Performance of T-Type Multi-level Inverter Based Open-End Winding Induction Motor Drive for Electric Vehicle Application

B. Harshini
PG Scholar
EEE Department VNR VJIET
Hyderabad, India

Dr. V. Ramesh Babu
Associate Professor
EEE Department VNR VJIET
Hyderabad, India

Dr. Ranjit. M
Assistant Professor
EEE Department VNR VJIET
Hyderabad, India

Dr. J. Srinivasa Rao
Associate Professor
EEE Department
VNR VJIET Hyderabad, India

***Abstract*:- Electric vehicles (EVs) plays a vital role to meet global demands on climatical variations. All EVs in today's market uses the classical two-level inverter as the propulsion inverter. To overcome constraints of conventional two-level inverter like electromagnetic interference,common mode voltage etc.,. Multi-Level Inverter topologies revolutionized in the industry because of its smart features over the conventional inverters. Now a days pulse width modulated voltage source inverters are used widely in applications like variable speed control drives in order to control magnitude and frequency of output voltage by using these voltage source inverter. But often in conventional two-level inverter fed induction motor drive operated at high frequency it yields to the production of common mode voltage (CMV) which leads to the production of shaft voltage and high bearing currents damages motor bearings. MIs have emerged to reduce CMV. In MIs with increase in levels of output it results in high dv/dt stress on individual switching devices and high switching losses. To getrid flow of bearing currents and to reduce dv/dt stress on individual switching devices open end winding induction motor drive can be implemented. This work proposes operational strategy of MI and T-Type inverter fed open end winding induction motor drive using MATLAB/SIMULINK environment.**

Keywords—Common Mode Voltage (CMV),Multi-level Inverter (MI),Open-End Winding Induction Motor (OEWIM)

1. INTRODUCTION

Inverters are also called as power inverter which is an electrical power device,which is used to convert DC to AC whose output is of desired voltage and frequency. 2-level inverters are preferrable in low voltage and low power application which produces harmonic waveform which the affects the performance of the converter. The first solution is to add passive power filter at specific harmonic order which becomes complex. So, an alternative is to improve switching frequency of Voltage Source Inverter (VSI) which affects converter losses as well as efficiency. MIs became the better alternative for VSI to reduce the harmonic content without the need of passive filter or improving switching frequency. MI are more preferrable in high voltage and high power applications. The conventional topologies of MIs are Diode Clamped (DC) or Neutral Point Clamped Converter (NPC), Cascaded H-Bridge (CHB) Converter and Flying Capacitor (FC) converter. The disadvantages with these MIs are the circuit complexity which thereby increases the elements in the circuit. This paper deals with T-Type Inverter has advantages of less switching elements and better efficiency when compared with conventional MI topology. As conventional 2-level inverter generates voltage with high dv/dt stress and also produce CMV which results in leakage current and damages the motor bearings. In order to mitigate CMV in variable speed motor drives dual inverter fed open-end winding induction motor drive is advantageous.

2. DESCRIPTION AND OPERATION OF THE TOPOLOGY

To obtain more number of levels in NPC MI, number of clamping diodes increases the power circuit complexity therefore reduces the converter efficiency. To overcome this problem presently researchers are focusing with reduced switching elements in MIs. T-Type Inverter is represented in Fig.1. It consists of 2-level inverter and are connected to auxiliary switches. The idea is to connect DC link midpoint with auxiliary switches which reduces switching conductors in the current path and thereby improves efficiency.

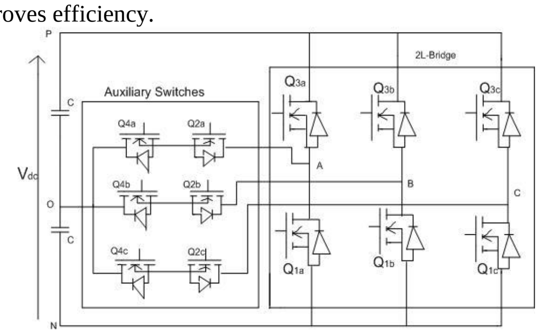

Fig. 1. Circuit of T-Type Inverter

Each phase of inverter has four switches.So,in each phase there exists three switching states and terminal voltages. Where P,O,N represents three terminal voltages i.e, $V_{dc}/2$,0,-$V_{dc}/2$ respectively. Operation of T-Type Inverter is to obtain three level voltages

