A five-level single-phase grid-connected Converter for renewable distributed systems

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Abstract: **In low-power renewable systems, a single-phase grid-connected converter is usually adopted. This paper deals with a novel five-level converter topology that follows this trend. A review of the state of the art of the five-level topologies and a theoretical power loss comparison with the proposed solution is realized. The proposed converter architecture is based on a full-bridge topology 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. This solution is designed for renewable energy systems, where unity power factor operations are generally required. Never the less, a variation of the proposed topology which allows four-quadrant operations.**

Key Words: **Half-Bridge NPC, Cascaded Full-Bridge, Hybrid Five-Level Topologies, SPWM, THD, DC to AC Conversion.**

INTRODUCTION

GENERAL

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 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 transformerless 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.

SCOPE OF THE PROJECT

This paper proposes a novel 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, is also described.

EXISTING SYSTEM

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, converters 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 because, they require several 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 converters.

EXISTING SYSTEMS TECHNIQUE:

Resonant inverters produce sine waves with LC circuits to remove the harmonics from a simple square wave. Typically there are several series- and parallel-resonant LC circuits, each tuned to a different harmonic of the power line frequency.

PROPOSED SYSTEM

This project present a five-level converter based on a full-bridge converter 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.

PROPOSED SYSTEM TECHNIQUE

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 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.

ADVANTAGES OF PROPOSED TECHNIQUE

- Reduced harmonic.
- Less EMI.
- Smaller & Cheaper filter.
- Reduced switching power losses.
- Power factor improvement.

Given I/P & Expected O/P

- Vin=400V dc
- Vac= five level 400Vac
- THD< 4%
- Hardware
- Vdc=12V RPS
- Vac=24Vac pk to pk

SIMULATION RESULTS

TECHNIQUES USED

- Multi level inverter

TECHNIQUES DESCRIPTION

Grid Tie Inverter

Inverters take DC power and invert it to AC power so it can be fed into the electric utility company grid. The grid tie inverter must synchronize its frequency with that of the grid (e.g. 50 or 60 Hz) using a local oscillator and limit the voltage to no higher than the grid voltage. A high-quality modern GTI has a fixed unity power factor, which means its output voltage and current are perfectly lined up, and its phase angle is within 1 degree of the AC power grid. The inverter has an on-board computer which will sense the current AC grid waveform, and output a voltage to correspond with the grid. However, supplying reactive power to the grid might be necessary to keep the voltage in the local grid inside allowed limitations. Otherwise, in a grid segment with considerable power from renewable sources voltage levels might rise too much at times of high production, i.e. around noon.

Grid-tie inverters are also designed to quickly disconnect from the grid if the utility grid goes down. This is an NEC requirement that ensures that in the event of a blackout, the grid tie inverter will shut down to prevent the energy it transfers from harming any line workers who are sent to fix the power grid.

Properly configured, a grid tie inverter enables a home owner to use an alternative power generation system like solar or wind power without extensive rewiring and without batteries. If the alternative power being produced is insufficient, the deficit will be sourced from the electricity grid.

MODULATION STRATEGIES: DOUBLE FREQUENCY SPWM Technique

The proposed topology can also work with double-frequency SPWM to achieve a higher equivalent switching frequency. In the double-frequency SPWM, the five power switches are separated into two parts, and are modulated with two inverse sinusoidal waves respectively. S_1, S_2, and S_3 are modulated with u_{g1}, while S_4 and S_5 are modulated with u_{g2}. During the positive half grid cycle, the circuit rotates in the sequence of “state 4 – state 1 – state 2 – state 1,” and the output voltage v_{AN} varies between +Vdc and the zero with twice of the carrier frequency. During the negative half grid cycle, the circuit rotates in the sequence of “state 4 – state 3 – state 2 –state 3,” and the output voltage v_{AN} varies between $-V_{dc}$ and zero.

