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DTC SVPWM: Advanced Techniques for Reduced Common Mode Voltage

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Abstract

This paper presents a new direct torque control (DTC)algorithm that is space vector pulse witch modulation(SVPWM) with imaginary switching states for induction machine drives capable of reducing the common –mode (Vcm)conducted emissions of the drive.It is based on the application of only odd or even voltage vectors in each sector in which the stator flux lies.In conventional SVPWM the reference vector is generated by time averaging the two near by active voltage vectors and two zero voltage vectors in every sample time (Ts).In new SVPWM the common mode emissions has been reduced and the complexity involved in calculating the Vref is decreased.

Keywords: *DTC ,SVPWM, Vcm.*

1.Introduction

Induction motors were widely used in industries due to its robustness ,low-cost and high reliability. Direct torque control(DTC)is an emerging technique for controlling the PWM inverter-fed induction motor drives when compared with vector controlled induction motor drives[1]. The basic concept of DTC is it controls both electromagnetic torque and flux of the machine simultaneously by the selection of optimum inverter switching states.DTC is simple robust to parameter variation,does not require any current regulator ,co-ordinate transformation and gives fast dynamic response compared to FOC[2-3].Inspite of its simplicity DTC has certain drawbacks such as steady state ripple and generation of high level common mode voltage variations.

II. Conventional SVPWM ALGORITHAM

Eight possible switching states and the corresponding voltage vectors produced by a three phase two-level voltage source inverter divide the space vector plane into six sectors as shown in the fig1.

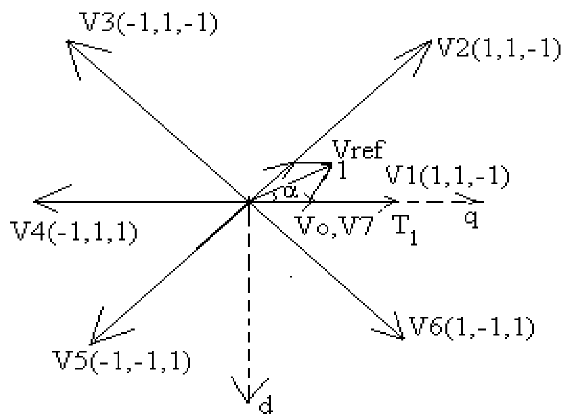


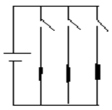
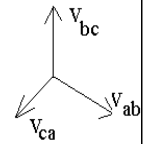
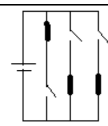
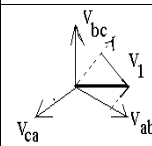
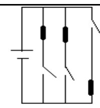
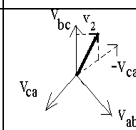
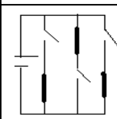
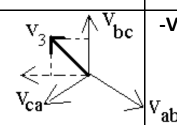
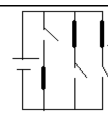
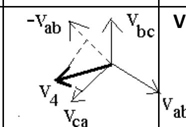
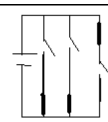
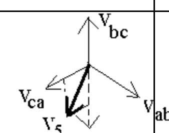
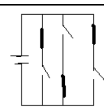
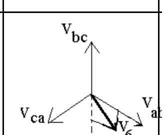
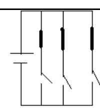
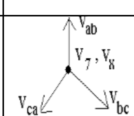
FIG1

Fig 1:VSI-space vector

In conventional SVPWM, the reference voltage space vector (Vref) is sampled in every sub cycle T_S in an average sense. Voltage vectors that can be used to generate any sample are the zero voltage vectors and the two active voltage vectors forming the boundary of the sector in which the sample lies. Given a sample V_{ref} at angle α in sector-1 as shown in fig1, two adjacent active voltage vectors V_1 and V_2 in combination with the two zero voltage vectors V_0 and V_7 must be applied for time durations T_1,T_2,and T_z respectively within the sampling time period T_s to generate a sample. Tow zero voltage vectors and two active voltage vectors forming the boundary of sector in which

$$T_1=3/\pi\, M \sin(60^\circ-\alpha)/\sin(60^\circ)*T_s$$
$$=3/\pi\, v_{ref}/v_{dc} \sin(60-^\circ\alpha)/\sin(60^\circ)\text{-------}(1)$$

