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Research paper

Comparative analysis of scalar based SVPWM techniques for open end winding induction motor drive

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Abstract

In thiswork, scalarbased SVPWM techniquesare implemented fordual inverterfed open end winding induction motor (IM) drive with single DC sourceand separate DC sources. To reduce the common modevoltage and to reduce the switching loss in conventional two level three phase voltage source inverter (VSI), scalar based SVPWM techniques are implemented for dual inverter configuration. By using thisscalarbased approach various discontinuous or Non-Centric PWM techniques are obtained with the addition of zero sequence signal to the reference phasevoltage.Whereasin conventional SVPWM technique, it requirescalculation of sector identification and look up tableswhich iscumbersome. In Non-centric PWM techniqueseach phase isclamped to atmost 120 degreesforevery fundamental voltage cycle, which helps in reducing the switching losses. To validate the proposed work numerous simulations have been performed on both proposed configurations using MATLAB/SIMULINK environment and simulation results are presented and compared for both proposed models.

Keywords: *Induction Motor (IM); Non-Centric PWM (NCPWM); Space Vector Pulse Width Modulation (SVPWM); Voltage Source Inverter (VSI).*

1. Introduction

In industries AC drives are more utilized for variable speed applications. Variable speed operation of IM drive is achieved with the help of voltage source inverter [1] which has the capability to control the magnitude and frequency of the output voltage. For low and medium power applications Conventionaltwo levelinverters are preferred and to meet the high power demand applications, Multi-level inverters are used. Since conventional two levelinverters when operated at high frequency generates common mode voltage. It appears between the neutralpoint of the star connected stator winding of the motor to earth ground. The analysis of common mode voltage is very important in AC drives. Common Mode Voltage leads to production of shaft voltage and high bearing currents which causes premature failure to the bearings. It may also results in EMI effect. With the help of MLI‟S the reduction of common mode voltage and to avoid the flow of bearing currents is not achieved to a great extent. Many techniques have been suggested for solving the problem of common mode voltage. Few are based on incorporating additional circuit like filters, common mode choke and use of isolation transformers. One promising configuration to minimize CMVis by considering a dual inverter fed open-end winding induction motor drive. There are several pulse width modulation techniques are present to reduce the CMVbut the most popular technique is SVPWM where the reduction of CMV is achieved greatly when compared with other PWM techniques. Space Vector PWM technique [2] provides less harmonic distortion and produces 15% higher ac voltage when compared with other PWM techniques. The dual inverter configuration can achieve the same maximum output voltage as the conventional inverter with reduced DC input voltage, which minimizes the voltage rating of the switches and further reduces the switching losses. This dual inverter configuration can be achieved in two different ways that is both inverters fed with single DC source and with separate DC sources. In utilization of input DCsupply SVPWM technique gives better performance when compared with other PWM techniques. To reduce the THD of output phase voltage and and also to reduce the switching losses dual inverter fed open end winding induction motor (OEWIM) [3] with single DC source and separate DC sources are proposed using scalar based SVPWM technique.

2. Space vector PWM TEC HNIQ UE

In this PWM technique, it uses the concept of revolving reference voltage vector instead of three phase modulating waves used in Sinusoidal PWM. The fundamental component in line side is controlled by magnitude and frequency of reference vector. The fundamentalpeakvalue of phase is very less in sinusoidal PWM when compared with SVPWM. Also in utilization of DC bus voltage and generation of less THD is more efficient in SVPWM[4] technique when compared with SPWM technique. The circuit demonstrates the foundation of a two-level voltage source inverters represented as Fig.1. It has six switches and each of these are represented with an IGBT switching device and a, b, c represents the three phases. Depending on the switching combination the inverter will produce eight switching patterns. Out of them six are active vectors and remaining two are zero vectors. For the implementation of SVPWM technique it is necessary to transform the voltage equations in abc reference frame to stationary d-q reference frame.

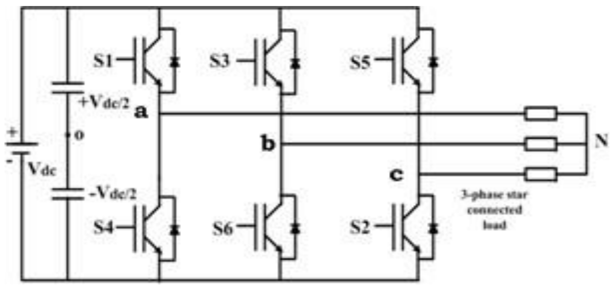


Fig. 1: Voltage Source Inverter.

Vref is calculated by considering two active vectors and two zero vectors in each sector. For sector 1 which is from zero degrees to 60 degrees is calculated with the vectors V0, V1 and V2,V7 and the timing durations expressions are represented in below equations.

