

Multi-Level Single Phase Grid Connected Converter for Renewable Distributed System

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ABSTRACT

The Single-phase grid-connected converters are commonly used in low-power renewable energy systems such as solar and wind applications. This paper presents a study of different multilevel converter topologies along with a theoretical comparison of power losses between conventional structures and the proposed converter. The proposed system is based on a modified full-bridge inverter that includes two additional power switches and two diodes connected to the midpoint of the DC-link capacitors. By utilizing the discharge of the split DC-link capacitors, additional voltage levels are generated at the output. A suitable pulse width modulation (PWM) technique is applied to maintain proper balance of the midpoint voltage. Multilevel converters have gained significant attention in recent years due to their improved power quality and suitability for industrial applications. Continuous developments in converter topologies, modulation techniques, and control strategies have expanded their practical use. This paper also highlights the growing role of multilevel converters in non-traditional and emerging applications. The proposed topology is mainly intended for renewable energy systems operating at unity power factor, and a modified version of the converter can support four-quadrant operation.

Keywords:- Cascaded full-bridge converter, hybrid five-level topology, sinusoidal PWM (SPWM), total harmonic distortion (THD), DC-AC power conversion, distributed generation, grid-connected converters, single-phase multilevel converter, power quality, harmonic reduction.

1. INTRODUCTION

The converter topologies using a high-frequency transformer instead of a low-frequency one have been made to bring down the size and weight. Power Electronics is the skill of changing electrical energy from one form to another form in an efficient, compact manner for convenient use. It is the technology that powers the efficient conversion, control and conditioning of electric power from its input source into the desired output form. The grid-connected power converters that produce harmonic distortion, power factors and dc components, must have their output current conform to the requirements of electricity supply companies. It has been noted that power and energy control is the core of modern technology and, thus, wherever the situation calls for efficiency and low cost, the power electronic architectures have to be most efficient and low cost. These architectures, however, have a difficult task because they need multiple power stages. In the case of low-power applications, international standards allow the usage of grid-connected power converters without any galvanic isolation, thus giving rise to transformerless architectures. The present paper deals with the application of multilevel technique for single-phase converters. The area of high power devices has been one of the most active fields in the research and development of power electronics over the last few decades. Industrial processes have been demanding more and more power, which in turn opened up new fields of power semiconductors, converter topologies, and control methods. Series connection of power switches is the solution for dealing with large voltages in order to meet the industrial demand. However, unipolar PWM applied to a full bridge topology is taken as a reference to link the concept to a practical implementation. It should be pointed out that, in this paper, the term unipolar PWM denotes a three-level output voltage, whose first switching harmonic lies at twice the switching frequency. The concept of multilevel converter to achieve high power is to use a series of power semiconductor switches with several low voltage sources to perform the conversion by synthesizing a staircase voltage waveforms.

2. LITERATURE SURVEY

Grid-connected power converters have been widely studied due to the increasing use of renewable energy sources such as solar and wind power systems. Early grid-connected inverters mainly used two-level converters with transformers, which resulted in high harmonic distortion, large filter size, and increased power losses. To

improve efficiency, transformer-less inverter topologies were introduced; however, they faced challenges related to leakage current and electromagnetic interference. Multilevel converter technology was developed to overcome these limitations. Cascaded full-bridge converters provided good harmonic performance but required multiple DC sources. Neutral-point-clamped and hybrid multilevel converters reduced the number of DC sources and switching losses but introduced voltage balancing issues. Recently, modified full-bridge-based converters such as the H6 topology have gained attention due to their reduced harmonics, lower switching losses, and improved power quality. These advantages make multilevel single-phase grid-connected converters suitable for renewable energy applications.

3. SINGLE-PHASE MULTILEVEL TECHNIQUE

The use of multilevel converters has become a standard feature in the power electronics of today's most modern systems. These converters are based on the idea of splitting the DC-link voltage by means of several capacitors, thus allowing the generation of intermediate voltage levels between the reference point and the total DC-link voltage. As a result, the output voltage waveform is not only smoother but also closer to that of a pure sine wave.

