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Reduction of Common Mode Voltage for 3-Level Inverter Fed DTC of open end Winding Induction Motor Drive

S. Sarada, Ph.D. Scholar, Dept. Of Eee, Jntua, Anantapuramu, saradasasi@gmail.com

Dr. N. Ravisankara Reddy, Member, IEEE, Dept. Of Eee, G.Pulla Reddy Engineering College, Kurnool, netapallyravi@gmail.com

C. Ganesh, DEPT. OF EEE, Annamacharya Institute Of Technology & Sciences, Rajampet, ganesh.challa@gmail.com

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Abstract:
A scalar based carrier comparison Reduced Common Mode Voltage Pulse Width Modulated (RCMVPWM) schemes is implemented for 3-level dual inverter fed Direct Torque Control (DTC) of Open End Winding Induction Motor (OEWIM drive). In scalar based approach, the modulating signal is obtained by adding zero sequence signal to sinusoidal signal. In this paper, a simplified Space Vector Pulse Width Modulation (SVPWM), RCMVPWM algorithms such as Active Zero State Pulse Width Modulation (AZSPWM) and Near State Pulse Width Modulation (NSPWM) algorithms were obtained by scalar approach. SVPWM algorithm utilizes zero voltage vectors which are responsible for generation of CMV. Moreover, the CMV injects Common Mode Currents (CMC) into the bearings. As a result, the bearings were damaged. Since the RCMVPWM techniques were not utilized zero voltage vectors and therefore CMV is reduced significantly. The analysis of CMV and the Total Harmonic Distortion in stator current of induction motor carried out in this paper. The present work can be illustrated by the simulation results of the MATLAB.

Keywords: *COMMON MODE VOLTAGE, DTC, SVPWM, DPWM, AZSPWM, NSPWM, THD.*

I. Introduction

The Direct Torque Control (DTC) scheme offers robust control and good dynamic response [1]. The DTC scheme was simple to implement compared to vector control scheme since latter method involves complex mathematical manipulations and coordinate transformations. Conventional DTC scheme employs torque and flux hysteresis controllers which make the drive to operate in variable switching frequency. The variable switching frequency operation results in high flux and torque ripples also causes burden on switches and associated losses. Constant switching frequency operation can be obtained by employing Pulse Width Modulation (PWM) techniques for the generation of pulse pattern for the operation of inverter switches. The torque and flux ripples can be reduced by implementing the DTC by Multi Level Inverters (MLI).

When an induction motor is fed by three phase balanced sinusoidal supply, the Common Mode Voltage (CMV) will be zero. But modern adjustable speed drives employing PWM converters which act as power modulator between the supply and the motor. The PWM algorithms generate constant switching frequency pulses at higher rate. Which when applied to power semiconductor devices, lower order harmonics can be eliminated. But the PWM techniques cause CMV which drives Common Mode Currents (CMC) through bearings, which will results in consequent failure of bearings.

Continuous Pulse Width Modulation (CPWM) schemes like Space Vector PWM (SVPWM) and Discontinuous PWM (DPWM) schemes generate high amount of CMV. In order to mitigate CMV, Reduced Common Mode Voltage (RCMV) techniques such as Active Zero State PWM

(AZSPWM) and Near State PWM (NSPWM) techniques were proposed for two level inverter. The analysis of CMV for two level inverter was presented in [2]-[4].

These PWM techniques can be implemented by either space vector or carrier based approach. A space vector and carrier based PWM schemes for two-level inverter was analyzed in [5]-[6]. The CMV can be further reduced by increasing the no.of levels of the inverter by switching the desired non zero vectors.

II. Dual Inverter Topology

Among the various MLI topologies, dual inverter topology is the most promising one.

This employs two 2-level inverters operating in alternative manner.

Fig.1 shows the schematic diagram of dual inverter fed three level OEWIM drive.

III. Common Mode Voltage

Let the effective pole voltages of the inverter-1 be Vao, Vbo, and Vco and that of inverter-2 are Va^1o, Vb^1o, and Vc^1o then the CMV generated in the inverter-1 and inverter-2 as under

$$V_{CMV1} = \frac{(V_{ao1} + V_{bo1} + V_{co1})}{3} \quad \text{..... (1)}$$

$$V_{CMV2} = \frac{(V_{ao2} + V_{bo2} + V_{co2})}{3} \quad \text{..... (2)}$$

The resultant CMV of the dual inverter is given by

$$V_{CMV} = \frac{(V_{ao} + V_{bo} + V_{co})}{3} \quad \text{..... (3)}$$

$$V_{CMV} = \frac{(V_{aa^1} + V_{bb^1} + V_{cc^1})}{3} \quad \text{..... (4)}$$

IV. Direct Torque Control Scheme

The torque exerted by 3-Φ induction motor can be given by

$$T_e = \frac{3}{2}\frac{P}{L_s^1}\frac{L_m}{L_r}|\psi_s||\psi_r|\sin\delta \quad \text{----- (5)}$$