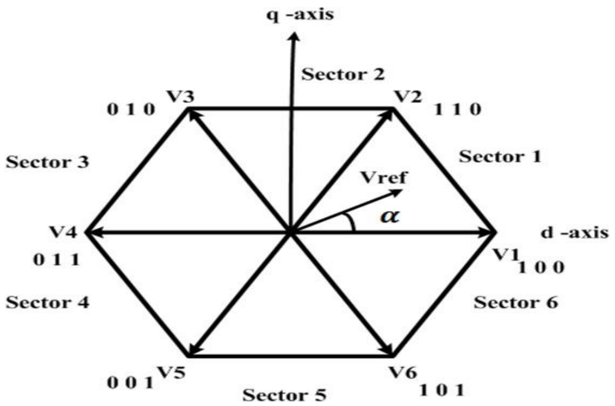


Fig. 2: Space Vector Diagram for Two Level Inverter.

The generalized expression defined for sector „K" is given by

$$V_{ref} T_s = V_k T_k + V_{k+1} T_{k+1} + V_0 T_0 + V_7 T_7 \quad (1)$$

Where,

$$T_s = T_k + T_{k+1} + T_z \quad (2)$$

The duration of active and zero voltage vectors can be obtained for each sector „k" is given in (3),(4) and (5).

$$T_k = \frac{2\sqrt{3}}{\Pi} M_i \left[\sin\left(\frac{k\Pi}{3} - \alpha\right)\right] T_s \quad (3)$$

$$T_k = \frac{2\sqrt{3}}{\Pi} M_i \left[\sin\left(\alpha - (k-1)\frac{\Pi}{3}\right)\right] T_s \quad (4)$$

$$T_z = T_s - T_k - T_{k+1} \quad (5)$$

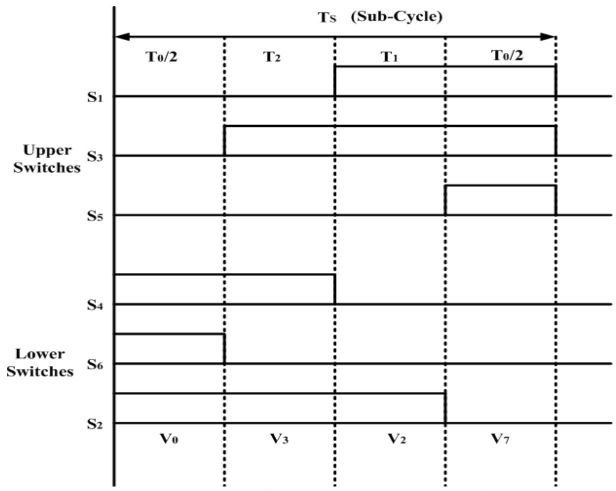


Fig. 3: Timing Diagram for Sector-1(0 2 1 7) Configuration.

3. SVPWM technique using scalar approach

In Scalar based SVPWM technique by adding a zero sequence signal to the reference phase voltage, modulating signalis generated .The comparison of modulating signal with a triangular or ramp carrier signal generates pulses to the inverter.
Here V max and V min are the maximumand minimum values of V in

$$V^*_{in} = V_{in} + V_{zs} \quad (6)$$

$$V_{in} = V_{ref} \cos\left(\theta - \frac{2(r-1)\Pi}{3}\right)$$

Where i= a,b,c and r= 1, 2, 3. (7)

$$V_{zs} = \frac{V_{dc}}{2(2a-1)} - a * V_{max} + (a-1) * V_{min} \quad (8)$$

$$V_{ix} = V_{ref} \cos\left(\theta - 2(r-1)\frac{\Pi}{3} - \frac{\Pi}{6}\right) \quad (9)$$

$$V_{max,\ x} = \max(V_{ix}) \quad (10)$$

$$V_{min,\ x} = \min(V_{ix}) \quad (11)$$

a) A .Non-Centric PWM Technique

These are also called as Bus Clamping PWM techniques or discontinuous PWM techniques. In this technique any one of the zero vectors is considered either 00 0 state or 1 1 1 state to calculate the sampling time period. In this DPWM Techniques one phase is clamped to either positive or negative rail for at most of 120 degrees. By this technique, when compared with conventional SVPWM there will be reduction of switching losses about 33.3%.The timing diagram for the discontinuous or non-centric PWM technique are shown in below fig.4.11 for the configuration of 721 sequence.

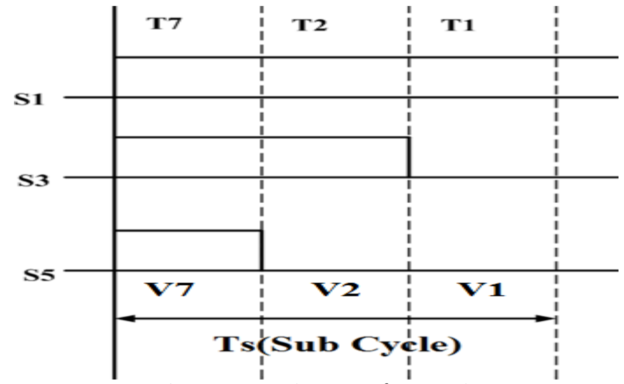


Fig. 4: Sector-1(7 2 1 Configuration).

