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Reduction of Steady State Ripple of Vector Controlled Induction Motor Drives by Combining the Techniques of FOC and DTC

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ABSTRACT

To reduce the disadvantages of the existing Methods of field oriented control and direct torque control algorithms, the proposed method of the vector control algorithm mix the ideology of mutually field oriented control as well as direct torque control. The proposed algorithms generate the d-axis plus q-axes current references with the theory of existing field oriented control. As a result, by evaluate the current references as well as the actual currents error present signal is produced. As a result of with the error signals along with the lookup-tables, and the appropriate voltage vector will be chosen based on the theory of the direct torque control. Hence, the proposed method reduces the complexity when evaluated through the field oriented control as well as decreases the stable condition of the torque swells, when evaluate with the direct torque control method. So In this article, propose a 6-sector, 12-sector and 24-sector based lookup-tables designed for the vector control algorithm. The Mat-Lab-simulation results are exhibits the efficiency of the proposed techniques.

Keywords
Direct Torque Control (DTC), Field Oriented Control (FOC), vector control algorithm, lookup-table.

I. INTRODUCTION

In the present days asynchronous motors are uses in variable-speed drives appliance because of with a reduction of maintenance as well as lesser weight to volume proportion. So many existing algorithms are developed for the speed-control of motor drives. One of the existing algorithms is the scalar control, and also identified as the volts/hertz control method is easy for the execution. But, the main disadvantage of the scalar control offer slow reaction due to the coupling consequence flanked by the torque along with flux. To attain the decoupling controller in asynchronous motor drive related to the separately excited dc motor method, FOC method, and also known as vector based control method have been proposed [2]. The development of the field oriented control brings resumption in the field of the ac related drives. Afterward, a lot of enhancements have been proposed for the field oriented control [3]-[5]. The field oriented control offers quick transient response due to the decoupled control of torque as well as flux. Although, the field oriented control provides high-quality transient retort, the complexity taken addicted to more due to the revolution of reference framework.

To reduce the complexity worried in field oriented control (FOC), in the year 1980s, Takahashi expand proposed DTC method for motor drives [6]. The direct torque control (DTC), is simple for the suitable performance as well as it sprightly control the mutually torque as well as flux. It utilizes two hysteresis types of comparators designed for torque as well as flux loops along with a lookup-table for the selection of right voltage vector Method. However, the direct torque control method provides quick dynamic reaction related to that of field oriented control method, it presents massive stable condition deviation in current values, torque characteristics, and flux characteristics. A total evaluation involving field oriented control method as well as direct torque control method has been presented [7]. Additionally, the advantages and disadvantages of field oriented control method as well as direct torque control method are discussed. To reduce the complexity concerned in current controlled drives suitable to the transformation of reference framework, a

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novel algorithm has been proposed in with the lookup-table advance. These advances employ the hysteresis type of comparators along with switch chart for the choice of appropriate voltage vector method. Moreover, a a 6-sector, 12-sector base direct torque control algorithm has been projected.
Therefore, in the direction of defeat the drawbacks of conservative vector method of the control algorithm, in this article new vector control design, which associations the main beliefs of in cooperation field oriented control method as well as direct torque control method, is proposed. The proposed system expands the indication currents with the main beliefs of field oriented control method. Then, the error current signals are produced by similar the current references along with actual currents. These error indications will be particular to the hysteresis type of comparators, as well as the suitable voltage vector is chosen with the theory of the direct torque control (DTC). In this manuscript 6-sector, 12-sector along with 24-sector based lookup-tables are utilize for the proposed method.

II. CONVENTIONAL VECTOR CONTROL

In the field oriented control (FOC) method, the decoupling control method of torque along with flux be able to attain through a transmit all the magnitude to SRF Method also determination of the current vector (i_s^*) of stator as torque is fabricate current module i_{qs}^* as well as flux is creating current vector component is i_{ds}^*. The increasing torque equation for Inductor motor Drive is specified as below

$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}\left(\psi_{dr} i_{qs} - \psi_{qr} i_{ds}\right) \qquad (1)$$

To attain decoupled control method of i_{ds}^* is similar while alongside the rotor of the flux linkage vector method, and i_{qs}^* is standard to the i_{ds}^* Value. Therefore, the entire rotor flux linkage vector is united next to d-axis as well as therefore the q-axis flux vector method is turn into 0. Afterward, the customized torque expression can be specified as in (2).