It can be found that torque developed by the motor is proportional to magnitude of stator flux, rotor flux and the sine of phase angle between them. Stator flux control based DTC scheme was implemented in this paper. The performance equations of DTC of induction motor was expressed from equations (5) through (11)

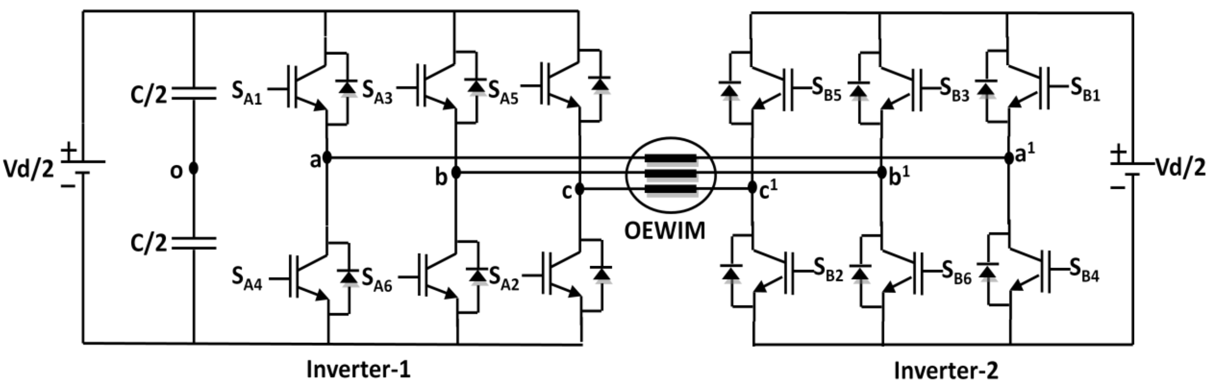

Fig.1. Configuration of d

ual inverter fed open end winding induction motor drive

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$$\bar{V}_s = \bar{I}_s R_s + \frac{d\bar{\psi}_s}{dt} \text{ ----- (6)}$$

$$\Delta\bar{\psi}_s = \bar{V}_s \Delta t \text{ ----- (7)}$$

$$\Delta\bar{\psi}_{ds} = \bar{\psi}^*_{ds} - \bar{\psi}_{ds} \text{ ----- (8)}$$

$$\Delta\bar{\psi}_{qs} = \bar{\psi}^*_{qs} - \bar{\psi}_{qs} \text{ ----- (9)}$$

$$V_{ds}{}^* = I_{ds} R_s + \frac{\Delta\psi_{ds}}{T_s} \text{ ----- (10)}$$

$$V_{qs}{}^* = I_{qs} R_s + \frac{\Delta\psi_{qs}}{T_s} \text{ ----- (11)}$$

V. SCALAR PULSE WIDTH MODULATION SCHEME

SVPWM not only enhances the DC bus utilization but also reduces the harmonics [8]. Likewise DPWM techniques reduce the switching losses [11]. But the main disadvantage of these PWM techniques is that, higher CMV. The SVPWM and DPWM techniques give the common mode voltage of ± $V_d/3$. In RCMV schemes, the null switching vector which causes large amount of CMV is not operating; therefore the maximum CMV is limited to ± $V_d/6$. The analysis of CMV for three inverter fed OEWIM drive was carried out here. Though AZSPWM techniques reduce the CMV, but switching losses are more in this case, because the modulating wave used in these techniques is continuous signal. On the other hand, NSPWM technique not only reduces the CMV but also reduces the switching losses to one third of the losses occurred in the CPWM, because it uses same modulating signal as that of DPWM1. SVPWM, AZSPWM and NSPWM schemes were implemented by scalar approach here.

