GENERALIZED SCALAR APPROACH FOR THE GENERATION OF REDUCED COMMON MODE VOLTAGE PWM ALGORITHMS FOR INDIRECT VECTOR CONTROLLED INDUCTION MOTOR DRIVE

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Abstract - This paper presents a simple generalized scalar approach based reduced common mode voltage pulsewidth modulation (RCMV-PWM) techniques for indirect vector controlled induction motor drive. The classical space vector PWM (SVPWM) algorithm gives superior waveform quality. But, the complexity is more due to several calculations and also it gives large common mode voltage (CMV) variations due to the usage of zero states. Hence, to reduce the complexity and CMV, a simple scalar approach is presented for the generation of various RCMV-PWM techniques such active zero state PWM (AZSPWM) and near state PWM (NSPWM) techniques. In the proposed scalar approach, the modulating signals for the RCMV-PWM techniques are derived by adding a suitable zero sequence signal to the phase voltages. Then, based on the region (sector), suitable triangular wave (positive or negative) is selected for the comparison with modulating signal. The intersecting points will give the pulse pattern for the proposed RCMV-PWM techniques. The RCMV-PWM techniques did not use the zero states, which results in the reduction of CMV variations. With the proposed RCMV-PWM techniques the CMV will be reduced from $V_{dc}/2$ to $V_{dc}/6$ when compared with the SVPWM technique.
The proposed RCMV -PWM techniques have been verified by conducting simulation tests and results are presented and compared.

Keywords - AZSPWM, common mode voltage, NSPWM, SVPWM, vector control.

I. INTRODUCTION

The induction motors are propagating in many industrial and process applications and kenned as backbone of the industry due to their rugged and simple construction. But, the scalar control predicated induction motor drive gives lethargic response due to the coupling effect between air-gap flux and torque [1]. To overcome this problem, in 1970s F. Blaschke has proposed field oriented control (FOC) or vector control, which controls the induction motor similar to that of a separately excited dc motor [2]. This brought an incipient revolution in the field of high-performance drive applications. Cautiously, more changes were brought for the further development in the performance of vector controlled drive as explained in [1, 3-4].

The classical vector control uses the hysteresis based current controllers for the generation of gating pulses for the inverter. This results in variable switching frequency operation and increased harmonic distortion in the line current. This can be overcome by using PWM techniques for the inverters, which will give constant switching frequency operation. By selecting a suitable PWM technique, the performance will be improved. The performance characteristics of different PWM techniques are analyzed in detailed in [5] and concluded that the SVPWM technique will give good waveform quality. In the SVPWM technique, the switching times of the inverter devices are calculated by using active and zero states [6]. Due to the several calculations, the complication involved is more. A novel voltage modulation based on the concept of effective time is proposed in [7-9] to generate various PWM techniques such as SVPWM and discontinuous PWM (DPWM) techniques. Various simplified approaches are discussed in detailed in [10] for the generation of SVPWM and DPWM techniques. Though, the SVPWM and DPWM techniques result in good waveform quality, these results in increased CMV variations due to the usage of zero states.

The increment in the CMV leads to the flow of common mode current (CMC), which results in bearing failure as explained in [11]. The detailed study on the effects of CMV and CMC is explained in [11-26]. The CMV can be decreased by using the active filters [15] or passive filters [12-14]. But, the usage of filters increases the cost and complexity of the additional hardware. Hence, many researchers are aimed at the development of various PWM techniques for the VSI [16-26]. These PWM techniques can be classified as AZSPWM, NSPWM and remote state PWM (RSPWM) techniques as explained in [23]. But, the classical space vector approach based PWM techniques involved in more complexity due to the various calculations [16-23]. To reduce the complexity of the PWM techniques, a simple scalar approach has proposed in [24-26] by using the voltage magnitudes test.

This paper presents a simple generalized scalar approach for the vector controlled drives. In the proposed approach, by varying a constant in unique

expression of the zero sequence signal, AZSPWM and NSPWM modulating signals are derived. Then, by comparing the modulating signals with the suitable triangular signals, the pulse patterns for the various techniques are derived.