$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}\left(\psi_{dr} i_{qs}\right) \qquad (2)$$

Consequently, the rotor flux of the $\psi_r = \psi_{dr} = L_m i_{ds}$, which is next to i_{ds}^* as well as sustain constant Value. Thus, the torque of the Motor is directly proportional to the i_{qs}^*. In this manuscript, the major notice has been alert on roundabout vector control algorithm, in which the arrangement of rotor flux angle is able to be considered as of (3).

$$\theta_s = \theta_r + \theta_{sl} = \int(\omega_r + \omega_{sl})dt \qquad (3)$$

Where $\omega_{sl} = \frac{L_m R_r}{L_r \lambda_r} i_{qs}^*$.

III.PROPOSED VECTOR CONTROL

The Equation of the torque of an Induction motor is specified as

$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}\left|\bar{\lambda}_r\right|\left|\bar{i}_s\right|\sin\delta \qquad (4)$$

Where δ is the angle between $\bar{\lambda}_r$ and $\bar{i}_s$. From (4), it is determined to the electromagnetic of the torque can be distorted by changeable the δ. Therefore, quick torque controller can be consummate by changeable δ in the necessary method. Appropriate toward the huge inertia of Motor path, the rotor flux is almost stable designed for a small time gap. For this reason, by varying the Current stator vector into the essential method,

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the torque preserve to be proscribed afford to the indication of torque Characteristics. By reduction the Value of resistance stator fall, the stator voltage expression is in equation (7).

$$\bar{v}_s = \frac{d\bar{\psi}_s}{dt} \qquad (5)$$

The equation of the flux linkage of induction motor with stator space vector is in (6)

$$\bar{\psi}_s = L_s\bar{i}_s + \frac{L_m}{L_r}\psi_r - \frac{L_m^2}{L_r}\bar{i}_s \qquad (6)$$

For little time period, by assumption the ψ_r as unaffected, the Voltage regulation of stator voltage is in (7):

$$\bar{v}_s = \frac{d\bar{\psi}_s}{dt} = \left(L_s - \frac{L_m^2}{L_r}\right)\frac{d\bar{i}_s}{dt} = \sigma L_s \frac{d\bar{i}_s}{dt} \qquad (7)$$

In the above equation, σ is motor coefficient of leakage.

From the equation (7), for a little time period of change of time is Δt, so the current vector of the induction motor drive is achieved as

$$\Delta\bar{i}_s = \frac{1}{\sigma L_s}\bar{v}_s\Delta t \qquad (8)$$

As a result, the current vector of the stator actions by the $\Delta\bar{i}_s$ in the path of the voltage vector of the stator at the speed is proportional toward scale of the V_S Value. As a result of prefer a suitable vector of the voltage it is then possible to modify the current of stator in the essential method. The vector stator currents of the induction motor is in the following postion of the figure 1.

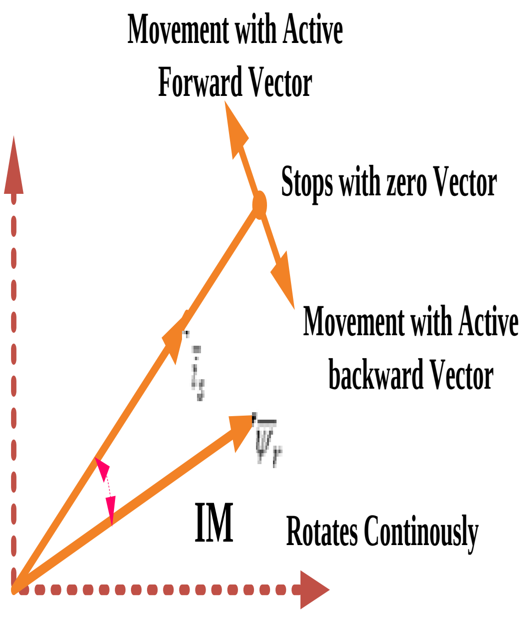

Figure. 1 The arrangement of the current vector of the stator current of the Induction Motor Drive

In the figure 2 is the proposed FOC control Method is expressed. In the proposed Vector control Method, the apparatus of reference currents of the stator are rotating synchronous position outline. These preserve developing with the theory of Existing Voltage vector control method. After that, during the proposed control method is using total two hysteresis types of comparators are utilized for flux and torque control

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methods. With the reference apparatus of the stator current signals as well as the real stator current apparatus, the error current signals are extended.