Table 1: Realization of Different PWM Techniques

PWM Technique	Value of ‘a’
Centric PWM	0.5
Non-Centric PWM MIN	0
Non-Centric PWM MAX	1
Non-Centric PWM0	If $V_{max,x}+V_{min,x}<0$=> a=1 If $V_{max,x}+V_{min,x}>=0$ => a=0
Non-Centric PWM1	If $V_{max}+V_{min}<0$ => a=0 If $V_{max}+V_{min}>=0$ => a=1
Non-Centric PWM2	If $V_{max,x}+V_{min,x}<0$ => a=0 If $V_{max,x}+V_{min,x}>=0$ => a=1
Non-Centric PWM3	If $V_{max}+V_{min}<0$ => a=1 If $V_{max}+V_{min}>=0$ => a=0

The generation of this Non-Centric (or) Discontinuous PWM techniques and the duration of zero state in each sector is diagramatically shown below

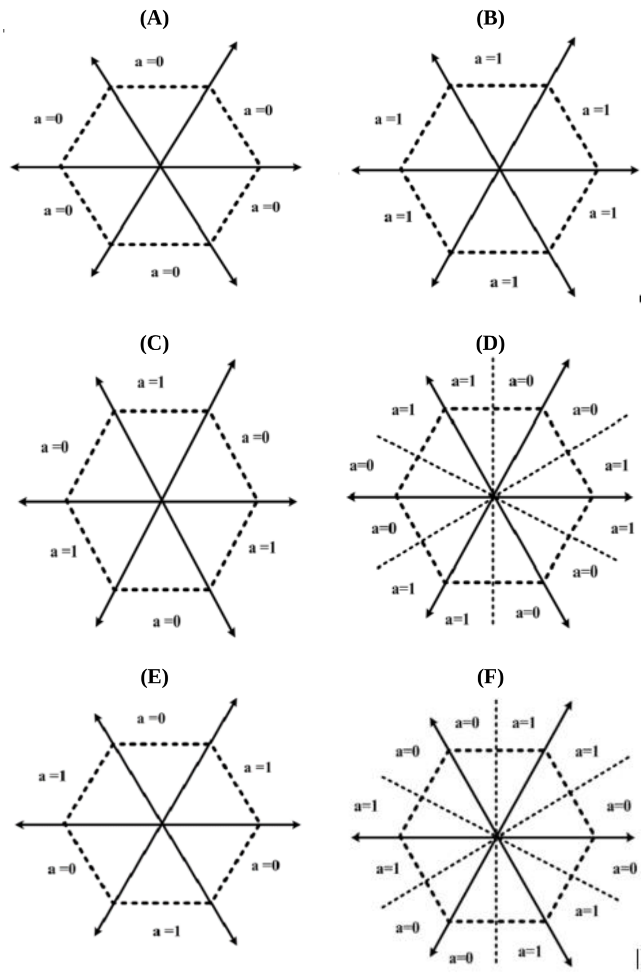
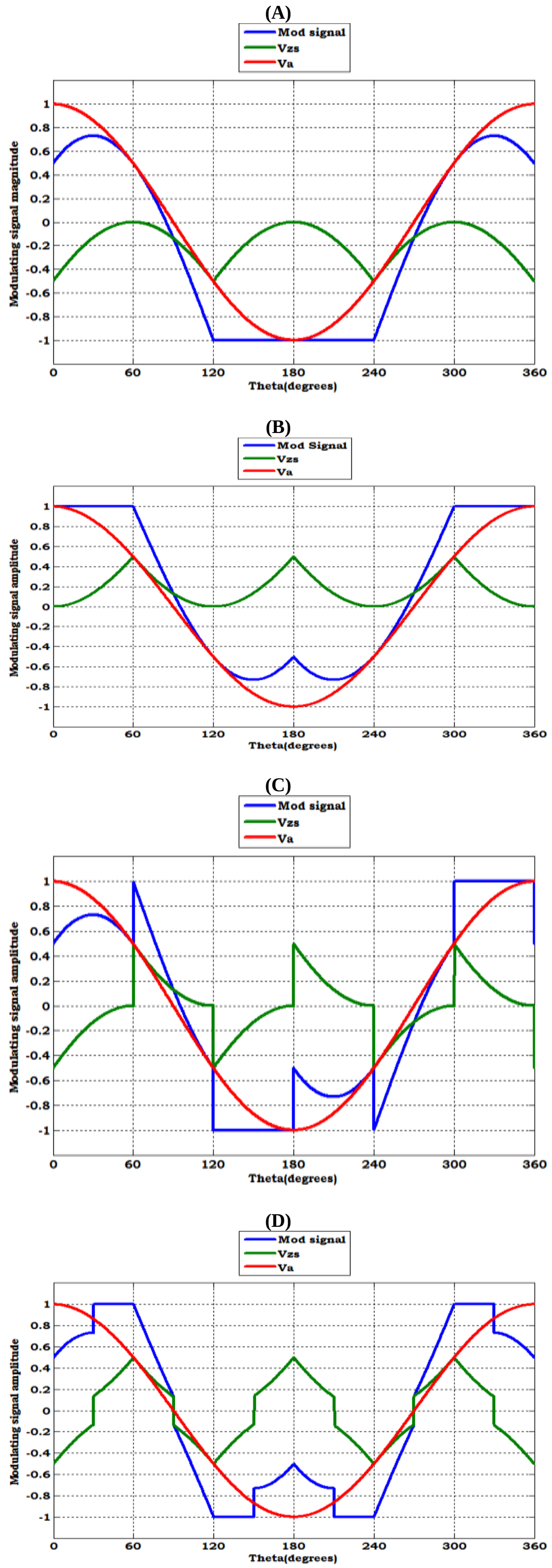
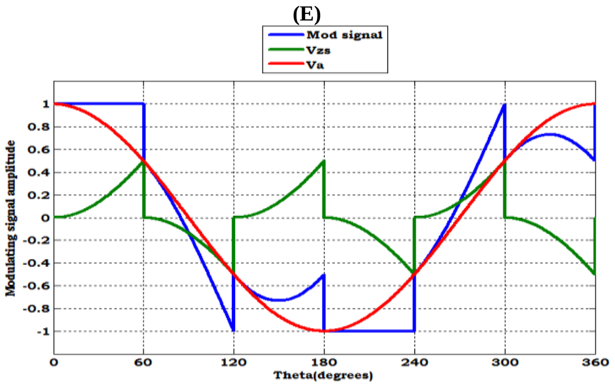