The aforementioned two modulation strategies both have their own advantages. The double-frequency SPWM can provide a higher equivalent switching frequency so that the size and weight of the filter inductor can be reduced. On the other hand, the unipolar SPWM can guarantee that the virtual dc bus C_2 is charged by the real bus every switching cycle, so that the current stress on S_1 and S_3 caused by the operation of the switched capacitor can be reduced. In this paper, the unipolar SPWM is chosen as an example for the performance evaluation and experimental verification. For all of the four operation states, there is no limitation on the direction of the output current i_{grid}, since the power switches with antiparallel diodes can achieve bidirectional current flow. Therefore, the proposed topology has the capability of feeding reactive power into the grid to help support the stability of the power system.

The proposed topology is also immune against transient overvoltage of the grid. During the mains positive voltage spikes, the voltage at point A is clamped at V_{dc} by C_1 and the antiparallel diodes of S_1 and S_4. Similarly, during the negative voltage spikes, the voltage at point A is clamped at $-V_{dc}$ by C_2 and the antiparallel diodes of S_2 and S_5. Therefore, the mains transient over voltage does not pose a safety threat for the inverter.

Simulation Design without Modulation

A simulation design modulation technique as shown in Fig.1 & Fig.4 is implemented in MATLAB SIMULINK with the help of pulse generators where the Open & Closed loop is varied. The THD analysis is also compared for the two simulations which is shown below in Fig.3, 6. Voltage waveform of open & closed loop system is shown in fig 2 & 5