II. PROPOSED AZSPWM ALGORITHMS

A. Principle of Triangular Comparison Approach

The principle of scalar approach based PWM techniques is
volt-time balance per carrier cycle. Based on this principle, the reference voltage is generated in each carrier cycle. In the scalar approach based sinusoidal PWM (SPWM) technique, the sinusoidal modulating signals are compared with the triangular waves and intersecting points determine the pulse pattern for the inverter. Usually, the 3-phase inverter fed drives have isolated neutral points. The voltage between the neutral point of the load and mid-point of the dc bus is known as CMV as shown in Fig. 1. When, the load has a isolated neutral, the zero sequence voltage may be freely varied.

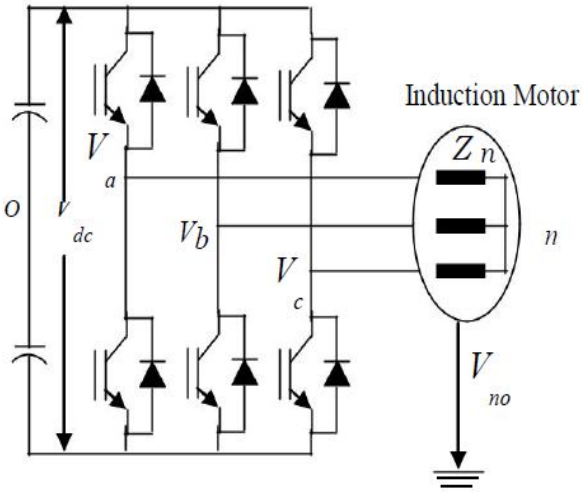


Fig. 1 Two-level inverter fed induction motor drive

Hence, by adding a suitable zero sequence voltage, the position of the pulses can be changed. This does not affect the average value of the line voltage. But, due to the change in the pulse position the harmonic properties and switching frequency characteristics will be affected. Based on the suitable zero sequence voltage, the SVPWM and DPWM algorithms can be derived.

B. Proposed Scalar Appraoch

In the proposed generalized scalar approach, by adding a suitable zero sequence signal the modulating waves of AZSPWM and NSPWM techniques are derived. Assume a set of reference phase voltages as

$$V_{in} = V_{ref} \cos(\theta - 2(r-1)\pi/3) \quad \text{for } i = a, b, c \text{ and } r = 1,2,3 \tag{1}$$

Based on the voltage magnitude tests, a unique zero sequence signal (V_{zs}) is calculated as given in (2).

$$V_{zs} = \frac{V_{dc}}{2}(2k_o - 1) - k_o V_{max} + (k_o - 1)V_{min} \tag{2}$$

Here the V_{max} and V_{min} are maximum and minimum values of V_{in} . By adding this zero sequence signal to the V_{in} , the modulating waves (V_{in}^*) are derived as given in (3).

$$V_{in}^* = V_{in} + V_{zs} \tag{3}$$

In V_{zs} by varying the constant k_o value between 0 and 1, the modulating signals for various PWM techniques such as SVPWM, AZSPWM, NSPWM and DPWM algorithms can be derived. But, this paper focuses on AZSPWM and NSPWM techniques only. The modulating signals of AZSPWM and NSPWM are similar to SVPWM and DPWM1 techniques respectively, and these can be derived as given in Table. 1.

TABLE.1 GENERATION OF SVPWM AND NSPWM MODULATING SIGNALS BY VARYING k_o VALUE S

PWM algorithm	value of k_o
SVPWM	0.5
DPWM1	if $V_{max} \square V_{min,} \square 0 \square k_o \square 0$ if $V_{max} \square V_{min} \square 0 \square k_o \square 1$

Usually, in the scalar approach, the three-phase modulating signals are compared with a common triangular signal to generate the pulse pattern. But, to generate the pulse pattern of AZSPWM algorithms, two triangular signals (V_{tri} and $-V_{tri}$) which are in phase opposition are required. By changing the polarity of the triangular waves different AZSPWM algorithms such as AZSPWM1, AZSPWM2 and AZSPWM3 can be generated. In order to change the triangular polarities based on the region, the following procedure is used:

Assume three sets of 3-phase voltages as test signals, which are given in (4)-(6). For the selection of triangular waves for AZSPWM1, AZSPWM2 and AZSPWM3 techniques, the test signals are selected as in (4), (5) and (6) respectively.

