# Field Oriented Control for Induction Motor Using Four Switch Three Phases Inverter


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### Abstract

This paper presents a space vector pulse width modulation (SVPWM) technique for four-switch three-phase (4S3P) inverter topology. The method aims to apply Field Oriented Control (FOC) of Induction motor using 4S3P. The simulations are carried out and the experimental results are given to verify the feasibility of this method.

Key words: FOC, SVPWM, four switch three phase inverter.


## 1. Introduction

Variable-speed induction motor drives have been already found in wide spread practical application. In the recent two decades, some researchers have developed inverter topologies with low cost [1-3], and the three phase inverter employing four-switch has been suggested as shown in Fig. 1.

The authors of [4][5] presented a modulation strategy based on the analysis of space voltage vectors and flux space vector. A study on SVPWM has been carried out by [6], where the sequence vector and the duration time of 4S3P inverter are calculated based on six-switch 3 phase inverter case.

In this paper, a cost-effective 4S3P inverter fed IM drive are implemented successfully for 3 Hp induction motor using FOC method with SVPWM technique.

Firstly, a review of four switch three phase inverter topology and SVPWM analysis are presented. And then, the principle of FOC using the SVPWM with 4S3P is explained in detail. The simulation and some experimental results are displayed to show the effectiveness and robustness of the FOC with 4S3P.

## 2. Four switch three phase inverter topology and space vector analysis

### 2.1 Four switch three phase inverter topology

The 4S3P inverter topology consists of four power switches that provide two of the inverter output phases. The third phase is connected to the midpoint of split capacitors, as shown in Fig. 1.

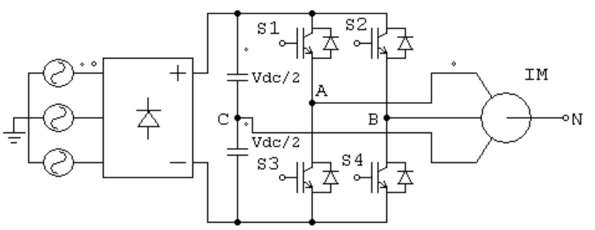


Fig. 1 Four Switch three phase inverter induction motor drive

According to Fig. 1, the voltage $V_{A0}$ , $V_{B0}$, $V_{C0}$ are obtained from the states of the power switch:

$$V_{A0}=(2S_1-1)\frac{V_{dc}}{2} \quad (1)$$

$$V_{B0}=(2S_2-1)\frac{V_{dc}}{2} \quad (2)$$

$$V_{C0}=0 \quad (3)$$

where $S_1$, $S_2$ are the binary number 0 or 1: “0” means switch open and “1” means switch closed.

Assume that the load is balance, then

$$V_{AN}+V_{BN}+V_{CN}=0 \quad (4)$$

The 4S3P inverter output voltage can be derived as follows:

$$V_{AN}=\frac{2V_{A0}-V_{B0}}{3} \quad (5)$$

$$V_{BN}=\frac{2V_{B0}-V_{A0}}{3} \quad (6)$$

$$V_{CN}=\frac{-V_{A0}-V_{B0}}{3} \quad (7)$$

Using space vector modulation technique, the variable vectors in stationary frame are given by

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix}=\sqrt{\frac{2}{3}}\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix}\begin{bmatrix} V_{AN} \\ V_{BN} \\ V_{CN} \end{bmatrix} \quad (8)$$

The calculation of phase voltages and the available vectors in stationary reference frame are presented in the Table 1.

Table 1 The Voltage Values Of Line-Neutral Load And Available Vectors In αβ Plane

| $S_1$ | $S_2$ | $V_{AN}$ | $V_{BN}$ | $V_{CN}$ | $V=V_\alpha+jV_\beta$ |
|---|---|---|---|---|---|
| 0 | 0 | $-V_{dc}/6$ | $-V_{dc}/6$ | $V_{dc}/3$ | $V_1=V_{dc}/\sqrt{6}e^{-j2\pi/3}$ |
| 1 | 0 | $V_{dc}/6$ | $-V_{dc}/3$ | $V_{dc}/6$ | $V_2=V_{dc}/\sqrt{2}e^{-j\pi/6}$ |
| 1 | 1 | $V_{dc}/6$ | $V_{dc}/6$ | $-V_{dc}/3$ | $V_3=V_{dc}/\sqrt{6}e^{j\pi/3}$ |
| 0 | 1 | $-V_{dc}/3$ | $V_{dc}/6$ | $V_{dc}/6$ | $V_4=V_{dc}/\sqrt{2}e^{j5\pi/6}$ |

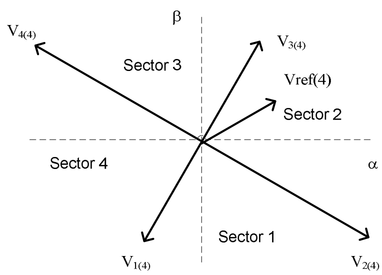


Fig. 2 Four vectors in the αβ plane

Fig. 2 shows the equivalent voltage space vector of the 4S3P topology, which includes four active vectors: these vectors have different magnitudes, and there is not zeros vector.

