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Research Paper

A MULTI-LEVEL SINGLE-PHASE GRID CONNECTED CONVERTER FOR RENEWABLE DISTERBUTED SYSTEM

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In low-power renewable systems, a single-phase grid-connected converter is usually adopted. This project deals with a five-level converter that follows this trend. The proposed converter architecture is based on a full-bridge with two additional power switches and two diodes connected to the midpoint of the dc link. Since the two added levels are obtained by the discharge of the two capacitors of the dc link, the balancing of the midpoint voltage is obtained with a specific Pulse Width Modulation (PWM) strategy. The hardware design is implemented by PIC16F877A controller circuit.This project proposes a five-level converter based on a full-bridge topology with two added power switches and two diodes connected to the midpoint of the dc link. In order to balance the midpoint voltage, a specific PWM strategy was developed. This solution is designed for renewable energy systems, where unity power factor operations are generally required. nevertheless, a variation of the proposed topology which allows four-quadrant operations. Multilevel converter allow to reduces the harmonic content of the converter output voltage, allowing the use of smaller and cheaper output filters. Moreover, these converters are usually characterized by a strong reduction of the switching voltages across the power switches, allowing the reduction of switching power losses.

Keywords: Terms-clamp circuit, MOSFET circuit, DC-converter, PIC microcontroller

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INTRODUCTION

With regard to harmonic distortion content, power factors, and dc components, the output current of grid connected power converters must comply with the requirements of electricity supply companies. Recently, converter topologies employing a high-frequency transformer instead of a line frequency one have been investigated in order to reduce size and weight. The tradeoff between high efficiency and low cost is a hard task for these architectures because they require several

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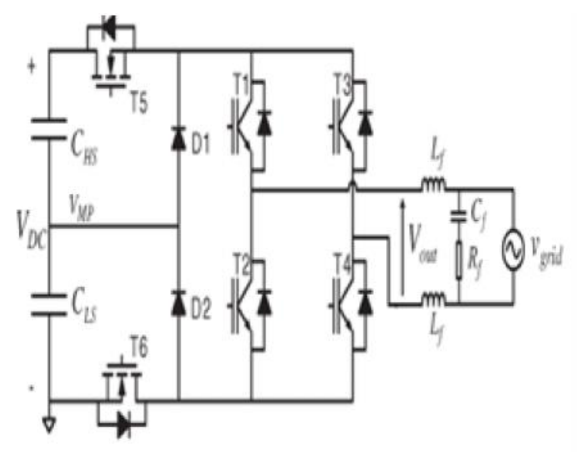
power stages. On the other hand, in low-power applications, international standards allow the use of grid-connected power converters without any galvanic isolation, thus allowing the so called transformer less architectures. This paper concerns the use of multilevel topologies for single-phase converters, but in order to remain linked to a practical implementation, the unipolar PWM applied to a full bridge topology is taken as reference. It is important to note that, in this paper, the term unipolar PWM refers to a three-level output voltage, whose first switching harmonic resides at twice the switching frequency. The unipolar PWM is always applied to a full-bridge structure.

Multilevel converterreduces the harmonic content of the converter output voltage, allowing the use of smaller and cheaper output filters. Moreover, these converters are usually characterized by a strong reduction of the switching voltages across the power switches, allowing the reduction of switching power losses and electromagnetic interference.The cascaded full-bridge allows multiple PWM strategies, i.e., carrier-based modulations or space-vector approaches. In the field of carrier-based PWM, unipolar and hybrid modulations can be applied.

Proposed Multilevel Inverter and Modeling

This converter architecture, known as the H6 bridge, was originally developed, in combination with a suitable PWM strategy, in order to keep constant the output common-mode voltage in case of a transformerless inverter for photovoltaic applications. With the same purpose, another PWM strategy for the H6 bridge was developed. In this paper, this converter structure is used to obtain a five-level grid-connected converter for single-phase applications. In steady-state conditions, due to the low voltage drop across the inductance Lf of the output filter, the output voltage of the converter has a fundamental component very close to the grid voltage. The frequencies of these two voltages are identical, whereas the amplitude and their phase displacement are only slightly different. As a consequence, the shape of the modulation index m of the power converter is very similar to the grid voltage waveform.