$$V_{ix} = V_{ref} \cos(\theta - 2(r-1)\pi/3) \quad \text{for } i = a, b, c \text{ and } r = 1,2,3 \tag{4}$$

$$V_{iy} = V_{ref} \cos(\theta - 2(r-1)\pi/3 + 2\pi/3) \quad \text{for } i = a, b, c \text{ and } r = 1,2,3 \tag{5}$$

$$V_{iz} = V_{ref} \cos(\theta - 2(r-1)\pi/3 - 2\pi/3) \quad \text{for } i = a, b, c \text{ and } r = 1,2,3 \tag{6}$$

In AZSPWM and NSPWM techniques, the division of the regions is as shown in Fig. 2. Based on the

region, the polarity of the carrier signals is changed. For all AZSPWM algorithms, if the slope of the corresponding test signal is positive then the corresponding modulating signal of that phase will be compared with the $+V_{tri}$. If the slope of the test signal is negative then the modulating signal of that phase will be compared with the $-V_{tri}$. Similarly, based on the voltage magnitude tests, the triangular signals will be selected for different regions as explained in [24]. The selection of triangular signals for different regions is given in Table. 2. The proposed scalar approach is as shown in Fig. 3.

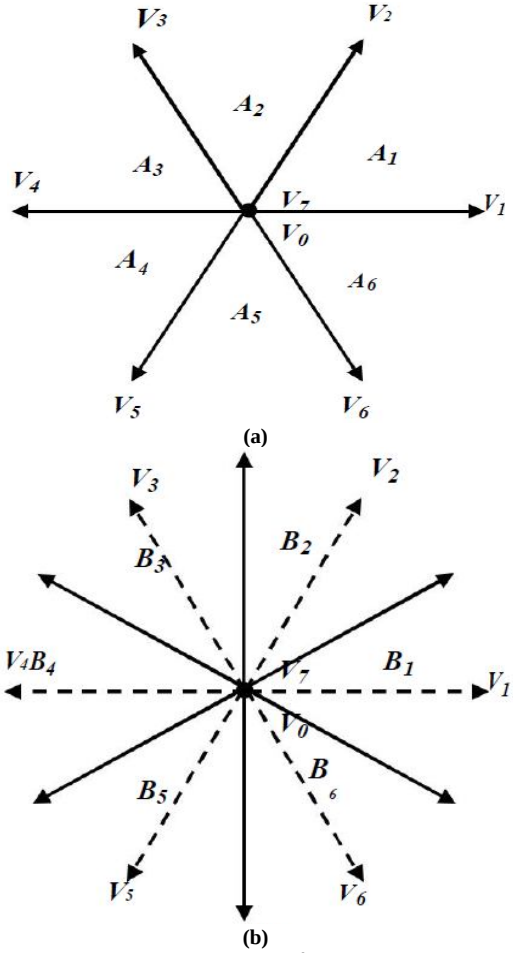


Fig. 2 Voltage space vectors and 60° sector definitions for (a) AZSPWM techniques (b) NSPWM technique

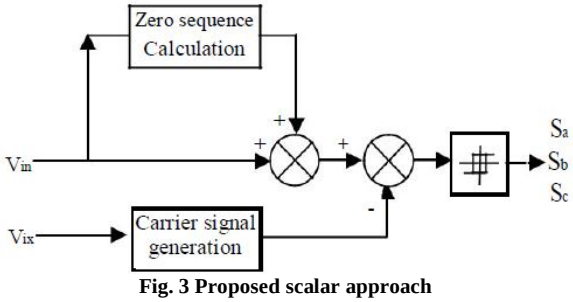


Fig. 3 Proposed scalar approach

The modulating signals, carrier signals and corresponding pole voltage and CMV for SVPWM and proposed AZSPWM and NSPWM algorithms are shown in Fig. 4 - Fig. 8. From these, it can be observed that the proposed RCMV-PWM algorithms did not use the zero states. The CMV can be defined as voltage of neutral point of the load with respect to the midpoint of the dc bus as shown in Fig. 1. This can be represented as given in (7).

$$V_{no} = V_{com} = \frac{V_{ao} + V_{bo} + V_{co}}{3} \quad (7)$$

As per (7), the CMV of SVPWM may take a value of $\pm V_{dc}/2$ due to the usage of zero states. But, the RCMV-

PWM algorithms may take a value of $\pm V_{dc}/6$. Thus, by using the RCMV-PWM algorithms the CMV variations and hence CMC can be reduced.