Fig. 5: Generation of Scalar Based Non-Centric PWM Techniques.

Centric PWM (b) Non-Centric PWMMIN (c) Non-Centric PWMMAX (d) Non-Centric PWM0 (e) Non-Centric PWM1 (f) Non-Centric PWM2 (g) Non-Centric PWM3

The reference phase voltage, zero sequence voltage and modulating wave form of different PWM techniques are shown in Fig.6 at a modulation index of 1.





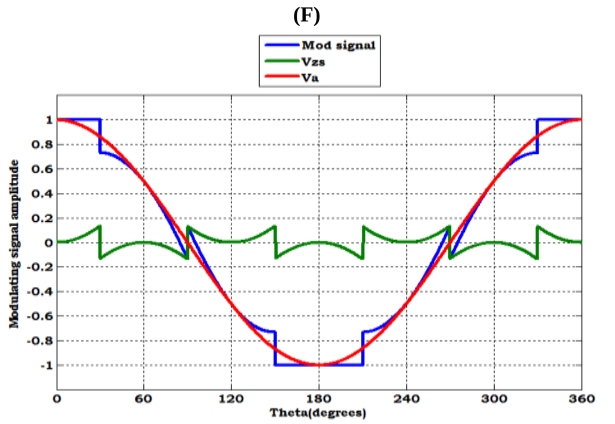


Fig. 6:.Reference Phase Voltage,Zero Sequence Voltage and Modulated Wave Formfor Different PWM Techniques(A)Centric PWM(B)Non-Centric PWMMIN (C) Non-Centric PWMMAX(D) Non-Centric PWM0 (E) Non-Centric PWM1(F) Non-Centric PWM2(G) Non-Centric PWM3.

In NCPWMMAX and NCPWMMIN technique, the clamping of 1200 takes place for every 360o of fundamental voltage cycle. In NCPWM0 and NCPWM2 techniques, 60° of clamping takes place from 0°−180° for NCPWM0 and 180°-360o for NCPWM2 of fundamental voltage cycle. In
NCPWM1 technique, clamping of 60° takes place at the middle of fundamental voltage cycle. In NCPWM3 sequence, clamps every phase between 0° to 180° and from 1800 to 360° of fundamental voltage cycle.
The below figures represents the block diagrams of the proposed work of dual inverter fed open end winding configuration[6-9].

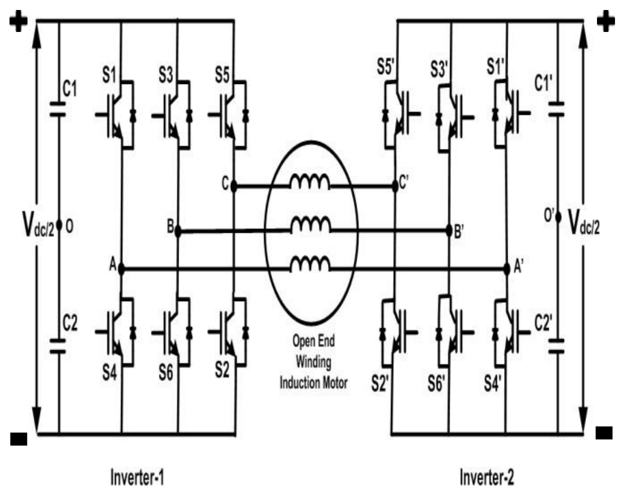


Fig. 7: Dual Inverter Fed OEWIM by Using Separate DC Sources.

