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State of the art review on induction motor control

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I dedicate this thesis to all the wonderful people in my life. To those who cannot be thanked with just a paragraph I dedicate my hard work.

To my mother who taught me the most important lessons, to my father, to my sisters Yasmine and Naziha.

To all my family, and to all my friends.

To my dearest friend who helped me at all times.

u5TBQA3

ملخص:

هذا العمل عبارة عن مراجعة مستوى التقدم الجاري لطرق التحكم في محرك غير متزامن الذي يتم تزويده بالطاقة بواسطة مموج التوتر ذو مستويين. حيث يتم تقديم مراجعة حول التحكم القياسي، وطرق التحكم المباشر وغير المباشر في المجال والتحكم المباشر في عزم الدوران. يتم ايضا عرض ومقارنة تحسينات التحكم المباشر في عزم الدوران و يتم إجراء مراجعة لطرق تقدير التدفق المختلفة. اخيرا يتم تقديم طرق التحكم الذكية والتحكم غير المستشعر.

الكلمات المفتاحية: استعراض مستوى التقدم الجاري، التحكم العددي، التحكم المباشر في عزم الدوران، التحكم الشعاعي، التحكم في المحرك.

Abstract:

This work is a state-of-the-art review on two-level voltage source inverter fed induction motor control methods. A review on scalar control, Direct and Indirect Field-oriented Control and Direct Torque Control methods is given. Improvements of DTC are presented and compared. A review of different flux estimation methods is performed. Finally, Intelligent control methods and sensorless control are presented.

Keywords: State-of-the-art, scalar control, DTC, FOC, motor control.

Résumé:

Ce travail est un état de l’art des méthodes de commande des machines asynchrones alimentées par un onduleur de tension à deux niveaux. Les commandes scalaires, orientation de flux directe et indirecte et la commande directe de couple sont passés en revue. Les améliorations de la DTC sont présentées et comparés. Une revue de différentes méthodes d’estimation du flux est réalisée. Les méthodes de commande intelligentes et de commande sans capteur sont enfin présentées.

Mots clés: Etat de l’art, commande scalaire, DTC, FOC, commande des machines.

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List of Abbreviations

AC	Alternative Current
ANN	Artificial Neural Network
CSI	Current Source Inverter
DAC	Digital-Analog Converter
DC	Direct Current
DSC	Direct Self-Control
DSP	Digital Signal Processor
DTC	Direct Torque Control
DVC	Direct Vector-Controlled
FLC	Fuzzy Logic Controller
FOC	Field-Oriented Control
GA	Genetic Algorithm
GTO	Gate Turn-off Thyristor
IGBT	Insulated-Gate Bipolar Transistor
IM	Induction Motor
MPC	Model Predictive Control
MRAS	Model Reference Adaptive System
PI/PID	Proportional-Integral /Proportional-Integral-Derivative (Regulator)
PMSM	Permanent Magnet Synchronous Motor
PWM	Pulse Width Modulation
SMC	Sliding Mode Control
SVM	Space Vector Modulation
THD	Total Harmonic Distortion
V/f	Voltage over frequency
VSI	Voltage Source Inverter

List of Symbols

d,q	Direct, Quadrature
f	Frequency
f_v	Viscous friction coefficient
I	Current
i_d, i_q	Direct current, quadrature current
J	Moment on inertia
K_i	Integral gain
K_p	Proportional gain
L	Leakage inductance
L_s, L_r	Stator leakage inductance, Rotor leakage inductance
M	Mutual inductance
p	Pole pairs
R_s, R_r	Stator resistance, Rotor resistance
T_e	Electromagnetic torque
T_l	Load torque
V	Voltage
V_s	Stator voltage
ζ	Damping ratio
σ	Blondel leakage coefficient
Φ_s, Φ_r	Stator flux, Rotor Flux
Ω	Mechanical speed
ω_n	Natural frequency
ω_r	Rotor speed
ω_s	Stator pulsation
ω_{sl}	Slip speed

General Introduction

The induction motor (IM), thanks to its well-known advantages of simple construction, reliability, ruggedness and low cost, has found very wide industrial applications. Furthermore, in contrast to the commutation DC motor, it can be used in an aggressive or volatile environment since there are no problems with spark and corrosion. These advantages, however, are superseded by control problems when using an IM in industrial drives with high performance demands. For several years, academic and industrial research has been carried out to remedy the control problem of the IM and to develop robust and efficient controls.[1]

Scalar controls are simple to implement and offers good steady state response. However, the dynamics are slow because the transients are not controlled. To obtain high precision and good dynamics, vector control schemes have been invented for use with closed-loop feedback controls. At the beginning of 1970s, the principle of flux control was introduced and called 'field oriented control' or 'vector control' for squirrel cage induction machines and later for synchronous machines. [2]

Other vector control methods and intelligent control techniques were developped since, each having it's own advantages, drawbacks and use cases.