ASPWM1						
Phase	A1	A2	A3	A4	A5	A6
A	$-V_{tri}$	$-V_{tri}$	$-V_{tri}$	$+V_{tri}$	$+V_{tri}$	$+V_{tri}$
B	$+V_{tri}$	$+V_{tri}$	$-V_{tri}$	$-V_{tri}$	$-V_{tri}$	$+V_{tri}$
C	$-V_{tri}$	$+V_{tri}$	$+V_{tri}$	$+V_{tri}$	$-V_{tri}$	$-V_{tri}$
ASPWM2						
A	$-V_{tri}$	$+V_{tri}$	$+V_{tri}$	$+V_{tri}$	$-V_{tri}$	$-V_{tri}$
B	$-V_{tri}$	$-V_{tri}$	$-V_{tri}$	$+V_{tri}$	$+V_{tri}$	$+V_{tri}$
C	$+V_{tri}$	$+V_{tri}$	$-V_{tri}$	$-V_{tri}$	$-V_{tri}$	$+V_{tri}$
ASPWM3						
A	$+V_{tri}$	$+V_{tri}$	$-V_{tri}$	$-V_{tri}$	$-V_{tri}$	$+V_{tri}$
B	$-V_{tri}$	$+V_{tri}$	$+V_{tri}$	$+V_{tri}$	$-V_{tri}$	$-V_{tri}$
C	$-V_{tri}$	$-V_{tri}$	$-V_{tri}$	$+V_{tri}$	$+V_{tri}$	$+V_{tri}$
NSWM						
	B1	B2	B3	B4	B5	B6
A	$+V_{tri}$	$-V_{tri}$	$-V_{tri}$	$+V_{tri}$	$+V_{tri}$	$+V_{tri}$
B	$+V_{tri}$	$+V_{tri}$	$+V_{tri}$	$-V_{tri}$	$-V_{tri}$	$+V_{tri}$
C	$-V_{tri}$	$+V_{tri}$	$+V_{tri}$	$+V_{tri}$	$+V_{tri}$	$-V_{tri}$

Table.2 Selection Of Triangular Signals Based On The Regions For Azspwm And Nspwm Techniques

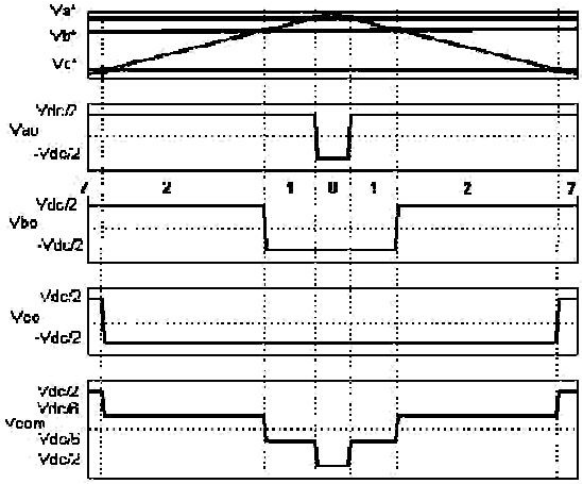


Fig. 4 Modulating and carrier signals for one PWM period and corresponding pole voltages and CMV for SVPWM technique

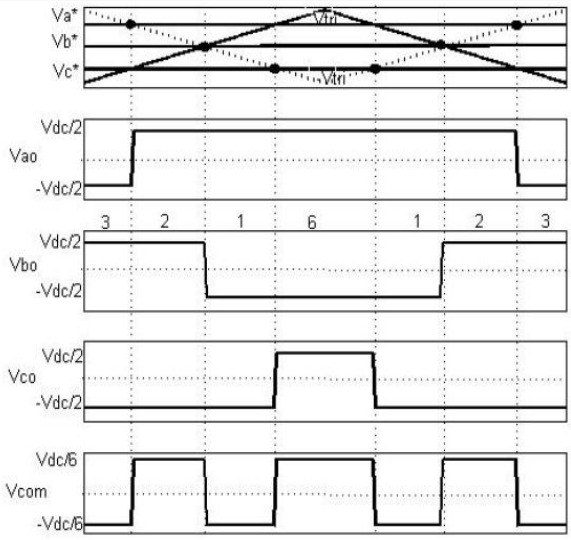


Fig. 5 Modulating and carrier signals for one PWM period and corresponding pole voltages and CMV for AZSPWM1 technique

