SINGLE-PHASE T-TYPE TRANSFORMERLESS NPC- MLI

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Abstract

This inverter topologies highly suffered with leakage current flow through the ground path and the inverter power circuit. Hence, these inverters had a shoot-through (shot circuit) problem in the inverter bridge legs and hence leakage current in the inverter should be suppressed through via their freewheeling or overwhelming conduction path. The NCP-MLI topologies is being immensely used in PV application due to its enhanced performance as compared to two-level voltage source inverter. In NPC-MLI topology, compare to "I" type, "T" type has a great compatibility, since it is free from clamping diodes. Hence, in this research develop a T – type transformer less NPC-MLI topology for PV grid connected system. The main objective of this work is to build a closed loop grid connected PV tied single phase T - type transformer less NPC-MLI. The proposed inverter model, modes of operation and control for PV tie system is presented in detailed. The MATLAB/Simulink based study show that the proposed inverter attains high efficiency operation for PV input, and parades leakage currents reductions, and fulfils the transformerless inverter topology regulations and norms.

Keywords— *current THD, voltage THD, modulation index, T-type transformer-less inverter.*

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1. INTRODUCTION

Several inverter topologies for integrated PV module grid inverters have been developed. However, this method is expansive, inefficient. To tackle the issue of transformer utilization, researchers developed PV powered transformer-less inverters for 1-ɵ and 3-ɵ to grid linked power systems. Although many innovations in 1-ɵtransformer less(TL) inverter topologies are aimed at improving current circulation by adding more power switches to the inverter circuitry. Compared to two-level voltage source inverters, multilevel inverters(MLI)have reduced harmonic content in input current and output voltage, and need less common mode voltage suppression and EMI filters. The neutral point clamped MLI family is a potential transformer-less grid linked inverter family.

A 1-Phase T-Type transformer-less NPC-MLI is shown as a result of this. Its suggested inverter eliminates switching shoot-through and low-frequency oscillations, ensuring negative balance voltage across the modulation range. Detailed descriptions of the proposed inverter topology's operating mode and DC-link current voltage are provided. In addition to the input and output requirements, the proposed single phase t type transformer-less NPC is described in detail. The detailed MATLAB-Simulink simulation and experimentation study is conducted. The results are confirming the advantages of the proposed inverter.

2. 1-ɵ NPC-MLI T-Type Transformer-less

Solar PV-based inverters, on the whole, operate at power levels that are far lower than their rated ones. NPC-MLI approaches are becoming more common as IGBTs and diodes have a higher voltage/current ratio at low and medium power levels. TNP-MLI is a good choice for solar power systems. Using a TNP-MLI configuration with three levels and simplified switch circuits, as shown in Fig.4.1, No clamping diodes are utilized in this circuit since four semiconductors and four anti parallel freewheeling diodes are used instead (C_1 and C_2). S_1/D_1 and S_2/D_2 and S_3/D_3 are the top and bottom switches of a medium power TNP-MLI design, respectively, which operate at 1200V. Switching and conduction losses are minimized as a result of a lower blocking voltage. There is no need for a slew of devices to prevent the entire dc-link voltage from flowing V_{DC}, unlike the three-level DC-MLI.

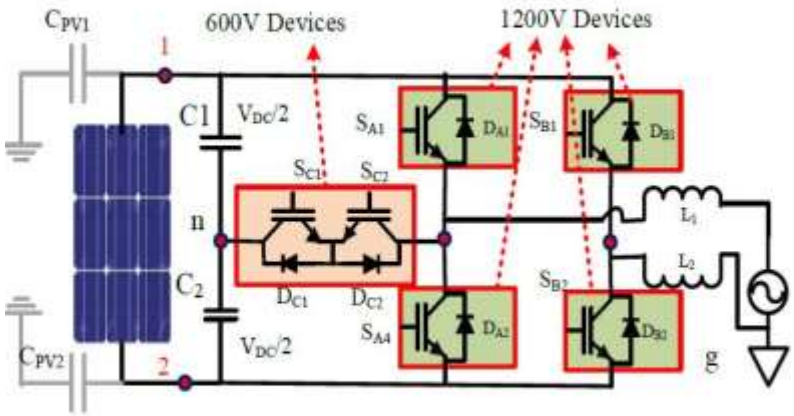


Figure 1: Single-phase t-type transformer less NPC- MLI

During a transient, both IGBTs connected in series must be turned off at the same time to prevent uneven voltage sharing. In a T-type topology, this cannot happen. With TNP-MLI, a pair of equal-value inductors (L_1 and L_2) are used to supply sinusoidal current from the inverter to the grid. While PV clusters do not need the ground connection, TL inverter designs do [4]. By connecting PV cluster midpoint and grid neutral, suggested TNP-MLI transformer-less design (G).

3. Operation of 1-ɵ T-Type Transformer-less NPC- MLI

DC-link capacitors connect the inverter's front to the PV panels, making it a TLI. H-bridge outputs are connected to split inductors (L1 =L2=L) that supply the grid with a sine wave. All TL inverter designs need a ground connection (G) except for PV clusters [14]. DC link capacitors may be connected to the cluster of solar panels. The operative solar PV to test the TL-TNP-MLI switching operation the positive and negative half-cycles of the grid voltage are used.

These assumptions are made before moving into modes of operation:

- All IGBTs are ideal devices.;
- Divide the DC-link voltages equally ($C_1 = C_2 = V_{PV}/2$), and the DC-link capacitors do so.

When the TLI is running at unity power factor, the inverter current (i_L) and grid voltage (Vg) are in zero-degree phase shift (PF).