Table1:VSI space vectorinformation

Voltage vectors	Switching states			v_a	v_b	v_c	v_{a0}	v_{b0}	v_{c0}	v_{ab}	v_{bc}	v_{ca}	v_{qs}	V_{ds}	Inverter switch connection	Vector	common mode voltage
	s_a	s_b	s_c														
V_0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			**$-V_{dc}/2$**
V_1	1	0	0	v_{dc}	0	0	$-v_{dc}/2$	$-v_{dc/2}$	$-v_{dc/2}$	v_{dc}	0	$-v_{dc}$	2/3 v_{dc}	0			**$-V_{dc}/6$**
V_2	1	1	0	v_{dc}	v_{dc}	0	$v_{dc/2}$	$v_{dc/2}$	$-v_{dc/2}$	0	v_{dc}	$-v_{dc}$	1/3 v_{dc}	$-v_{dc}/\sqrt{3}$			**$V_{dc}/6$**
V_3	0	1	0	0	v_{dc}	0	$-v_{dc/2}$	$v_{dc/2}$	$-v_{dc/2}$	$-v_{dc}$	v_{dc}	0	-1/3 v_{dc}	$-1/3v_{dc}$			**$-V_{dc}/6$**
V_4	0	1	1	0	v_{dc}	v_{dc}	$-v_{dc/2}$	$v_{dc/2}$	$v_{dc/2}$	$-v_{dc}$	0	v_{dc}	1/3 v_{dc}	$-2/3v_{dc}$			**$V_{dc}/6$**
V_5	0	0	1	0	0	v_{dc}	$-v_{dc/2}$	$-v_{dc/2}$	$v_{dc/2}$	0	$-v_{dc}$	v_{dc}	2/3 v_{dc}	$-1/3v_{dc}$			**$-V_{dc}/6$**
V_6	1	0	1	v_{dc}	0	v_{dc}	$v_{dc/2}$	$-v_{dc/2}$	$v_{dc/2}$	v_{dc}	$-v_{dc}$	0	1/3 v_{dc}	$1/3v_{dc}$			**$V_{dc}/6$**
V_7	1	1	1	v_{dc}	v_{dc}	v_{dc}	$v_{dc/2}$	$v_{dc/2}$	$-v_{dc/2}$	0	0	0	0	0			**$V_{dc}/2$**

T_2***=3/π M sin (α)/sin (60°)****T_s

=3/π v_{ref}/v_{dc} ***sinα/sin60**** T_s***------------(2)***

M=modulation index

M=π $V_{ref}/2*V_{dc}$***------(3)***

M=modulation index

M=π $V_{ref}/2*V_{dc}$

$T_Z=T_s-(T_1+T_2)=T_S=T_Z+T_1+T_2$***-------(4)***

T_z is divided usually among the two zero voltage vectors.V_7 is applied at the and of sampling time a here as the V_o is applied at the beginning of sampling time V_1V_7.

II.1.Common mode voltage

As per the switching states of the inverter the common mode voltage[3] Vcm is given by

Vcm=(Va0+Vb0+Vc0)/3--------------(5)

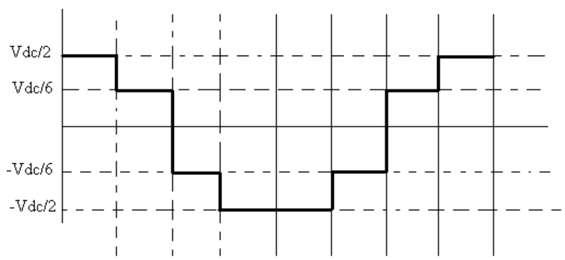


Fig2 :Common mode vltage-CSVPWM

The common mode voltage,pole voltages,switching diagrams and vector information is tabulated in Table 1.