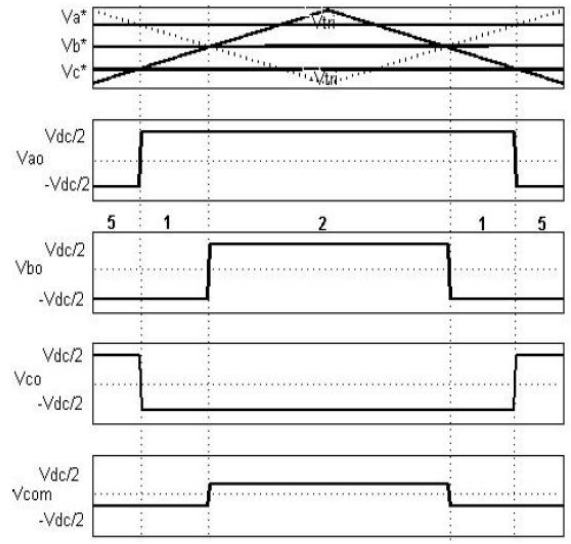


Fig. 6 Modulating and carrier signals for one PWM period and corresponding pole voltages and CMV for AZSPWM2 technique

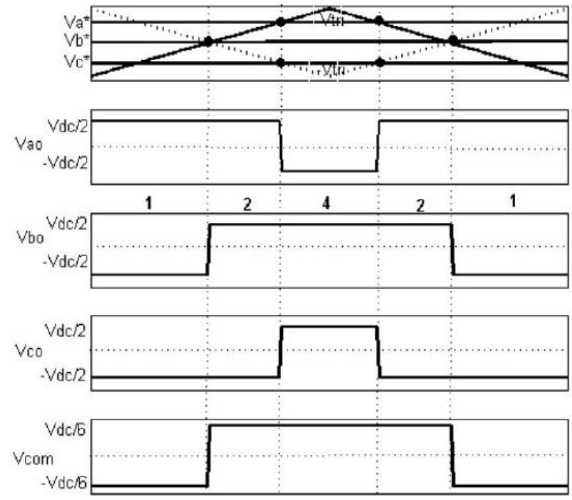


Fig. 7 Modulating and carrier signals for one PWM period and corresponding pole voltages and CMV for AZSPWM3 technique

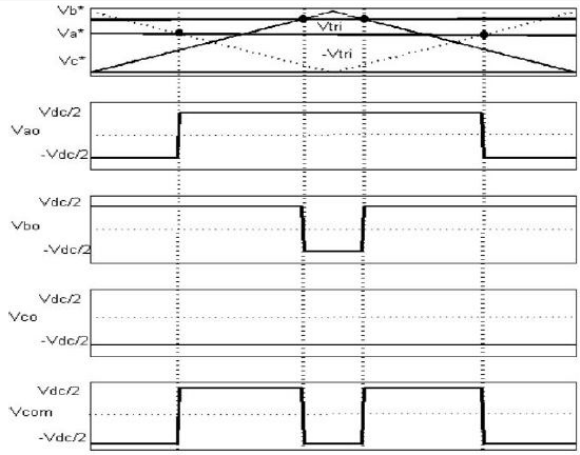


Fig. 8 Modulating and carrier signals for one PWM period and corresponding pole voltages and CMV for NSPWM technique

From Fig. 4 to Fig. 8, it can be observed that the number of commutations in each sampling time period is 3 for SVPWM and AZSPWM techniques. But, the number of commutations is 2 for NSPWM technique. Hence, in order to maintain constant average switching frequency, the switching frequency for SVPWM and AZSPWM techniques is taken as f_s and for NSPWM technique it is taken as $1.5f_s$.

III. PROPOSED AZSPWM ALGORITHMS BASED INDIRECR VECTOR CONTROLLED DRIVE

The induction motor can be operated as a separately excited dc motor with the help of vector control. Among the two popular vector control techniques, indirect vector control is popular in various industrial and process applications. In this technique the rotor position angle is calculated in a feed-forward manner. The block diagram of proposed AZSPWM algorithms based indirect vector controlled induction motor drive is as shown in Fig. 9.

