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Application of Multilevel Inverter in Induction Motor Drive with Reduced Total Harmonic Distortion

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Abstract:- *The Zero Sequence Voltage generated by a conventional two level inverter fed induction motor drive results to various adverse effects like bearing currents and electromagnetic interference. By using conventional multilevel inverter the switching losses, complexity and the cost of the equipment increases as the number of levels increases and also the bearing currents still exists. In this proposed work, the techniques to overcome the drawbacks due to conventional inverter and multilevel inverter have been presented i.e, by using proposed multilevel inverter fed open end winding. In this paper, the performance characteristics of Induction motor with different PWM techniques like SPWM, THIPWM have been analyzed and the harmonic analysis has been carried out using MATLAB/SIMULINK environment and to validate the results for different modulation index are listedout.*
Keywords: *Zero Sequence Voltage (ZSV),bearing currents, open end winding induction motor drive, SPWM, THIPWM, modulation index.*

I. Introduction:

An inverter is a power electronic device used to convert constant DC power to adjustable voltage adjustable frequency AC power drives. To raise the blocking capacity in conventional two-level inverter the switching devices are connected in series. The simultaneous switching of series connected fast devices generates voltage with a high dv/dt at the output terminal of the inverter[1-2].Due to this the conventional inverter are known to generate "Zero Sequence voltage" or "common mode voltage" because of parasitic stray capacitors inevitably exists inside the AC motorThey also result in leakage currents which act as sources of conductive electromagnetic interference in the drive system and also lead to permanent failure in motor bearings. In order to eliminate the zero sequence voltage in the context of variable speed motor drives different techniques have been employed and are classified as[3][4][5]:

[A] Using isolation transformer, zero sequence impedance, filters
[B] using multilevel inverters, using dual bridge inverter fed induction motor drive(open end winding) or
[C] using different modulation techniques like sinusoidal PWM (SPWM), third harmonic injection PWM (THIPWM) and Space vector PWM (SVPWM) techniques.

The methods proposed in [A] above increases the system cost as it employs some extra hardware circuitry and complexity in control.

Multilevel inverters are also employed and are extensively used in high power, high-voltage variable speed drive systems. As the number of voltage levels increases, the harmonic content of the output voltage waveform decreases due to which low total harmonic distortion (THD) with high efficiency and power factor is obtained [4]. But the complexity, number of switches increases as the number of level increases in order to overcome this, this paper is mainly focused on by using proposed inverter fed open end winding(5,6 level) operated with different control strategies like SPWM, Third harmonic injection control techniques.

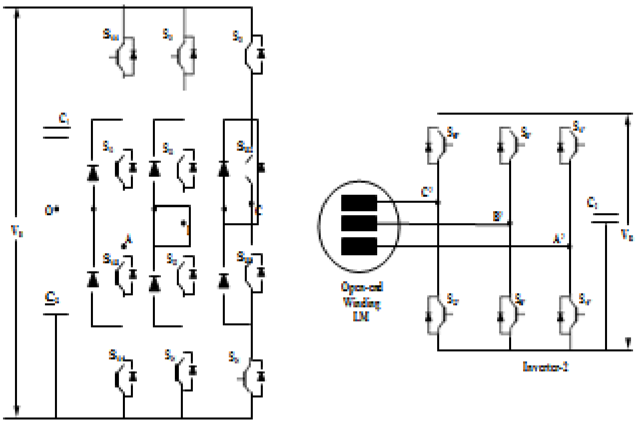
The advantages of dual-inverter fed induction motor drive topologies are that the voltage amplitude required to produce air- gap flux in the machine is divided among the two inverters. Therefore, the device ratings as well as dv/dt stress are reduced, which is very important for high power applications and reduces the zero sequence voltage up to great extent and also reduces bearing currents.

II. Multilevel Inverters Fed Open End Winding Induction Motordrive:

Configuration-I 5&6-level inverter:

In this configuration Induction Motor is fed by two inverters from either side which are operated by isolated power supply, Where INV1 is a 3-level diode clamped multilevel inverter and INV2 is a conventional two level inverter. A schematic diagram of proposed inverter fed open end winding Induction Motor drive is shown in the Fig.1

From the Fig.1, S_1-S_{12} are the switches of inverter-1 and $S_{1''}$-$S_{6''}$ are the switches of inverter-2. These two inverters are supplied with half of DC–link voltage (i.e. Vs1= Vs2= $V_{DC}/2$) then the configuration resembles to five level inverter. The phase winding can attain five levels namely +$V_{DC}/2$(+state), +$V_{DC}/4$(+state), 0,-$V_{DC}/2$(-state) and -$V_{DC}/4$ (-state).If the inverters are supplied with isolated DC –link voltage (i.e. $V_{S1}=2V_{DC}/3$ & $V_{S2}=V_{DC}/6$) then the configuration resembles to that of a six level inverter whose working principle is similar to five levelinverter.