III. Software Implementation of SVPWM

Space vector PWM can be implemented by the following steps:

step1: Determine V_d, Vq, Vref and angle (α)

step2: Determine the time duration T1, T2, and T0

step3: Determine the switching time of each transistor (S_1 to S_6)

III .I .Step 1.Determine Vd, Vq, Vref and angle (α)

From figure 3 V_d, Vq, Vref and angle (α) can be determined as follows.

$V_d = V_{an}-V_{bn}.\cos60-V_{cn}\cos30$

$= V_{an}-1/2\ V_{bn}-1/2V_{cn}$

$V_q = 0+V_{bn}\cos30-V_{cn}\cos30$

$=V_{an}+\sqrt{3}/2\cos30-\sqrt{3}/2\cos30$

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = 2/3 \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3/2} & -\sqrt{3/2} \end{bmatrix} \begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix}$$

-----(6)

$$\left| V_{ref} \right| = \sqrt{V_d^2 + V_q^2}$$

--------------(7)

$\alpha=\tan^{-1}(v_d/v_q) = wt = 2\pi ft$, where f=fundamental frequency

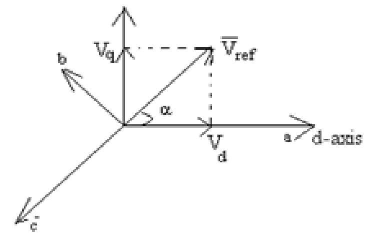


Fig 3:voltage space vector and its components in (d,q)

III.II.Step2: Determine the time duration T1, T2, and T0 From fig(4) the switching time duration can be calculated as follows;

Switching time at sector-1

T_1***=3/π*M* sin (60°-α)/sin (60°)****T_s ***-------(8)***

T_2***=3/π *M sin (α)/sin (60°)****T_s ***-----------(9)***

M=modulation index

M=π $V_{ref}/2*V_{dc}$

To keep the switching frequency constant, the remainder of the time is spent on the zero states, that is

$T_Z=T_s-(T_1+T_2)$***---------------(10)***

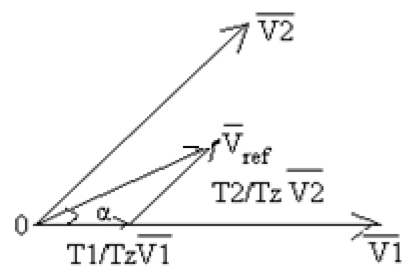


Fig4: Reference vector as a combination of adjacent vectors at sector-1

IV. Proposed PWM ALGORITHAMS

As the conventional SVPWM uses zero voltage vectors to compose the reference voltage vector common mode voltage is very high. It can be observed that the switching times T_1,T_2 depends upon the angle.

So to eliminate the complexity involved in reference voltage vector position dependency in conventional SVPWM algorithm and also to mitigate common mode voltage variations active zero state PWM techniques using the concept of imaginary switching times are proposed and applied to DTC fed induction motor drive. In the proposed PWM algorithm for the reduction of common mode voltage instead of using zero voltages vectors,two active opposite voltage vectors with equal time duration are utilized for composing the reference voltage vector by using the concept of imaginary switching times. In the proposed method switching times can be obtained as follows:

by the d-q transformation theory,the transformation from tw-phase voltages to three phase voltages can be obtained from the stationary frame reference voltages as given

$$\begin{bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -1/2 & -\sqrt{3}/2 \\ 1/2 & \sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_q \\ V_d \end{bmatrix} \text{------(11)}$$

If suppose the reference voltage vector lies in first sector .Then the actual switching times can be deduced as given in (8) and (9)

it is observed that

V_q=V_{ref}*cos α*, V_d=-V_{ref}*sinα* -------*(12)*

Hence the actual switching times in first sector can be obtained by substituting (12) in (8) and (9)