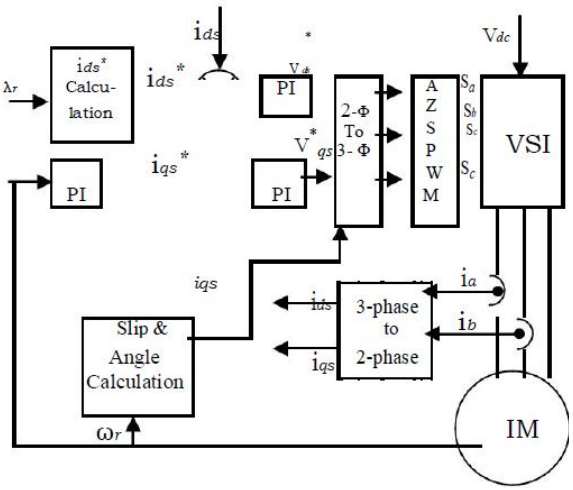


Fig. 9 Proposed AZSPWM algorithms based indirect vector controlled induction motor drive

By using the rotor flux and speed controller, the reference d-axis and q-axis current signals, which are

in synchronously rotating reference frame, are calculated. Then, these reference signals will be compared with the actual signals and error signals will feed to the PI controllers in order to calculate the voltage signals which are at synchronous speed. Then in 2-phase to 3-phase transformation block, these voltages are transferred to the stator reference frame by using the rotor flux position and then converted into three-phase voltages. By using these 3-phase voltages, the AZSPWM block will generate the switching pulses for the inverter as explained in the previous section.

IV. SIMULATION RESULTS AND DISCUSSION

To show the effectiveness of the proposed AZSPWM algorithms, the simulation studies have been carried out on indirect vector controlled induction motor drive. For the simulation studies, the switching frequency is taken as 5 kHz and the dc link voltage is taken as 540 V. The specifications of the induction motor, which is used in this case study, are as follows:

4 kW, 400V, 1470 rpm, 4-pole, 50 Hz, R_s=1.57Ω, R_r =1.21Ω, L_s=0.17H, L_r=0.17H, L_m =0.165 H and J = 0.089 Kg.m^2.

The steady state simulation results of SVPWM and proposed RCMV-PWM techniques based vector controlled induction motor drive are shown in from Fig. 10 to Fig. 19. From the simulation results of common mode voltage variations, it can be observed that the proposed RCMV-PWM algorithms give reduced CMV variations when compared with the SVPWM algorithm with slightly increased harmonic distortion in the line currents due to the opposite pulses in the line voltages.

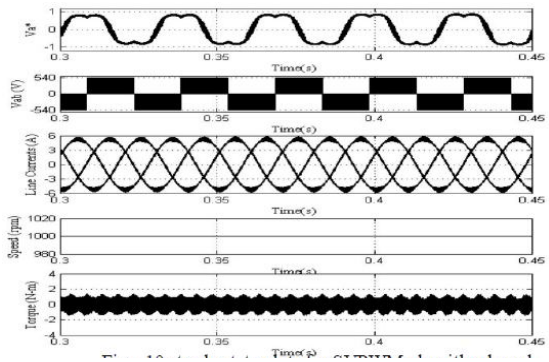


Fig. 10 steady state plots for SVPWM algorithm based vector controlled induction motor drive

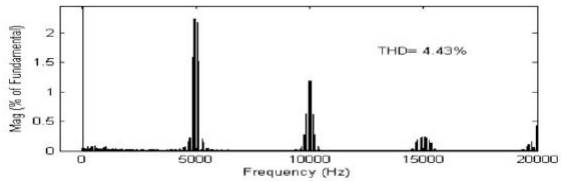


Fig. 11 Harmonic spectra of line current for SVPWM algorithm based vector controlled induction motor drive

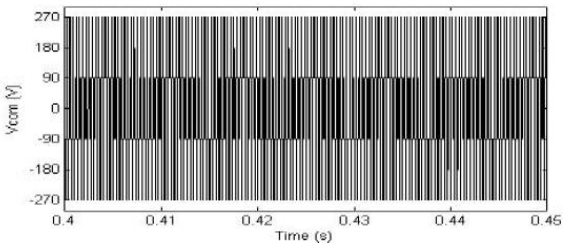


Fig. 12 Common mode voltage variations for SVPWM algorithm based vector controlled induction motor drive