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(P,O,N) which makes switches to turn on for longer time so that stress on the device increases as well conduction losses increases. To reduce stress on the switches modified switching scheme is helpful. The stress on the device can be reduced by means of any one of an auxiliary switches Q_2 or Q_4 can be turned ON so current in that phase is zero and results in zero conduction loss by conducting one of the auxiliary switch. Possible switching state with modified switching state wiring diagram and voltage levels is shown in Fig.2 and Table.I below respectively.

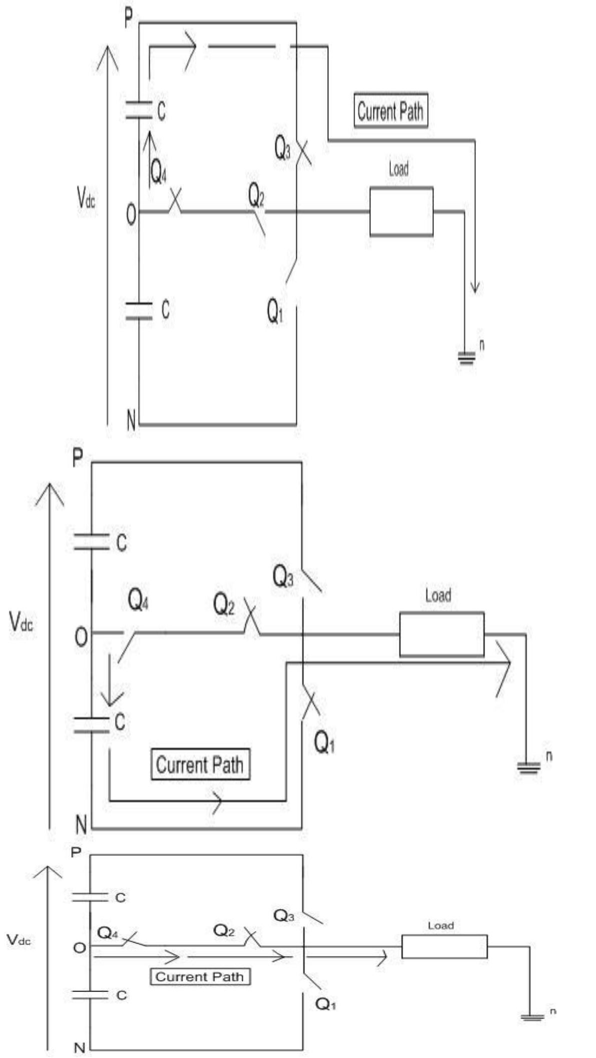

Fig. 2. Operating modes of T-Type Inverter

TABLE I. SWITCHING TABLE FOR T-TYPE INVERTER

Level	Q_{1x}	Q_{2x}	Q_{3x}	Q_{4x}	Output Voltage
P	0	0	1	1	$V_{dc}/2$
O	0	1	0	1	0
N	1	1	0	0	$-V_{dc}/2$

3. SPACE VECTOR PULSE WIDTH MODULATION(SVPWM)

SVPWM strategy is one of the advanced , computational method which is better among PWM techniques.In recent days it has been widely spread because of its performance.

3.1.Advantages of SVPWM:

SVPWM is one of the better strategy among PWM implementation with its merits such as :

Better spectral performance

Enhanced DC bus utilization

SVPWM generates less harmonics distortion

3.2.SVPWM for 2-level VSC:

This technique uses the theory of revolving reference voltage instead of modulating wave as in case of Sinusoidal PWM technique. The circuit validates 2-level inverter as depicted in Fig.3. It comprises of six switches and a,b,c represents three phases. This converter has eight switching states out of which six states are active states and remaining corresponds to zero vectors.