Figure 1: Multilevel Inverter Model



The output voltage of the converter can be written as Vout = mVdc. Depending on the modulation index value, the power converter will be driven by different PWM strategies. As a matter of fact, it is possible to identify four operating zones, and for each zone, the output voltage levels of the power converter will be different.

With reference to the schematic, the behavior of the proposed solution is shown for a whole period of the grid voltage, i.e., of the modulation index. During the positive semi period the transistors T1 and T4 are ON and T2 and T3 are OFF. In Zone 1, T5 is OFF and

T6 commutates at the switching frequency, whereas in Zone 2 T5 commutates at the switching frequency and T6 is ON. During the negative semi period the full-bridge changes configuration, with T1 and T4 OFF and T2 and T3 ON. With similarity to Zone 1 and 2, in Zone 3 T5.

This choice allows to obtain the minimum number of commutations but causes a voltage ripple in VMP at the same frequency of the grid voltage. In fact, it would be possible to reduce the ripple of the midpoint voltage VMP, but it would imply a greater number of commutations of T5 and T6. This choice is avoided in order to pursue the maximum efficiency.

Figure 2: MODE 1: T6 T5 T1 Operates

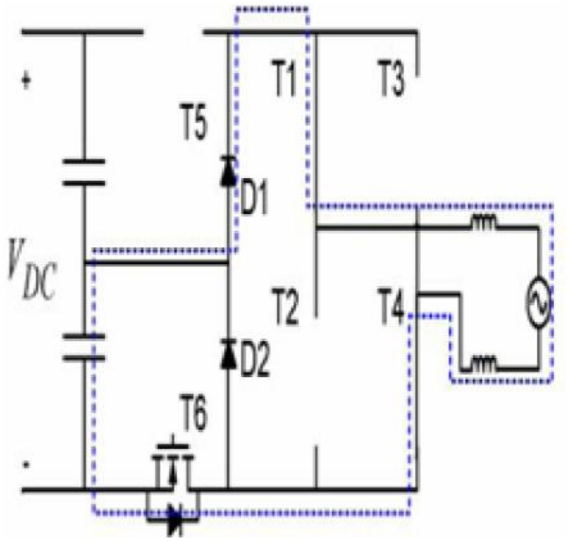


Figure 3: MODE 2: T5 T4 T1 Operates

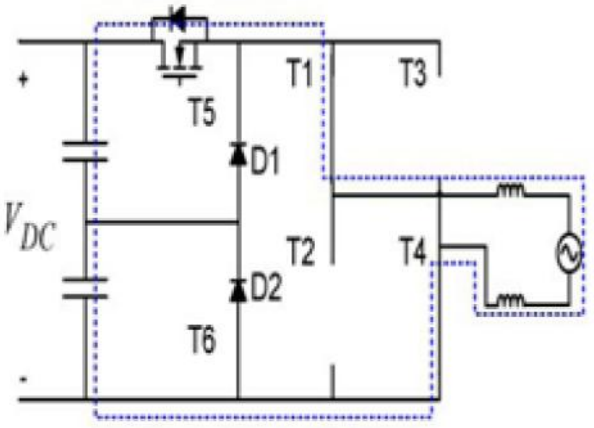


Figure 4: MODE: T1 T4 T6 Operates

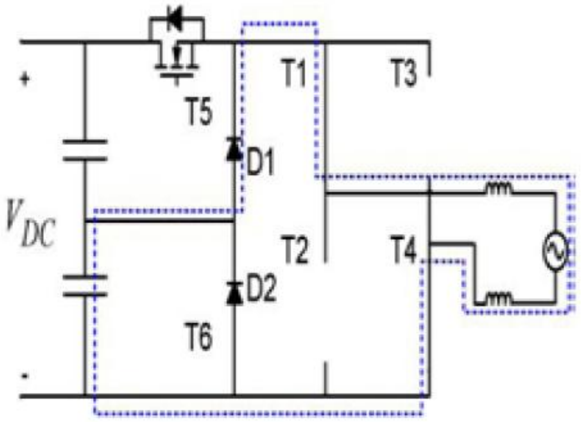
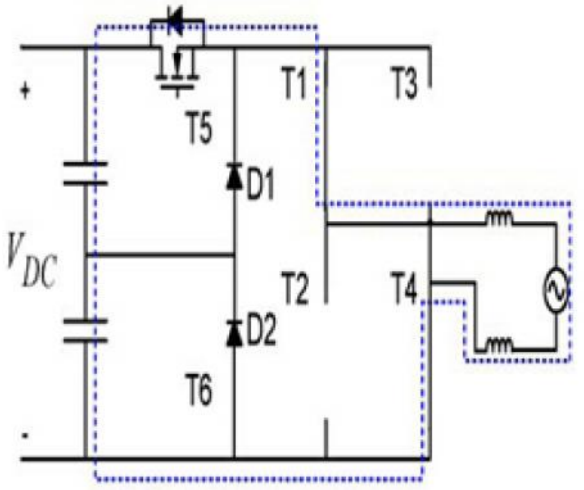