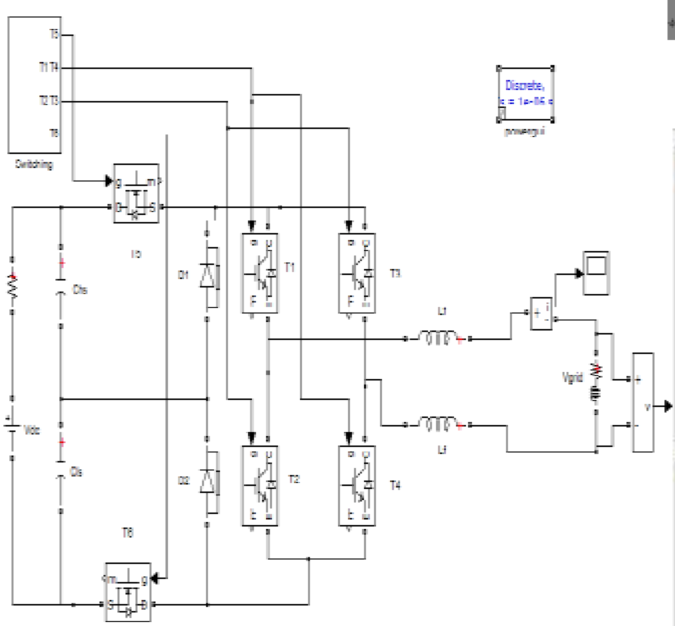


Fig.1. Proposed Open loop Five level Inverter

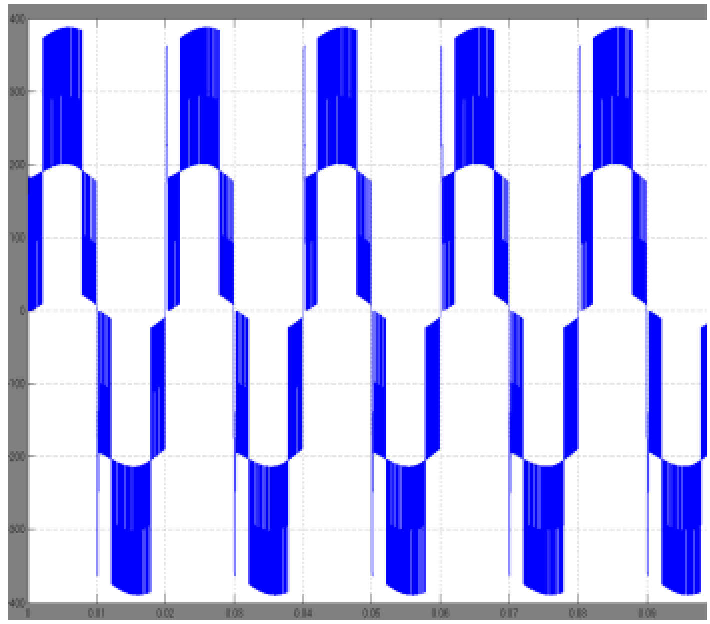


Fig.2. Output Voltage Waveform

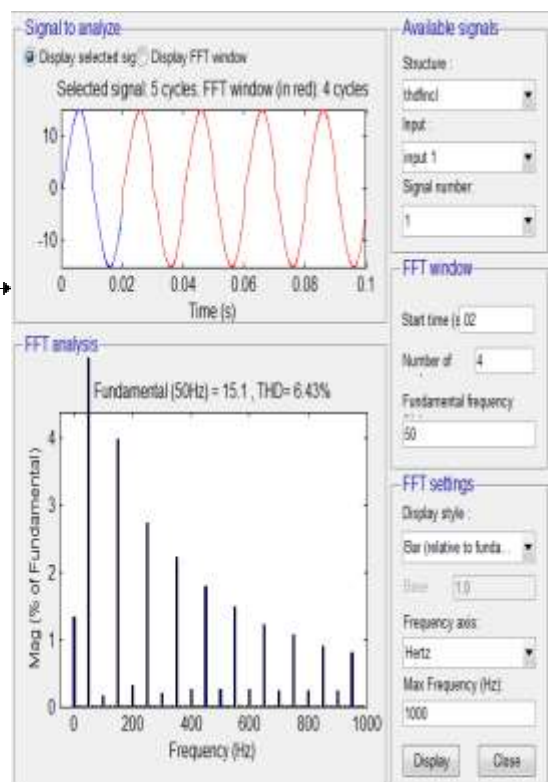


Fig.3. O/P Current Distortion

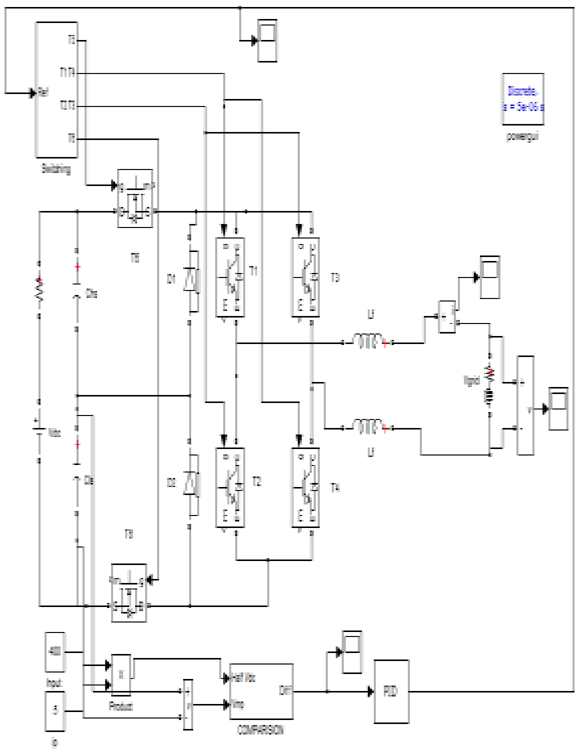


Fig.4. Proposed Closed loop Five level inverter

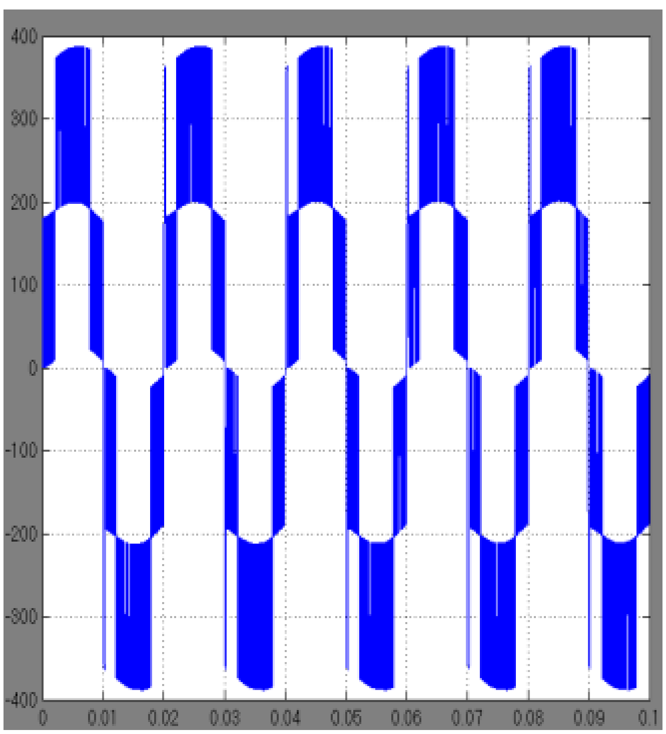


Fig.5.O/P Voltage Waveform

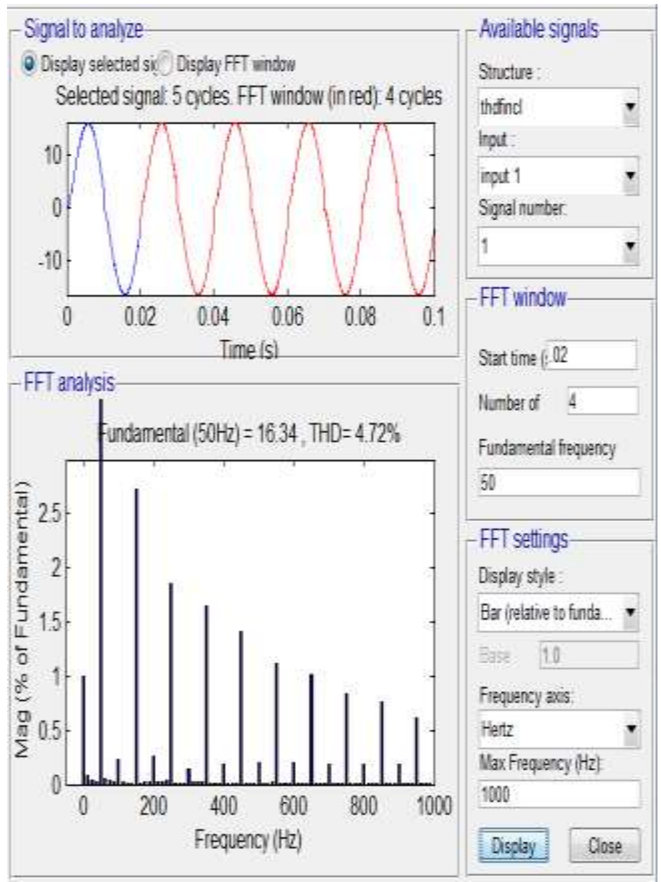


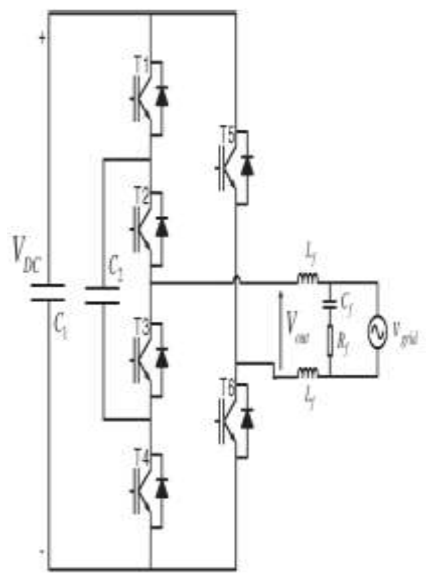
Fig.6. O/P Current Distortion

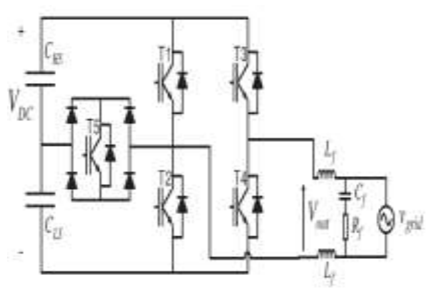
Modulation Technique

DERIVED TOPOLOGY AND MODULATION STRATEGY

Hybrid Five-Level Topologies

A variation on the NPC full-bridge was recently presented: it consists of an NPC three-level leg (four devices), whereas the other leg consists only of two devices, which switch at low frequency. A flying capacitor is employed to provide the additional voltage levels. An advantage of this architecture compared with the NPC full-bridge is that only three devices are conducting; however, these devices must have a breakdown voltage equal to the dc-link voltage. The voltage control of the flying capacitor was also realized.