This study will begin by a review on the primary motor control methods, namely scalar control (or constant V/f), Direct and Indirect Field-Oriented Control and Direct Torque Control. Many improvements of DTC are reported in litterature. DTC-SVM introduces a fixed switching frequecy to DTC to alleviate some of it's drawbacks, other recent improvement introduce more advanced control techniques like sliding modes or artificial intelligence to the DTC, these techniques are reviewed and their characteristics are compared in this work.

DTC is relient on a good estimation of the stator flux, but because in practice a pure integrator drifts over time due to errors and noise, tehcniques have been devolloped to reduce these influences and produce a good flux estimation, most of these rely on low-pass filters. A review of some of these techniques is given.

Finally, a review is given on recent and more advanced intelligent control methods namely AI based control and predictive control, concluding with an exposition on sensorless control.

I STATE OF THE ART ON THE MOST POPULAR CONTROL METHODS

I.1 Introduction

Induction motors are the most widely used motors in the world. Many control methods have been developed for these motors. A state-of-the-art review on induction motor control is given in this work. First, scalar control is presented. Then, a review on FOC, DTC and DTC-SVM is given. A review on multiple flux estimation techniques is then carried out. Finally, Intelligent control and sensorless control are introduced.

I.2 Scalar Control (V/f constant)

Scalar control is based on the steady-state model of the motor. The control is due to the magnitude variation of the control variables only and disregards the coupling effect in the machine. For example, the voltage of a motor can be controlled to control the flux, and frequency or slip can be controlled to control torque. However, flux and torque are also functions of frequency and voltage respectively. This method is simple and easy to implement, but the inherent coupling effect (i.e., both torque and flux are functions of voltage or current and frequency) gives sluggish response. As a result, the scalar control technique has poor dynamic performance. The scalar controller is usually used in low-cost and low-performance drives.[3]

The principle of this control is to maintain constant the ratio V/f, which means keeping the core stator flux constant. If the value of the resistance of the stator windings is neglected, like it is often the case, the electromagnetic torque-slip characteristic in the stationary regime takes the following form:

$$T_e = \frac{3p}{\omega_s}.V_s^2.\frac{\frac{R'_r}{s}}{\left(\frac{R'_r}{s}\right)^2 + (L\omega_s)^2} \quad \text{(I.1)}$$

With s: slip, $\frac{R'_r}{s}$: Equivalent resistance of rotor conductors reduced to the stator, p: number of pole pairs, ω_s: Stator pulsation, V_s: stator voltage, L: leakage inductance converted to the primary side.

Often, we are interested in the maximum value of the torque. To calculate it, we look for the value of s that maximizes the expression of the electromagnetic torque T_e and then replace it in Eq.(I.1) which yields:

$$T_e = \frac{3p}{2L}\left(\frac{V_s}{\omega_s}\right)^2 \tag{I.2}$$

Therefore, the maximum torque in steady-state is proportional to the square of $\frac{V_s}{2\pi f_s}$.

I.3 FOC

Scalar controls are simple to implement and offer good steady-state response, however the dynamics are slow because the transients are not controlled and the decoupling effect is not taken into consideration, that is why vector control schemes have been invented for use with closed-loop feedback controls in 1970s and 1960s by Blaschke and Hasse in two different approaches : the Direct Field oriented control (FOC)[4], and the Indirect field oriented control[5].

The concept behind FOC is to control the induction motor similar to a separately excited DC motor, the advantage being that in a DC motor flux and torque are inherently decoupled which allows the control of the DC motor in a simple and more efficient manner[6]. This also allows to control the torque and flux of an IM independently through the proper transformation[7]. The processing of vector control is however complex and computational-heavy, it requires the use of high-speed microcontrollers and DSPs[6].

Figure I.1 shows a general representation of vector control strategy for a three-phase induction motor.

