

Design of Single-Phase AC DC AC Bidirectional Three-Arm Converter with Reduced Switches

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Abstract: The paper proposes a 1 ϕ unidirectional five-level three arm inverter. It is comprised of a T-Type arm in the output side with bidirectional capability. The proposed inverter provides the voltage with regulation of magnitude and frequency. It also provides better power quality in terms of Total Harmonic Distortion and power factor, and also reduces the number of components as we are using shared arms or leg. The space-vector PWM strategy was designed in order to increase the performance and also to get 5 level output at both ends and also eliminates the unbalance caused in the DC-link due to the DC capacitance with midpoint connection. The simulation is carried out in MATLAB/Simulink 2018b version software.


1 INTRODUCTION

Due to applications like Active Power Filters (APF), and Uninterruptible Power Supply (UPS), Unified Power Quality Conditioners (UPQC), fascinate in 1 ϕ AC-AC converters have considerably expanded recently. These converters supply steady ac voltage to serve essential loads including computers, telecommunication systems, and biomedical instruments. They also deliver sinusoidal source currents with unity power factor (N. B. de Freitas 2018). The three-leg six-switch converters have been employed as a less expensive option to a four-leg arrangement in the aforementioned applications. This structure offers identical voltage capacity as its four-leg equivalent when the input and output voltages are at the same frequency (N. Rocha 2018). Numerous three-leg configurations are being suggested in the literature as a result of these properties. It was suggested to use a unidirectional, single-phase, three-leg AC-DC-AC converter (Wang 2020).

Comparing this design to a three-leg converter, it is more effective and less expensive (referred to as a 3L2D converter) (Sandeep 2019). The rise in

harmonic distortion is its lone flaw. Three-legged converters have also been used with multilevel topologies. These topologies combine the shared leg's ability to minimise switch count with the key advantages of multilevel systems, including reduced voltage strain across the power components, minimum switching losses, and less harmonic distortion. For unidirectional applications, the multilevel three-leg topologies cascaded, and parallel 3L2D converters are all appropriate (K. Yadav 2019). Due to its simplicity, the suggested topology—referred to here as converter 3LNPC2D—is of particular importance. Based on the unidirectional leg, it is more efficient and retains all the benefits of its bidirectional form despite having just 10 active switches. The 3LNPC2D converter's primary drawback is the more number of components in the current path, which maximizes the conduction losses (Lopez 2017). The application of this finding to the 3L2D and 3LNPC2D converter is possible. Therefore, the ordinary 3L2D converter is unquestionably the best option when performance is the primary criterion for selection. T-type inverters are often used in industrial settings, including automated and renewable energy systems. There are just four switches in a 3-level T-type leg, which combines the satisfaction of minimal conduction losses with excellent output voltage quality. T-type inverters have therefore been the subject of extensive

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investigation in the literature. The T-type inverter evolved from having four levels to having n levels. These were known as nested multilevel converters because the central points of the limbs are connected to the same spot. T-type inverters are being used with different multilevel topologies to enhance the number of levels. For instance, a T-type leg can be used to create a nine-level inverter. A T-type inverter may be used to combine a wide range of hybrid topologies. There hasn't been much research done on using a T-type converter for single-phase ACDC-AC conversion.

Determining a single-phase T-type unilateral AC-DC-AC converter is the goal of this work. A unidirectional T-type arm and 2 bidirectional T-type arms make up the suggested converter. A typical two-level leg forms the T-type leg, which is connected to the DC-link midway by an active bidirectional switch. The bidirectional switch can be implemented in several ways.

In this paper, two switches are connected with common source or emitter and create a bidirectional switch which is used in proposed 3 leg 5 level inverter. The new inverter possesses minimized number of switches compared to other traditional multilevel inverters of same levels with bidirectional capability. Due to this and improved performance based on power quality, it can be utilized in uninterruptible power supplies and active filters.