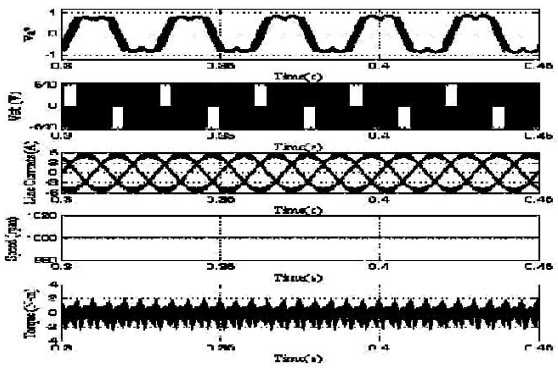


Fig. 13 steady state plots for AZSPWM1 algorithm based vector controlled induction motor drive

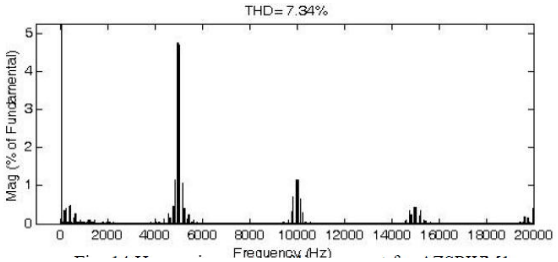


Fig. 14 Harmonic spectra of line current for AZSPWM1 algorithm based vector controlled induction motor drive

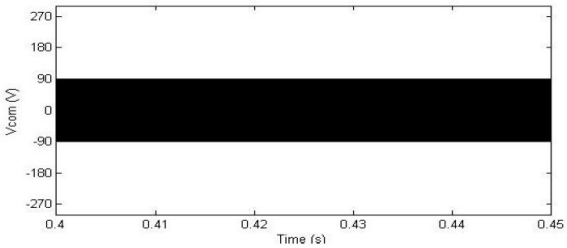


Fig. 15 Common mode voltage variations for AZSPWM1 algorithm based vector controlled induction motor drive

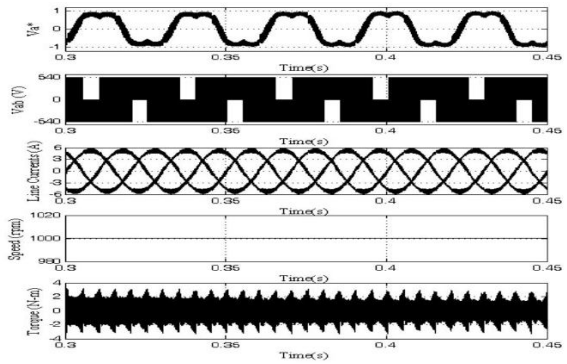


Fig. 16 steady state plots for AZSPWM2 algorithm based vector controlled induction motor drive

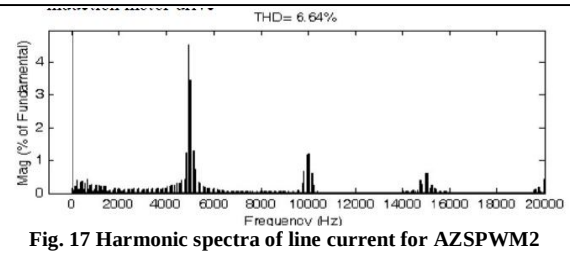


Fig. 17 Harmonic spectra of line current for AZSPWM2 algorithm based vector controlled induction motor drive

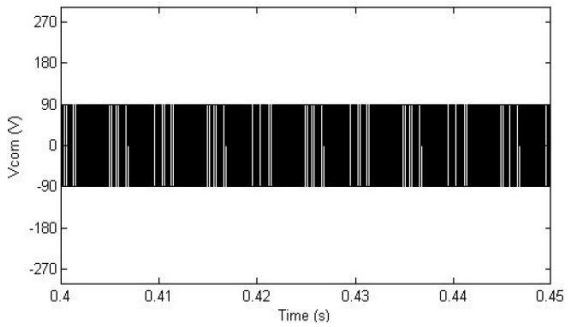


Fig. 18 Common mode voltage variations for AZSPWM2 algorithm based vector controlled induction motor drive

