DIRECT TORQUE CONTROL OF INDUCTION MOTOR IN WIDE SPEED REGION.

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Abstract- **This paper presents, an effective scheme which is based on variable switching sectors that is possible to improve the stator flux response in constant-torque and field weakening regions and reduce the flux locus distortion as well as the harmonics contents of stator currents. Results of extensive simulation will be presented to prove the effectiveness of the scheme in wide speed region.**

I. INTRODUCTION

For over fifty years, dc motors have been widely used in variable speed drives applications principally due to their dynamic response and the possibility to use these motors in whichever mode of operation. However, the characteristics of the induction motor: high efficiency, robust, low costs, volume and maintenance, and the capacity to work in practically all environments in a safe and reliable way, makes the induction motor attractive in variable speed drives applications.

With the introduction of new techniques in vector control as proposed F. Blaschke and K. Hasse, a new stage was set in which the control of induction motors started replacing the control of dc motor. Vector control methods based in the orientation of the machine's magnetic field along one of the rotating reference axis makes it possible to uncouple the rotor magnetic field from the electromagnetic torque. The equations obtained within the reference framework selected permit the implementation of a control scheme for the induction motor, thus achieving dynamic response similar to that given by a separately excited dc motor.

In vector control methods, it is necessary to determine correctly the orientation of the rotor flux vector, lack of which leads to degradation in the speed control of the motor [7].

The complexity of vector control and its sensitivity to parameters makes the DTC a good solution in high performance drives [8].

II. DIRECT TORQUE CONTROL

DTC has demonstrated its potential in optimizing the operating characteristics of the induction motor drive fed by a PWM inverter [1]. It can achieve a response as quick as in a dc motor. Although the motor is not controlled by a conventional field oriented method, PWM waveforms have been obtained owing to the on – off control of both the stator flux and the torque by using an optimum switching table (six non zero voltage vectors have phase displacement of 60 degrees from each other, and two zero voltage vectors are selected to stop the stator flux). For the case, which must be performed with less sensitivity to the motor parameters [1], the stator flux and torque are either measured or estimated and used as feedback signals for control. The inputs of the selection table used are the torque error, the error in the magnitude of the stator flux space vector, and the angle of the stator flux space vector. The magnitude error signal of the stator flux is discretized into two levels by means of a hysteresis regulator. The torque error signal is discretized into three levels by means of three-stage hysteresis regulator. The output of the selection table is the setting for the power-switching device of the inverter [9].

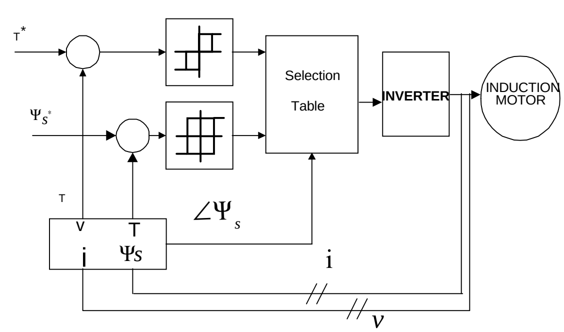


Fig. 1. Conventional DTC

The basic equations for the DTC are shown below [1]:
The phase output vector is given by

$$\begin{bmatrix} VA \\ VB \\ VC \end{bmatrix} = \frac{1}{3} V_{DC} \begin{bmatrix} +2 & -1 & -1 \\ -1 & +2 & -1 \\ -1 & -1 & +2 \end{bmatrix} \begin{bmatrix} A \\ B \\ C \end{bmatrix} \qquad (1)$$

where V_{DC} - is the DC supplying voltage.
$[A\ B\ C]^T$ is the switching vector (fig. 2).
The stator voltage space vector is given by

$$\overline{V_s} = \sqrt{\frac{2}{3}}\left[VA + VBe^{j\frac{2\Pi}{3}} + VCe^{j\frac{4\Pi}{3}}\right] \tag{2}$$

Equation (2) can be implemented using an inverter where the eight conduction modes can be achieves using an appropiate combination of the switches A, B and C whose value can be 1 or 0 (fig. 2).