The difference between Indirect or feedforward field-oriented control and the direct or feedback method of field-oriented control is the principle of generation of control angle theta (θ), in the first it is obtained by using rotor position measurement and machine parameter’s estimation while in the latter it is obtained by the terminal voltages and currents.[6]

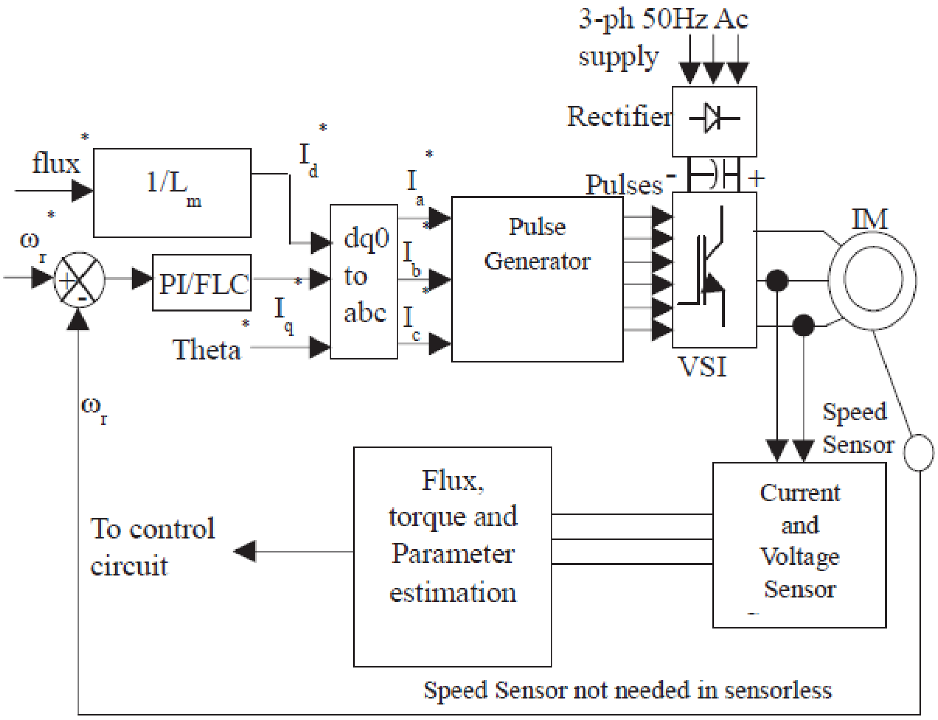

Figure I.1 : Block diagram of general vector control scheme

I.3.1 Indirect Field Oriented Control

It was presented in [5] by HASSE in 1969. In this scheme the unit vector θ_e is calculated in an indirect manner using the measured speed ω_r and the slip speed ω_{sl} as show in Eq.(I.3).

$$\theta_e = \int (\omega_r + \omega_{sl})dt \tag{I.3}$$

This computation was complex and resulted in high cost, but with the advent of microprocessors, the computation process has been simplified greatly and can now be implemented on high speed processors and DSPs with reduced cost and time [6].

The main research topics in this control scheme is the motor parameter estimation, the modulation strategies, controller performance and efficiency optimization.

In [8] a new identification technique was described where it is possible to calculate the resistance online by injecting the negative current component and identifying the negative voltage component, while [9] proposes an expression involving calculation of rotor parameter through stator current and stator voltage which has the advantage of not requiring the calculation of stator resistance and integration but with a higher cost.

A space vector modulation has been proposed in [10] requiring no time-varying coordinate transformation and no complicated calculation.

In addition, the proposed controller uses the extra information of error derivative to reduce the switching frequency greatly.

[11] proposes a fuzzy adaptive control scheme for vector controlled IM drive to estimate rotor parameters and [12] proposed a combined feedforward and feedback control technique to improve the robustness of vector controlled IM drive system.

A method involving optimization of flux vector based on power loss equation in terms of decupled current component has been proposed in [13].

I.3.2 Direct Field oriented Control

This scheme was first proposed by BLASCHKE in 1972 [4]. In direct FOC the rotor angle is obtained by the terminal voltages and currents directly by using flux estimators. It is also known as feedback vector control. Multiple controllers have been implemented to improve the performance of the drive.

[14] proposes a feedforward neural network technique for estimation of feedback signals of a direct vector-controlled (DVC) IM drive, it has the advantage of quicker processing, greater tolerance to fault and lesser harmonic ripple and in [15] a neuro fuzzy approach for a stator flux oriented vector controlled drive is proposed.