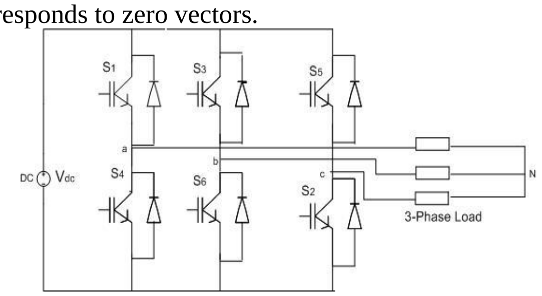

Fig. 3. 2-level inverter

To implement SVPWM technique the voltage equations in abc reference frame is converted to dq reference frame. For each sector V_{ref} is calculated with the help of two zero states and two non-zero states. The Space Vector (SV) diagram for 2-level inverter is represented in Fig.4. Sector-1 has been intended with vectors V_0,V_1,V_2,V_7 which is from zero degrees to 60 degrees.The timing duration calculations are shown below:

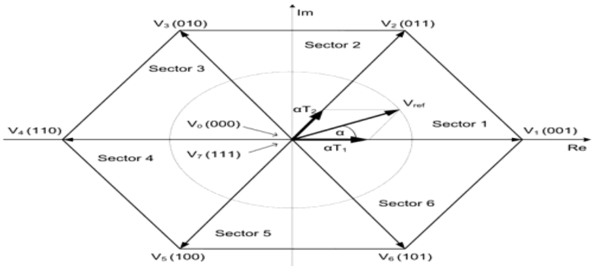

Fig. 4. SV Diagram for 2-level inverter

The general expression for sector-m is given as

$$V_{ref}T = V_mT_m+V_{m+1}T_{m+1}+V_0T_0+V_7T_7 \quad (3.1)$$

Where $T = T_k+T_{k+1}+T_0$

The period of active and zero vectors can be determined for each sector 'm' is mentioned in below equations:

$$T_m = \frac{\sqrt{3T|Vref|}}{Vdc}\sin(\frac{n}{3}\pi - \alpha) \quad (3.2)$$

$$T_m = \frac{\sqrt{3T|Vref|}}{Vdc}(\sin(\alpha - \frac{n-1}{3}\pi)) \quad (3.3)$$

3.3.SVPWM for 3-level T-Type Inverter:

For 3-level inverter there are 3^3 i.e., 27 conduction states. Among 27 sectors 3 are null vectors and 24 are active vectors out of which 12 are small of magnitude $V_{dc}/3$, 6 are medium of amplitude $V_{dc}/\sqrt{3}$ and 6 are large vectors of magnitude $2V_{dc}/3$. The SV diagram of 3-level inverter is depicted in Fig.5 which has six sectors and each sector is broken to four sub-sectors. The reference voltage vector is generated with combinations of switching states existing in each sector. The expression is given as:

$$V_{ref}T_s = T_aV_1 + T_bV_2 + T_cV_3 \quad (3.4)$$

Where Total period is $T_s = T_a + T_b + T_c$

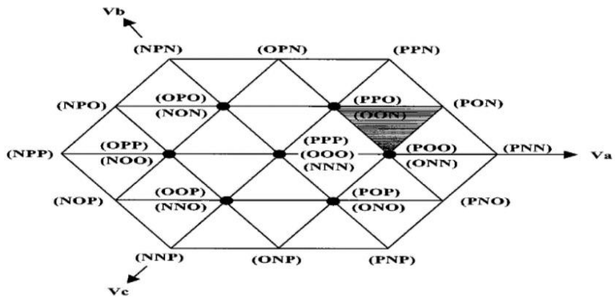

Fig. 5. SV Diagram for 3-level inverter

4. OPEN-END WINDING INDUCTION MOTOR DRIVE

The diagrammatic representation of 3-level converter, 4-level converter and T-Type converter is depicted in Fig.6, Fig.7, Fig.8 respectively. From Fig.8. it can been seen that V_{az},V_{bz},V_{cz} represents the pole voltage of converter-1 and $V_{a'z'}$,$V_{b'z'}$,$V_{c'z'}$ represents the pole voltage of converter-2. In this topology the converters are fed with distinct DC source to stop the flow of zero sequence currents into motor.