The stator flux linked space vector is given by the integral of the voltage vector

$$\overline{\psi_s} = \int \left(\overline{V_s} - \overline{I_s} R_s\right) dt \tag{3}$$

And the developed torque is given by

$$T = \frac{L_m}{L_s L_r - L_m^{\ 2}} \left[\overline{\psi_s}\right]\left[\overline{\psi_r}\right] sin\delta_{sr} \tag{4}$$

where δ_{sr} - Angle between the stator and the rotor flux space vector.

The angle of stator flux space vector is given by

$$\angle\psi_s = tan^{-1}\left(\frac{\psi_{sq}}{\psi_{sd}}\right) \tag{5}$$

The change of the stator flux and torque is defined by the selection of six non zero voltage vectors and the zero voltage vectors (fig. 3). A selection table can be obtained to control the stator flux and torque of an induction motor in optimal way.

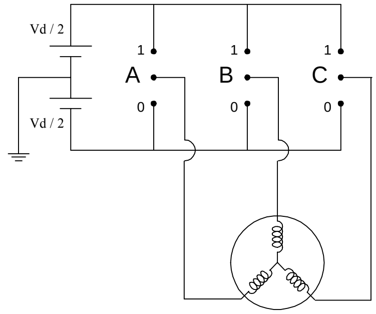


Fig. 2. Diagram of PWM Inverter.

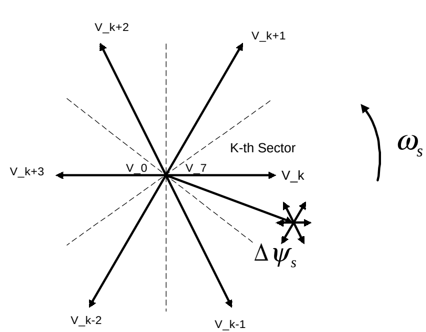


Fig. 3. Space vector voltage.

	V_k	V_k+1	V_k+2	V_k+3	V_k-2	V_k-1	V_0 V_7
Stator Flux	↑ ↑	↑	↓	↓ ↓	↓	↑	—
Torque	↑	↑	↑	↓	↓ ↓	↓ ↓	↓

Table 1. Space vector voltage influence on torque and stator flux space vector.

III. STATOR FLUX PROBLEMS.

The problem of the conventional DTC method is that just after the stator flux vector changes its position from one sector to another sector, there is no “active” voltage vector available that can assure an increase of stator flux [3,4]. So at low speeds of rotor, especially with heavy load, stator flux drops systematically, i.e. six times per flux cycle, below the lower boundary of hysteresis band as shown in fig. 4. In that figure, results for two different hysteresis band amplitudes in constant-torque and field weakening regions are shown.

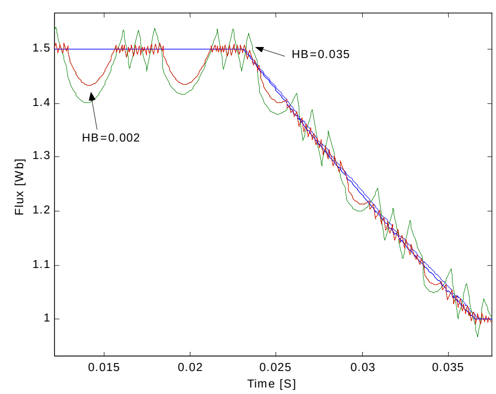
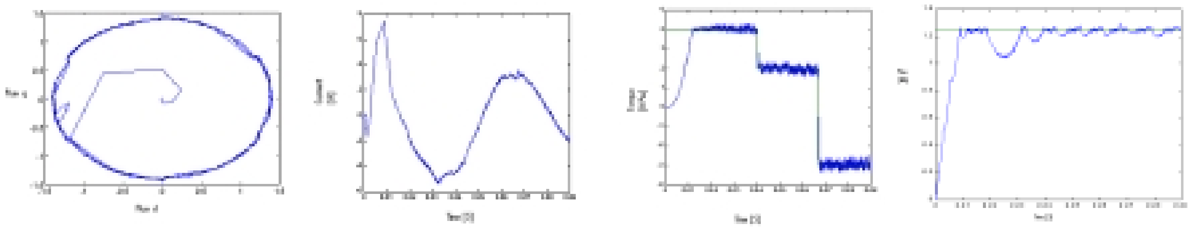