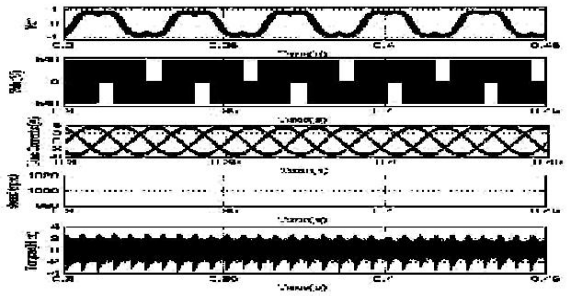


Fig.19 steady state plots for AZSPWM3 algorithm based vector controlled induction motor drive

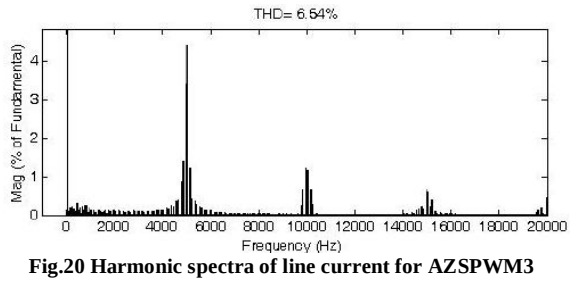


Fig.20 Harmonic spectra of line current for AZSPWM3 algorithm based vector controlled induction motor drive.

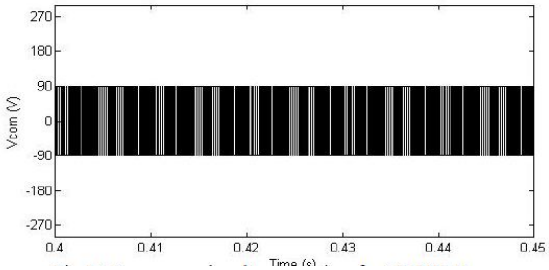


Fig. 21 Common mode voltage variations for AZSPWM3 algorithm based vector controlled induction motor drive

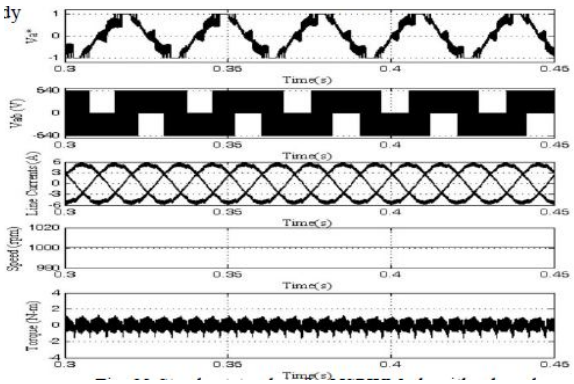


Fig. 22 Steady state plots for NSPWM algorithm based vector controlled induction motor drive

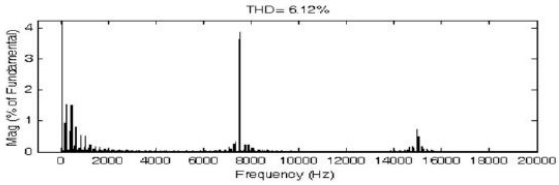


Fig. 23 Harmonic spectra of line current for NSPWM algorithm based vector controlled induction motor drive

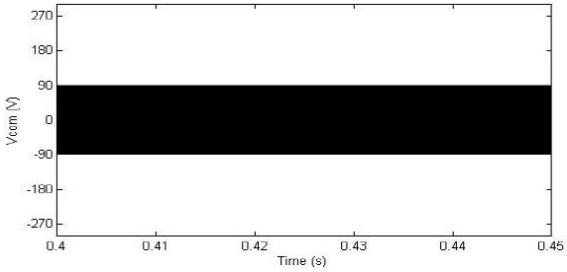


Fig. 24 Common mode voltage variations for NSPWM algorithm based vector controlled induction motor drive

CONCLUSIONS

The classical space vector approach based RCMV-PWM techniques need more calculations, which result in increased complexity. For reduced complications, a simple generalized scalar approach has been presented in this paper. To evaluate the performance of the proposed approach based PWM algorithms, simulation studies have been carried out and results were presented. From the results it can be observed that the SVPWM algorithm gives large common mode voltage variations between $\pm V_{dc}/2$. But, the proposed RCMV-PWM algorithms give reduced CMV variations between $\pm V_{dc}/6$. Moreover, it can be observed that the proposed RCMV-PWM algorithms give opposite pulses in the line to line voltages, which causes the increased harmonic distortion in the line current.

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