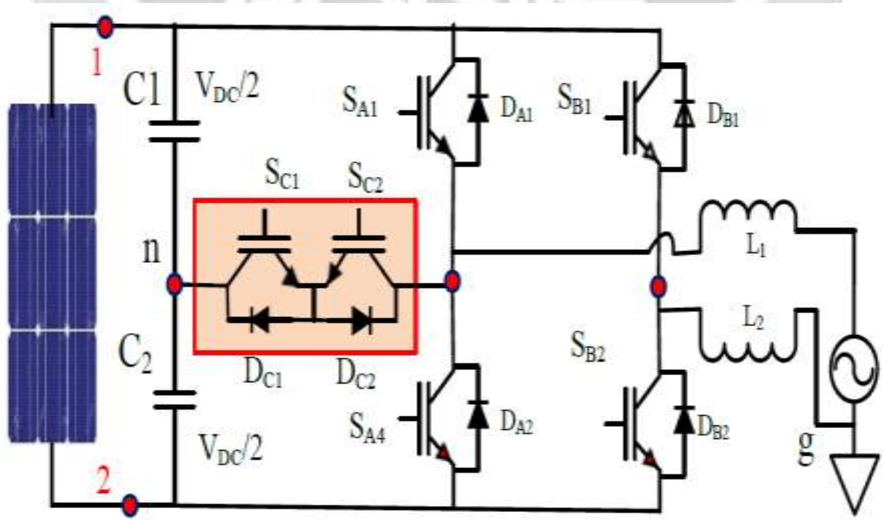


Figure 2: 1-ɵ TL-TPC-MLI power circuit

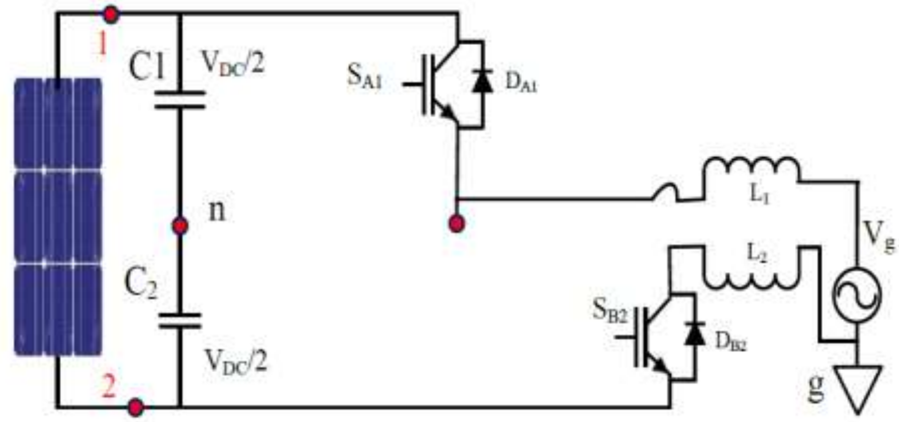


Figure 3: 1-Ɵ VO = V_{PV} Mode-1 of operation for TL-TPC-MLI

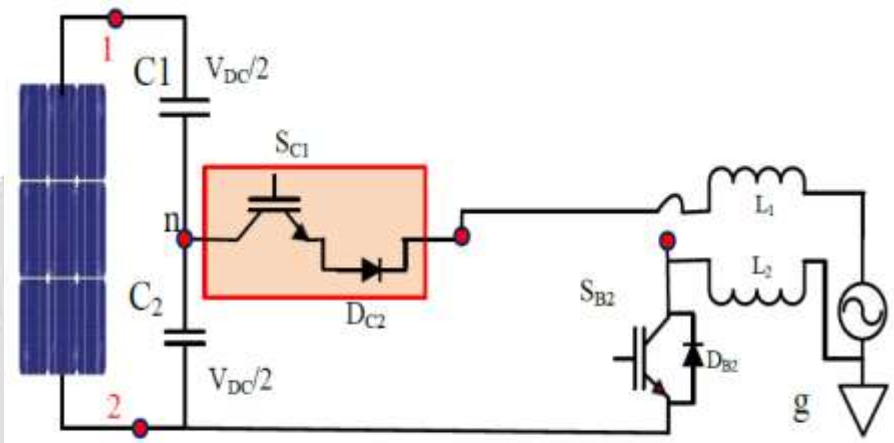


Figure 4: 1-Ɵ $V_O = V_{PV}/2$ Mode-2 of operation for TL-TPC-MLI

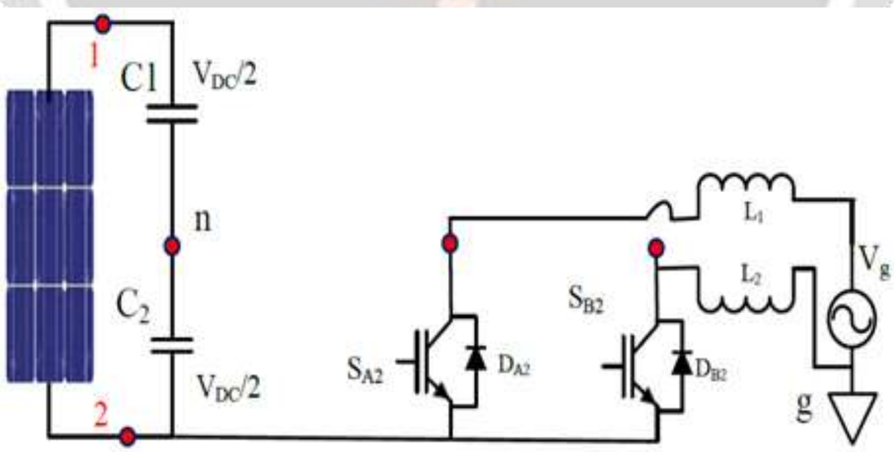


Figure 5: 1-ɵ TL-TPC-MLI Mode-3.