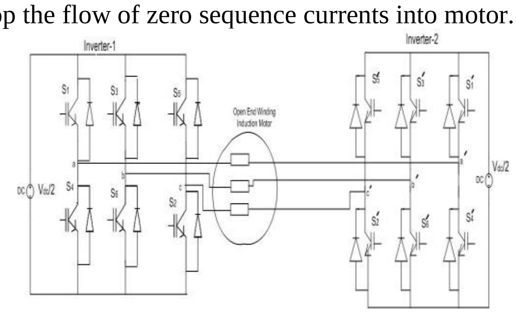

Fig. 6. 3-level inverter fed OEWIM drive

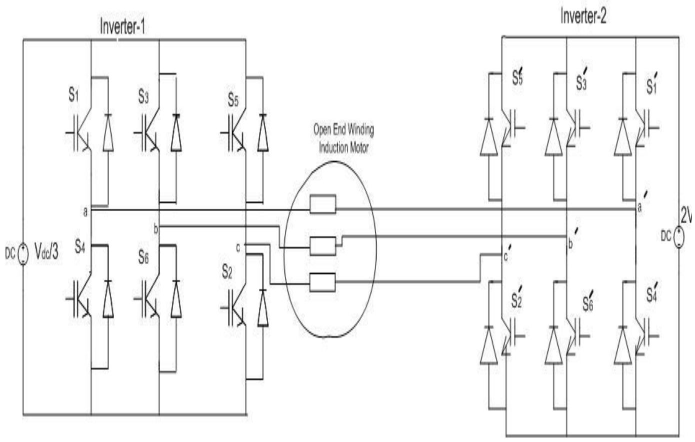

Fig. 7. 4-level inverter fed OEWIM drive

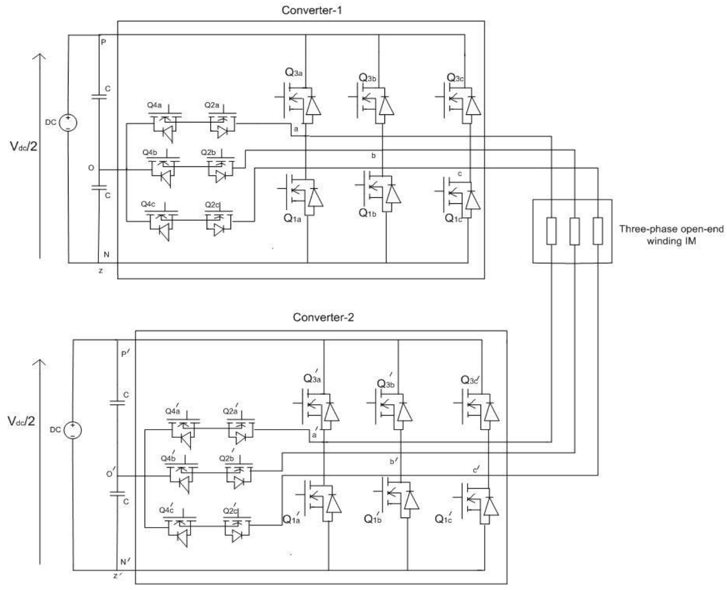

Fig. 8. T-Type inverter fed OEWIM drive

Net phase voltage of this topology is given as:

$$V_{dzd'z'} = V_{dz} - V_{d'z'} \text{ ,Where } d = a,b,c$$

The zero sequence voltage is estimated across the extremes of z and z' is as follows as:

$$V_{zz'} = (V_{aa'}+V_{bb'}+V_{cc'}) /3$$

5. SIMULATION RESULTS

All parameter specifications as per Table.II which is used the verify the simulation results of various MI fed OEWIM drive using SVPWM are compared for different modulation indices.

TABLE II. SPECIFICATIONS

Parameters	Values
DC Voltage Source	400V
Resistance Load(R)	1 Ohm
Switching Frequency(f_s)	3KHz
Modulation Index(m)	0.8

For Three-level inverter fed IM drive with SVPWM control:

3-level inverter fed IM drive is simulated by SVPWM for m = 0.8 and modulating signal,Phase voltage,CMV are shown in Fig.9. The first waveform shows modulating signal of amplitude of 0.8. The second waveform denotes the phase voltage of various magnitudes such as $2V_{dc}/3$, $V_{dc}/3$, 0. And last waveform represents the CMV (V_{CMV}) which is attained as $V_{dc}/6$.