Research has produced a variety of single-phase multilevel converter configurations. Each topology has its own benefits regarding the reduction of harmonics, the process of conversion, and the amount of stress on the switching devices. The main structures of the single-phase multilevel converters that have been reported in the literature are presented in the following techniques.

3.1 Cascaded Full-Bridge

The Cascaded full bridges represent another approach for implementing a non-uniform three-phase output, where multiple full bridge units are connected in series. While the structure requires an increased number of separate DC input sources, it does provide another alternative because it employs a transformer to connect these units in series and uses just one DC input source. Using this transformer connection to cascade the full bridge configurations allows for several different frequency/rates, and thus several different types of PWM (Pulse Width Modulation) techniques. As previously stated, PWM techniques can be of the unipolar or hybrid variety; however, using the unipolar version in combination with a 90 degree phase difference between the carriers produces a much lower harmonic current/ripple than if all three full bridges were operated at the same switching frequency. At the switching frequency used for the suggested hybrid PWM technique, the current/ripple produced is 4 times the line frequency due to the switching of both types of PWM controlled full bridge circuits within the same switching time frame (hybrid PWM) and using low frequency for one of the full bridges, which results in a reduction of conduction power loss when the frequency of operation is lower than the switching frequency.

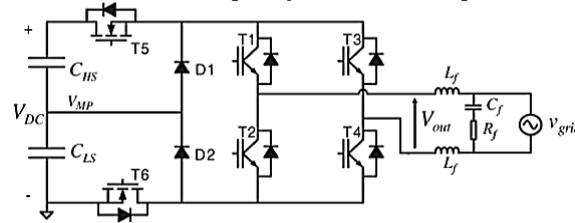
3.2 Combined Multilevel System

A modified version of the neutral-point-clamped (NPC) full-bridge converter has been proposed in recent studies. In this configuration, one leg of the converter operates as a three-level NPC leg using four power switches, while the other leg consists of only two switches operating at line frequency. A flying capacitor is used to generate the additional voltage levels. One major advantage of this structure is that only three switches conduct at any time, which helps reduce conduction losses. However, the conducting switches must be rated for the full DC-link voltage, increasing voltage stress on the devices. Proper control of the flying capacitor voltage is also required for stable operation. Another approach uses a full-bridge converter with four low-frequency switches and an additional bidirectional switch connected between the output and the midpoint of the DC-link capacitors. This structure is capable of producing five voltage levels and has been applied in photovoltaic systems. Although this method offers high efficiency, it does not adequately address DC-link capacitor voltage balancing. In another hybrid topology, the positive terminal of the full-bridge can be connected either to the DC link or to the midpoint of the split capacitors. This design uses only six switches and limits the number of conducting devices to three. However, capacitor voltage imbalance remains a major limitation, restricting its use mainly to reactive power compensation applications. Overall, hybrid multilevel converters reduce the number of conducting devices but increase voltage stress on the switches.

4. PROPOSED MULTILEVEL SINGLE-PHASE SOLUTION

The proposed converter is based on the H6 bridge topology, which was initially introduced for transformer-less photovoltaic inverters. In its original form, this structure was combined with an appropriate PWM control method to maintain a constant common-mode voltage at the output. This feature helps reduce leakage current and improves system reliability. Later, alternative PWM techniques were also developed to enhance the performance of the H6 bridge. In this work, the same converter topology is applied to develop a multilevel single-phase grid-connected converter. By generating multiple voltage levels at the output, the proposed

converter significantly reduces the harmonic content of the output voltage. This reduction makes it possible to use smaller and more economical output filters. Another important advantage of multilevel converters is the reduced voltage stress on power semiconductor devices. Since the switching voltage across each device is lower, switching losses and electromagnetic interference are also reduced. As a result, the overall efficiency of the converter is improved. Further more, the full-bridge-based structure supports different PWM control techniques, including carrier-based modulation methods and space-vector modulation. Among these, carrier-based PWM strategies are commonly preferred due to their simplicity and ease of implementation in practical systems.