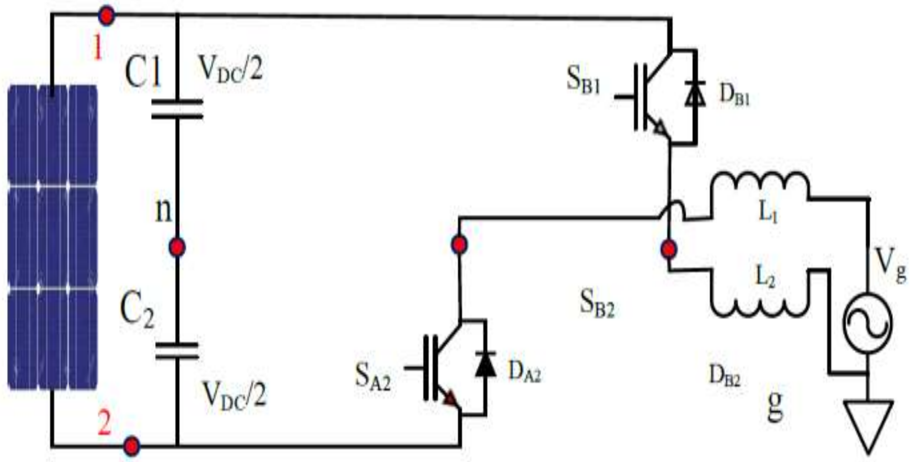


Figure 6: 1-Ɵ TL-TPC-MLI operation mode-4: $V_O = -V_{PV}$

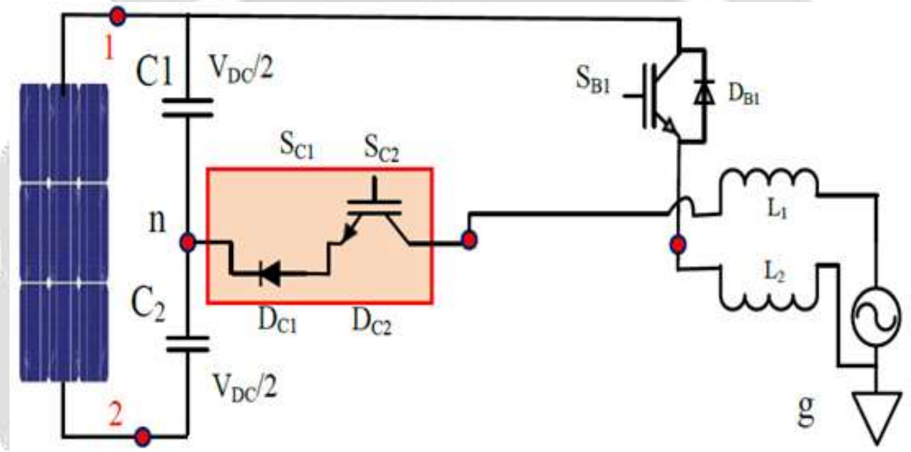


Figure 7: 1-Ɵ TL-TPC-MLI operation mode-5: $V_O = -V_{PV}/2$

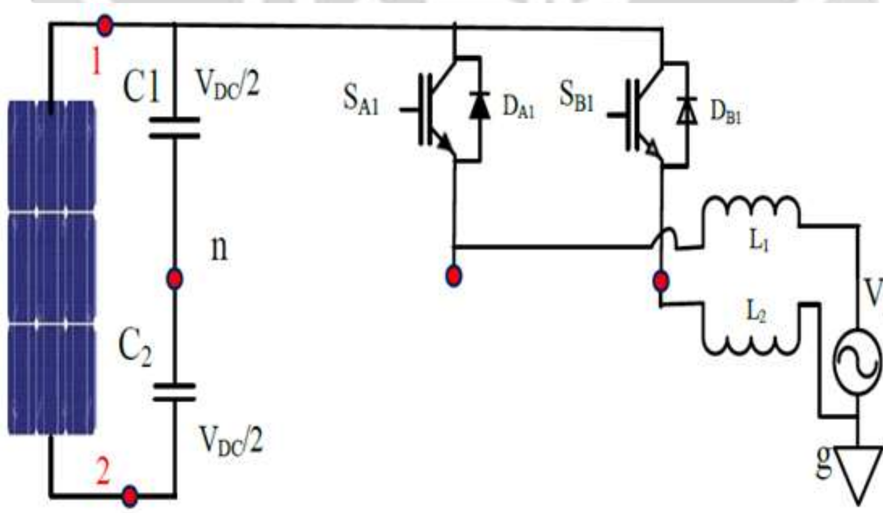


Figure 8: 1-Ɵ TL-TPC-MLI operating mode-6, leakage current is freewheeled

As shown in Table 1 of this paper, the proposed TL-TPC-MLI inverter generates five levels of output voltage on the inverter output side based on the mode of operation. As a result of the freewheeling mode of the inverter modes 3 and 6, inductor leakage current is suppressed. A leak-free inverter means the PV panels are safe from damage. Fig.9 shows the CMV-equivalent circuit proposed by TLI.