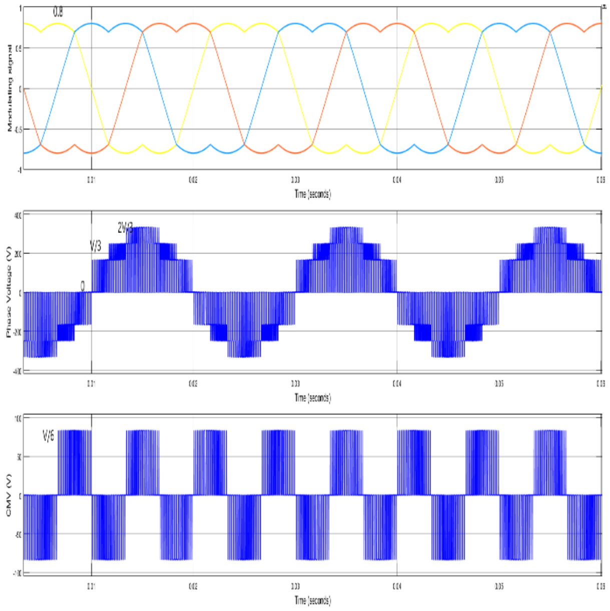

Fig. 9. Modulating signal,Phase voltage and CMV of 3-level inverter

Performance characteristics of IM drive with SVPWM controlled 3-level inverter i.e., stator currents, speed and torque is shown in Fig.10. The steady state is attained at 0.2 second and load is applied from 0.5 to 0.8 seconds stator current suddenly increased and speed got decreased to 1450 rpm and therefore reaches steady-state.

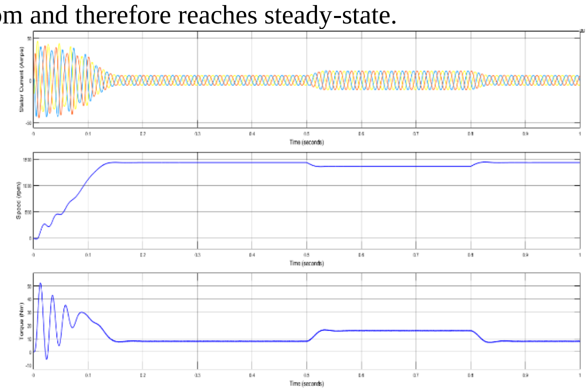
Fig.10. Stator current,Speed and torque characteristics condition of 3-level inverter

For 4-level inverter fed IM drive with SVPWM control:
4-level inverter fed IM drive is simulated by SVPWM for m = 0.8 and modulating signal,Phase voltage,CMV are shown in Fig.11. The first waveform denotes modulating signal of magnitude of 0.8. The second waveform represents the phase voltage of amplitudes like $2V_{dc}/3$, $V_{dc}/3$, $V_{dc}/8$, 0. And last waveform shows the CMV (V_{CMV}) which is obtained as $V_{dc}/3$.

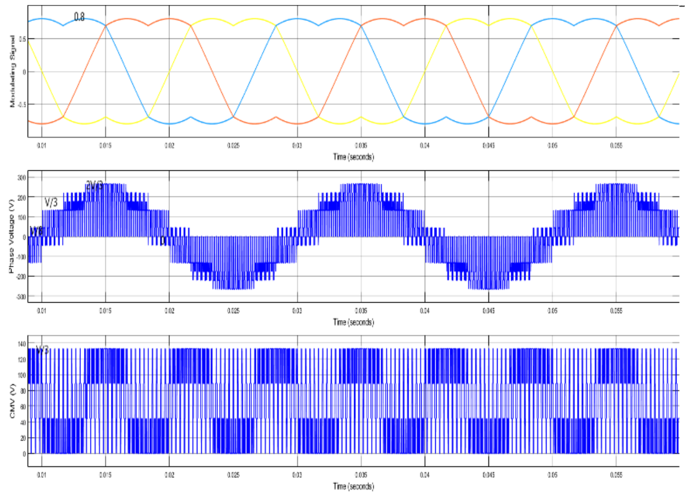

Fig. 11. Modulating signal,Phase voltage and CMV of 4-level inverter

The performance characteristics of IM drive with SVPWM controlled 4-level inverter i.e., stator currents, speed and torque is represented in Fig.12.The steady state is achieved at 0.15 second and load is applied from 0.5 to 0.8 seconds stator current abruptly improved and speed got reduced to 1380 rpm and therefore attains steady-state.