The proposed converter configuration is illustrated in Fig. This topology, commonly referred to as the H6 bridge, was initially introduced for transformer-less photovoltaic inverter systems. In its original application, the H6 bridge was combined with an appropriate PWM control technique to maintain a constant common-mode voltage at the output, which helps in reducing leakage current. Later, alternative PWM strategies were also developed to further improve its performance.

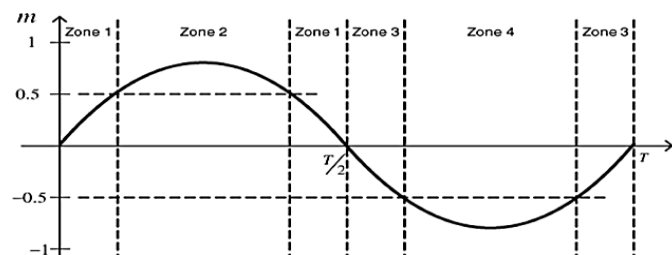
In this work, the same H6 bridge structure is utilized to realize a five-level single-phase grid-connected converter. Under steady-state operating conditions, the voltage drop across the output filter inductance L_f is very small. Therefore, the fundamental component of the converter output voltage closely follows the grid voltage. Both voltages have the same frequency, while their amplitudes and phase angles differ only slightly. As a result, the modulation index m of the converter follows a waveform similar to that of the grid voltage. The output voltage of the converter can be expressed as

$$V_{out} = m V_{dc}$$

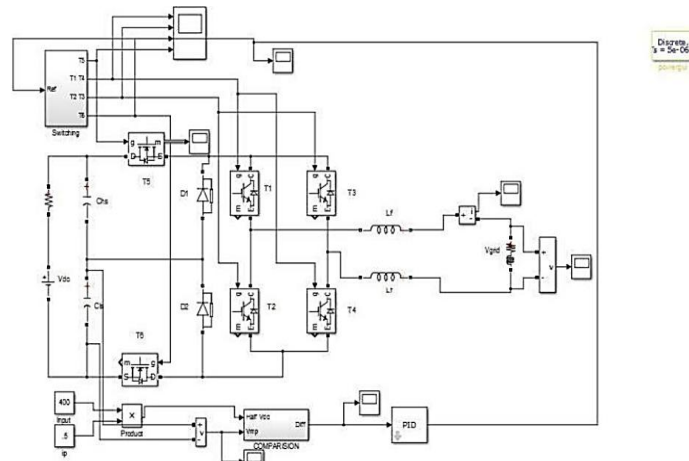
Depending on the value of the modulation index, different PWM control patterns are applied. The operation of the converter can be divided into four distinct operating zones, as shown in Fig. 4, with each zone producing different output voltage levels, as summarized in Table I.

During the positive half cycle of the grid voltage, switches T1 and T4 conduct, while T2 and T3 remain off. In Zone 1, switch T6 operates at the switching frequency while T5 remains off, whereas in Zone 2, T5 switches at high frequency and T6 remains on. During the negative half cycle, the bridge configuration reverses, with T2 and T3 conducting and T1 and T4 turned off. Similarly, in Zone 3, T5 switches while T6 is off, and in Zone 4, T6 switches while T5 remains on.

The modulation index waveform under steady-state operation illustrating the four different PWM operating zones.