Table 1: The suggested TLI mode of operation

Mode of operation	**Switches Involved**	**Inverter output, Vo**
Mode-1	V_{PV}	V_{PV}
Mode-2	S_{C1},S_{B2}	$V_{PV}/2$
Mode-3	S_{A2},S_{B2}	Vo =0 ; freewheeling the leakage current
Mode-4	S_{A2},S_{B1}	$-V_{PV}$
Mode-5	S_{C2},S_{B1}	$-V_{PV}/2$
Mode-6	S_{B1},S_{B2}	Vo =0; freewheeling the leakage current

Table 2: TLI Mode of operation for proposed

Mode of operation	V_{DM}	V_{CM}	V_{TCM}
Mode-1	$V_{PV}/2$	$3V_{PV}/4$	$V_{PV}/4$
Mode-2	0	0	$V_{PV}/2$
Mode-3	0	0	0
Mode-4	$-V_{PV}/2$	$-3V_{PV}/4$	$-V_{PV}/4$
Mode-5	0	0	$-V_{PV}/2$
Mode-6	0	0	0

There are no "short or long" commutation routes in the 'I-type' NPC-MLI T-type TNP commutation mode operations; all paths have the same geometric length and inherit one outer switch and two inner switches. NPC-MLI 'I-type'.

4. Equivalents Circuit of Inverter Switching Frequency Circuit Model with Common-Mode Voltage

The TL PV inverters' switching frequency common mode voltage (CMV) [14, 15], leakage current between an inverter and the load ground is generated. a PV linked grid-connected inverter is equipped with an isolation transformer. In this design, the PV array (CG-PV) has a parasitic capacitance coupled to common ground and PV. It is, nevertheless, a common feature of TL inverters, which results in leaking ground currents [4, 10]. Because of this, the inverter's switching or topological structure must be examined in light of high frequency CMV. The suggested SI-TL-TMLI design analyses the simplest CMV and DMV conceivable, starting with publications [15] and [26] and the PV-fed SI-TL-TMLI equivalent circuit in Figure.

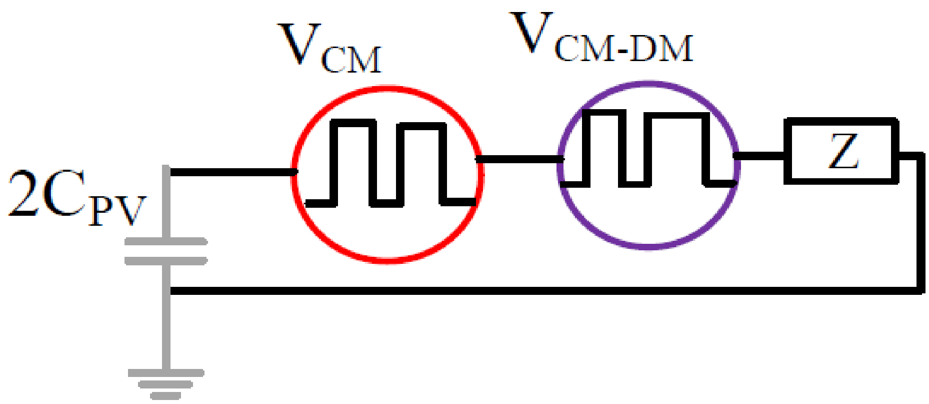


Figure 9: Single phase equivalent circuit using the common-mode voltage model TL-TPC-MLI

DM to CMV impact via VCM-DM is equivalent to -VDM/2 in this example.

$$V_{CM\_DM}=\frac{V_{DM}}{2} \quad \text{..... (1)}$$

During positive half-cycle

$$V_{CM\_DM}=\frac{V_{AN}+V_{CN}}{2} \quad \text{..... (2)}$$

$$V_{DM}=V_{AN}-V_{CN} \quad \text{..... (3)}$$

During negative half-cycle

$$V_{CM}=\frac{V_{BN}+V_{CN}}{2} \quad \text{..... (4)}$$

$$V_{DM}=V_{BN}-V_{CN} \quad \text{..... (5)}$$

The total CMV including

$$V_{CM\_DM}, V_{TCM}=V_{CM}+V_{CM\_DM} \quad \text{..... (6)}$$

The many conceivable switching operations of PV-linked TL-TNP-MLI are investigated for the positive and negative half-cycles of the grid voltage indicated in Fig.10 (a) to (d) . The proposed TL-TNP-MLI has four distinct modes of operation and switching options, as illustrated in the table below.

Mode-1

The mode of operation S_1 is ON, and S_2, S_3 and S_4 are OFF V_{CA} = (1/2)V_{PV} is now delivered to the grid through L_1as measured by the voltage across the capacitor C_1 (V_{C1}). L_1's current surged to a new record high (i_{L1}) during this time period.

$$L1\ \frac{\mathrm{diL1}}{\mathrm{dt}} = \frac{V_{PV}}{2} - Vg \qquad \text{….. (7)}$$

Here, $V_{AM} = V_{PV}$; $V_{BM} = Vg - \frac{V_{PV}}{2}$; $V_{CN} = \frac{V_{PV}}{2}$

Hence, $V_{DM} = \frac{V_{PV}}{2}$; $V_{CM} = \frac{3V_{PV}}{2}$; $V_{CM\_DM} = -\frac{V_{PV}}{4}$; $V_{TCM} = \frac{V_{PV}}{4}$

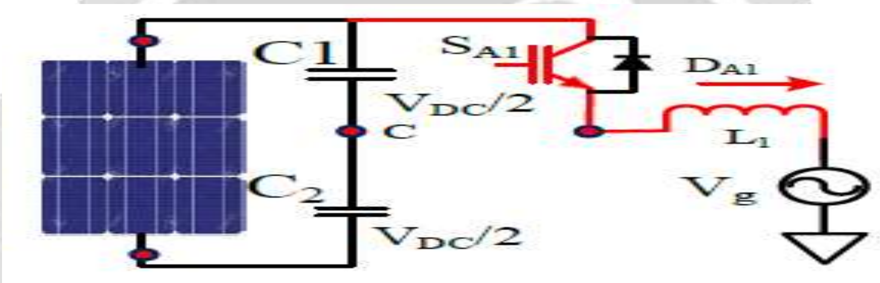
Mode-2

In This mode of operation the switches are S_2-ON, and S_1, S_3, S_4 -OFF the zero potential point linked to the grid is connected to this mode, and the output-voltage of the bridge-leg-zero, i.e. $V_{CA} = 0$. During this time, iL1 begins to drop-zero.