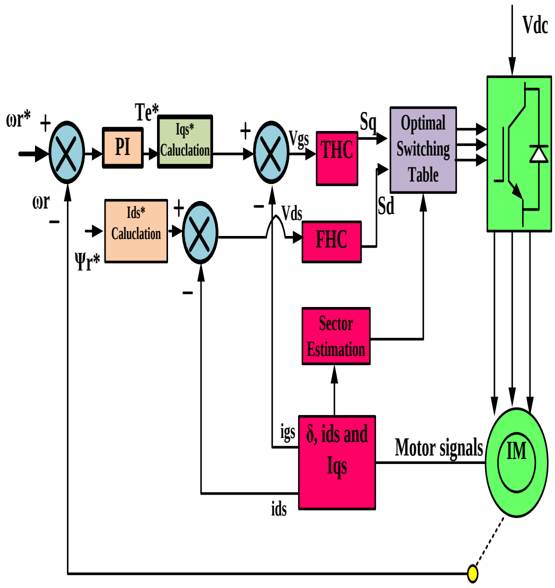

Figure. 2 Block diagram of the vector controlled proposed method with Induction Motor drive

These error signals are to be specified toward the torque based hysteresis comparator (THC) along with the flux based hysteresis comparator (FHC). These types of the hysteresis comparators will produce the desired outputs stands to the place of the error magnitude values. Related the digit outputs values of the hysteresis type comparators as well as the position value of the current stator, the appropriate vector voltage are chosen thus the continuously error standards restricted by the particular bandwidth of the hysteresis type of the comparators.

A. Proposed 6- Sector Based field oriented control (FOC)

Designing of the 2-Level inverter based positions is shown in figure 3. Its consists of total 2 zero states as well as 6 active states.

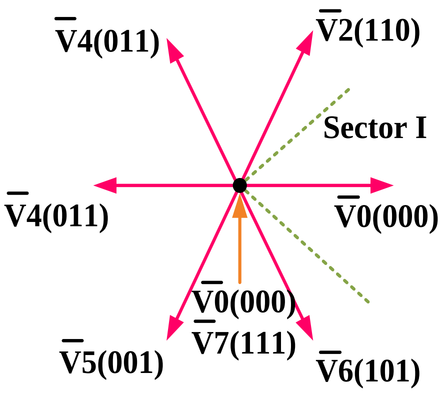

Figure. 3 Possibility of 6- Sector Based voltage vectors for VSI

In the position of the stator current vector, it is possible to control the suitable vector voltage toward the controlling of both the currents of d-axis and q-axis $\bar{i}_{ds}$ and $\bar{i}_{qs}$ .while the total six divisions are equal, in this article the discussion is limited to the initial sector only. While, the stator current $\bar{i}_s$ is in the initial division

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as exposed in the Figure .4, after that vector voltages of $\bar{V}_2$ along with $\bar{V}_6$ preserve enhance the d-axis current $\bar{i}_{ds}$,third position voltage $\bar{V}_3$ and fifth position voltage $\bar{V}_5$ reduce the $\bar{i}_{ds}$. Correspondingly second position voltage $\bar{V}_2$ along with third position voltage $\bar{V}_3$ preserve to enhance the torque current elements $\bar{i}_{qs}$ along with fifth position voltage $\bar{V}_5$ in addition to sixth position voltage $\bar{V}_6$ preserve reduce the $\bar{i}_{qs}$. In the same way the appropriate vectors of the voltage are to be selected for special sectors.

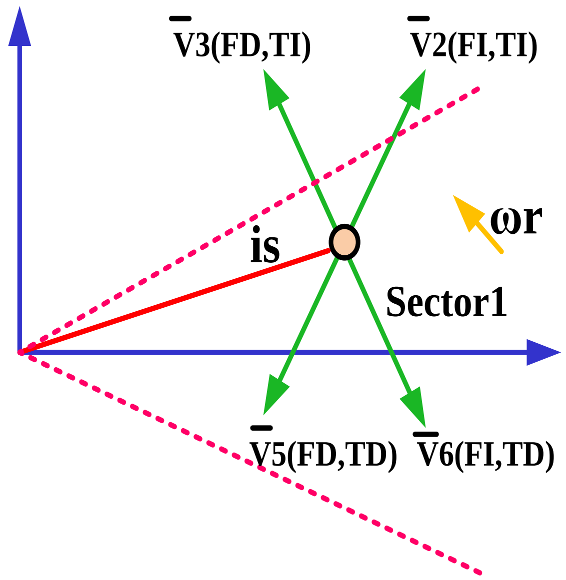

Figure.4 choice of appropriate voltage space vector in the position of -30^0 to 30^0.

In this proposed control method, the current error magnitudes are controlled to $2\Delta\bar{i}_{ds}$ and $2\Delta\bar{i}_{qs}$ inside their particular hysteresis type of bands. In the 6-sector control method of a both Two-level flux linkage of hysteresis type plus 3-level torque hysteresis type comparators are utilized related to the classical direct torque control (DTC) algorithm. The output indicators from the hysteresis type of controller of the flux linkage of the component FHC as well as hysteresis type controller of the THC as mentioned in Table. 1.