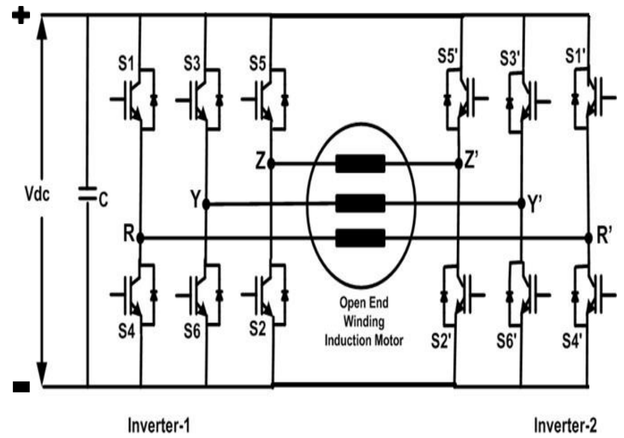


Fig. 8: Dual Inverter Fed OEWIM by Using Single DC Source.

4. Results and discussion

To verify the proposed models, various simulations have been performed using MATLAB/SIMULINK environment. The switching frequency is considered as 3 kHz and dc link voltage is considered as 300V for each individual inverter. Output wave-forms of modulating signal, pole voltage, phase voltage and com-mon mode voltage are plotted and represented for each proposed configuration in below figures.

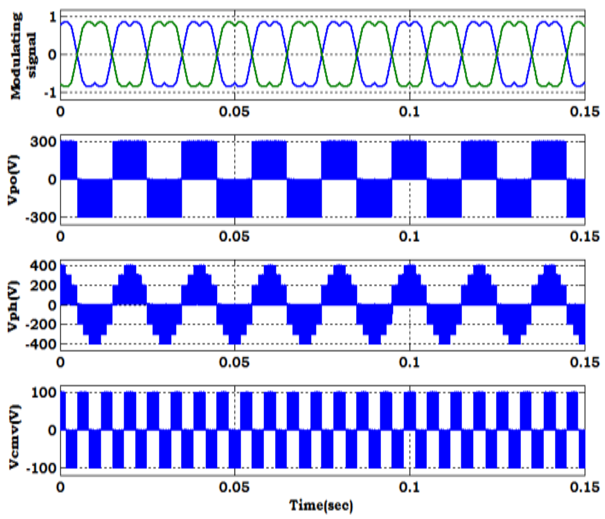


Fig. 9: Simulation Traces of Centric PWM Technique for Dual Inverter Fed OEWIM Drive Fed with Separate DC Sources (Modulating Signal, Pole Voltage, Phase Voltage and Common Mode Voltage) at M=0.8.

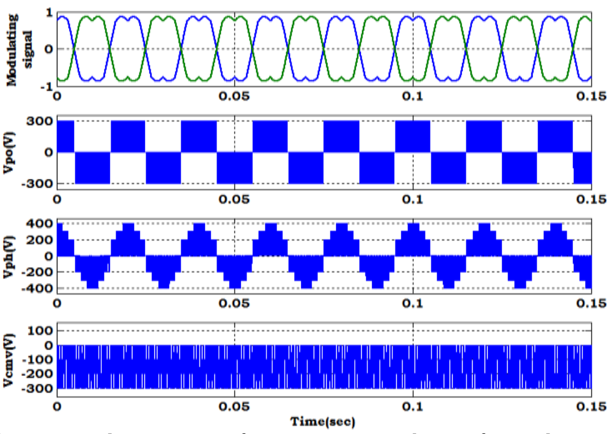


Fig. 10: Simulation Traces of Centric PWM Technique for Dual Inverter Fed OEWIM Drive Fed with Single DC Source (Modulating Signal, Pole Voltage, Phase Voltage and Common Mode Voltage) at M=0.8.

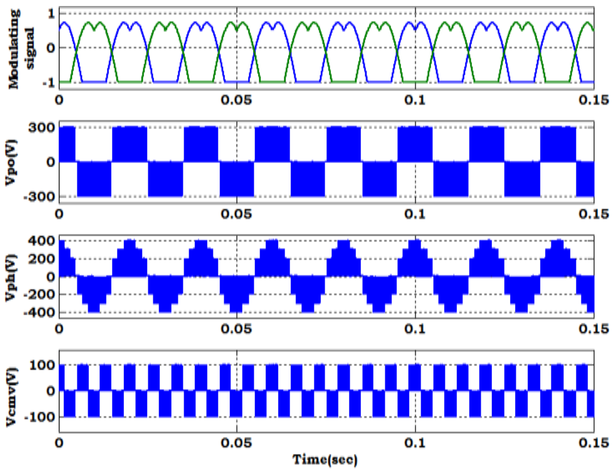


Fig. 11: Simulation Traces of NCPWM MIN Technique for Dual Inverter Fed OEWIM Drive Fed with Separate DC Sources (Modulating Signal, Pole Voltage, Phase Voltage And Common Mode Voltage) at M=0.8.