5. SIMULATION MODEL DESIGN OF THE PROPOSED CIRCUIT



Simulation Model Of Proposed Circuit

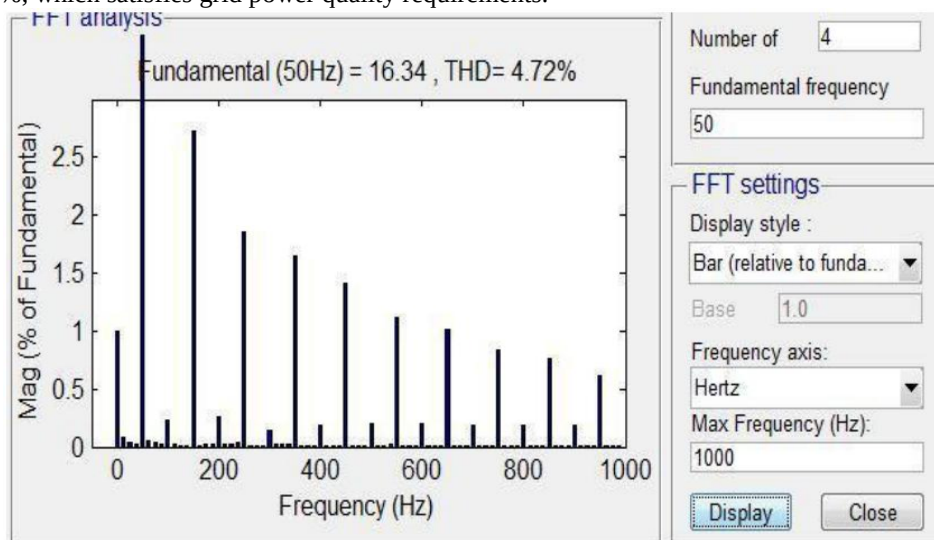
Grid-connected inverters are designed with built-in safety features to disconnect automatically from the utility grid whenever a grid failure or blackout occurs. This function, known as anti-islanding protection, ensures that the inverter stops supplying power during grid outages, thereby preventing any risk to maintenance personnel working on the power lines.

When properly configured, a grid-tie inverter allows users to connect renewable energy sources such as solar or wind systems directly to the existing electrical network without the need for complex wiring or battery storage. The power generated by the renewable source is first used to supply the load, and if the generated power is insufficient, the remaining demand is met by the utility grid.

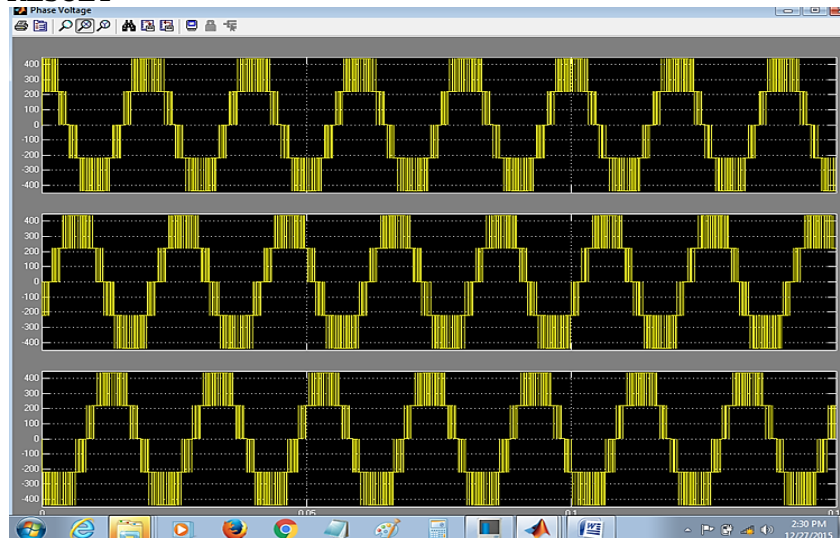
In this work, the proposed multilevel converter is modeled as a grid-connected system. The simulation includes a closed-loop control scheme using unipolar PWM for generating the required gate pulses. The complete simulation model of the proposed converter connected to the grid is shown in Fig.