TABLE.1 VALUES OF THE OUTPUTS OF THE HYSTERESIS CONTROLLERS

Controller	Condition	Output of the controller
FHC	$\bar{i}_{ds} \le \bar{i}^*_{ds} - \Delta\bar{i}_s$	$S_d = 1$
	$\bar{i}_{ds} \ge \bar{i}^*_{ds} + \Delta\bar{i}_s$	$S_d = 0$
THC	For anti-clockwise rotation	
	$\bar{i}^*_{qs} - \bar{i}_{qs} \ge \Delta\bar{i}_{qs}$	$S_q = 1$
	$\bar{i}_{qs} \ge \bar{i}^*_{qs}$	$S_q = 0$
	For clockwise rotation	
	$\bar{i}_{qs} \le \bar{i}^*_{qs}$	$S_q = 0$
	$\bar{i}^*_{qs} - \bar{i}_{qs} \le -\Delta\bar{i}_{qs}$	$S_q = -1$

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The values of the S_d and S_q the position as mentioned in the Table 2 the position of the current stator vector, the essential voltage vector is elected as of the switch lookup-table as specified in the Table. 2.

TABLE.2 6 Switching Table of the 6-Sector Based 2-Level Inverter

Sector		I	II	III	IV	V	VI
Sd	Sq						
1	1	$\overline{V}_2$	$\overline{V}_3$	$\overline{V}_4$	$\overline{V}_5$	$\overline{V}_6$	$\overline{V}_1$
	0	$\overline{V}_7$	$\overline{V}_0$	$\overline{V}_7$	$\overline{V}_0$	$\overline{V}_7$	$\overline{V}_0$
	-1	$\overline{V}_6$	$\overline{V}_1$	$\overline{V}_2$	$\overline{V}_3$	$\overline{V}_4$	$\overline{V}_5$
0	1	$\overline{V}_3$	$\overline{V}_4$	$\overline{V}_5$	$\overline{V}_6$	$\overline{V}_1$	$\overline{V}_2$
	0	$\overline{V}_0$	$\overline{V}_7$	$\overline{V}_0$	$\overline{V}_7$	$\overline{V}_0$	$\overline{V}_7$
	-1	$\overline{V}_5$	$\overline{V}_6$	$\overline{V}_1$	$\overline{V}_2$	$\overline{V}_3$	$\overline{V}_4$

B. Proposed 12- Sector Based field oriented control (FOC)

In the existing technique of the six-sector support vector control method, simply small amounts of quantity of active voltage vectors are employ every segment. In path near utilize all the six active circumstances in each one segment along with to reduce the Total Harmonic Distortion is more, the space vector plane is owed addicted to 12 sectors in its place of six vectors as exposed in the Figure 5. Though, it is significant toward identify little as well as huge deviation. It is observed that V_1 will construct a huge improves inside leakage flux as well as a little improve in torque in present 12 sectors. In the additional method it is experimental that V_2 will create a great addition in the torque as well as a little pay rise in Linkage flux. The 12-sector technique support vector method manage employ a 4 stage torque hysteresis controller along through a 2 level flux-Linkage hysteresis type controller.

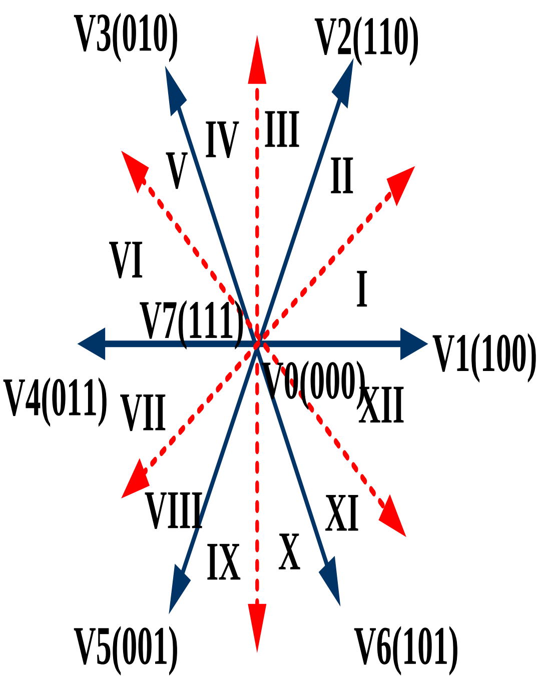

Figure. 5 12- sector based Voltage vectors in favor of field oriented control (FOC) technique

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TABLE.3 6 Switching Table of the 12-Sector Based 2-Level Inverter