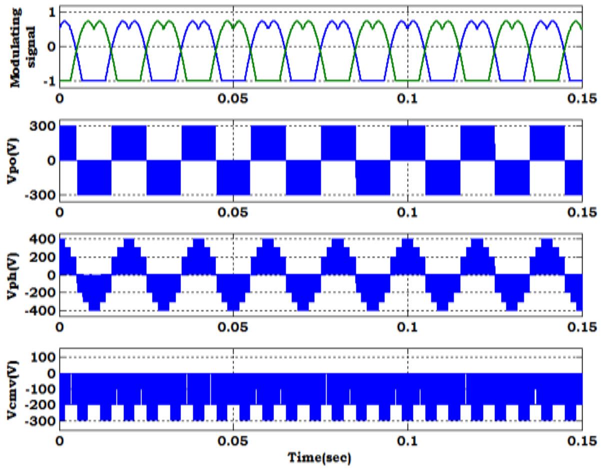


Fig. 12: Simulation Traces of NCPWM MIN Technique for Dual Inverter Fed OEWIM Drive Fed with Single DC Source (Modulating Signal, Pole Voltage, Phase Voltage and Common Mode Voltage) at M=0.8.

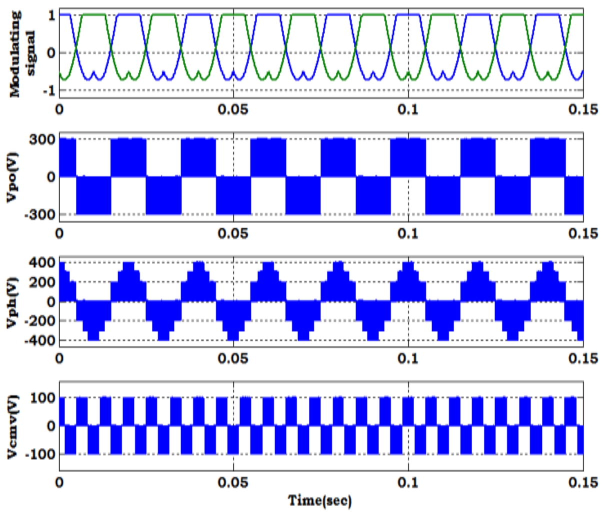


Fig. 13: Simulation Traces of NCPWM MAX Technique for Dual Inverter Fed OEWIM Drive Fed with Separate DC Sources (Modulating Signal, Pole Voltage, Phase Voltage and Common Mode Voltage) at M=0.8.

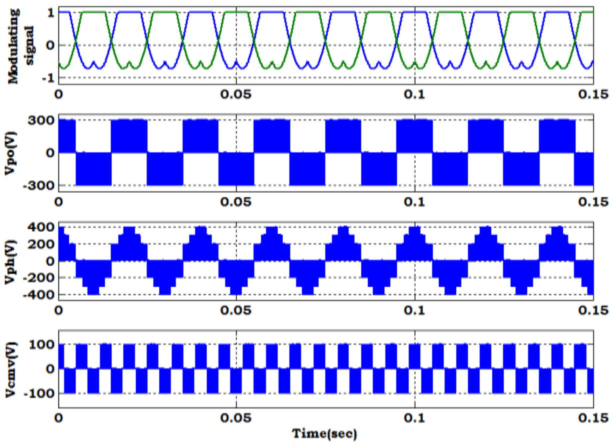


Fig. 14: Simulation Traces of NCPWM MAX Technique for Dual Inverter Fed OEWIM Drive Fed with Single DC Source (Modulating Signal, Pole Voltage, Phase Voltage and Common Mode Voltage) at M=0.8.

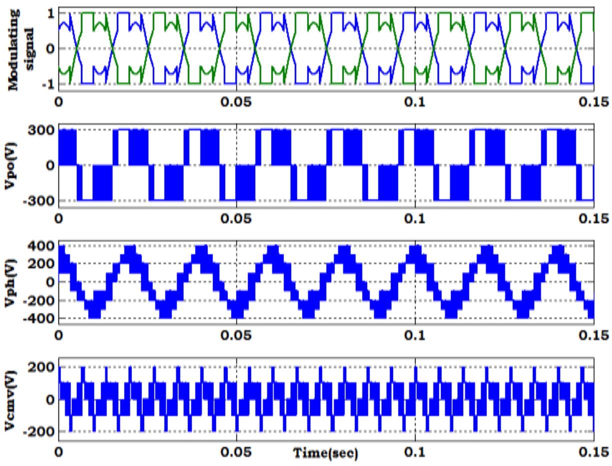


Fig. 15: Simulation Traces of NCPWM 0 Technique for Dual Inverter Fed OEWIM Drive Fed with Separate DC Sources (Modulating Signal, Pole Voltage, Phase Voltage and Common Mode Voltage) at M=0.8.