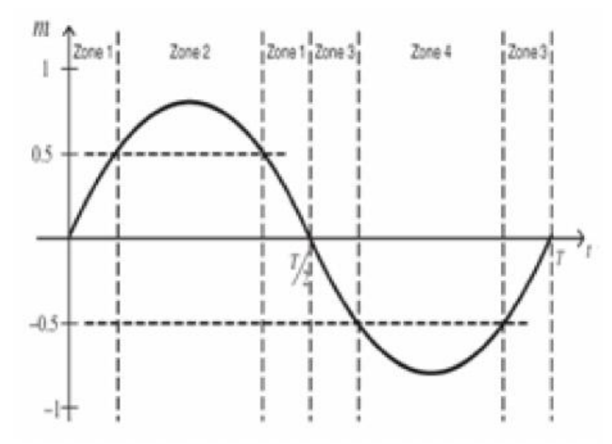
Figure 5: MODE 4: T6 T5 T1 T4 Operates



Modulation Strategies

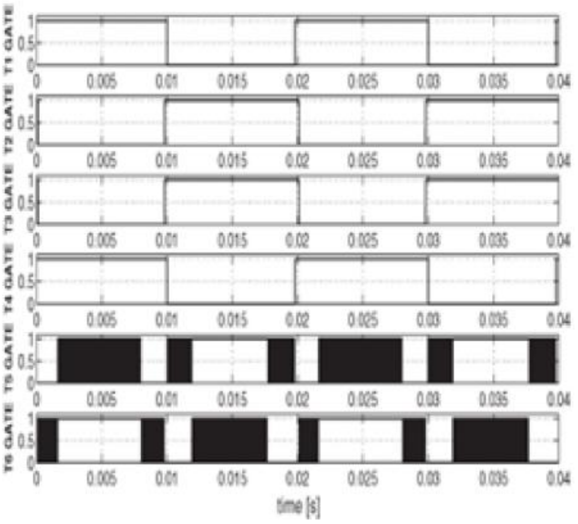
In Zone 1 the switching of the transistor T6 changes the output value between +VMP [that is provided by the low-side capacitor] and 0 V. During the freewheeling phase both diodes D1 and D2 are ON, imposing an almost null voltage at the full-bridge output. In Zone 2 T6 is ON and the switching of T5 changes the output voltage from +Vdc to +VMP. A similar analysis can be repeated for the negative semi period, Zones 3 and 4. It must be noted that only a transistor is switching for every zone.

Figure 6: Modulation Index Waveform in Steady State Conditions and Definitionof the Four Different PWM Zones



Furthermore, the antiparallel diode of every power switch is not used allowing the use of MOSFETs for all the transistors. The gate signals for the proposed five level modulation strategies. In the above described operations, the output voltage level +VMP is provided by the discharging of CLS, whereas the output voltage level “VMP is provided by the discharging of CHS. In fully symmetric conditions, the midpoint voltage will be equal to VMP = Vdc/2, however, an asymmetry could unbalance the system. This choice allows to obtain the minimum number of commutations but causes a voltage ripple in VMP at the same frequency of the grid voltage. In fact, it would be possible to reduce the ripple of the midpoint voltage VMP, but it would imply a greater number of commutations of T5 and T6. This choice is avoided in order to pursue the maximum efficiency.