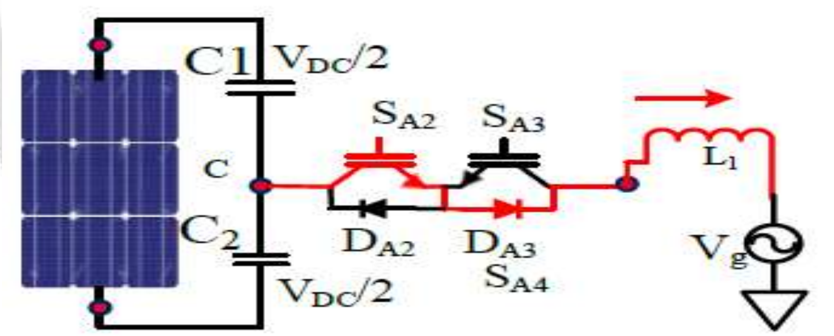
$$L1\ \frac{\mathrm{diL1}}{\mathrm{dt}} = 0 - Vg \qquad \text{….. (8)}$$

Here, $V_{AM} = \frac{V_{PV}}{2}$; $V_{BM} = Vg$; $V_{CN} = \frac{V_{PV}}{2}$

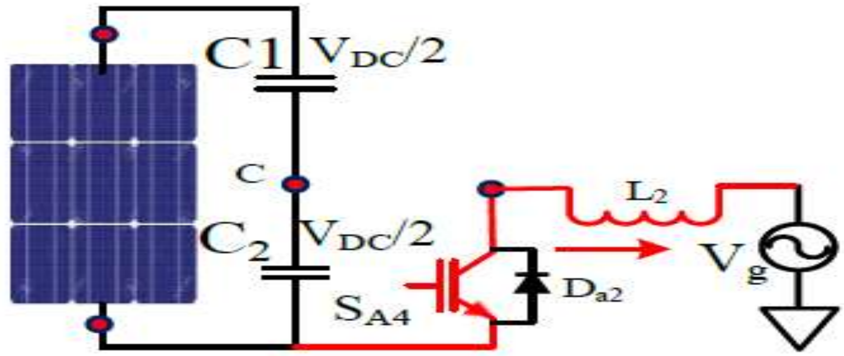
Hence, $V_{DM} = 0$; $V_{CM} = \frac{V_{PV}}{2}$; $V_{CM\_DM} = 0$; $V_{TCM} = \frac{V_{PV}}{2}$



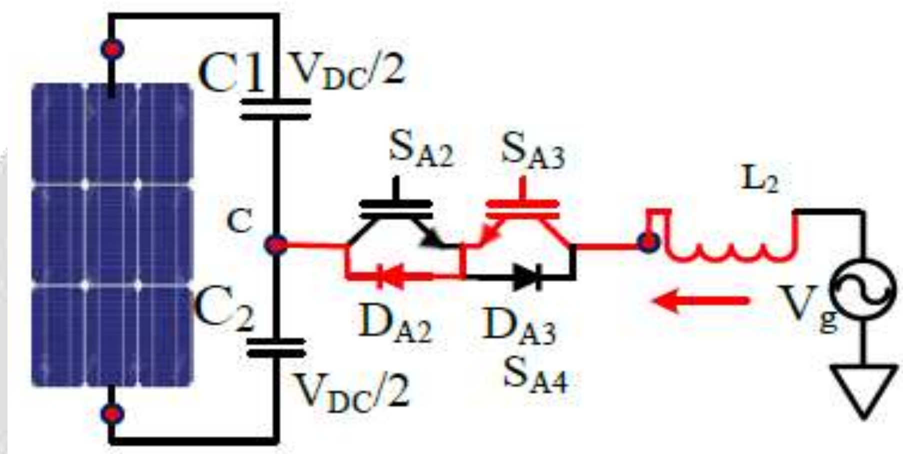
(a)



(b)



(c)



(d)

Figure 10: TL-TNP-MLI Modes of operation

Mode-3

The mode of operation the switches S_4-ON, and S_1, S_2 and S_3 -OFF Now, L_2, capacitor-voltage C_2 (V_{C2}), i.e. V_{CB}= (1/2) V_{PV}, is to the grid. During the time, inductor L_2 current (iL_2).

$$L1\,\frac{\mathrm{diL1}}{\mathrm{dt}} = -\frac{V_{PV}}{2} - Vg \qquad \text{….. (9)}$$

Where;

VAM $=-Vg-\frac{V_{PV}}{2}$; VBM=0; VCN=$\frac{V_{PV}}{2}$

Hence, VDM=$-\frac{V_{PV}}{2}$;VCM=$\frac{V_{PV}}{4}$; VCM_DM =$\frac{V_{PV}}{4}$;VTCM = $\frac{V_{PV}}{2}$

Mode-4

The mode of operation switches S_3 -ON, and S_1, S_2, S_4-OFF the zero potential point linked to the grid is connected to this mode, and the output voltage of the bridge leg-zero, i.e. V_{CB} = 0. During this time, i_{La} to drop-zero..

$$L1\ \frac{diL1}{dt} = 0 - Vg \qquad \text{….. (10)}$$

Where;

VAN $=-Vg$; VBN=$\frac{V_{PV}}{2}$; VCN=$\frac{V_{PV}}{2}$

Hence, VDM=0; VCM=$\frac{V_{PV}}{2}$; VCM_DM =0 ;VTCM= $\frac{V_{PV}}{2}$

In commutation modes, the NPC-MLI and TNP-MLI have no "short" or "long" commutation routes; all paths have the same geometric length and inherit one outside switch (indices 1 or 4; either IGBT or diode) and two inside switches (either T_2 and D_3 or T_3 and D_2). T_1/D_1 and T_4/D_4 do not share a commutation route, which is rare since a single outer switch and two inner switches are impacted in normal operation. The commutation interval voltage and current route for each of the four operating modes are shown in Tables 3.3 and 3.4. (positive voltage and positive current, positive voltage and negative current, negative voltage and negative current and negative voltage and positive current).