S_d	S_q	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}
1	TI	$\overline{V}_2$	$\overline{V}_3$	$\overline{V}_3$	$\overline{V}_4$	$\overline{V}_4$	$\overline{V}_5$	$\overline{V}_5$	$\overline{V}_6$	$\overline{V}_6$	$\overline{V}_1$	$\overline{V}_1$	$\overline{V}_2$
	TsI	$\overline{V}_2$	$\overline{V}_2$	$\overline{V}_3$	$\overline{V}_3$	$\overline{V}_4$	$\overline{V}_4$	$\overline{V}_5$	$\overline{V}_5$	$\overline{V}_6$	$\overline{V}_6$	$\overline{V}_1$	$\overline{V}_1$
	TsD	$\overline{V}_1$	$\overline{V}_1$	$\overline{V}_2$	$\overline{V}_2$	$\overline{V}_3$	$\overline{V}_3$	$\overline{V}_4$	$\overline{V}_4$	$\overline{V}_5$	$\overline{V}_5$	$\overline{V}_6$	$\overline{V}_6$
	TD	$\overline{V}_6$	$\overline{V}_1$	$\overline{V}_1$	$\overline{V}_2$	$\overline{V}_2$	$\overline{V}_3$	$\overline{V}_3$	$\overline{V}_4$	$\overline{V}_4$	$\overline{V}_5$	$\overline{V}_5$	$\overline{V}_6$
0	TI	$\overline{V}_3$	$\overline{V}_4$	$\overline{V}_4$	$\overline{V}_5$	$\overline{V}_5$	$\overline{V}_6$	$\overline{V}_6$	$\overline{V}_1$	$\overline{V}_1$	$\overline{V}_2$	$\overline{V}_2$	$\overline{V}_3$
	TsI	$\overline{V}_4$	$\overline{V}_4$	$\overline{V}_5$	$\overline{V}_5$	$\overline{V}_6$	$\overline{V}_6$	$\overline{V}_1$	$\overline{V}_1$	$\overline{V}_2$	$\overline{V}_2$	$\overline{V}_3$	$\overline{V}_3$
	TsD	$\overline{V}_7$	$\overline{V}_5$	$\overline{V}_0$	$\overline{V}_6$	$\overline{V}_7$	$\overline{V}_1$	$\overline{V}_0$	$\overline{V}_2$	$\overline{V}_7$	$\overline{V}_3$	$\overline{V}_0$	$\overline{V}_4$
	TD	$\overline{V}_5$	$\overline{V}_6$	$\overline{V}_6$	$\overline{V}_1$	$\overline{V}_1$	$\overline{V}_2$	$\overline{V}_2$	$\overline{V}_3$	$\overline{V}_3$	$\overline{V}_4$	$\overline{V}_4$	$\overline{V}_5$

C. *Proposed 24- Sector Based field oriented control (FOC)*

To decrease the Total harmonic Distortion additional, in this present article a Proposed 24- Sector Based field oriented control (FOC) has be proposed system. In this technique the vector space is separated into 24 segments as exposed in the Figure. 6. During this technique, parallel to the segment support of manage method, the present fault magnitudes are controlled to $2\Delta\bar{i}_{ds}$ and $2\Delta\bar{i}_{qs}$ inside their particular to hysteresis group. In this present 24 sector manage, Three levels of hysteresis controllers are utilized in support of d-axis as well as q-axes current regulators.

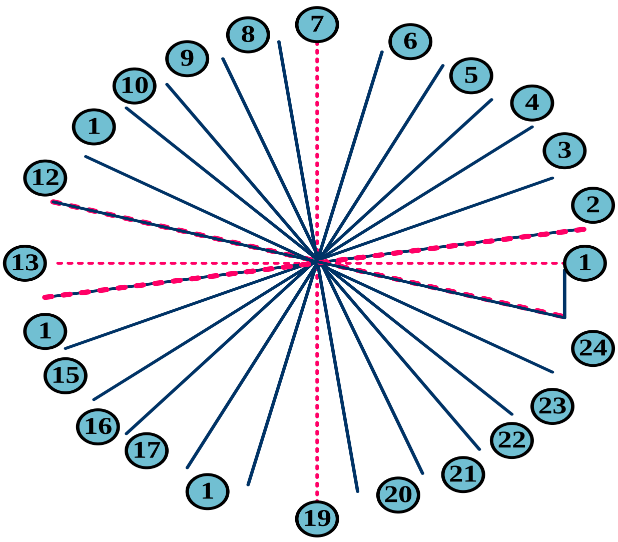

Figure. 6 24- sector based Voltage vectors in favor of field oriented control (FOC) technique