2 SYSTEM IMPLEMENTATION

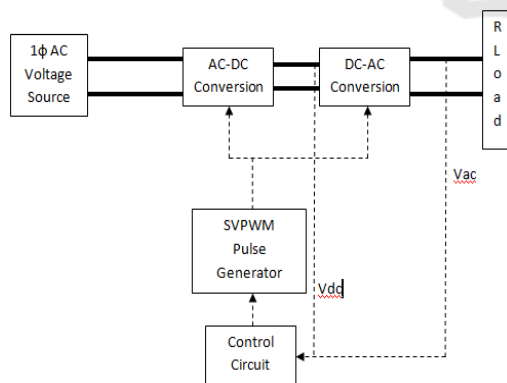


Figure 1: Modified system block diagram.

The block diagram of the new inverter is given below in Figure 1. AC voltage source is provided to the proposed AC-AC converter which operates based on the reference voltage provided to the controller. The output voltage and DC-link voltage is given back to controller and based on the modulation signal,

SVPWM pulse generator provides the pulses to the converter. It is also possess bidirectional capability so that the path of power flow can be reversed. The modified converter consists of five-level unidirectional and bidirectional voltage arms, DC-link capacitor bank (C_{01} and C_{02}) and filters.

The unidirectional leg is composed of q_1 and \bar{q}_1 and by the bidirectional switch q_{13} . By this, we can able to achieve power flow from grid to load and load to grid.

The proposed 5 level 3 leg T-type inverter is given below in Figure 2:

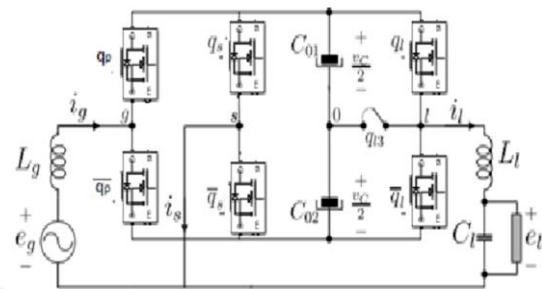


Figure 2: Proposed 5-level Inverter.

Modes 1, 2 and 3 are for positive half cycle of voltage supply and modes 4, 5 and 6 are for negative half cycle.

Mode 1:

In this mode, the inductor L_g gets charged as the switches q_p and q_s is turned ON. The load is supplied from the energy stored in C_l . The operational circuit for mode 1 operation is given below in Figure 2 (a):

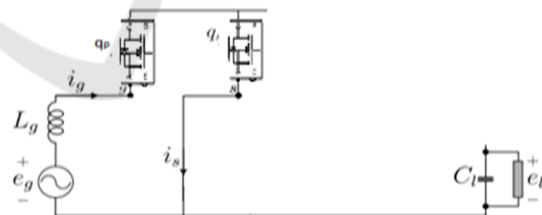


Figure 2(a): Mode 1 circuit of 5-level T-type inverter.

Mode 2:

In this mode, q_p and q_{13} are turned ON. The inductor L_g discharges and charges the capacitor C_{01} along with supplying the load. The load voltage is around $V_g + V_{ind} - V_{c01}$. The operational circuit for mode 2 operation is given below in Figure 2(b):

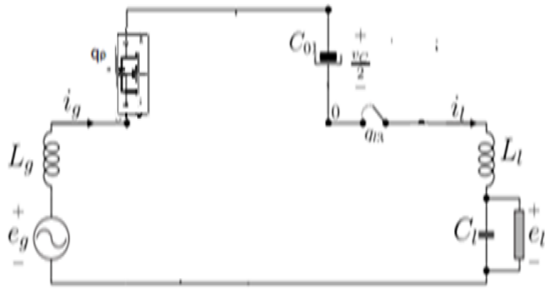


Figure 2(b): Mode 2 circuit of 5-level T-type inverter.

Mode 3:

In this mode, q_p and q_l are turned ON. The inductor L_g discharges and supplies the load. The load voltage is around $V_g + V_{ind}$. The operational circuit for mode 3 operation is given below in Figure 2(c):



Figure 2(c): Mode 3 circuit of 5-level T-type inverter.