Inverter-1

Fig.1 Schematic of proposed inverter fed open end winding I.M drive

V_{A0}, V_{B0}, V_{C0} are the pole voltages of inverter-1 and $V_{A''0''}$, $V_{B''0''}$, $V_{C''0''}$ are the pole voltages of inverter-2. $V_{AA''}$, $V_{BB''}$, $V_{CC''}$ are the voltages across the phase winding of Induction Motor. Here the sum of all these phase voltages is not equal to zero, which results as zero sequence component in motor due to this the bearing currents will flow inside the motor.

$V_{AA'} = V_{A0} - V_{A'0'}$ (1)

$V_{BB'} = V_{B0} - V_{B'0'}$ (2)

$V_{CC'} = V_{C0} - V_{C'0'}$ (3)

Where V_{A0},V_{B0},V_{C0} are the pole voltages of inverter-1 $V_{A''0''}$,$V_{B''0''}$,$V_{C''0''}$ are the pole voltages of inverter-2 & $V_{AA''}$,$V_{BB''}$,$V_{CC''}$ are the Phase voltages of the inverter VA20, VB20, VC20 are the pole voltages of inverter-1 and VA‟0‟, VB‟0‟,VC‟0‟arethepolevoltagesofinverter-2.VAA‟,VBB‟,VCC‟is the voltage across the phase winding of induction motor it can be obtained by the difference between the pole voltages ,which is given by the equations (1)-(3) and the phase winding can attain fivelevels.

The Zero Sequence voltage or common mode voltage is given by

$\underline{V_{AA'} + V_{BB'} + V_{CC'}}$

DC-link voltage of inverter-1 and inverter-Y is $V_{DC}/4$ each and the DC-link voltage of inverter-2 is $V_{DC}/2$. This configuration resembles to that of a five level inverter. For the given input of $V_{DC}/4$, inverter-Y attains two levels namely + $V_{DC}/8$ and - $V_{DC}/8$. Inverter-X can attain three levels depending on the switching state. When the switches $S_{11}$and S_{24} is turned ON the pole voltage obtained is $-V_{DC}/2$, S_{14} and S_{21} is ON the pole voltage attains $V_{DC}/4$ and S_{21} and S_{24} is OFF the pole voltage attains zero („0‟).

V_{A20}, V_{B20}, V_{C20} are the pole voltages of inverter-1 and $V_{A''0''}$, $V_{B''0''}$,$V_{C''0''}$arethepolevoltagesofinverter-2.$V_{AA''}$,V_{BB}‟,V_{CC}‟is the voltage across the phase winding of induction motor it can be obtained by the difference between the pole voltages ,which is given by the equations (1)-(3) and the phase winding can attain fivelevels.

The Zero Sequence voltage or common mode voltage is given by the equation (4).The line voltages is obtained from the equations

$$V_{ZS} \text{ or } CMV = \frac{V_{AA'} + V_{BB'} + V_{CC'}}{3} \qquad (4)$$

The Zero Sequence voltage or common mode voltage is given by the equation (4).The line voltages is obtained from the equations

The line voltages isobtained (5)-(7)
For a six level inverter whose working is same five level it is supplied with the asymmetrical DC –link voltages, where DC-

$V_{AN} = V_{AA'} - V_{ZS}$ (5)
$V_{BN} = V_{BB'} - V_{ZS}$ (6)
$V_{CN} = V_{CC'} - V_{ZS}$ (7)

Configuration-II:
5&6-level Inverter:

A schematic diagram of inverter fed open end winding Induction Motor drive is shown in the Fig.2, Where INV-X is a 3-level inverter and INV-Y is a conventional two level inverter. The three level inverter (i.e. INV-X) is comprised of two, two level inverters (i.e. INV-1 &INV-2) connected in cascaded so that it resembles to that of a three levelinverter. link voltage of inverter-1 and inverter-2 is $2V_{DC}/6$ each and the DC-link voltage of inverter-Y is $V_{DC}/6$

III. Modulating techniques:

In order to have efficient and better performance of inverter different modulation techniques have been proposed. Multilevel inversion is a power conversion strategy in which the output voltage is obtained in steps thus bringing the output closer to a sine wave and reduces the Total Harmonic Distortion. In Pulse Width Modulation (PWM) for a fixed DC input we get a controlled AC output by adjusting turn on and turn off of device. In this method, it mitigates lower order harmonics. But, more pulses mean more switching losses [7].