5. Simulation Study of Proposed Inverter

To validate the proposed T-type transformer less inverter MATLAB-Simulink simulations were implemented using sinusoidal-level-shifted modulation strategy. The simulation is performed consent PV of 1kWp power with common mode performance variables. Fig. 11. shows a circuit with R_L = 20 ohm that replaces the grid voltage, i.e. Vg = Ri_L, in the simulation modelled in MATLAB-Simulink. The load resistor is selected to operate like a grid-connected inverter that injects pure active power response. As a result, the inverter may be used to focus on the influence of the PWM approach with leakage current, while disregarding the effect of the control arrangement.

Table 3: Simulation Parameters for single phase TL-TNP-MLI

Parameters	**Values**
PV voltage (VPV)	200-250V
Inverter DC-Link voltage (VDC-link)	200V
Output frequency (Hz)	50Hz
Switching frequency (f_S)	15kHz
DC-Link Capacitor (C1 &C2)/µF	470 µF/500V
Inductors (L_1& L_2)(mH)	4 mH
Capacitors-CM (CY1 & CY2)/nF	2.86nF
Parasitic-Capacitor, (µF)	0.25 µF
ground impedance (RG)	25 Ohm
corner frequency (*fc*)	4 kHz
EMI filter are fixed to Lcm1, Lcm2 and CCM	1.5 mH, 0.5 mH, and 1 μF respectively

The simulation results for initially performed for 200V DC-link voltage for inverter with different modulation index value. The modulation index Ma=1 and Ma=0.6 fig.11 shows the Vout (V_{AB})findings.

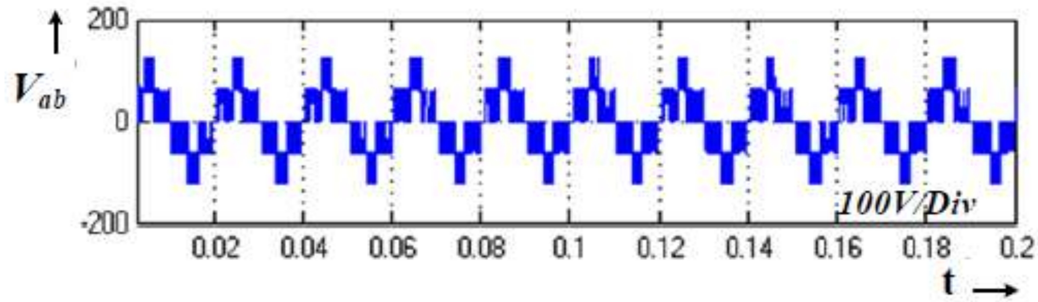


Figure 11: Single phase T-Type transformer-less inverter output voltage for Ma=0.6, fo = 50 Hz, and Vdc=200 V.

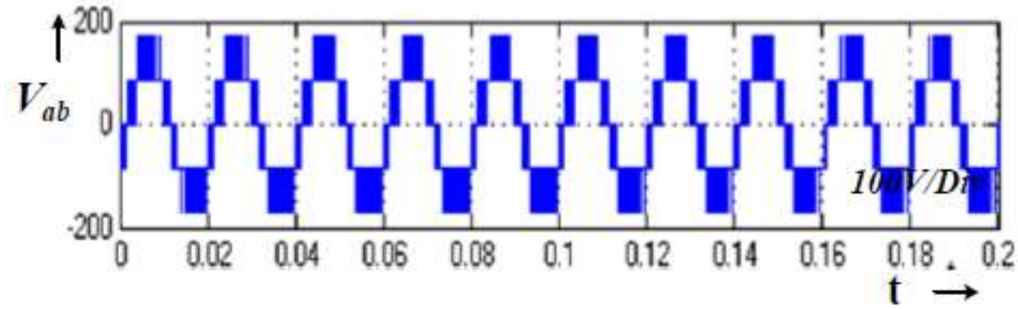


Figure 12: For Ma=1, fo = 50 Hz, and Vdc=200 V, of single phase T-Type transformer-less inverter output voltage.