Mode 4:

In this mode, the inductor L_g gets charged as the switches q_p and q_s is turned ON. The load is supplied from the energy stored in C_1 . The operational circuit for mode 4 operation is given below in Figure 2(d):

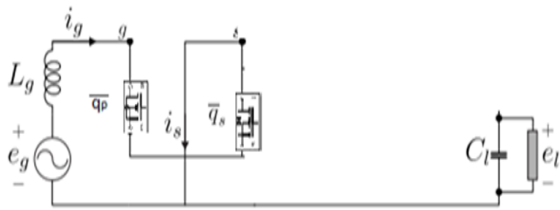


Figure 2(d): Mode 4 circuit of 5-level T-type inverter.

Mode 5:

In this mode, q_p' and q_{l3}' are turned ON. The inductor L_g discharges and charges the capacitor C_{o2} along with supplying the load. The load voltage is around $-(V_g + V_{ind} - V_{co2})$. The operational circuit for mode 5 operation is given below in Figure 2(e):

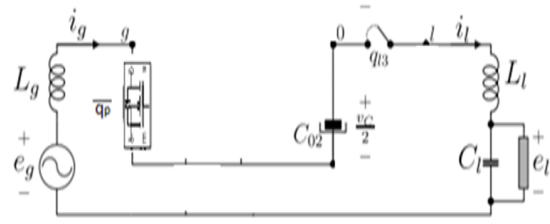


Figure 2(e): Mode 5 circuit of 5-level T-type inverter.

Mode 6:

In this mode, q_p' and q_l' are turned ON. The inductor L_g discharges and supplies the load. The load voltage is around $-(V_g + V_{ind})$. The operational circuit for mode 6 operation is given below in Figure 2(f):

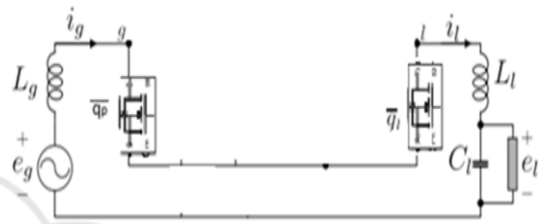


Figure 2(f): Mode 6 circuit of 5-level T-type inverter.

3 PROPOSED CONTROL STRATEGIES

To synchronise the grid side and load side, a control circuit is suggested for regulating the capacitor voltages. The control scheme has a series framework, with an exterior loop in charge of adjusting the electrical grid current reference i_g and an inner loop in charge of adjusting the voltage at the DC link $V_C = V_{C01} + V_{C02}$. A PI regulator controls the reference grid current's amplitude and modifies V_C to match its reference value. Since the converter's power flow is unidirectional in nature the control method should be able to eliminate the distortion caused by the input current zero-crossing.

This issue is resolved by using a PLL (Phase Lock Loop Technique) to synchronise the grid current i_g relative to the rectifier voltage v_g . The topology can nevertheless function using a power factor that is near to unity because the shift angle among e_g and v_g is so tiny. With respect to I_g^* and g , the block G_{ig} specifies the grid current reference as $i_g = I_g \sin g$. Resonant control (R_g) was utilised to modify i_g to match its reference. The block G_{v1} , i.e., $v_1 = V_1 \sin g$, establishes a reference voltage using v_1 and g .

It only operates when the load voltage is in phase with grid voltage with reduced magnitude and also by balancing the dc capacitor voltages v_{C01} and v_{C02} .

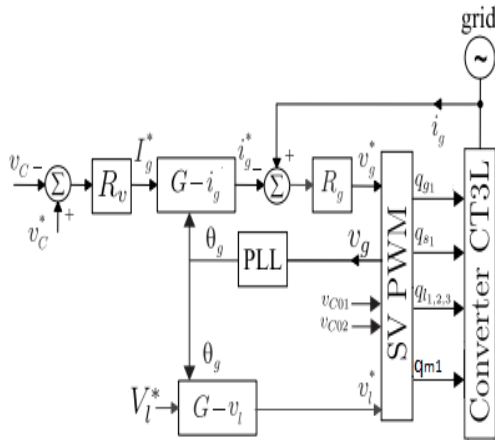


Figure 3: Proposed control strategy for three-leg five-level T-type inverter.