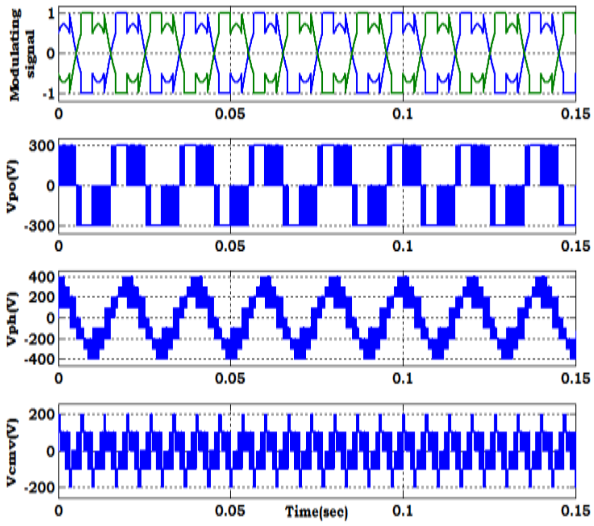


Fig. 16: Simulation Traces of NCPWM 0 Technique for Dual Inverter Fed OEWIM Drive Fed with Single DC Source (Modulating Signal, Pole Voltage, Phase Voltage and Common Mode Voltage) at M=0.8

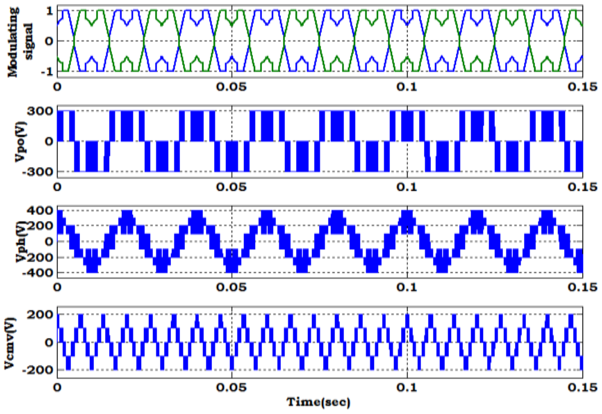


Fig. 17: Simulation Traces of NCPWM 1 Technique for Dual Inverter Fed OEWIM Drive Fed with Separate DC Sources (Modulating Signal, Pole Voltage, Phase Voltage and Common Mode Voltage) at M=0.8.

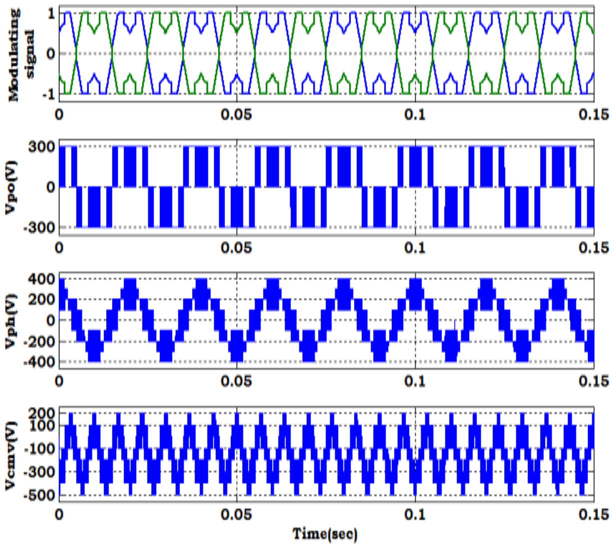


Fig. 18: Simulation Traces of NCPWM 1 Technique for Dual Inverter Fed OEWIM Drive Fed with Single DC Source (Modulating Signal, Pole Voltage, Phase Voltage and Common Mode Voltage) at M=0.8.

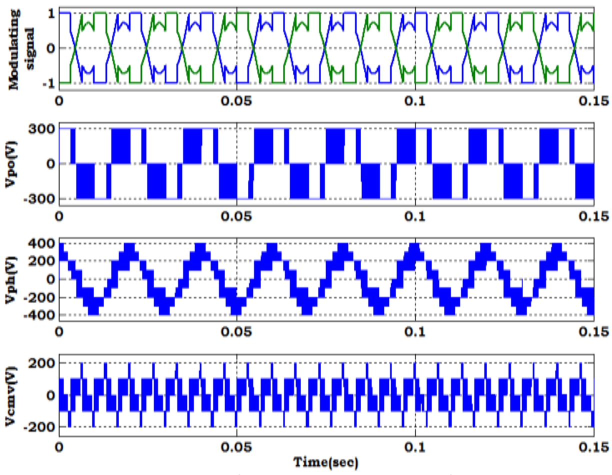


Fig. 19: Simulation Traces of NCPWM 2 Technique for Dual Inverter Fed OEWIM Drive Fed with Separate DC Sources (Modulating Signal, Pole Voltage, Phase Voltage and Common Mode Voltage) at M=0.8.