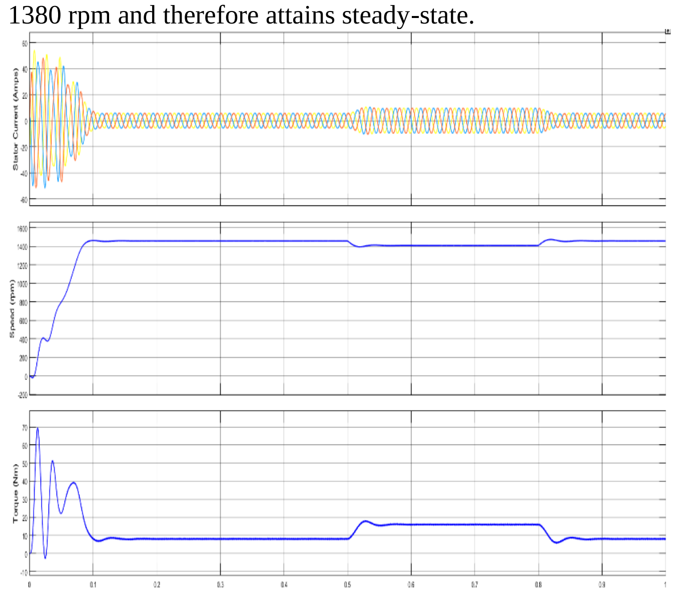
Fig.12. Stator current,Speed and torque characteristics of 4-level inverter

For T-Type inverter fed IM drive with SVPWM control:
T-Type inverter fed IM drive is simulated by SVPWM for m = 0.8 and Phase voltage,CMV are shown in Fig.13. The first waveform denotes modulating signal of amplitude of 0.8. The second waveform represents the phase voltage of different magnitudes $V_{dc}/2$, $V_{dc}/3$, $V_{dc}/4$, $V_{dc}/8$, 0. And last waveform shows the CMV (V_{CMV}) which is obtained as $V_{dc}/6$.

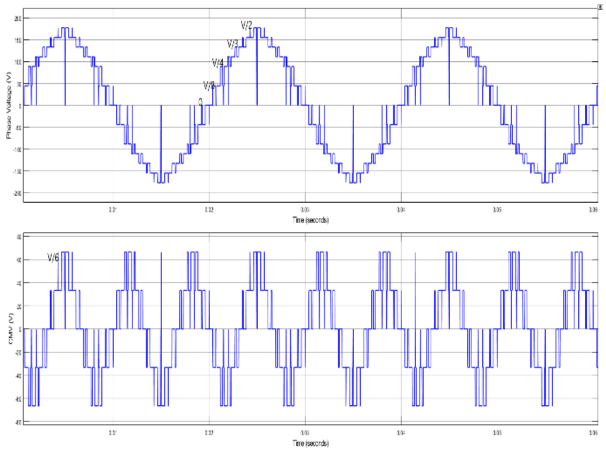

Fig. 13. Modulating signal,Phase voltage and CMV of T-Type inverter

Performance characteristics of IM drive with SVPWM controlled T-Type inverter i.e., stator currents, speed and torque is represented in Fig.14.The steady state is achieved at 0.1 second and load is applied from 0.5 to 0.8 seconds stator current rapidly amplified and speed got declined to 1475 rpm and therefore obtains steady-state.