The reference load voltage and grid voltage can be incorporated using SVM strategy. The space-vector plane for the proposed inverter is given below in Figure 4.

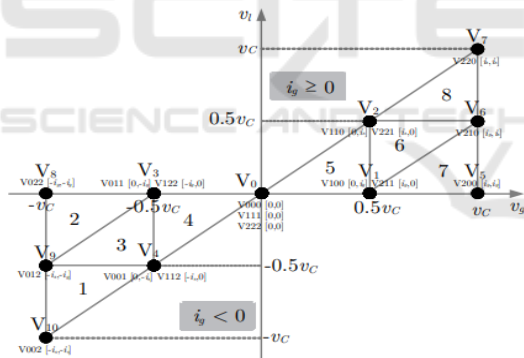


Figure 4: Switching states of proposed inverter.

From above figure, there are nine active switching vectors ($V_1 \rightarrow V_{10}$), eight sectors in addition with a null vector (V_0). The vectors are provided in the equation shown below:

$$V^* = k_g + k_l + k_s = v_g^* + jv_l^*$$

Where, the inconsistencies can be expressed as V k_g, k_l, k_s , where k_g, k_l , and k_s represent the switching phases of arms g, l , and s , respectively. The grid and load voltages correspond towards the real (Re) and imaginary (Im) axes, respectively. There are opportunities to create the model vector V since there are duplicate switching states. The switching patterns

are intended to balance the imbalance brought on through the DC-link mid-point interconnection and minimise the loss of power (conduction and switching losses).

The reference vector must be incorporated as:

$$V^* = V_x \frac{t_1}{T_s} + V_y \frac{t_2}{T_s} + V_z \frac{t_3}{T_s}$$

In the above equation, t_1, t_2 and t_3 are time weights for the vectors V_x, V_y and V_z , respectively, and the switching cycle time is defined by $T_s = t_1 + t_2 + t_3$. The time weights are determined using the following relation:

$$\begin{bmatrix} t_1 \\ t_2 \\ t_3 \end{bmatrix} = \begin{bmatrix} \frac{\text{Re}(V_x)}{T_s} & \frac{\text{Re}(V_y)}{T_s} & \frac{\text{Re}(V_z)}{T_s} \\ \frac{\text{Im}(V_x)}{T_s} & \frac{\text{Im}(V_y)}{T_s} & \frac{\text{Im}(V_z)}{T_s} \\ 1 & 1 & 1 \end{bmatrix}^{-1} \begin{bmatrix} v_g^* \\ v_l^* \\ T_s \end{bmatrix}$$

4 SIMULATION FRAMEWORK & OUTCOME

The simulation parameters for the modified inverter are provided below in Table 2:

Table 2: Simulation Parameters.

Input Voltage	110 Volt
Output Voltage	210 Volt
Frequency	50 HZ
Output power	100 Watt
Load Resistance	100 Ohm

The simulation circuit is given below in Figure 5.

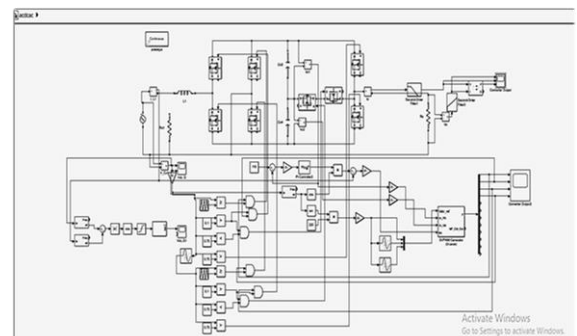


Figure 5: Simulation circuit of 3-leg 5-level inverter.