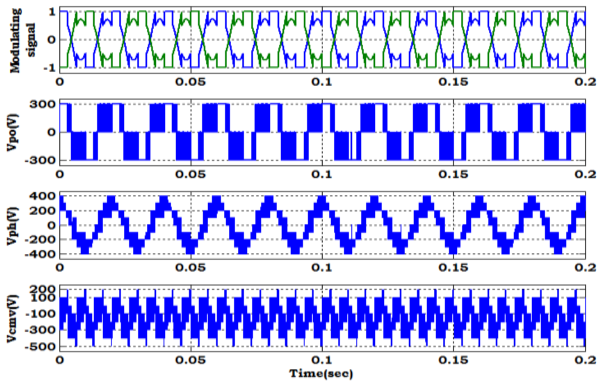


Fig. 20: Simulation Traces of NCPWM 2 Technique for Dual Inverter Fed OEWIM Drive Fed with Single DC Source (Modulating Signal, Pole Voltage, Phase Voltage And Common Mode Voltage) at M=0.8.

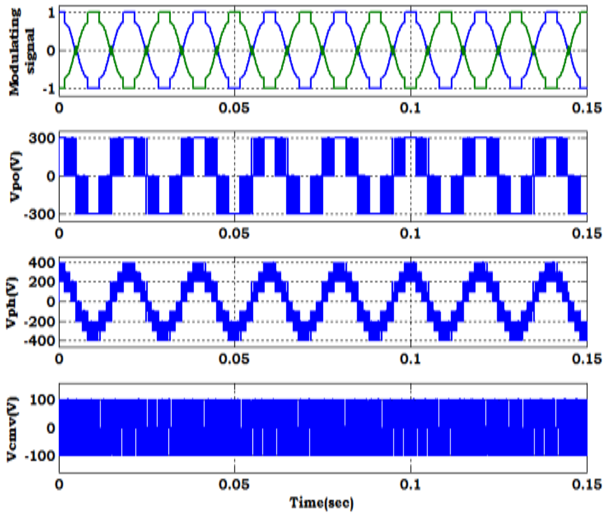


Fig. 21: Simulation Traces of NCPWM 3 Technique for Dual Inverter Fed OEWIM Drive Fed with Separate DC Sources (Modulating Signal, Pole Voltage, Phase Voltage and Common Mode Voltage) at M=0.8.

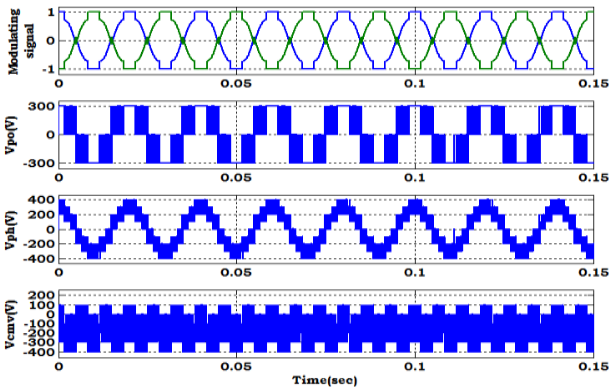


Fig. 22: Simulation Traces of NCPWM 3 Technique for Dual Inverter Fed OEWIM Drive Fed with Single DC Source (Modulating Signal, Pole Voltage, Phase Voltage and Common Mode Voltage) at M=0.8.

Table 2: Comparison of THD for Different PWM Techniques

S. No	PWM techniques	For Dual Inverter fed OEWIM with single DC source %THD at M=0.8		For Dual Inverter fed OEWIM with separate DC sources %THD at M=0.8	
		Phase voltage	Stator current	Phase voltage	Stator current
1	CPWM	38.18	4.53	38.81	7.89
2	NCPWM MIN	36	5.25	36.92	9.03
3	NCPWM MAX	35.6	5.67	36.62	7.75
4	NCPWM 0	24	3.96	25.83	4.44
6	NCPWM 2	24.85	3.87	26.34	4.51
7	NCPWM1	29.15	3.94	30.10	5.12
7	NCPWM3	17.88	3.72	20.32	4.03

5. Conclusion

The proposed Space Vector PWM Technique generates a wide range of Non-Centric PWM Techniques along with the Centric PWM Technique by using the instantaneous phase voltages. In the proposed discontinuous or Non-Centric PWM Techniques each phase is clamped to either positive or negative DC bus for at most 120 degrees in every fundamental cycle and hence reduce the switching loss by 33.33%. From the comparison tables of THD at different modulation indices, for both configurations of dual inverter fed open end winding induction motor fed with single DC source and separate DC sources we observe that out of all the Non-Centric PWM techniques, NCPWM3 gives superior performance over remaining PWM techniques.

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