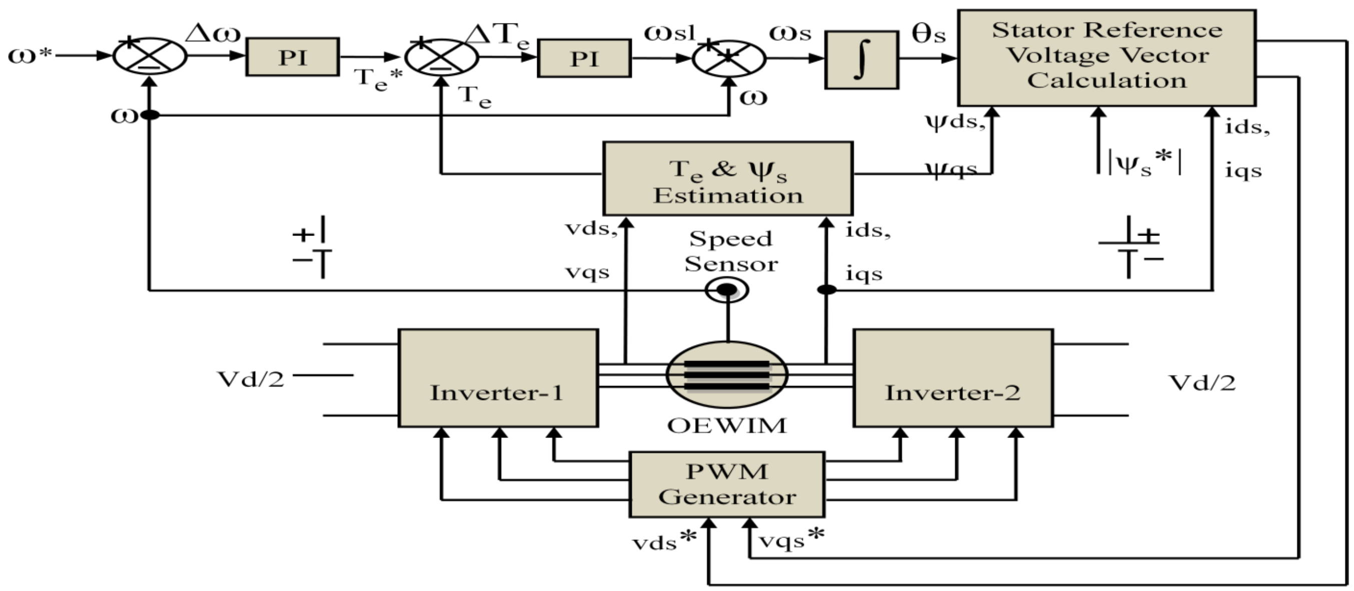

Fig.2. Block Diagram of Direct Torque Control of open end winding induction motor drive

In scalar approach, addition of zero sequence signal to the sinusoidal voltage [11] was implemented. Addition of zero sequence signal to the sinusoidal signal various modulating signals were obtained. Accordingly, Total Harmonic Distortion (THD) in stator current and CMV for SVPWM, AZSPWM and NSPWM were studied.

The sinusoidal signals can be obtained by

$$Uref = V_m \cos(\omega t - 2(x-1)\pi/3) \text{ ----- (9)}$$

Where $ref = a, b, c$ and $x = 1, 2, 3$

The expression for zero sequence signal and modulating signal are given as under.

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$$U_{Zero} = \frac{Vd}{2}(2k_o - 1) - k_o U_{\max} + (k_o - 1)U_{\min} \text{ ----- (11)}$$

Where U_{max} = max (U_{ref}) and U_{min} = min (U_{ref})

Modulating signals for SVPWM and DPWM schemes are generated by adding zero sequence signal to the reference signal as under.

$$U^*_{ref} = U_{ref} + U_{Zero} \text{ ----- (12)}$$

Proper selection of k_o and U_{ref} various modulation signals can be generated as given in Table.I.

TABLE-I GENERATION OF MODULATING SIGNAL AS A FUNCTION OF k_o

S. No.	Mod. Scheme	Ref. Signal	Condition	k_o
1	SVPWM	U_{ref}	---	0.5
2	AZSPWM1	U_{ref}	---	0.5
3	AZSPWM3	U_{ref}	---	0.5
4	NSPWM	U_{ref}	$U_{\max} + U_{\min} < 0$	0
			$U_{\max} + U_{\min} \geq 0$	1

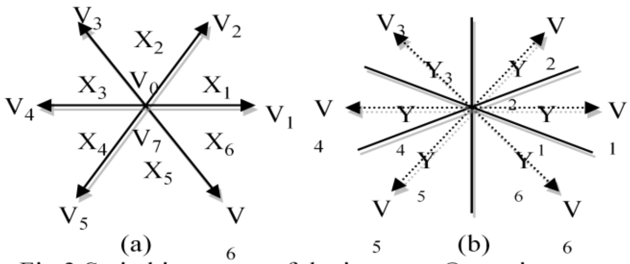


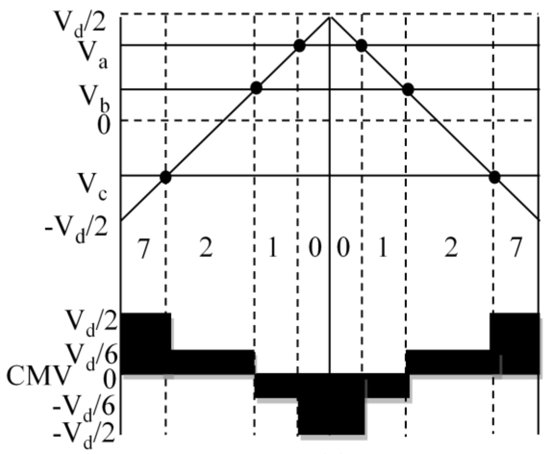
Fig.3 Switching states of the inverter, Operating regions