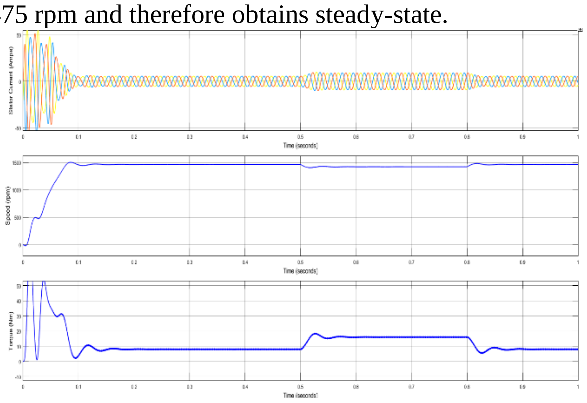

Fig.14. Stator current,Speed and torque characteristics of T-Type inverter

The THD analysis for three-phase inverter fed OEWIM drive are listed in Table.III:

TABLE III. COMPARISON OF HARMONIC ANALYSIS OF 3-LEVEL AND 4-LEVEL INVERTERS

S.No.	m	% THD of 3-level inverter	% THD of 4-level inverter
1	0.8	1.82	1.41

The THD analysis for NPC and T-Type inverter are listed in Table.IV:

TABLE IV. COMPARISON OF HARMONIC ANALYSIS OF NPC AND T-TYPE INVERTERS

S.No.	m	% THD of NPC	% THD of T-Type inverter
1	0.8	10.92 [7]	2.6

6. CONCLUSION

The performance of MI and T-Type inverter fed OEWIM drive is presented in this paper. To get rid the flow of bearing currents and to minimize CMV dual inverter configuration is advantageous using SVPWM technique over other topologies. It can be concluded that T-Type inverter gives better performance when compared to NPC MI. This work can be extended by using Discontinuous PWM techniques and also in real time.

REFERENCES

[1] A. Salem,M. A. Abido "T-Type Multilevel Converter Topologies: A Comprehensive Review", Arabian Journal for Science and Engineering (2019) 44:1713–1735.

[2] Ahmed Sheir,Member, IEEE, Mohamed Z.Youssef , and Mohamed Orabi , Senior Member, IEEE "A Novel Bidirectional T-Type Multilevel Inverter for Electric Vehicle Applications", IEEE TRANSACTION on Power Electronics, VOL. 34, NO. 7, JULY 2019.

[3] X. Liu et al., "A novel Diode-Clamped modular multilevel converter with simplified capacitor voltage-balancing control," IEEE Trans. Ind. Electron., vol. 64, no. 11, pp. 8843–8854, Nov. 2017.

[4] M. Forouzesh, Y. P. Siwakoti, S. A. Gorji, F. Blaabjerg and B. Lehman, "Step-Up DC–DC Converters: A Comprehensive Review of VoltageBoosting Techniques, Topologies, and Applications," IEEE Transactions on Power Electronics, vol. 32, no. 12, pp. 9143-9178, Dec. 2017.

[5] A. M. Y. M. Ghias, J. Pou, M. Ciobotaru and V. G. Agelidis, "VoltageBalancing Method Using Phase-Shifted PWM for the Flying Capacitor Multilevel Converter",IEEE Transactions on Power Electronics, vol. 29, no. 9, pp. 4521-4531, Sept. 2014.

[6] Z. Shu, X. He, Z. Wang, D. Qiu and Y. Jing, "Voltage Balancing Approaches for Diode-Clamped Multilevel Converters Using Auxiliary Capacitor-Based Circuits," IEEE Transactions on Power Electronics, vol. 28, no. 5, pp. 2111-2124, May 2013.

[7] P.Satish Kumar, J.Amarnath and S.V.L.Narasimham "An Effective Space-Vector PWM Method for Multi-level Inverter Based on Two-level Inverter", International Journal of Computer and Electrical Engineering, Vol. 2, No.2, April, 2010 1793-8163.

[8] Renu Sharma*1, Deepak Kumar Goyal*2, Harpreet Singh*3 "Analysis of Space Vector PWM for Three Phase Inverter and Comparison with SPWM", IJAREEIE Vol. 5, Issue 1, January 2016.

[9] Jae Hyeong Seo, Member, IEEE, Chang Ho Choi, Member, IEEE, and Dong Seok Hyun, Senior Member, IEEE "A New Simplified Space–Vector PWM Method for Three-Level Inverters", IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 16, NO. 4, JULY 2001.

[10] Aboubakr Salem,Frederik De Belie, and Jan Melkebeek, "A Novel Space-Vector PWM Computations for A Dual Three-Level T-Type Converter Applied to An Open End-Winding Induction Machine", 978-1-4673-9063-7/16/$31.00 c IEEE.