied to the power components.
- Reduction in voltages applied to main power switches, enabling operation at higher load voltages.
- Transient voltages automatically limited.

The main disadvantage associated with the multilevel configurations is their circuit complexity, requiring a high number of power switches that must be commutated in a precisely determined sequence by a dedicated (and complex) modulator circuit; they also require a great number of auxiliary dc levels, provided either by independent supplies or, more commonly, by a cumbersome array of capacitive voltage dividers.

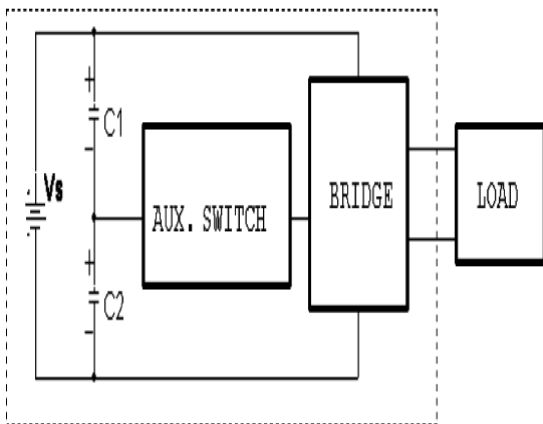


Figure 2 New topology block diagram.

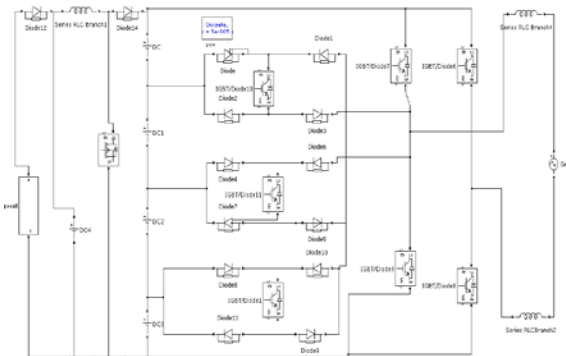


Figure 3. Proposed Nine Level Circuit

The multilevel inverters have drawn tremendous interest in the power industry. They present a new set of features that are well suited for use in reactive power compensation. Increasing the number of voltage levels in

the inverter without requiring higher ratings on individual devices can increase the power rating. The unique structure of multilevel inverters allows them to reach high voltages with low harmonics without the use of the transformers or series connected synchronized switching devices. As the number of voltage levels increases, the harmonic content of the output voltage waveform decreases significantly.

Fig 3.1 shows the proposed nine level inverter for grid connected photovoltaic systems. In the proposed circuit just by adding a single switch the voltage level is increasing from seven to nine. This will reduce the harmonic content in output, and decreases the number of switches required to increase the number of voltage levels compared to any other multilevel inverter configuration.

#### ADVANTAGES OF THE PROPOSED CONVERTER

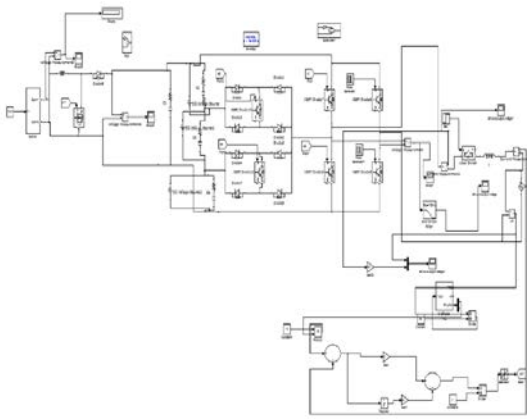
1. They are suitable for high voltage and high current applications.
2. They have high efficiency because the switches are switching at a low frequency.
3. Power factor is close to unity for multilevel inverters used as rectifiers to convert ac to dc.
4. No EMI problem exists.
5. No charge unbalance problem exists when the converters are in either rectification mode or in inversion mode.

#### 4. SIMULATION RESULTS

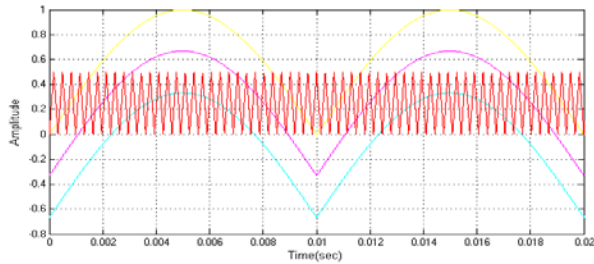
MATLAB/SIMULINK was invented in late 1970s by Cleve Moler. It is a high-level language and its interactive environment helps us to perform computationally intensive tasks faster than with traditional programming languages such as C, C++, and FORTRAN. Another important feature of MATLAB is that it helps in modeling, simulating, and analyzing dynamic systems using SIMULINK, so it is widely used in applications that describe real-world phenomena. It supports linear and nonlinear systems, modeled in continuous time or sampled time. Simulink encourages us to try things out. We can easily build models from scratch, or take an existing model and add to it. We have instant access to all the analysis tools in MATLAB, so we can take the results and analyze and visualize them. The goal of simulink is to give us a sense of the fun of modeling and simulation, through an environment that encourages us to pose a question, model it, and see what happens. The simulations done in this present paper are discussed below.