Here, the input AC voltage of 110 Volt is connected to the modified inverter which boosts up to 210V and provided to the resistive load of 100Ω. It consists of 8

switches including a bidirectional switch. The pulses generated from the s pulse generator are provided below in Figure 6.

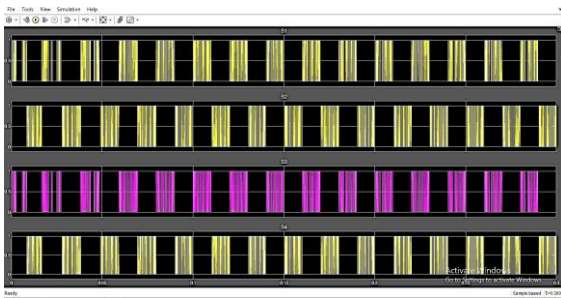


Figure 6: Switching Pulses of proposed inverter.

The output voltage and current along with power is given below in Figure 7.

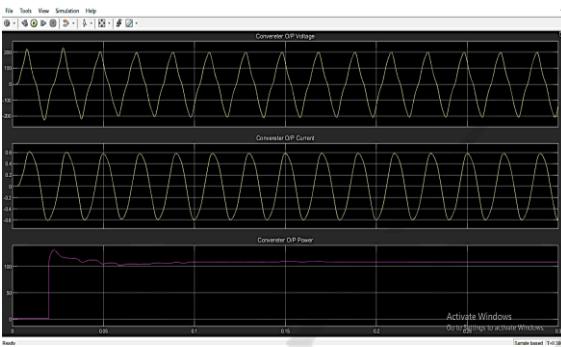


Figure 7: Output voltage, current and power waveforms of 3-leg 5-level inverter.

The peak output voltage is around 210V and the current is around 0.6 A with power is around 106VA. The %THD of the load current is given below in Figure 8.

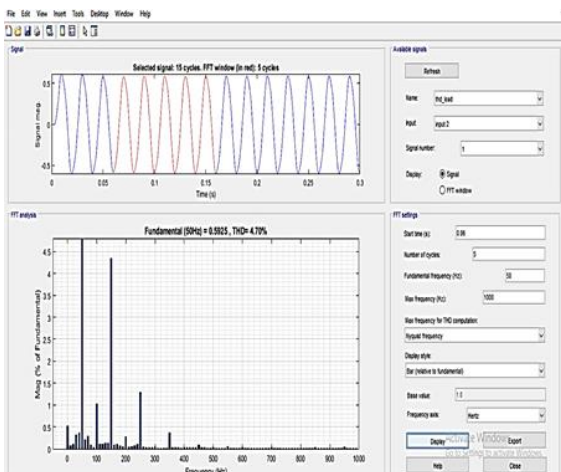


Figure 8: %THD of modified inverter.

The %THD of the load current is around 4.7%. The power factor measured at the input side is given below in Figure 9.

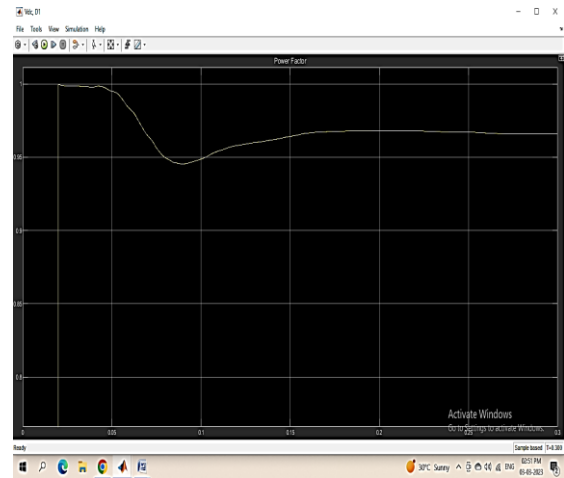


Figure 9: Power Factor of proposed system.

The power factor is around 0.964.

A hardware prototype of modified inverter with input voltage of 12V, 50 Hz is developed with 24V as load voltage with load resistance of 100 ohm. The hardware parameters are given below in the following Table 3.