(a) X-region (b) Y-region

Fig.3 shows the switching states of the inverters. Here V_1-V_6 are the non-zero vectors and V_0,V_7 are the zero voltage vectors which acts same role as that of the zero sequence signal in scalar PWM techniques.The vector space can be divided into sectors. There are six X-type and six Y-type sectors. X-type region utilized for SVPWM, DPWM and AZSPWM techiniques, whereas NSPWM technique utilizes Y-type region. Keeping the same reference signal and varying the carrier wave polarities according to regions shown in fig.10, pulse pattern can be generated. The selection of carrier wave polarities for AZSPWM and NSPWM can be tabulated in the Table-II [10].`

TABLE-II SPACE VECTOR DEPENDENT CARRIER SIGNAL POLARITY DETERMINATION

AZSPWM1						
Carrier	**X_1**	**X_2**	**X_3**	**X_4**	**X_5**	**X_6**
a	-Vt	-Vt	-Vt	Vt	Vt	Vt
b	Vt	Vt	-Vt	-Vt	-Vt	Vt
c	-Vt	Vt	Vt	Vt	-Vt	-Vt
AZSPWM3						
Carrier	**X_1**	**X_2**	**X_3**	**X_4**	**X_5**	**X_6**
a	Vt	Vt	-Vt	-Vt	-Vt	Vt
b	-Vt	Vt	Vt	Vt	-Vt	-Vt
c	-Vt	-Vt	-Vt	Vt	Vt	Vt
NSPWM						
Carrier	**Y_1**	**Y_2**	**Y_3**	**Y_4**	**Y_5**	**Y_6**
a	Vt	-Vt	-Vt	Vt	Vt	Vt
b	Vt	Vt	Vt	-Vt	-Vt	Vt
c	-Vt	Vt	Vt	Vt	Vt	-Vt



(a)

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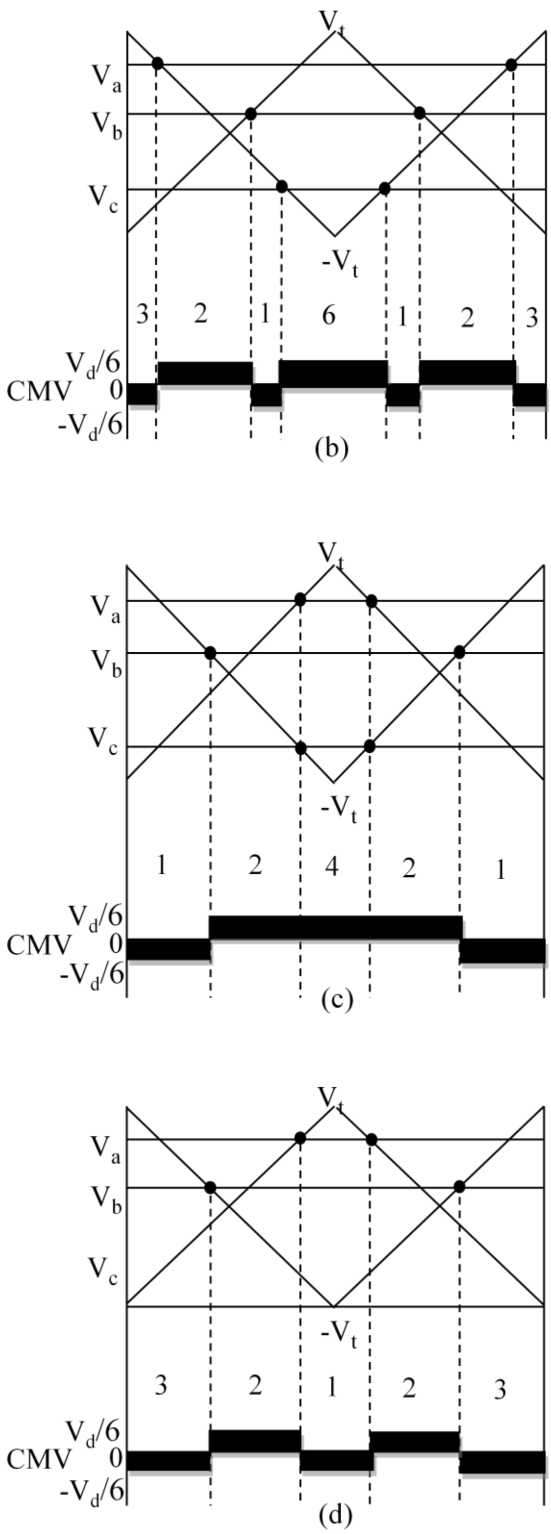


The carrier signal polarity can also be obtained by comparing the reference signals;