TABLE.4 OUTPUTS OF THE HYSTERESIS CONTRLLERS

Controller	Condition	Output of the controller
FHC	For anti-clockwise rotation	
	$\bar{i}_{ds}^{*} - \bar{i}_{ds} \geq \Delta\bar{i}_{ds}$	$S_q = 1$
	$\bar{i}_{ds} \geq \bar{i}_{ds}^{*}$	$S_q = 0$
	For clockwise rotation	
	$\bar{i}_{ds} \leq \bar{i}_{ds}^{*}$	$S_q = 0$
	$\bar{i}_{ds}^{*} - \bar{i}_{ds} \leq -\Delta\bar{i}_{ds}$	$S_q = -1$
THC	For anti-clockwise rotation	
	$\bar{i}_{qs}^{*} - \bar{i}_{qs} \geq \Delta\bar{i}_{qs}$	$S_q = 1$
	$\bar{i}_{qs} \geq \bar{i}_{qs}^{*}$	$S_q = 0$
	For clockwise rotation	
	$\bar{i}_{qs} \leq \bar{i}_{qs}^{*}$	$S_q = 0$
	$\bar{i}_{qs}^{*} - \bar{i}_{qs} \leq -\Delta\bar{i}_{qs}$	$S_q = -1$

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TABLE. 5 Switching Table of the 24-Sector Based 3-Level Inverter

Sector $d_x d_y$		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	1	V_2	V_2	V_2	V_3	V_3	V_3	V_3	V_4	V_4	V_4	V_4	V_5	V_5	V_5	V_5	V_6	V_6	V_6	V_6	V_1	V_1	V_1	V_1	V_2
1	0	V_1	V_1	V_2	V_2	V_2	V_2	V_3	V_3	V_3	V_3	V_4	V_4	V_4	V_4	V_5	V_5	V_5	V_5	V_6	V_6	V_6	V_6	V_1	V_1
1	-1	V_6	V_1	V_1	V_1	V_1	V_2	V_2	V_2	V_2	V_3	V_3	V_3	V_3	V_4	V_4	V_4	V_4	V_5	V_5	V_5	V_5	V_6	V_6	V_6
0	1	V_3	V_3	V_3	V_3	V_4	V_4	V_4	V_4	V_5	V_5	V_5	V_5	V_6	V_6	V_6	V_6	V_1	V_1	V_1	V_1	V_2	V_2	V_2	V_2
0	0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0	V_0
0	-1	V_6	V_6	V_6	V_6	V_1	V_1	V_1	V_1	V_2	V_2	V_2	V_2	V_3	V_3	V_3	V_3	V_4	V_4	V_4	V_4	V_5	V_5	V_5	V_5
-1	1	V_3	V_4	V_4	V_4	V_4	V_5	V_5	V_5	V_5	V_6	V_6	V_6	V_6	V_1	V_1	V_1	V_1	V_1	V_1	V_2	V_2	V_2	V_2	V_3
-1	0	V_4	V_4	V_5	V_5	V_5	V_5	V_6	V_6	V_6	V_6	V_1	V_1	V_1	V_1	V_2	V_2	V_2	V_2	V_3	V_3	V_3	V_3	V_4	V_4
-1	-1	V_5	V_5	V_5	V_6	V_6	V_6	V_6	V_1	V_1	V_1	V_1	V_2	V_2	V_2	V_2	V_3	V_3	V_3	V_3	V_4	V_4	V_4	V_4	V_5

IV. MAT-LAB SIMULATION RESULT ANALYSIS

In the direction of validate the proposed Method look-up stand support vector based manage algorithm arithmetical study of Mat Lab-simulations comprise be approved out by with the use of MATLAB-SIMULINK Software. In favor of the revise of simulations of the Induction motor constraints are in use as R_s is 1.57 ohms, R_r is 1.21 ohms, L_m is 0.165 Henry, L_s is 0.17 Henry, L_r is 0.17 Henry along with J is 0.089 Kg-m^2. Additionally, used for the Matlab-simulation results equivalent to the band-widths comprise be in use intended for the hysteresis type of bands during the expected as well as offered current restricted FOC Motor. From the Mat-Lab simulink consequences of the stable condition designs of the existing methods of control by Induction Motor drive be exposed in the Figure.7 & Figure. 8. And the Mat-Lab simulink results of the stable condition designs of the six sector base vector restricted I.M drives are specified in the Figure .9 and Figure 10. The Mat Lab-Simulink consequences of simulation of stable position schemes of the 12 segment based field oriented control Motor drive be specified as of Figure. 11 toward Figure.12 and the MatLab-simulation consequences of the 24 segment base vector organize algorithm be shown in the Figure.13 & Figure.14.