Table 3: Hardware Parameters.

IRF 250N MOSFET	200Volt, 30A
U1560-Diode	200-400-600Volt, 15A
Capacitor	1000µF, 25Volt 1000µF,100Volt
Transformer	12Volt, 1A
TLP-250 Driver IC	12Volt, 1.5A
CD 4050 Buffer IC	3-18Volt, 0.32mA
12V Regulator 7812	12Volt, 1A
IN 4007 Diode	700Volt, 1A
Arduino UNO controller	7-12Volt, 20mA

The load voltage division setting is 20V/div for the above voltage waveforms.

Arduino UNO control is used to produce the pulses for the modified inverter and it is given to driver circuit (TLP 250) in order to navigate the MOSFETs IRF 250. The five-level three-leg inverter voltage is given below in Figure 10.

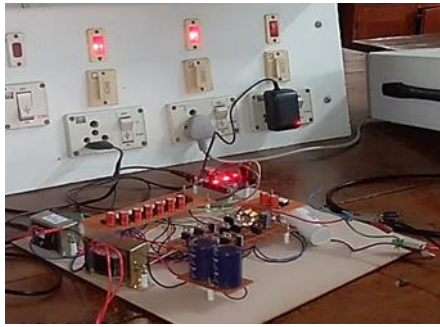


Figure 10: Five-level three-leg inverter voltage.

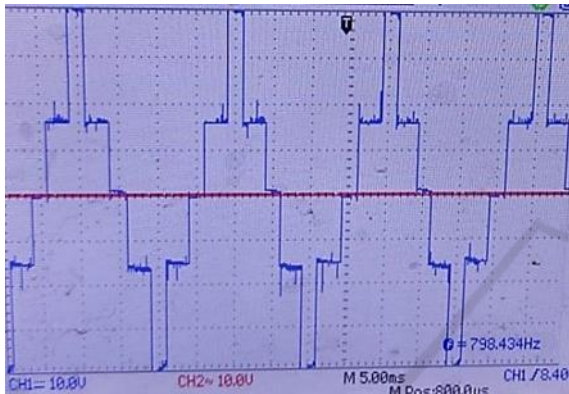


Figure 11: Load voltage with Capacitor filter.

In the above waveform, in positive cycle, two levels (one level is $V_{dc}-V_{c1}$ and second level is V_{dc}) and in negative cycle two levels and with zero level we get five-levels.

The load voltage with C filter is given below in Figure 12.

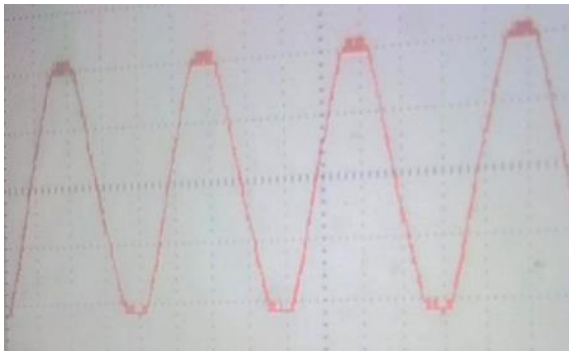


Figure 12: Hardware framework of modified system.

5 CONCLUSIONS

Here, a 5-level 3 leg T-type inverter with bidirectional power conduction capability is designed and the

modes of operation of the modified inverter was explored. A control structure is formulated to reduce the voltage distortions caused by DC-link capacitors. A space vector modulation based switching strategy is followed to reduce the unbalances and thereby reduce the harmonics as well as system losses. In this, the power factor is measured as 0.964 and the %THD is around 4.7% for the R load of 100 ohm. A hardware model is designed and the output voltage waveforms with and without filter is verified. The main advantage and applications of proposed AC-DC-AC converter are it possesses minimum number of switches and hence the losses will be low. In reference paper [1] total number of switches is ten, and here in this work it is reduced to eight. It is capable of bidirectional power flow; it can be used in AC drives with regenerative braking capability. It also possesses voltage boosting capability.

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