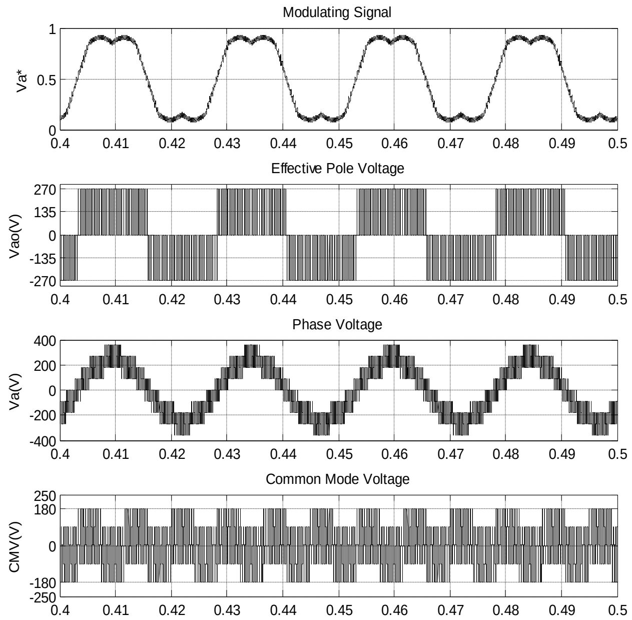
e.g. If $U_a > U_b$, U_c then the opertion is obtained in X_1-region and so on.

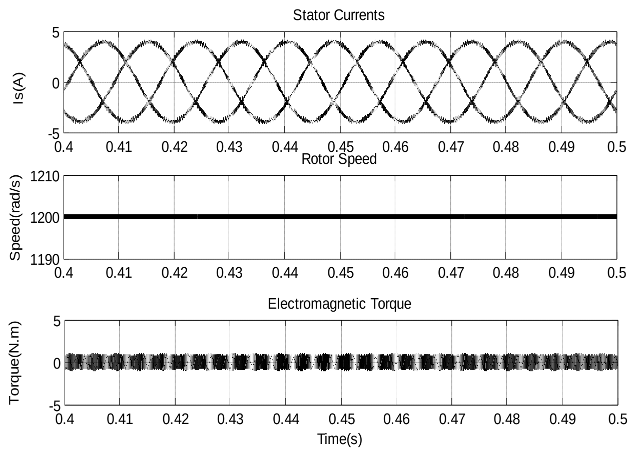
Fig.4 shows the CMV pattern for SVPWM, AZSPWM and NSPWM irrespective of the scalar or vector approach.

It is clear that, RCMV modulation techniques avoided the usage of null vectors. As a result, the CMV reduced from $\pm(V_d/3)$ to $\pm(V_d/6)$. The operation and switching logic used in this paper was described in [7].

Fig.4 CMV patterns and carrier signal polarity definition for (a) SVPWM (b) AZSPWM1 (c) AZSPWM3 (d) NSPWM

VI. Results & Discussion





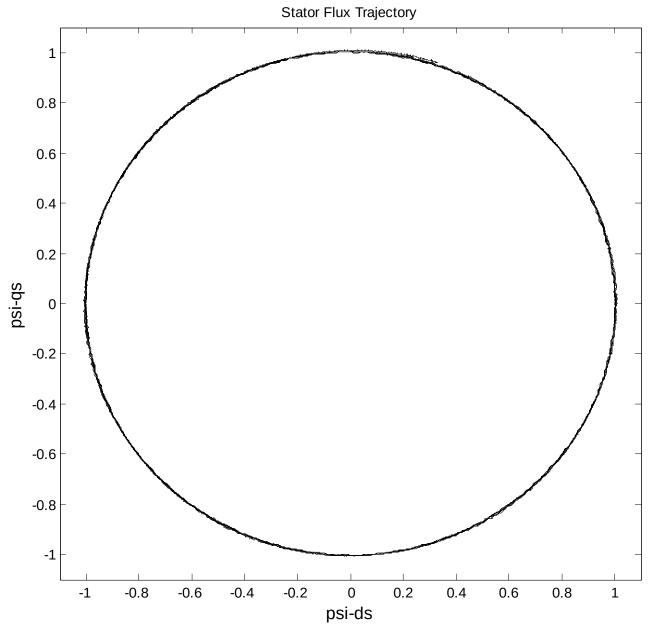
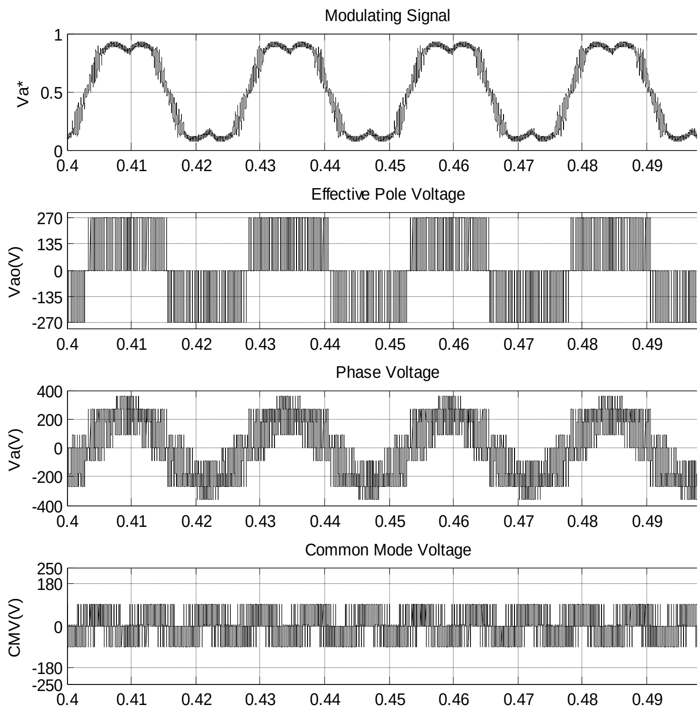