### 2.2 Space Vector PWM analysis

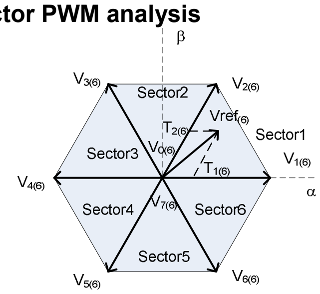

Fig. 3 The basic space vectors in 6S3P

Firstly, the voltage vector sequence and the duration of time in 6S3P are determined as follow.

Assume that the desired voltage vector $V_{ref(6)}$ locates in sector 1 and the angle between $V_{ref(6)}$ and $V_{1(6)}$ is α (as show in Fig. 3).

$$V_{ref\,(6)}=T_{1(6)}V_{1(6)}+T_{2(6)}V_{2(6)}+T_{0(6)}V_{0(6)} \tag{9}$$

From Fig. 3, we can also obtain the $T_{1(6)}$, $T_{2(6)}$, $T_{3(6)}$ :

$$T_{1(6)}=\sqrt{3}\frac{V_{ref(6)}}{V_{dc}}\sin(\pi/3-\alpha);T_{2(6)}=\sqrt{3}\frac{V_{ref(6)}}{V_{dc}}\sin(\alpha);T_{0(6)}=1-T_{1(6)}-T_{2(6)} \tag{10}$$

After calculating the duration of time in 6S3P, we can determine the duration of time in 4S3P as follows.

Let $V_{ref}$ represent the reference voltage, which locates in sector 1. According to the space vector technique, $V_{ref}$ can be expressed as

$$V_{ref}=V_{1(4)}T_{1(4)}+V_{2(4)}T_{2(4)}+V_{3(4)}T_{3(4)} \tag{11}$$

Assume the reference voltages in 4S3P and 6S3P have the same value, then $V_{ref}=V_{ref(6)}$, so the following relationship can be satisfied:

$$T_{1(6)}V_{1(6)}+T_{2(6)}V_{2(6)}+T_{0(6)}V_{0(6)}=V_{1(4)}T_{1(4)}+V_{2(4)}T_{2(4)}+V_{3(4)}T_{3(4)} \tag{12}$$

As show in Fig. 4, we have

$$V_{0(6)}=V_{1(4)}+V_{3(4)} \tag{13}$$

$$V_{1(6)}=1/2\left(V_{2(4)}+V_{3(4)}\right) \tag{14}$$

And, $T_{1(4)}$, $T_{2(4)}$, $T_{3(4)}$ is determined as following equations:

$$T_{1(4)}=\frac{T_{0(6)}}{2};T_{2(4)}=\frac{T_{1(6)}}{2};T_{3(4)}=\frac{T_{0(6)}}{2}+\frac{T_{1(6)}}{2}+T_{2(6)} \tag{15}$$

, where $T_{0(6)},T_{1(6)},T_{2(6)}$ are calculated from Eq. (10).