As of the MatLab-simulink results analysis, it is able to be experimental to the proposed look-up stand base FOC Proposed algorithms provide quick transient reaction similar to classical field oriented control(CFO Method) algorithm. Moreover, it preserve be experimental to the 6 Vector sector algorithm provide a reduced amount of the THD importance while evaluated through the CFO Method algorithm meant for similar band-width of the hysteresis type of comparators. In addition to the 6 segment support vector manage algorithm provides rigid switching regularity process while evaluate through the CFO algorithm, which preserve be experimental starting the line voltage.To decrease the Total Harmonic Distortion additional, a 12 & 24 Vector Based sector look-up tables stand FOC algorithms are projected in this article.

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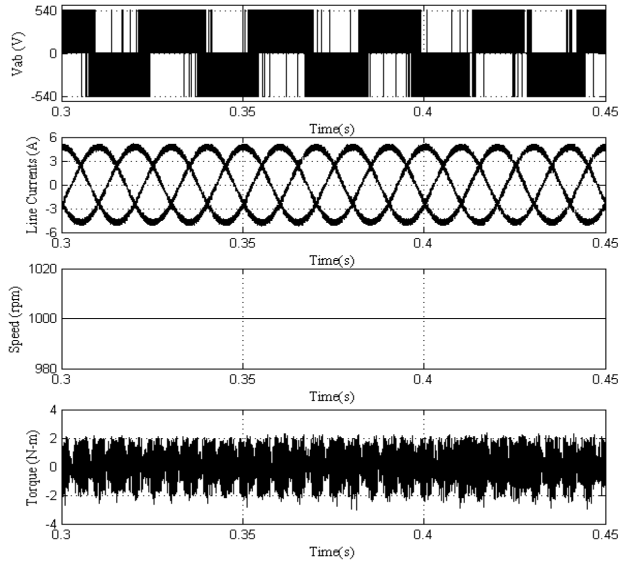

Figure. 7Simulation Results of the stable condition design of CFO Vector control algorithm based I.M drive

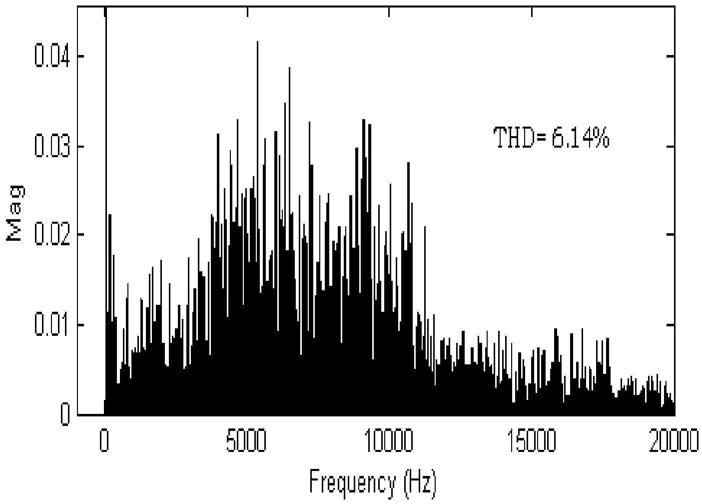

Figure. 8 FFT Analysis of the stable condition design of CFO Vector control algorithm based I.M drive

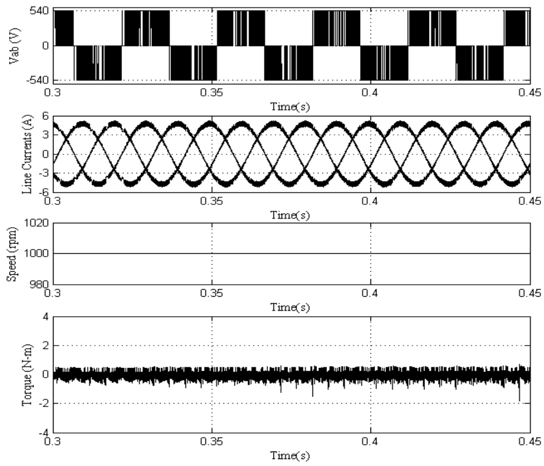

Figure. 9 Simulation Results of the stable condition design of Six - Sector based FOC based I.M drive

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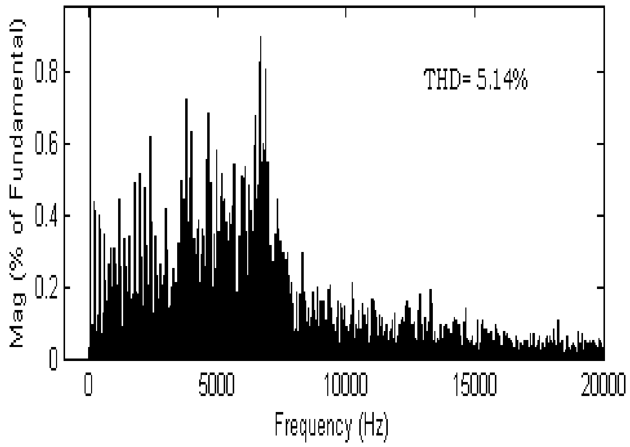