T_1=T_{as}-t_{bs},-------------------------(13)

T_2=T_{bs}-T_{cs}-------------------------(14)

The instantaneous phase voltages can be expressed in terms of imaginary switching times as

T_{as}=(V_{as}/V_{dc}) T_s ,--------(15)

T_{bs}=(V_{bs}/V_{dc}) T_s ---------(16)

T_{cs}=(V_{cs}/V_{dc})T_s ---------(17)

Where $T_s$is the sampling period

V.SVPWM-Advanced Techniques

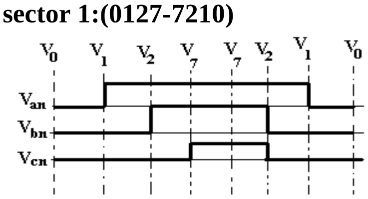
V.I.AZPWM 1 &2:

In this method the classical active (adjacent) voltage vectorsare complementedwith either two near opposing active vectors[3-5]The switching states and vector representation are shown in figure 6and 7.

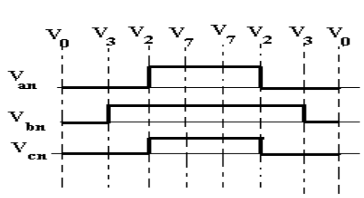
V.II.AZPWM 3 &4:

One of adjacent states and its opposite vector with equal time to effectively create voltage vectors. The switching states and vector representation are shown in figure 8 and 9.

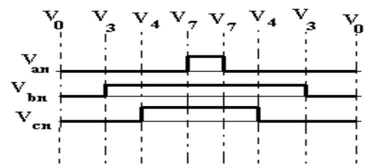
sector 1:(0127-7210)



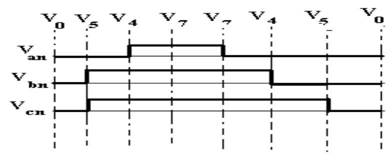
sector 2:(0327-7230)



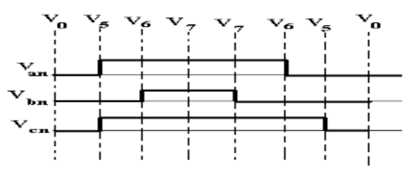
sector 3:(0347-7430)



sector 4:(0547-7450)



sector 5:(0567-7650)



sector 6:(0167-7610)

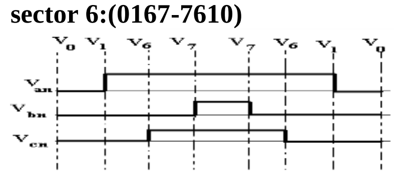
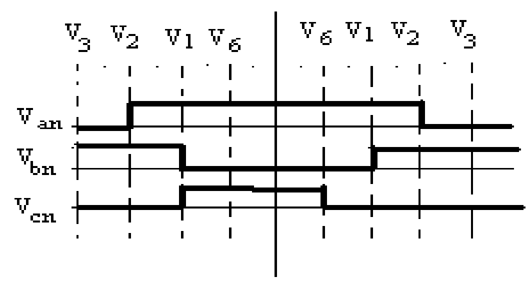


Fig 5: PWM wave forms and switching pattern of CSPWM

AZPWM1: SECTOR1(3216-6123)



SECTOR2(4321-1234):

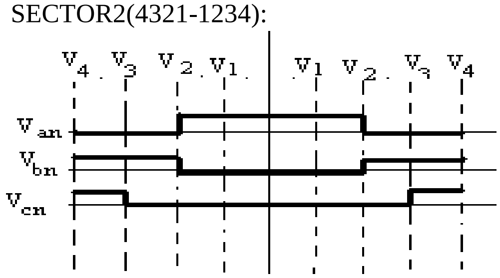


Fig6:Switching pattern of AZPWM1

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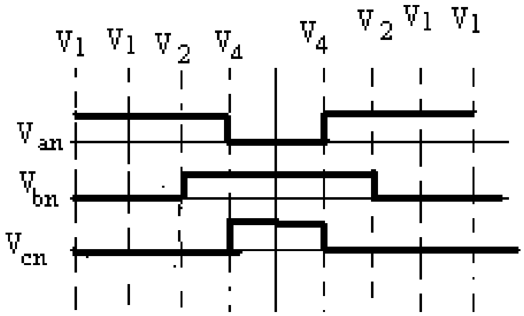
AZPWM2: SECTOR1(1124-4211)