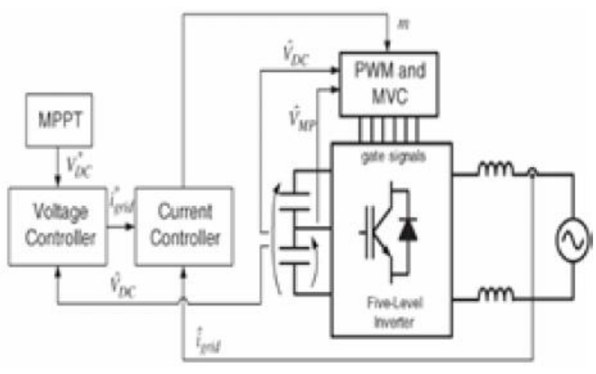
Figure 7: PWM Gate Signals for the Proposed Five-Level Modulation Strategy During Two Grid Voltage Periods



Applications of Renewable Energy Systems

The control system of the proposed topology with MVC fed by a renewable energy sourceis presented in Figure 15, which concerns a single-stage structure. The dc source can be either a photovoltaic field or a wind generator followed by a three-phaseactive or passive rectifier.The inner loop regulates the current injected into the grid, whereas the outer voltage loop fixes the dc-link voltage. In a single-stage solution, the dc link is directly connected to the energy source, and the logic onboard the converter regulates thedc-link voltage in order to extract the maximum available powerwith an Maximum Power Point Tracking (MPPT) algorithm [25], [26]. In order to track the maximum power point during abruptvariations of weather conditions, the injected grid current andthe dc-link voltage will be subject to sudden changes.In a double-stage converter, the proposed Ntopology is precededbya dc–dc converter, which implements the MPPTcontrol,

Figure 8: Block Scheme of the Proposed Converter Control in a Renewable Energy Application



whereas the dc–ac converter works with a fixed dc-link voltage. In this configuration, the dc-ac converter will be subject only to injected grid current variations.

Solar Panel

Depending on construction, photovoltaic modules can produce electricity from a range of frequencies of light, but usually cannot cover the entire solar range (specifically, ultraviolet, infrared and low or diffused light). Hence much of the incident sunlight energy is wasted by solar modules, and they can give far higher efficiencies if illuminated with monochromatic light. Therefore, another design concept is to split the light into different wavelength ranges and direct the beams onto different cells tuned to those ranges. This has been projected to be capable of raising efficiency by 50%.

Currently the best achieved sunlight conversion rate (solar module efficiency) is around 19.8% in new commercial products typically lower than the efficiencies of their cells in isolation. The most efficient mass-produced solar module have energy density values of up to 16.22 W/ft^2 (175 W/m^2). A research by Imperial College, London has shown that the efficiency of a solar panel can be improved by studding the light-receiving semiconductor surface with aluminum nanocylinders similar to the ridges on Lego blocks.

The scattered light then travels along a longer path in the semiconductor which meant that more photons could be absorbed and converted into current. Although these nanocylinders were used previously in which aluminum was preceded by gold and silver, the light scattering occurred in the near infrared region and visible light was absorbed strongly. Aluminum was found to have absorbed ultraviolet part of the spectrum and the visible and near infrared parts of the spectrum were found to be scattered by the aluminum surface.This, the research argued, could bring down the cost significantly and improve the efficiency as aluminum is more abundant and less costly than gold and silver. The research also noted that the increase in current makes thinner film solar panels technically feasible without “compromising power conversion efficiencies, thus reducing material consumption”.