5.1 Proposed System in MATLAB/Simulink Model Design

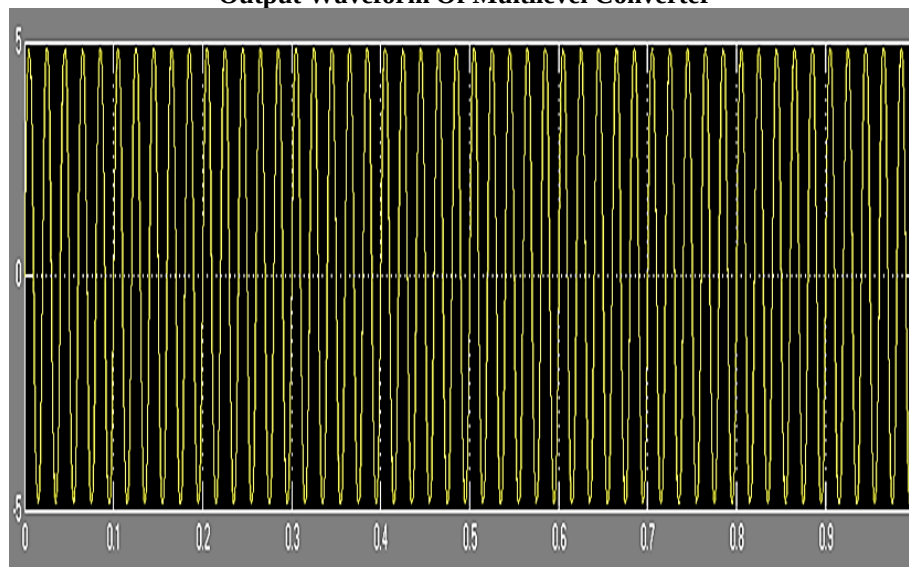
The proposed system offers the advantage of maintaining balanced voltages across the split DC-link capacitors based on the active power demand and the available power from the source. This balancing ensures stable operation of the multilevel converter under varying load conditions. The gate signals for the power switches are generated using a unipolar pulse width modulation technique, where a reference signal is compared with a carrier waveform of 10 kHz frequency. Simulation results show that the proposed five-level converter, implemented using a full-bridge topology with two additional power switches and two diodes connected to the midpoint of the DC link, produces an output voltage of approximately ± 400 V peak-to-peak. The corresponding voltage and current waveforms confirm proper multilevel operation. Harmonic performance is evaluated using fast Fourier transform (FFT) analysis. The results indicate that the total harmonic distortion of the grid current is around 4.72%, which satisfies grid power quality requirements.



SIMULATION RESULT



Output Waveform Of Multilevel Converter



Current Waveform Of Multilevel Converter

6. CONCLUSIONS

This paper has presented a multilevel solution for single-phase grid-connected converters with the objective of improving efficiency and power quality. To reduce the number of switching operations and increase overall efficiency, an appropriate PWM strategy was selected. The proposed converter topology uses the midpoint voltage of the DC link to generate multiple output voltage levels, which helps in reducing switching losses and electromagnetic interference. The performance of the proposed converter was compared with existing multilevel topologies by analyzing theoretical semiconductor power losses. The developed PWM control allows the use of MOSFETs as switching devices, which further reduces conduction losses. In addition, an effective midpoint voltage control (MVC) technique was implemented to maintain DC-link capacitor voltage balance.

It is observed that full multilevel operation is achieved when the converter operates at unity power factor. Under other operating conditions, the converter produces fewer voltage levels, leading to increased harmonic distortion and switching losses. Simulation and experimental results confirm the feasibility of the proposed converter and demonstrate good output current quality with a total harmonic distortion of approximately 4.7%.

6.1 Demands & future scopes of this technique

The demand for multilevel single-phase grid-connected converters is increasing rapidly due to the growing use of renewable energy sources such as solar photovoltaic and wind power systems. Modern power systems require converters that can deliver high efficiency, low harmonic distortion, and unity power factor while meeting strict

grid standards. Multilevel converter techniques are well suited for these requirements, making them highly demanded in distributed generation and smart grid applications.

In the future, this technique can be further developed for higher power ratings and wider grid voltage ranges. The converter structure can be optimized to support reactive power control and four-quadrant operation, allowing it to provide additional grid support functions. Integration with advanced digital controllers and intelligent control algorithms can improve dynamic performance and reliability. Hardware implementation and real-time testing will also help validate the system for commercial applications. Overall, the proposed multilevel technique has strong potential for future renewable energy and grid-interactive power systems.

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