SECTOR2(2235-5322)

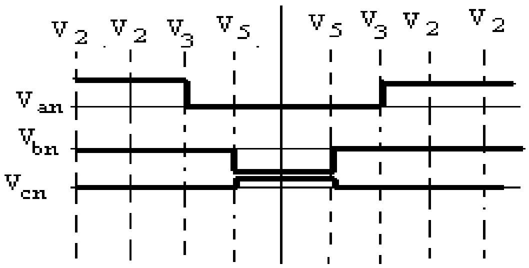
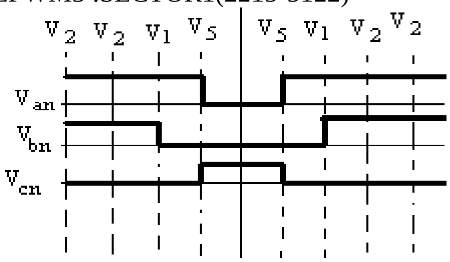


Fig7: Switching pattern of AZPWM2

AZPWM3 :SECTOR1(2215-5122)



SECTOR2(3326-6233)

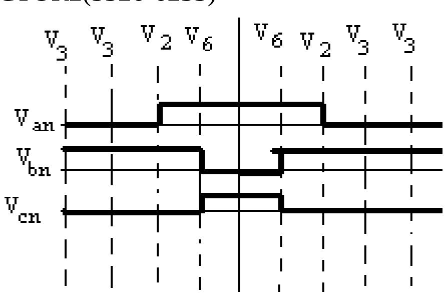
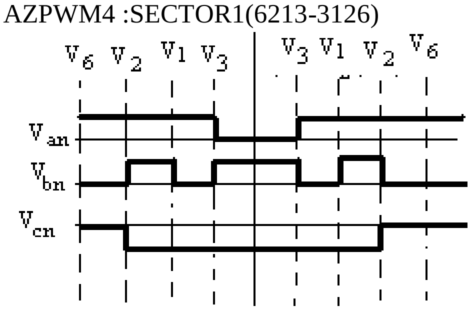


Fig8: Switching pattern of AZPWM3

AZPWM4 :SECTOR1(6213-3126)



SECTOR 2(1324-4321)

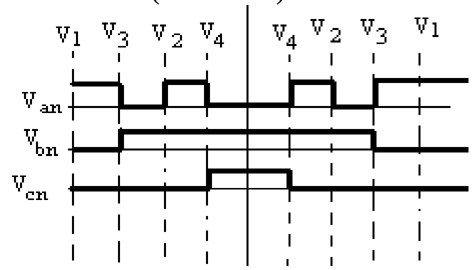


Fig9: Switching pattern of AZPWM4

The block diagram for proposed PWM algorithams based DTC is shown below fig(10)**:**in the proposed method induction motor torque is controlled by controlling the inverter pole voltages byselecting appropriate switching states