Sinusoidal PWM:

In this scheme, three sinusoidal reference waves each shifted by 120° are used. A triangular carrier wave is compared with the reference signal corresponding to a phase to generate the gating signals for that phase. At every instant sinusoidal signal at desired frequency is compared with each carrier signal at high frequency. In this comparison if modulating signal is greater than triangular carrier signal, then signal is given to appropriate semi- conductor switch in respective legs. The reference voltages for a three-phase topology for balanced three-phase system are given by.

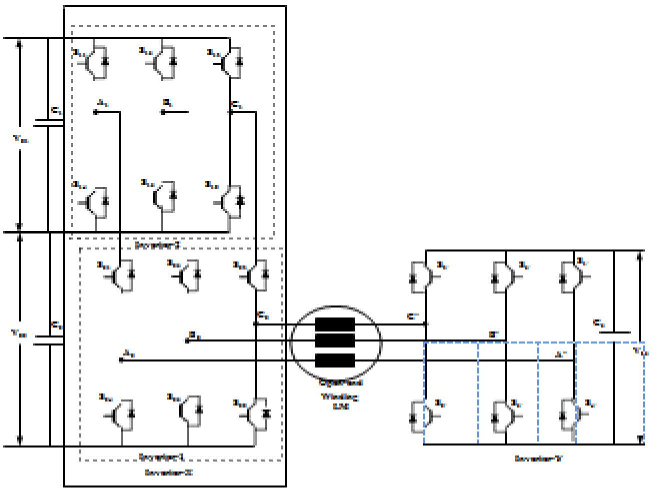


Fig.2 schematic of inverter fed open end winding I.M drive Here,S_{11}-S_{16}andS_{21}-S_{26}aretheswitchesofinverter-X and $S_{1''}$-$S_{6''}$ are the switches of inverter-Y. These two inverters aresuppliedwiththeasymmetricalDC–linkvoltages,where

DC-link voltage of inverter-1 and inverter-Y is $V_{DC}/4$ each and the DC-link voltage of inverter-2 is $V_{DC}/2$. This configuration resembles to that of a five level inverter. For the given input of $V_{DC}/4$, inverter-Y attains two levels namely + $V_{DC}/8$ and - $V_{DC}/8$. Inverter-X can attain three levels depending on the switching state. When the switches $S_{11}$and S_{24} is turned ON the pole voltage obtained is $-V_{DC}/2$, S_{14} and S_{21} is ON the pole voltage attains $V_{DC}/4$ and S_{21} and S_{24} is OFF the pole voltage attains zero („0").

$$V_{Aref}(t) = V_m \sin(\omega t)$$
$$V_{Bref}(t) = V_m \sin(\omega t - 2\pi/3)$$
$$V_{Cref}(t) = V_m \sin(\omega t - 4\pi/3)$$

Third Harmonic Injection PWM:

The sinusoidal PWM is unable to fully utilize the DC bus supply voltage and THD is also higher. So, the third harmonic injection pulse width modulation (THIPWM) technique was developed to increase the inverter performance. In this technique, a third harmonic component is superimposed on the fundamental which is given by the followingequation

$$y=\frac{2}{\sqrt{3}}\sin\omega t+K\sin 3\omega t$$

Here, k=1/6 i.e. Injecting one sixth of the third harmonic component to the fundamental component or K=1/4 i.e. Injecting one fourth of the third harmonic component to the fundamentalcomponent.

IV. Simulation results:

A) Configuration-I

For 5-level multilevel inverter fed I.M drive using SPWM :

5-level multilevel inverter fed I.M drive is modeled and is simulated by employing Sinusoidal pulse width modulation(SPWM) control technique with Modulation index=1(over modulation) and the reference and carrier wave comparison ,pole voltage, output phase voltage, line voltage and ZSV for 5 level inverter are shown in Fig.3