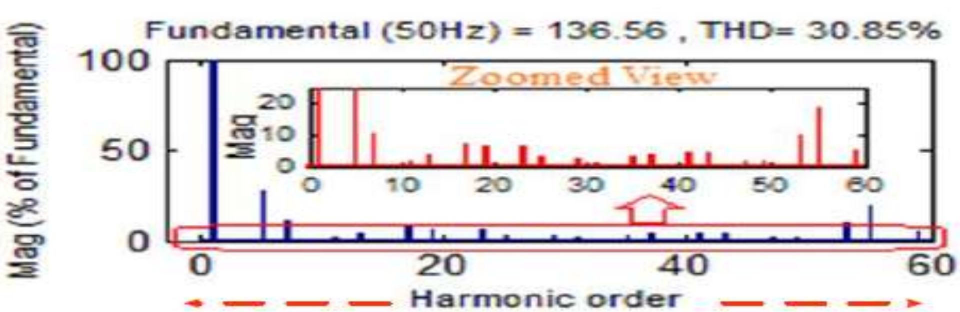


Figure 13: Simulation results for voltage harmonics Spectrum at Ma= 0.6

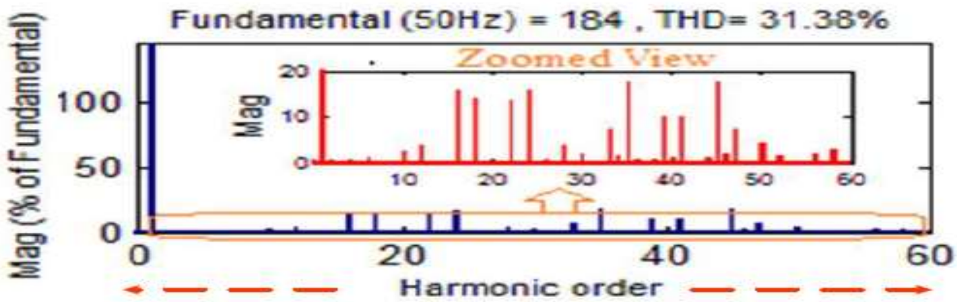


Figure 14: Simulation results for voltage harmonics Spectrum at Ma=1

The results of the voltage harmonics simulation An inverter with Ma=0.6 and Ma=1 is shown in Fig.13 and 14, respectively, to show the spectrum. According to simulation results, the proposed modulation strategy may reduce the voltage harmonics spectrum's lower order harmonics and provide a more fundamental voltage.

The inductor current (i_{L1} to i_{L2}) of a single phase T-Type transformer-less inverter is shown in Fig.15. The waveform shows that the inductor currents I_L meet at the same zero crossing point to achieve grid synchronization.

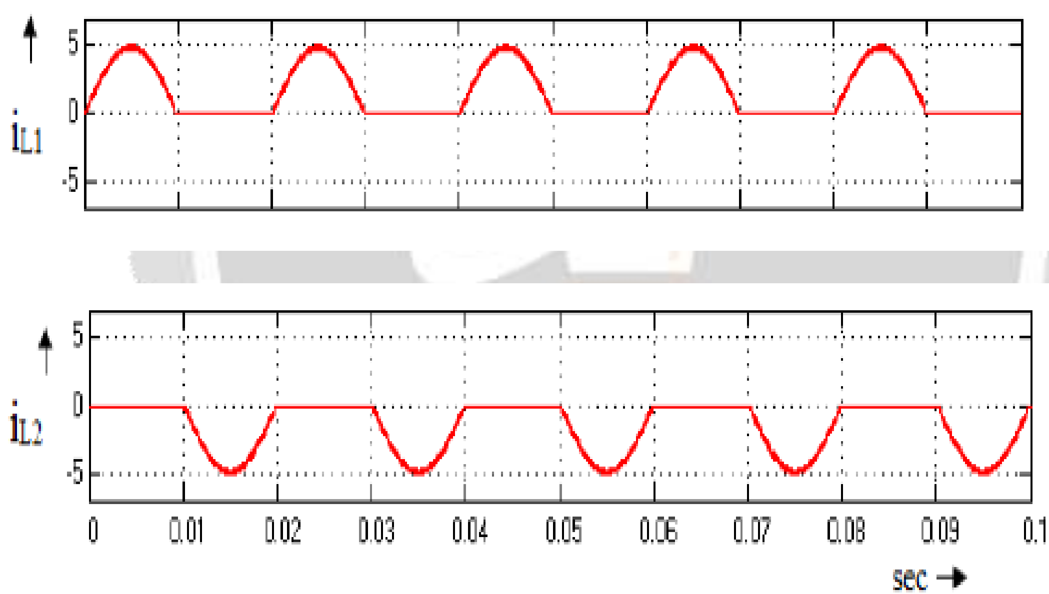


Figure 15 Simulation results for single phase T-Type transformer less inverter inductor current (i_{L1} to i_{L2})

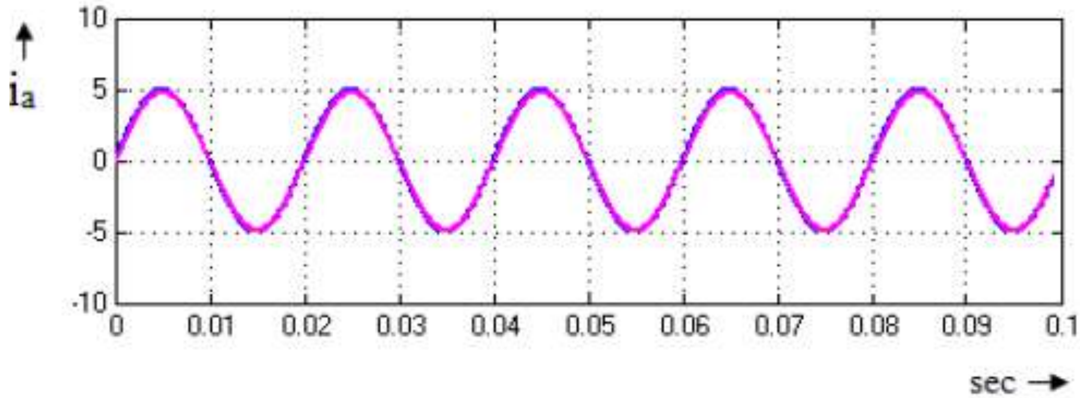


Figure 16: T-Type transformer less inverter output current simulation results for Ma=1 and fo=50 Hz.