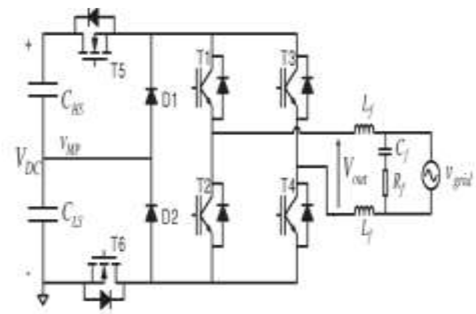




A similar approach was presented, where four low frequency devices (instead of the two employed) were employed in a full-bridge configuration. An alternative way to provide five voltage levels with a full-bridge topology was presented and employed in a photovoltaic application. In this latter proposal, the converter is constituted by a full bridge with an additional bidirectional switch (realized with an IGBT and four diodes), employed to connect the midpoint of the dc link to the converter output. The energy efficiency of this solution is potentially very high; however, the capacitor's voltage balancing is not taken into account. A different solution was proposed, where the positive rail of a full-bridge can be connected either to the dc link or to the midpoint of the dc-link capacitors. Only six devices are needed, and the maximum number of conducting devices is three. However, the balancing of the dc-link capacitors is a serious issue and limits the field of application to a reactive compensator.

PROPOSED FIVE-LEVEL SINGLE-PHASE SOLUTION

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



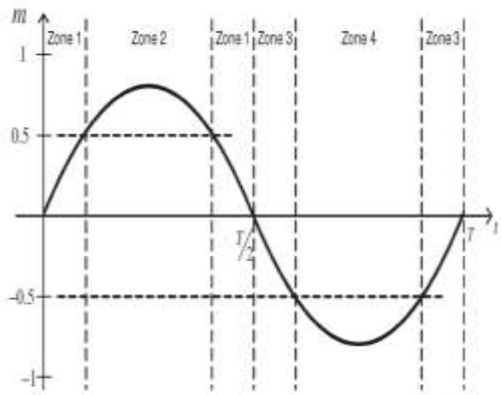
the same purpose, another PWM strategy for the H6 bridge was developed. In this paper, this converter structure is used to obtain a five-level grid-connected converter for single-phase applications. In steady-state conditions, due to the low voltage drop across the inductance Lf of the output filter, 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.

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, as shown in Table I.

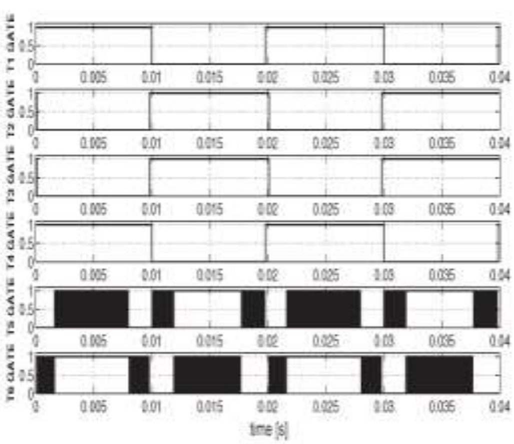
With reference to the schematic, the behavior of the proposed solution is shown for a whole period of the grid voltage, i.e., of the modulation index. During the positive semi period the transistors T1 and T4 are ON and T2 and T3 are OFF. In Zone 1, T5 is OFF and T6 commutates at the switching frequency, 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.