Figure.10 FFT Analysis of the stable condition design of 6–Sector techniques Algorithm based I.M drive

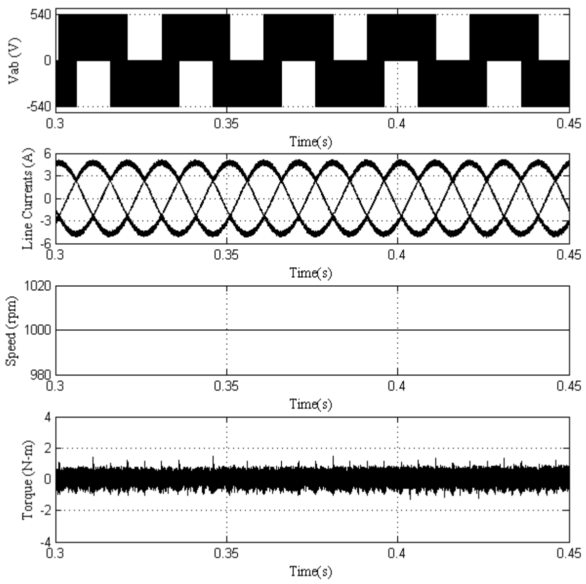

Figure. 11 Simulation Results of the stable condition design of Twelve - Sector based FOC based I.M drive

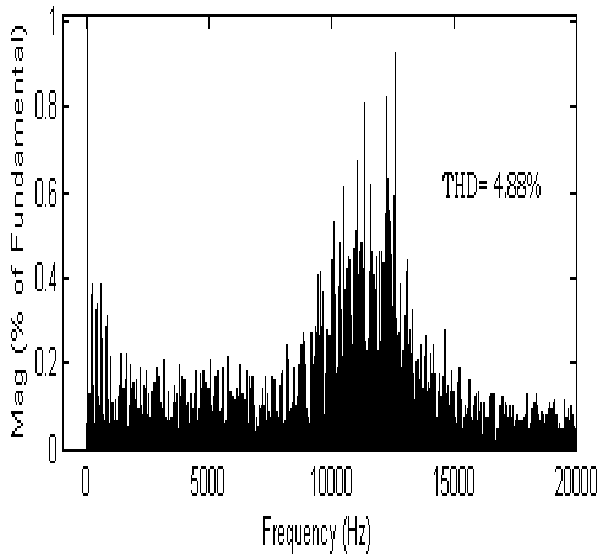

Figure. 12 FFT Analysis of the stable condition design of 12–Sector techniques algorithm based I.M drive

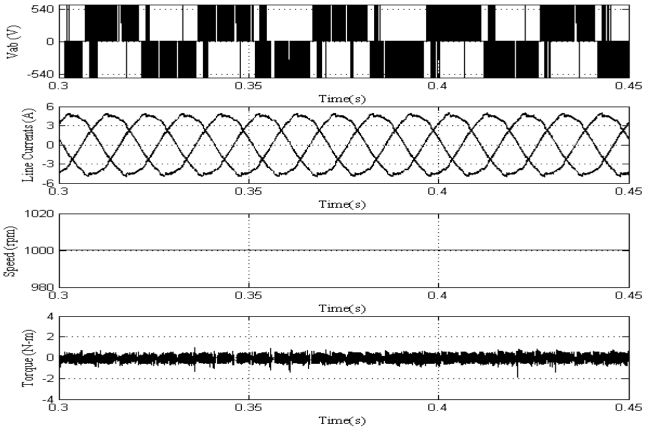

Figure. 13 Simulation Results of the stable condition design of 24 - Sector based FOC based I.M drive

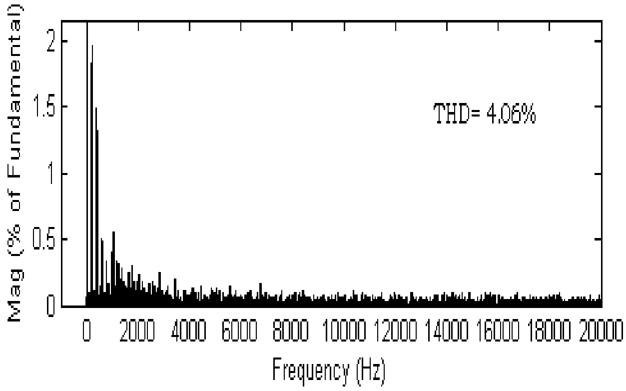

Figure. 14 FFT Analysis of the stable condition design of 12–Sector techniques algorithm based I.M drive

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