The PWM switching patterns were generated by comparing three reference signals ( $V_{ref1}$ ,  $V_{ref2}$ , and  $V_{ref3}$ ) against a triangular carrier signal.

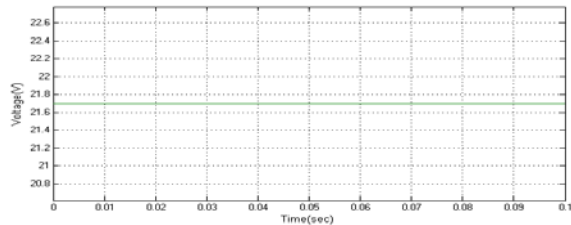
As  $I_{grid}$  is almost a pure sinewave at unity power factor, the total harmonic distortion (THD) can be reduced compared with the THD.



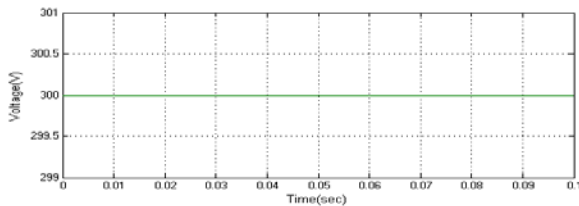
**Figure 4.** Seven Level Simulation Circuit



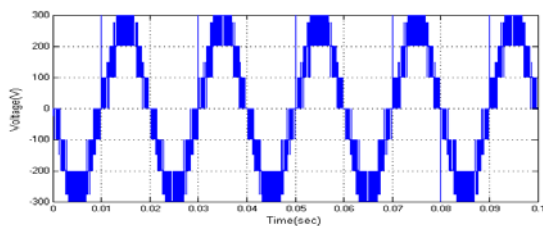
**Figure 5.** PWM Switching Signal Generation



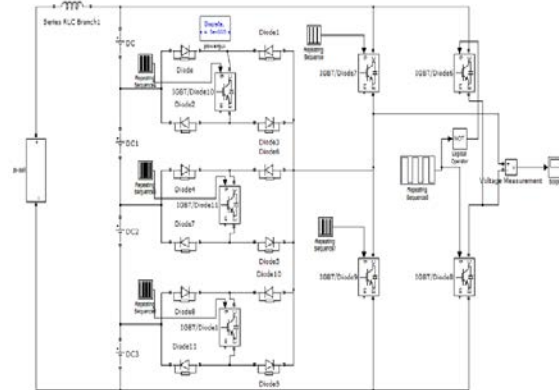
**Figure 6.** PV cell output



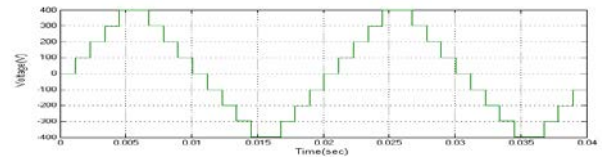
**Figure 7.** Boost Converter Output



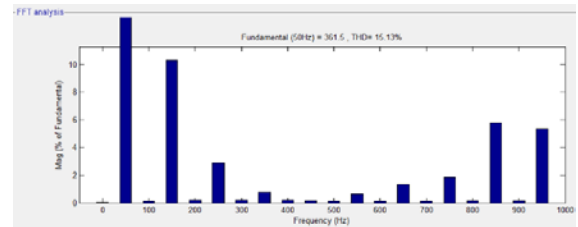
**Figure 8.** Seven Level Output



**Figure 9.** Nine Level Simulation Circuit



**Figure 10.** Nine Level out



**Figure 11.** %THD for nine level

**4. Conclusion**

Multilevel inverters offer improved output waveforms and lower THD. This paper has presented a novel PWM switching scheme for the proposed multilevel inverter. It utilizes three reference signals and a triangular carrier signal to generate PWM switching signals. The behavior of the proposed multilevel inverter was analyzed in detail. By controlling the modulation index, the desired number of levels of the inverter’s output voltage can be achieved. The less THD in the seven-level inverter compared with that in the five- and three-level inverters is an attractive solution for grid-connected PV inverters. Similarly a nine level inverter is also proposed and the proposed system is verified through simulation and the results were presented. Increasing the number of levels will reduce the THD and results in good output profile.



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