Fig.5 Modalting signal, inverter pole voltage, line voltage, stator currents of the motor, rotor speed and electromagnetic torque and stator flux trajectory with SVPWM.



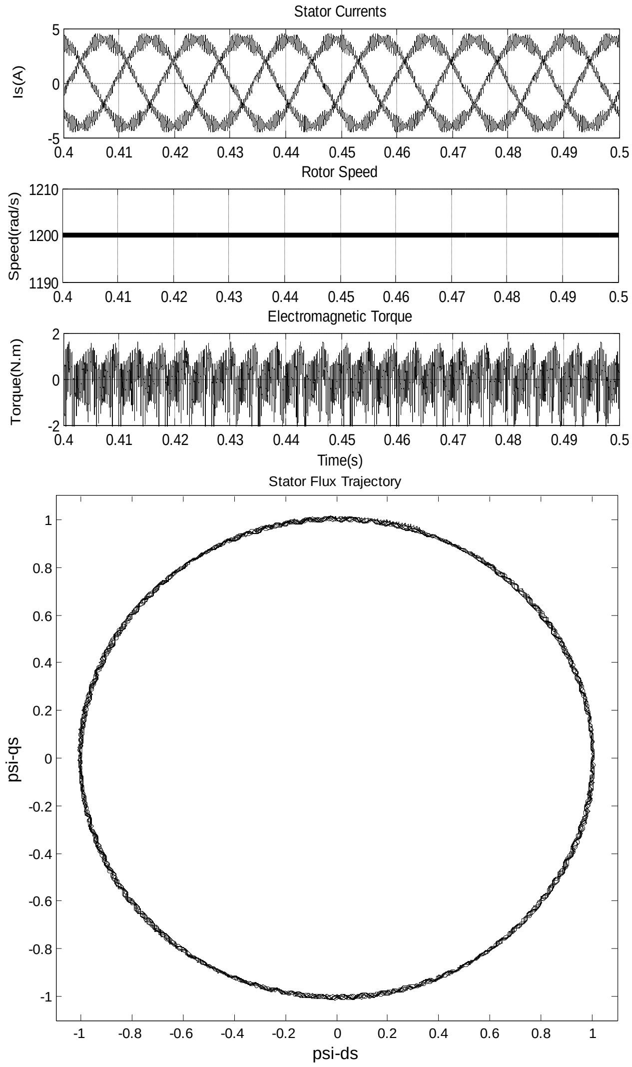
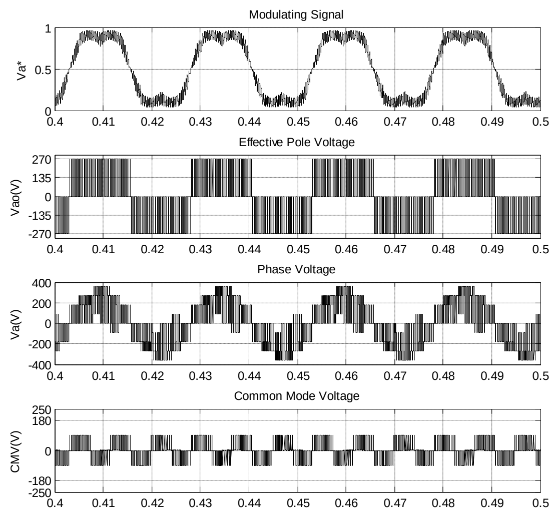


Fig.6 Modalting signal, inverter pole voltage, line voltage, stator currents of the motor, rotor speed and electromagnetic torque and stator flux trajectory with AZSPWM1.