HARDWARE PROTOTYPE

Figure 9: Hardware Model and MOSFETcircuit

Figure 10: Drive Circuit and PI Controller

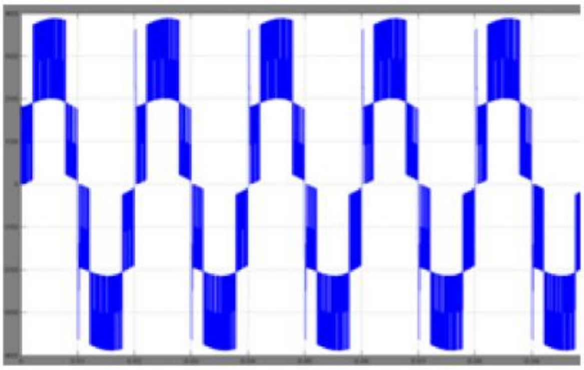
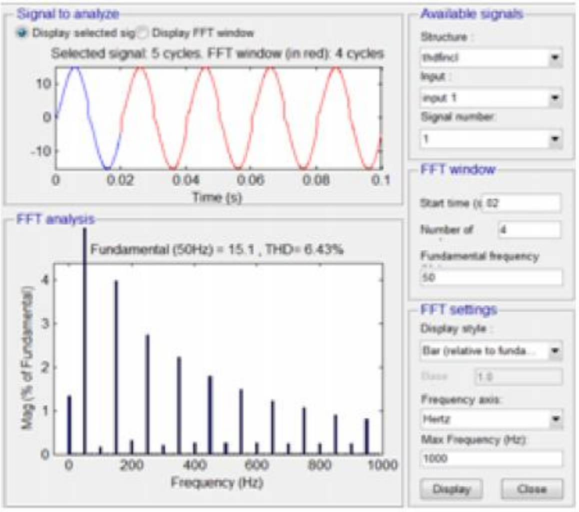


Figure 11: Output Voltage Waveform

SIMULINK DETAILS

MATLAB SIMULINK with the help of pulse generators where the Open and Closed loop is varied. The THD analysis is also compared for the two simulations which is shown below in Figure 13 Voltage waveform of open and closed loop system is shown in Figure 12.

In Zone 1 the switching of the transistor T6 changes the output value between +VMP [that is provided by the low-side capacitor, and 0 V. During the freewheeling phase both diodes D1 and D2 are ON, imposing an almost null voltage at the full-bridge output. In Zone 2 T6 is ON and the switching of T5 changes the output voltage from +Vdc to +VMP. A similar analysis can be repeated for the negative semi period, Zones 3 and 4.



Signal to analyze

● Display selected sig ○ Display FFT window

Selected signal: 5 cycles. FFT window (in red): 4 cycles

FFT analysis

Fundamental (50Hz) = 15.1 , THD= 6.43%

Available signals

Structure : thdlincl

Input : input 1

Signal number: 1

FFT window

Start time (s): 02

Number of: 4

Fundamental frequency: 50

FFT settings

Display style : Bar (relative to funda...

Base: 1.0

Frequency axis: Hertz

Max Frequency (Hz): 1000

Figure 12: O/P Current Distortion

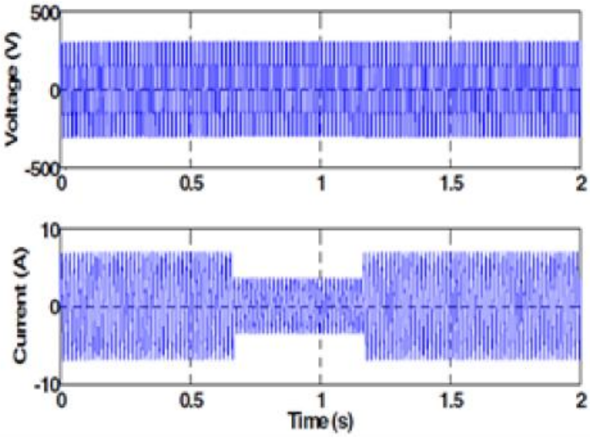


Figure 13: Load Voltage During Change in the Load

EXPECTED INPUT AND EXPECTED OUTPUT

Given I/P and Expected O/P

Simulation

- Vin = 400 V dc
- Vac = five level 400 Vac
- THD < 4%

Hardware

- Vdc = 12 V RPS
- Vac = 24 Vac pk to pk

ADVANTAGES

- Reduced harmonic waveforms at the output.
- Less EMI.
- Smaller and Cheaper filter.
- Reduces no of switches and hence reduced switching power losses.
- Power factor improvement.

APPLICATIONS

- Power conditioning.
- Motor drives.
- UPS.

FUTURE SCOPE

The system can be developed to high level that can further reduce the distortion. As the structure of this project itself implies that it can be very simple and very efficient one. Solar power plant is emerging trend to extract the electrical power. In future this design may more help to invert the power and directly fed to the grid.

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