MODULATION STRATEGIES

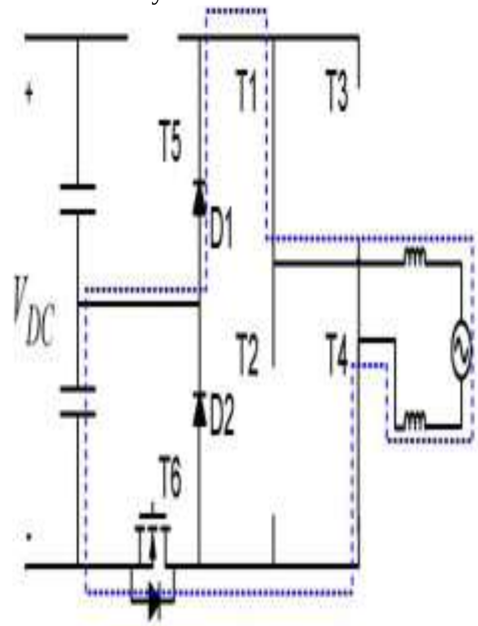
In Zone 1 the switching of the transistor T6 changes the output value between +VMP [that is provided by the low-side capacitor] and 0 V. During the freewheeling phase both diodes D1 and D2 are ON, imposing an almost null voltage at the full-bridge output. In Zone 2 T6 is ON and the switching of T5 changes 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.

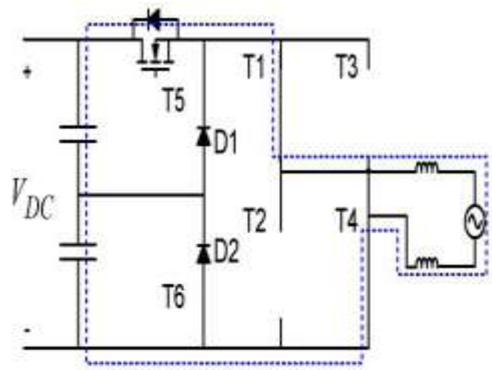


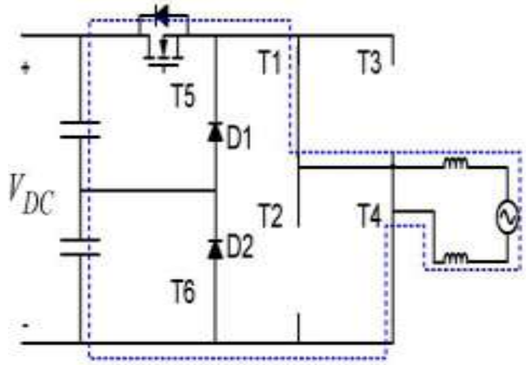
Furthermore, the antiparallel diode of every power switch is not used allowing the use of MOSFETs for all the transistors. The gate signals for the proposed five level modulation strategies. In the above described operations, the output voltage level +VMP is provided by the discharging of CLS, whereas 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.

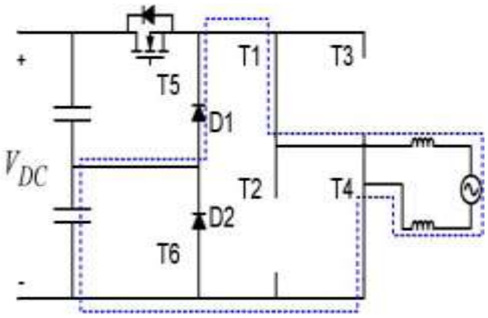


This choice allows to obtain the minimum number of commutations but causes a voltage ripple in VMP at the same frequency of the grid voltage. In fact, it would be possible to reduce the ripple of the midpoint voltage VMP, but it would imply a greater number of commutations of T5 and T6. This choice is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









EXPECTED INPUT AND EXPECTED OUTPUT

Given I/P & Expected O/P

Simulation

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

Hardware

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

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BIOGRAPHIES

Mekala Santhosh Reddy received his B.Tech degree in EEE from Jawaharlal Nehru Technological University, Hyderabad in the year 2015. Past, he was done his Job in the Unisoft Applications Pvt Ltd.,Hyderabad,Telangana,India His research area includes DTC and Drives. He presented1 research papers in various national and international conferences and journals. His research areas include PWM techniques, DC to AC converters and control of electrical drives.

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