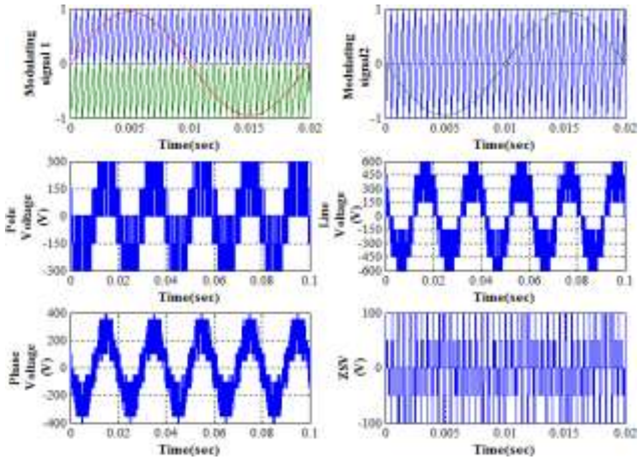


Fig.3 Modulating signal, Pole voltage, Line voltage,phase voltage, ZSV for 5-level inverter usingSPWM

For 6-level multilevel inverter fed I.M drive using SPWM:

6-level multilevel inverter fed I.M drive is modeled and is simulated by employing Sinusoidal pulse width modulation(SPWM) control technique with Modulation index=1(over modulation) and the reference and carrier wave comparison ,pole voltage, output phase voltage, line voltage and ZSV for 6 level inverter are shown in Fig.4

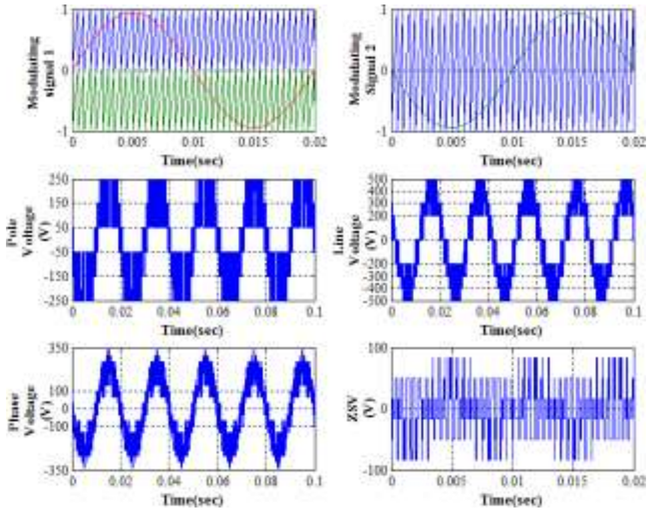


Fig.4 Modulating signal, Pole voltage, Line voltge, phase voltage, ZSV for 6-level inverter using SPWM

Configuration-II

For 5-level multilevel inverter fed I.M drive using SPWM technique :

5-level multilevel inverter fed I.M drive is modeled and is simulated by employing Sinusoidal pulse width modulation(SPWM) control technique with Modulation index=1(over modulation) and the reference and carrier wave comparison ,pole voltage, output phase voltage, line voltage and ZSV for 5 level inverter are shown in Fig.5

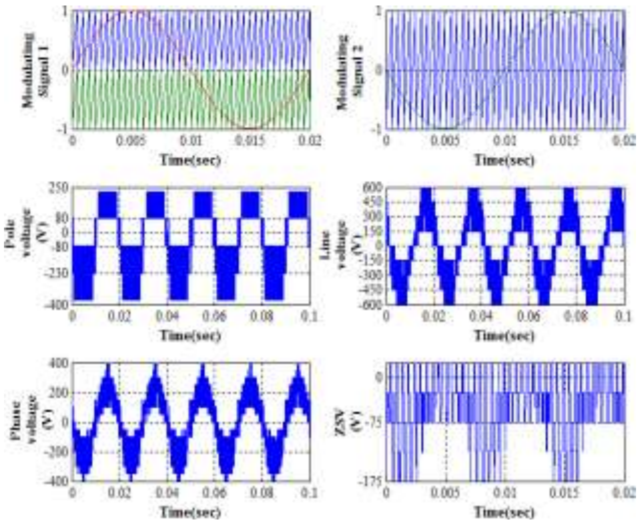


Fig.5 Modulating signal, Pole voltage, Line voltage ,phase voltage, ZSV for 5-level inverter using SPWM

For 6-level multilevel inverter fed I.M drive using SPWM technique:

6-level multilevel inverter fed I.M drive is modeled and is simulated by employing Sinusoidal pulse width modulation(SPWM) control technique with Modulation index=1(over modulation) and the reference and carrier wave comparison ,pole voltage, output phase voltage, line voltage and ZSV for 6 level inverter are shown in Fig.6