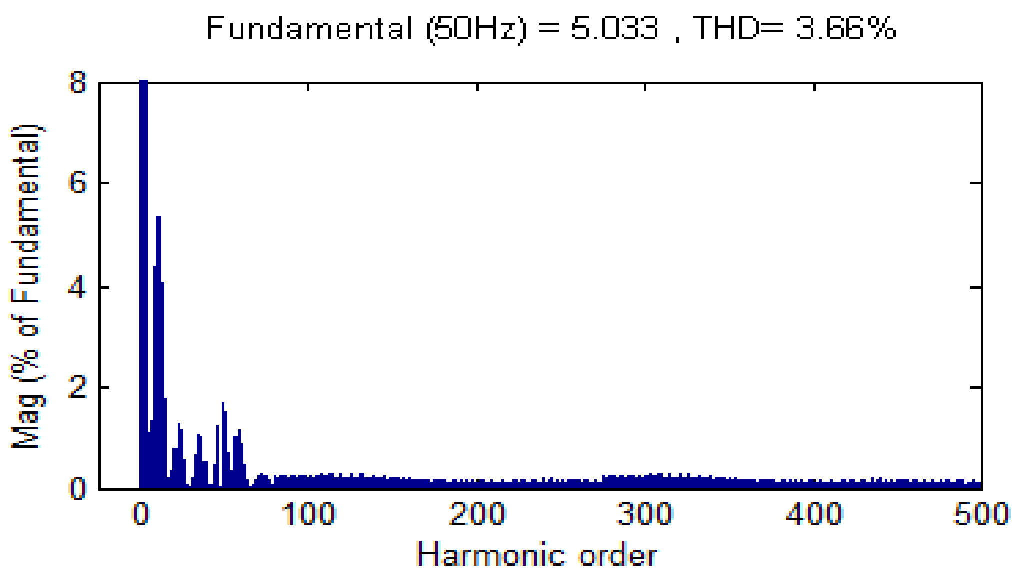


Figure 17: Simulation results for current THD Spectra at Ma=1

The load current i_L has a sinusoidal waveform with decreased high frequency switching ripple, as seen in the findings. It is also noticed the current harmonics spectrum is less and lower order harmonics in the current harmonics spectrum is considerably very low. Hence, it is expected, when inverter connected to grid system, the high frequency switching ripple should be less.

Finally, the simulation study is extended for analyzing the DC-link capacitors in the inverter input side. The simulation of DC-link capacitor voltages V_{C1} and V_{C2} is shown in Figure 18. When the inverter's DC link voltage neared 200V, the voltages of the DC-link capacitors C_1 and C_2, V_{C1} and V_{C2}, were measured as 99.5 V and 100.5 V, respectively. As a results, the proposed transformer less inverter causes less DC -link fluctuating as near to 1%, hence the proposed inverter DC-link voltage profiling is maintained well.

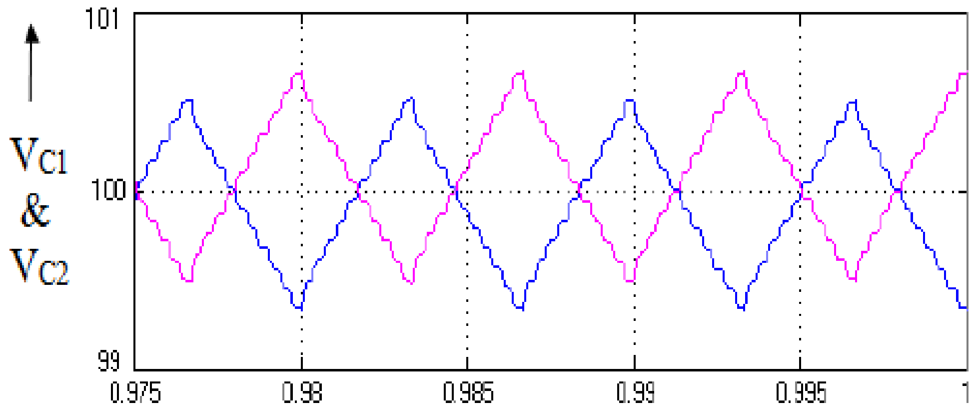


Figure 18: DC-link capacitor voltage profile simulation results for Ma=1

The performance of single phase T-Type transformer-less inverters for various modulation indexes is shown in Table 4. Ma ,Voltage, THD, and DC-link fluctuation values for the modulation index (Ma) range of 0.2 to 1 are shown in the table.

The suggested T-type inverter diode has transported near voltage conversion with low DC-link fluctuation over the whole inverter operation, as shown in the table above. The inverter's voltage harmonics are significantly lower in all operational regions than those reported for previous transformer-less inverters.

Table 2: Voltage, voltage THD and DC-link fluctuation with respect to different modulation index

Ma	**V_{Line}(V)**	**THD in %**	**NPF in %**
0.2	18.3	38.63	0.99
0.3	56.7	38.64	0.99
0.4	78.5	38.66	0.99
0.5	95.6	32.88	0.99
0.6	115.6	30.85	0.99
0.7	137.7	30.22	0.98
0.8	154.9	31.57	1.08
0.9	178.1	31.31	1.1
1	194.3	31.38	1

6. conclusion

The T-type TLI transformer-less topology for direct connected conversion is perform. The inverter's PWM is constructed using a sinusoidal-level-shifted modulation technique. Leakage current in PV-connected systems prompted the development of this modulation. In order to full-fill EMI requirements, a complete inverter equivalent based on a common mode EMI filter is created. The Common mode EMI filter, the Butterworth filter design guiding principle is employed to produce the inductance and capacitance expressed. Transformer-less inverter input DC-link utilization is much greater as compared to conventional designs using transformer-less inverter designs traditionally. The suggested transformer-less inverter's superiority is validated using simulation results using MATLAB/SIMULINK tool to characterizes of a 1-ө PV connected three-level multilevel transformer-less topology T-type TLI with modulation indices were varied.

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