Fig.4. Stator flux vector in constant-torque and field weakening regions for two different hysteresis band amplitudes.

The corresponding conventional DTC response is shown in fig.5. The graphs show that the stator flux trajectory is hexagonal near the six boundaries. This six-pulse flux distortion would be reflected in stator current harmonics.



a) Stator flux locus. b) Stator current c) Torque d) Stator flux

Fig.5. Conventional DTC response in constant torque region.

IV. PROPOSED TECHNIQUE.

The concept of variable switching sectors was originally proposed by Rossi et. al. [5]. The essence of the method consists in changing the angular position of the stator ($\overline{\psi_s}$), in the complex plane (fig. 3), obtaining in this way the reduction of the problem that arises during the rotation of $\overline{\psi_s}$, when passing from one sector to another. In [4] a control method is offered to regulate the value of the fictitious displacement of $\overline{\psi_s}$ according to its real position in the complex plane. It is also shown that it is possible to get the reduction in the content of the harmonics of stator current.

The reduction of these harmonics is obvious if it is taken into consideration that with this method it is possible to reduce considerably the distortion in the flux of the stator previously mentioned. (Fig. 5 (a)). When eliminating the distortion of stator flux, the harmonics of the magnetization current are reduced; therefore, the harmonics of the total stator current are reduced. In the method proposed in [4] it is not possible to improve the DTC dynamics response.

In this work it is demonstrated that without controlling the value of α in function of the position $\overline{\psi_s}$, the stator flux dynamics of DTC can be improved keeping α constant and independent from the position of $\overline{\psi_s}$.

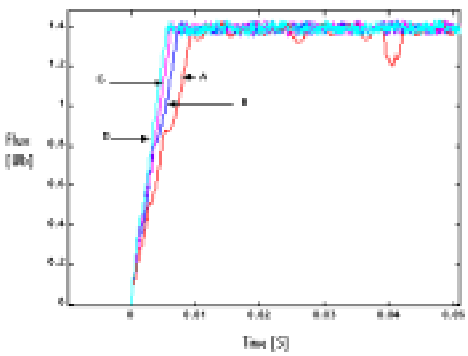
V. SIMULATION RESULTS.

The obtained results from the simulation of the dynamics behavior of the stator flux and torque during the start-up of the induction motor using different values of α are shown in fig.6. As it can be seen, the best dynamics response is obtained when $\alpha=\pi/3$ (maximum value).

Fig. 7 shows the stator flux locus, which has an almost circular behavior that allows a reduced content of the harmonics in the waveform of the stator current (fig. 8). Fig.9 shows the variation in the stator flux in constant-torque and field weakening regions. If figs. 5a and 7 are compared, it can be appreciated that with the offered method the beatings in the flux originated by the change of the sector during the trajectory $\overline{\psi_s}$ are eliminated.