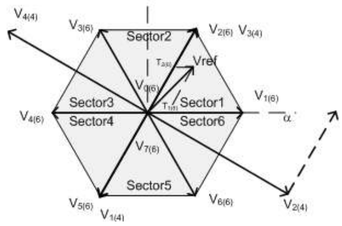

Fig. 4 Selection of switching vectors for 4S3P

Table 2 Sequence vector and duration of time

| Sector | Sequence | Duration of time |
|---|---|---|
| 1 | $V_{1(4)}$,$V_{2(4)}$,$V_{3(4)}$ | $0.5T_{0(6)},0.5T_{1(6)},0.5(T_{0(6)}+T_{1(6)}+2T_{2(6)})$ |
| 2 | $V_{1(4)}$,$V_{3(4)}$, $V_{4(4)}$ | $0.5T_{0(6)},0.5(T_{0(6)}+2T_{1(6)}+T_{2(6)}),0.5T_{2(6)}$ |
| 3 | $V_{1(4)}$,$V_{3(4)}$,$V_{4(4)}$ | $0.5(T_{0(6)}+T_{2(6)}),0.5(T_{0(6)}+T_{1(6)}),0.5(T_{1(6)}+T_{2(6)})$ |
| 4 | $V_{1(4)}$,$V_{3(4)}$,$V_{4(4)}$ | $0.5(T_{0(6)}+T_{1(6)}+2T_{2(6)}),0.5T_{0(6)},0.5T_{1(6)}$ |
| 5 | $V_{1(4)}$,$V_{2(4)}$,$V_{3(4)}$ | $0.5(T_{0(6)}+2T_{1(6)}+T_{2(6)}),0.5T_{2(6)},0.5T_{0(6)}$ |
| 6 | $V_{1(4)}$,$V_{2(4)}$,$V_{3(4)}$ | $0.5(T_{0(6)}+T_{1(6)}),0.5(T_{1(6)}+T_{2(6)}),0.5(T_{0(6)}+T_{2(6)})$ |

With the same analysis, the applying sequence and the duration of time for each voltage vectors can be obtained and they are shown in Table 2.

## 3. Principle of Field Oriented Control

Field oriented control (FOC) has become popular for the industrial induction motor drives. The block diagram of the indirect field oriented control of induction motor using VSI is shown in Fig. 5.

The principle of the FOC method can be described as follow.

The electromagnetic torque given by

$$t_e=\frac{3}{2}P\frac{L_m^2}{L_r}\left|\bar{i}_{mr}\right|i_{sq} \tag{16}$$

Where P is the pole-pairs of IM, $L_m$ is the magnetizing inductance, $L_r$ is the self-inductance of a rotor winding, $i_{mr}$ is flux-producing current component and $i_{sq}$ is the torque – producing stator current component.

Eq. (16) shows that the electromagnetic torque can be controlled by independently controlling flux-producing current component and the torque – producing stator current component. In the special selection of reference frame, the quadrature-axis rotor flux linkage $\psi_{rq}$ is zero and the direct-axis flux linkage $\psi_{rd}$ is constant.

As show in the Fig.5, the $i_{sd}$, $i_{sq}$ are compared to the reference $i_{sdref}$, $i_{sqref}$. $V_{Sdref}$ and $V_{Sqref}$ are obtained through the PI regulator. After that, they are applied to the inverse Park transformation. The outputs of this projection are $V_{S\alpha ref}$ and $V_{S\beta ref}$, the components of the stator voltage vector in stationary reference frame. These are the inputs of the SVPWM which is explained in detail in section 2, and the outputs of this block are applied to drive the inverter.

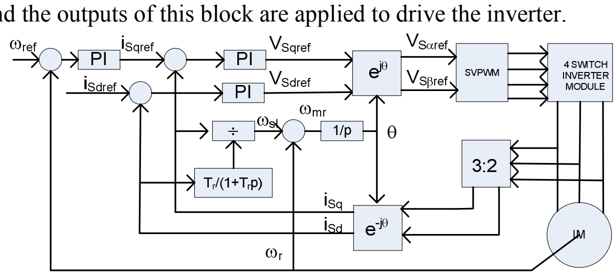

Fig. 5 The block diagram of the indirect FOC of IM using VSI

## 4. Simulation and experimental results

In order to verify the effectiveness of the proposed method, a simulation is carried out by Psim 6.0 software, and the control scheme is implemented according to Fig. 5.

Table 3 shows the parameters of induction motor used in this paper

Table 3 Induction motor parameter

| Parameter | Value |
|---|---|
| Rated Power | 3 [Hp] |
| Rated Voltage | 220/380 [V],60 [Hz] |
| Number of Poles | 4 |
| Stator Resistance | 2.077 [Ω] |
| Rotor Resistance | 1.964 [Ω] |
| Stator Leakage Inductance | 0.026 [H] |
| Rotor Leakage Inductance | 0.026 [H] |
| Mutual Inductance | 0.239 [H] |

### 4.1 Simulation results

Fig. 6 shows the rotor speed response at 1000 rpm and the 3 phase stator current. Fig. 7 presents the line-line voltage $V_{AB}$ and $V_{AC}$, where C is the third phase which connects to the center of split capacitors.