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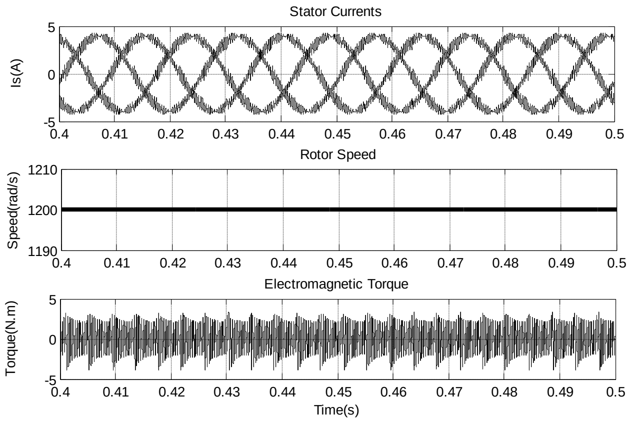


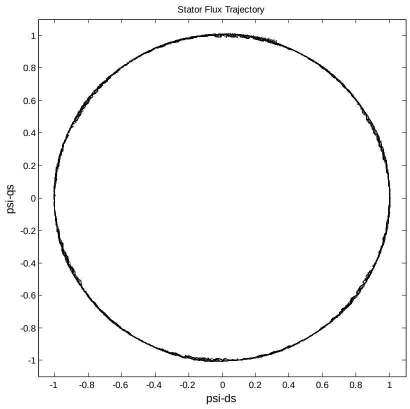
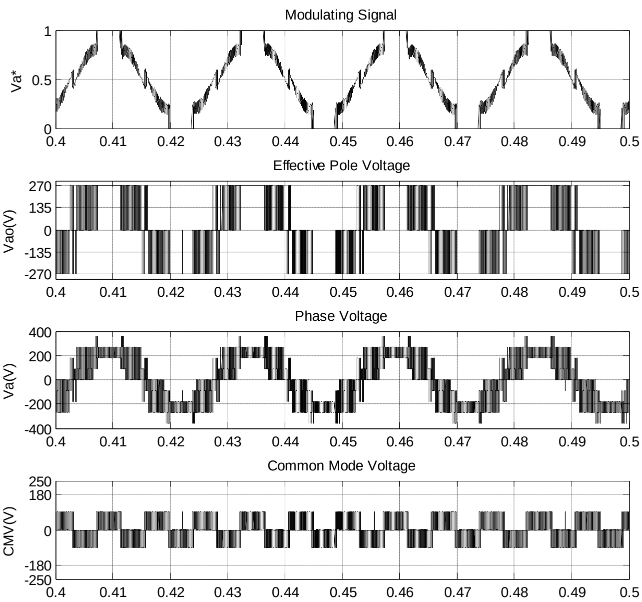
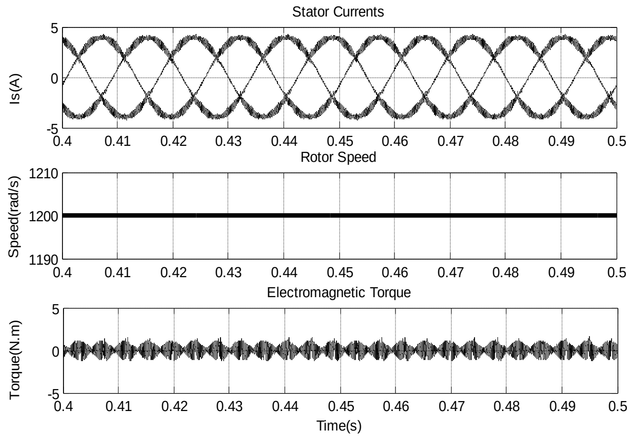


Fig.7 Modalting signal, inverter pole voltage, line voltage, stator currents of the motor, rotor speed and electromagnetic torque and stator flux trajectory with AZSPWM3.





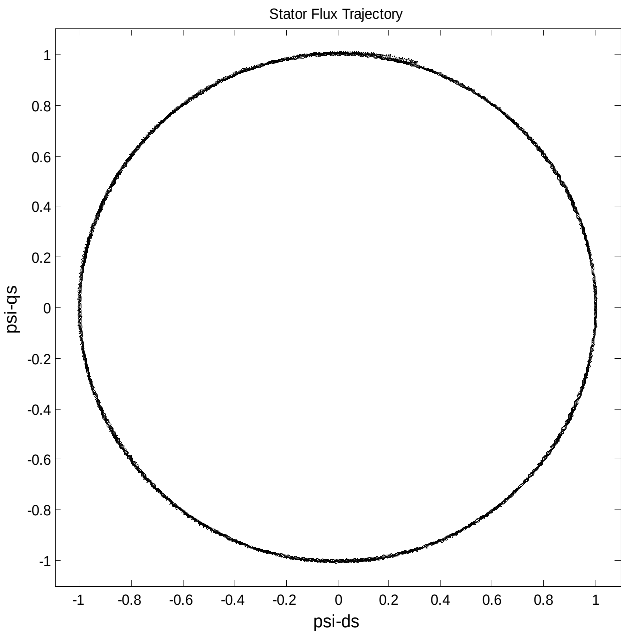


Fig.8 Modalting signal, inverter pole voltage, line voltage, stator currents of the motor, rotor speed and electromagnetic torque and stator flux trajectory with NSPWM.