I.4 DTC

Direct torque control was first patented in Germany on October 20th 1984 by Manfred DEPENBROCK [16][17] and termed the technique direct self-control, however a paper describing a similar technique was described earlier in September of the same year by Isao TAKAHASHI and Toshihiko NOGUCHI in an IEEJ paper termed Direct Torque Control [18], and later published in 1986 in English in an IEEE paper[19]. The difference between the two techniques is the path the flux vector is controlled on, in TAKAHASHI's approach it is circular, while in DEPENBROCK's it follows a hexagon. DSC is best suited for high power applications, as a low inverter switching frequency can justify higher current distortion [20]. Unlike FOC that aims to reproduce the electromagnetic behavior of a DC motor, DTC tries to exploit the torque and flux producing capabilities of the IM fed by a voltage source inverter (VSI).

The basic DTC scheme is characterized by the absence of a coordinate transformation, PWM signal generators and current regulators, but instead uses a Switching Table to determines the switching state selection and requires the estimation of stator flux vector and torque estimation[1].

Figure I.2 shows a block diagram of the conventional “TAKAHASHI” DTC scheme.

This scheme uses two hysteresis controllers. The stator flux controller imposes the time duration of the active voltage vectors, which moves the stator flux along the reference trajectory, and the torque controller determinates the time duration of the zero voltage vectors, which keeps the motor torque in the tolerance band of the hysteresis controller. At every sampling time the voltage vector the inverter switching state (S_a, S_b, S_c) are chosen according to the switching table as to reduce the instantaneous flux and torque errors [1].

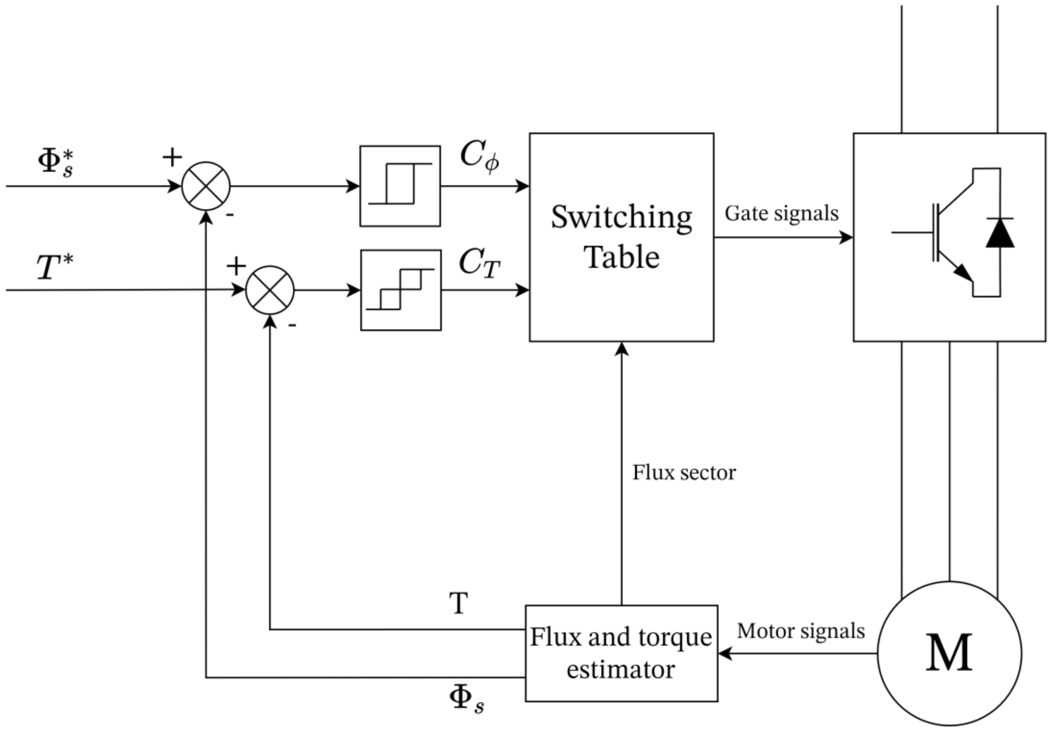

Figure I.2 : Block diagram of the generic DTC

The generic DTC introduced by TAKAHASHI and DEPENBROCK has may benefits, it is robust without the need of a speed/position sensor, the frequent calculation of optimum switching means that the drive can respond rapidly to external influences, no process interruptions after short supply outages, it can start into a motor which is running at any speed without waiting for the flux to decay [21]. It requires no current control loops, no extra block for voltage modulation and no coordinate transformation. This control method is superior to field-oriented control (FOC) in that it only relies on a simplified and qualitative machine behavior and doesn’t require and encoder, but achieves good flux and torque dynamic performance [22].

DTC however has many drawbacks. First, the use of a switching table leads to variable switching frequency, which makes it unsuitable for high power application, second is the high noise level, third the complicated starting and low frequency operation and lastly the undesirable torque ripples [22].