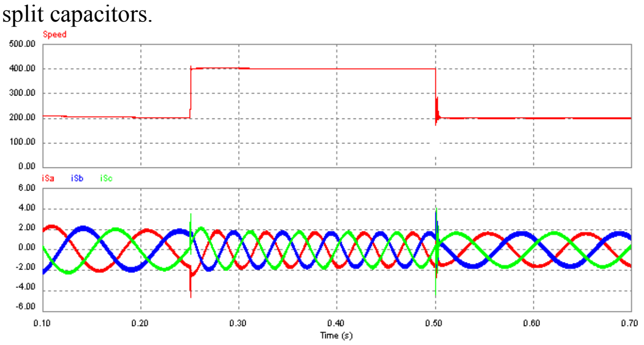

Fig. 6 Speed response (200 rpm and 400 rpm) and stator phase currents

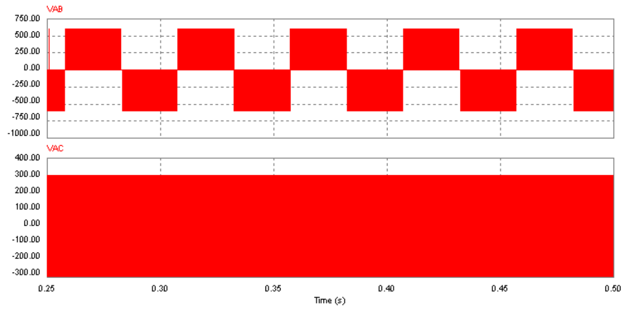

Fig. 7 Stator line –line voltage $V_{AB}$ and $V_{AC}$

### 4.2 Experimental results

Fig. 8 shows the speed response (from 200 rpm to 400 rpm) and the stator phase current. Fig 9 presents the line-line voltage ($V_{AB}$) and stator phase current. The line-line voltage $V_{AB}$ and $V_{AC}$ are shown in Fig. 10. The waveform of dc-link current is indicated in Fig. 11.

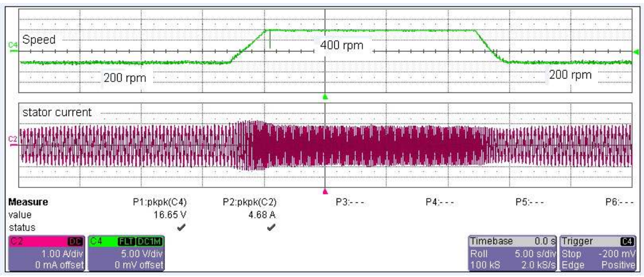

Fig. 8 Speed response (200 rpm and 400 rpm) and stator phase current

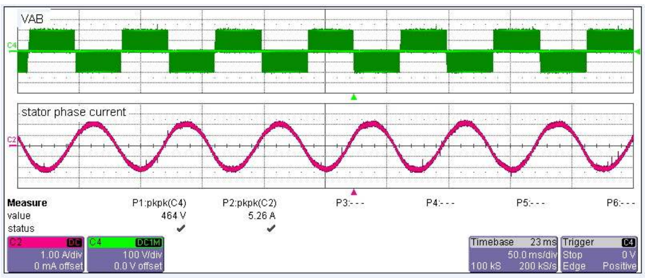

Fig. 9 Stator line-line voltage ($V_{AB}$) and phase current

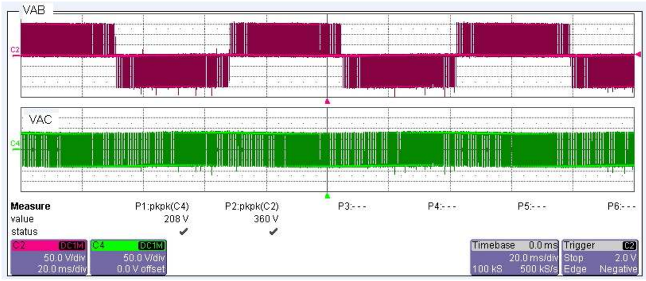

Fig. 10 Stator line voltage $V_{AB}$ and $V_{AC}$

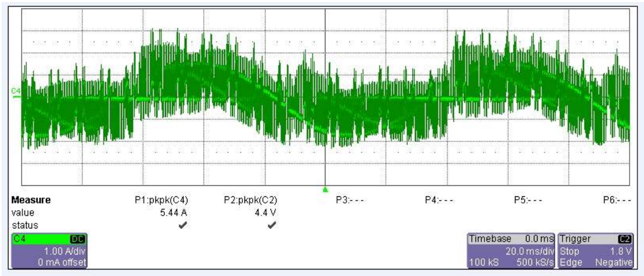

Fig. 11 DC link current

## 5. Conclusion

This paper investigated the FOC scheme using the 4S3P inverter for induction motor driving system. In the 6S3P inverter, there are two zero vectors, but there is no zero vector in the 4S3P inverter because zero vectors can be combined using non zero vectors. With a desired voltage vector, the sequence vector and the duration of time are calculated in this paper to obtain this desired vector. The simulation and experimental results verify that the 4S3P inverter fed IM under FOC runs steadily with acceptable performance.


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