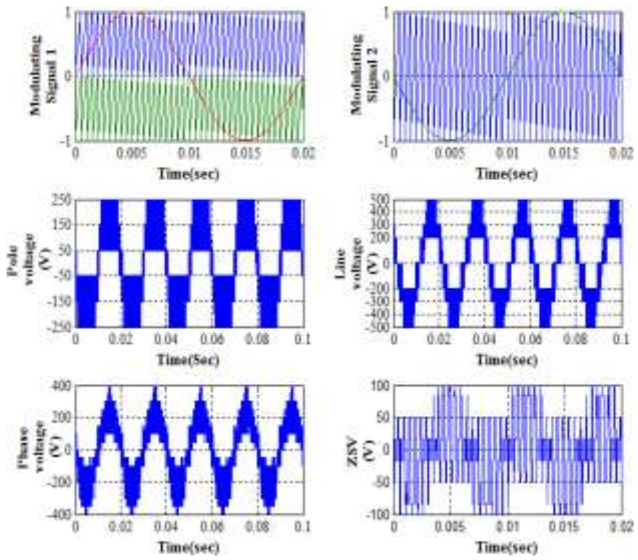


Fig.6 Modulating signal, Pole voltage, Line voltage ,phase voltage, ZSV for 6-level inverter using SPWM

B) Configuration-I

For 5-level multilevel inverter fed I.M drive using THIPWM technique:

5-level multilevel inverter fed I.M drive is modeled and is simulated by employing Third Harmonic Injection pulse width modulation(THIPWM) control technique with Modulation index=1(over modulation) and the reference and carrier wave comparison ,pole voltage, output phase voltage, line voltage and ZSV for 5 level inverter are shown in Fig.7

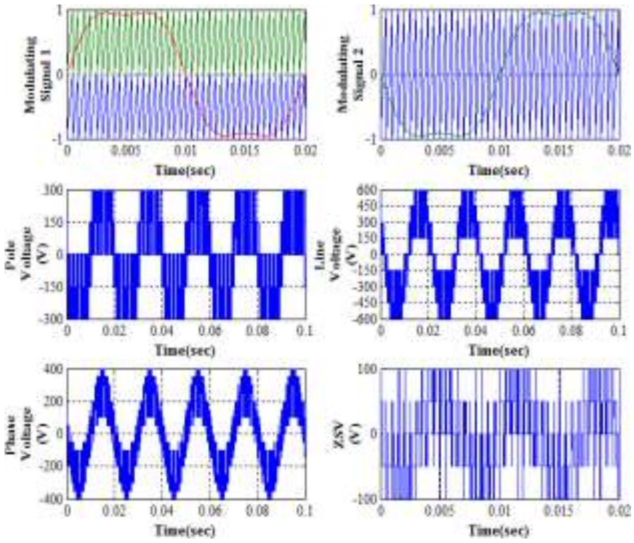


Fig.7 Modulating signal, Pole voltage, Line voltage, phase voltage, ZSV for 5-level inverter using THIPWM

For 6-level multilevel inverter fed I.M drive using THIPWM technique:

6-level multilevel inverter fed I.M drive is modeled and is simulated by employing Third Harmonic Injection pulse width modulation(THIPWM) control technique with Modulation index=1(over modulation) and the reference and carrier wave comparison ,pole voltage, output phase voltage, line voltage and ZSV for 6 level inverter are shown in Fig.8

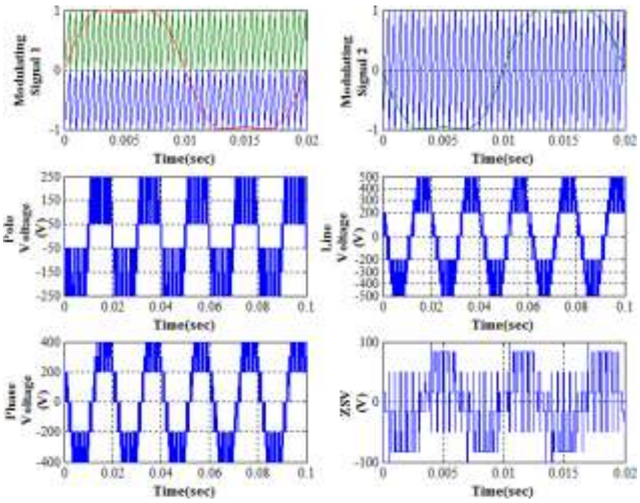


Fig.8 Modulating signal, Pole voltage, Line voltage, phase voltage, ZSV for 6-level inverter using THIPWM

Configuration-II

For 5-level multilevel inverter fed I.M drive using THIPWM technique:

5-level multilevel inverter fed I.M drive is modeled and is simulated by employing Third Harmonic Injection pulse width modulation(THIPWM) control technique with Modulation index=1(over modulation) and the reference and carrier wave comparison ,pole voltage, output phase voltage, line voltage and ZSV for 5 level inverter are shown in Fig.9

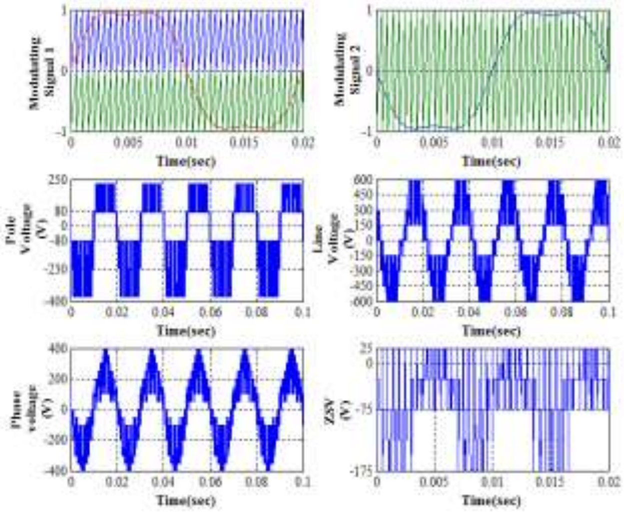


Fig.9 Modulating signal, Pole voltage, Line voltage, phase voltage, ZSV for 5-level inverter using THIPWM

For 6-level multilevel inverter fed I.M drive using THIPWM technique:

6-level multilevel inverter fed I.M drive is modeled and is simulated by employing THIPWM control technique with Modulation index=1(over modulation) and the reference and carrier wave comparison ,pole voltage, output phase voltage, line voltage and ZSV for 6 level inverter are shown in Fig.10

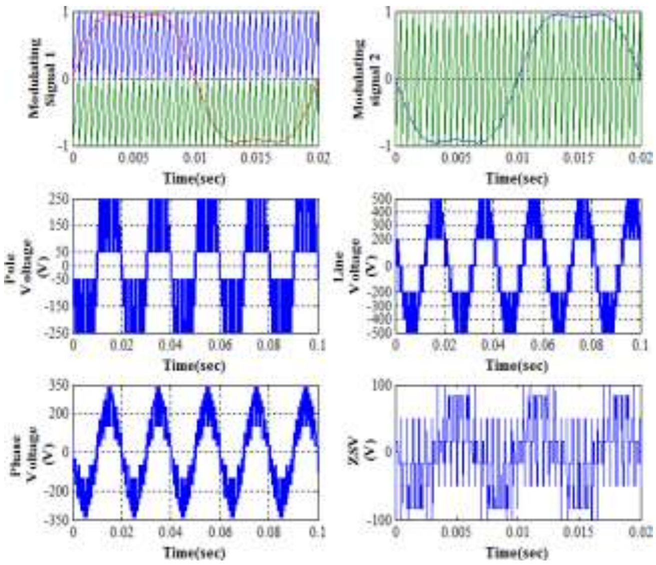


Fig.10 Modulating signal, Pole voltage, Line voltage ,phase voltage, ZSV for 6-level inverter using THIPWM

Table-I

Inverter type		THD of inverter voltage (V_{line})in under modulation (M.I=0.75) region (%)	THD of inverter Voltage (V_{line}THD) in over modulation (M.I=1)region(%)
Config-I	5-level	60.37	36.14
	6-level	45.41	29.39
Config-II	5-level	51.77	32.57
	6-level	45.01	29.12

Inverter type		THD of inverter voltage (V_{line} THD)in under Modulation (M.I=0.75) region (%)	THD of inverter (V_{line} THD) in over modulation (M.I=1) region (%)
Config-I	5-level	51.5	27.34
	6-level	40.55	20.62
Config-II	5-level	44.83	22.83
	6-level	40.53	20.19

Table-II

Table-I and II lists out the THD values of line voltages for SPWM and THIPWM techniques.

V. Conclusion:

In this paper, the implementation of inverter fed open winding I.M drive has been done by using different modulation techniques like SPWM and THIPWM. The Zero Sequence Voltage is also mitigated upto greater extent and there is gradual decrement in THD‟s using THIPWM because of maximum utilization of DC bus. This work can be extended by using advanced modulation techniques like SVPWM and Discontinuous PWM techniques.

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