The feasibility of this scheme can be validated by MATLAB/Simulink results. Stator flux control based DTC scheme was implemented for SVPWM, AZSPWM and NSPWM techniques.

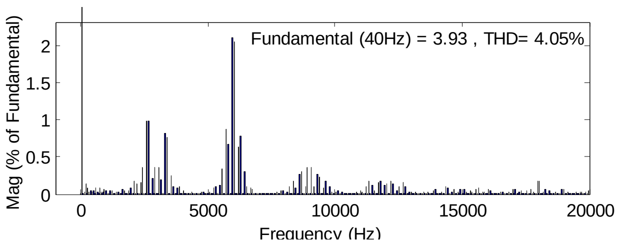


Fig.9 Harmonic spectrum of stator current of induction motor with SVPWM

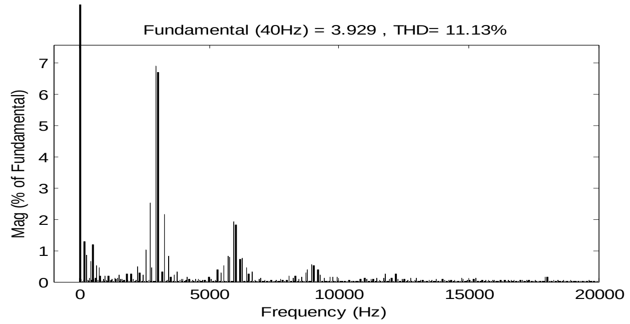


Fig.10 Harmonic spectrum of stator current of induction motor with AZSPWM1

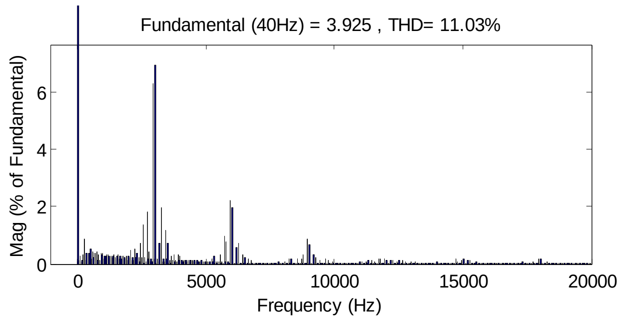


Fig.11 Harmonic spectrum of stator current of induction motor with AZSPWM3

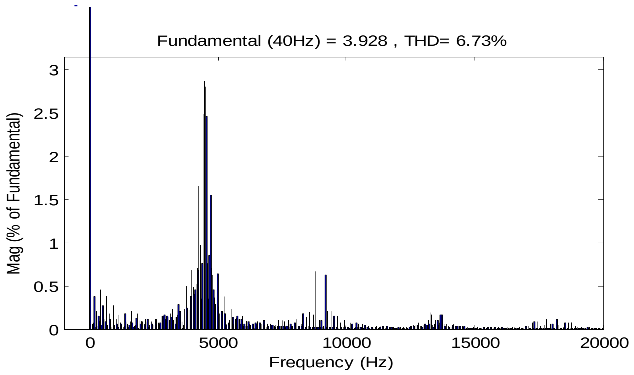


Fig.12 Harmonic spectrum of stator current of induction motor with NSPWM.

Inverter voltages such as pole voltage , phase voltage and CMV, induction motor performance parameters like current, torque response, speed response, stator flux trajectory and THD in stator current under steady state condition was examined from fig.4 through fig.12.The set speed of the drive was chosen to be 1200 rpm and the DC link voltage of each inverter is 270V. THD in stator current for different PWM techniques was tabulated in Table.III.

TABLE-III COMPARISON OF THD

S.No.	Modulation Scheme	% THD
1.	SVPWM	4.05
2.	AZSPWM1	11.13
3.	AZSPWM3	11.03
4.	NSPWM	6.73

VII. Conclusion

The DTC scheme was simple to implement, robust in control and posses high dynamic response. A scalar based SVPWM, AZSPWM and NSPWM algorithms for DTC of OEWIM drive were examined in this paper. PWM methods for two level inverter produce high CMV and causes bearing failure. In this paper PWM methods proposed for two level inverter were used for 3-level inverter to reduce CMV. SVPWM scheme produces common mode voltage of ±(Vd/3) i.e +180V to -180V, where as AZSPWM and NSPWM methods produces ±(Vd/6) i.e. +90V to -90V. Moreover, NSPWM not only reduces the CMV but also reduces the harmonic content in the stator current and reduces the switching losses to one third of the CPWM techniques.

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