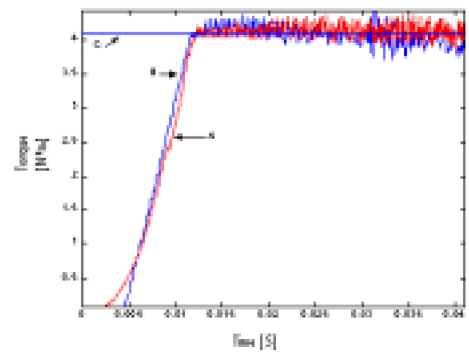
In [4] it was shown that for $\alpha > 0$ it is possible to reduce the switching frequency in the inverter and diminish the harmonic contents of stator current. Whit this work is possible to improve the dynamics response of the stator flux but the torque response has no significant difference (fig.6b). In [3] the previously mentioned advantages are achieved using a neuro-fuzzy control that substitutes to the selection table and the hysteresis controllers. With this kind of controller, the authors, besides of the advantages previously mentioned, successfully managed to keep the switching frequency constant, simple auto-tuning based on gradient algorithm, no problem during low speed operation and low sampling time. With the proposed method some of the operation problems of the conventional DTC can be solved without modifying it.

In [6] a speed estimation of the induction motor using a neural network applied to the conventional DTC is shown. The method proposed improves the DTC operation shown in [6] without increasing its complexity.



A ⇒ α= 0; B⇒ α= 15^0; C ⇒ α= 25^0 and
D ⇒ α= 30^0

a)



A ⇒ α= 0; B⇒α= 30^0 , and C⇒ Reference

b)

Fig.6. Start-up-stator flux (a) and torque (b).

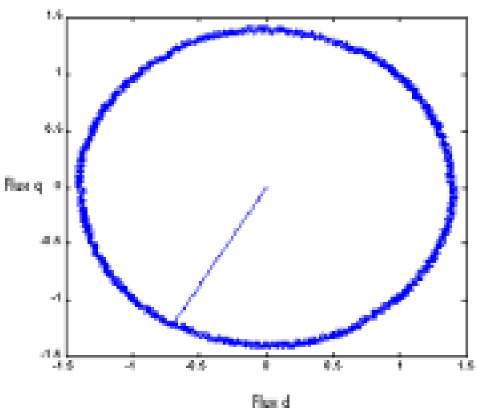


Fig.7. Stator flux locus (α=30^0 and HB=0.002).

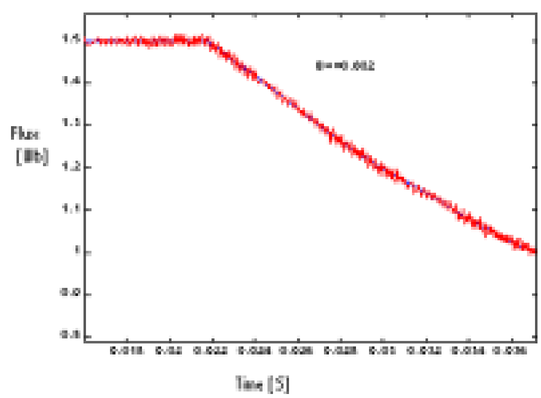


Fig.9. Stator flux in constant-torque and Field weakening regions (α=30^0 and HB=0.002).

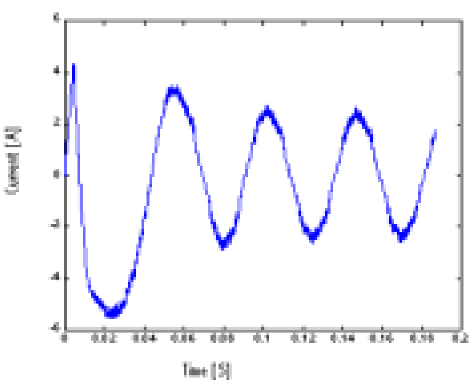


Fig. 8 Stator Current (α=30^0 and HB=0.002).

VI. CONCLUSIONS.

In this work it is being proposed a method to improve the conventional DTC operation without making modifications in the control scheme or increasing its complexity. The fictitious variation of the space vector angle (α) of the six sectors in which it is divided, allows the elimination of the problem at the moment of occurring the change of sector during the rotation of $\overline{\psi_s}$. In this work it is shown that for $\alpha=\pi/6$ the best results are obtained in wide speed region. Besides, it is possible to reduce the harmonics contents of stator current by getting a more circular trajectory from the stator flux vector ($\overline{\psi_s}$).

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