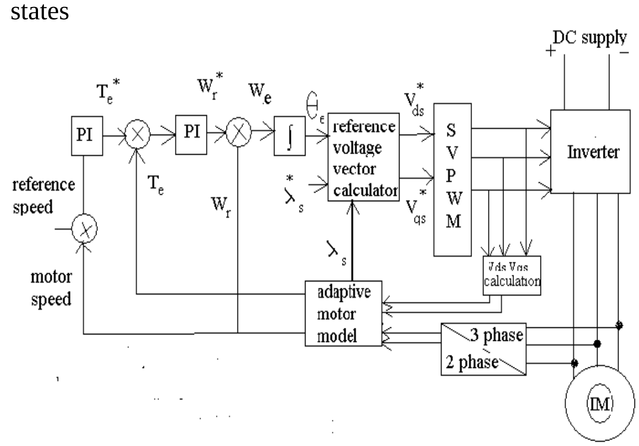


Fig10:Block diagram of proposed PWM –DTC Algorithm

VI: Simulation Results

To validate the proposed PWM Algorithm, numerical simulation studies has been carried out by using MATLAB/SIMULINK.Here the results of DTC,DTC-SVM and SVPWM techniques have been posted for the following specifications of 3-phase,400V ,inductor motor drive.

```
Rr=1.9;
Rs=1.635;
Lls=0.086;
Llr=0.086;
lm=0.243;
```

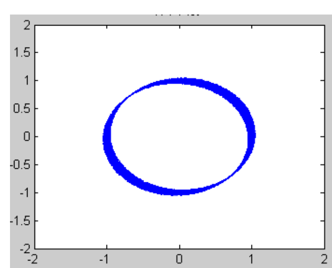


Fig11:Stator flux of DTC

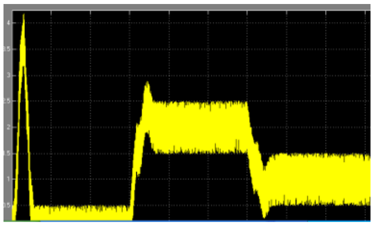


Fig12:Electromagnetic torque-DTC

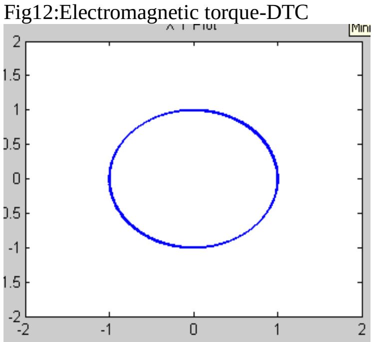


Fig13:Stator flux of DTC-SVM

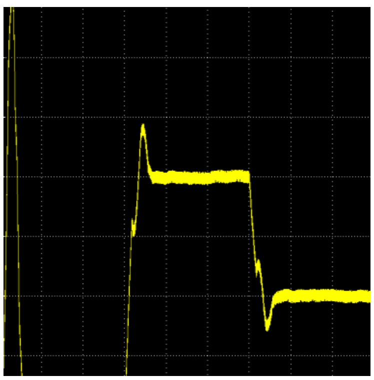


Fig14:Electromagnetic torque-DTC-SVM

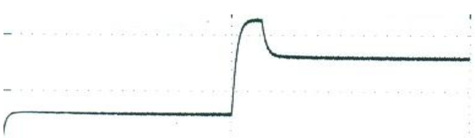


Fig15:electromagnetic torque of a svpwm induction motor

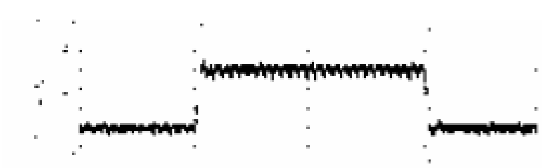


Fig 16: **electromagnetic torque of a svpwm induction motor with imaginary switching states**

VII.**CONCLUSIONS**

This paper reviewed the DTC SVPWM algorithm and new DTCSVPWM algorithm using imaginary switching states to reduce common mode voltage variations. Though the conventional DTC algorithm is simple and gives fast torque response it has high common mode voltage variations. To reduce the common mode voltage variations a simple space vector based PWM algorithms are proposed to DTC algorithm. In this proposed PWM algorithm only active voltage vectors (V1 to V6) are used to calculate the V_{ref} in each sector and zero voltage vectors(V0,V7) are eliminated, with this the common mode emissions are reduced and these variations are very less in the proposed algorithm.

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