A comparison between the primary characteristics of FOC and DTC are presented in Table I.1.

To alleviate these problems many improvements to DTC have been introduced. Figure I.3 classifies these techniques in a diagram [23].

Table I.1 compares between FOC and DTC [24][25].

TABLE I.1 : COMPARISON BETWEEN FOC AND DTC

Comparison property	DTC	FOC
Dynamic response to torque	Very fast	Fast
Coordinates reference frame	alpha, beta (stator)	d, q (rotor)
Low speed (< 5% of nominal) behavior	Requires speed sensor for continuous braking	Good with position or speed sensor
Controlled variables	torque & stator flux	rotor flux, torque current iq and rotor flux current id vector components
Steady-state torque/current/flux ripple & distortion	Low (requires high quality current sensors)	Low
Parameter sensitivity, sensorless	Stator resistance	d, q inductances, rotor resistance
Parameter sensitivity, closed-loop	d, q inductances, flux (near zero speed only)	d, q inductances, rotor resistance
Rotor position measurement	Not required	Required (either sensor or estimation)
Current control	Not required	Required
PWM modulator	Not required	Required
Coordinate transformations	Not required	Required
Switching frequency	Varies widely around average frequency	Constant
Switching losses	Lower (requires high quality current sensors)	Low
Audible noise	spread spectrum sizzling noise	constant frequency whistling noise
Control tuning loops	speed (PID control)	speed (PID control), rotor flux control (PI), id and iq current controls (PI)
Complexity/processing requirements	Lower	Higher
Typical control cycle time	10-30 microseconds	100-500 microseconds

The first typical improvement to be proposed is the use of space vector modulation (SVM) in controlling the voltage inverter, which is referred to as DTC-SVM and was introduced in the early 1990s for constant frequency operation by HABELTER et al. in [26].

[27] proposed a method of direct torque control of an IM based on fixed switching frequency pulse width modulation (PWM), developed in discrete time to allow easy implementation on a DSP or a microcontroller.

Figure I.3 shows a diagram classifying the different improvement techniques of direct torque control.

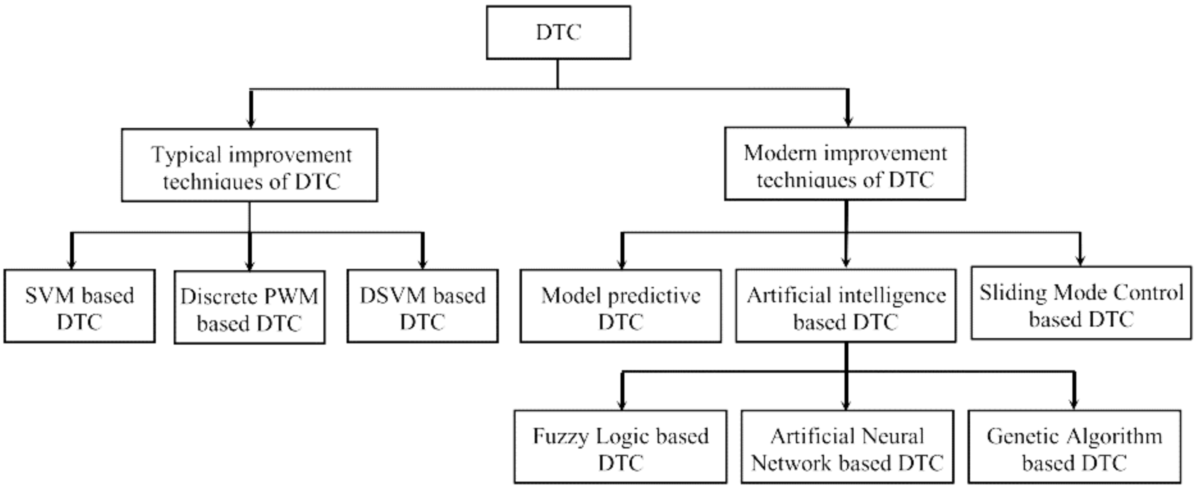

Figure I.3 : Classification of improvement techniques of direct torque control

Other advanced improvements of DTC have been studied, including Sliding Mode Control introduced by Utkin in 1993 in [28], model predictive DTC which is based on the calculation of the future behavior of the system based on the dynamic model of the process inside the real-time controller to calculate the optimal values of the adjustment parameters [23] and other AI based DTC schemes based on artificial neural networks, fuzzy logic, genetic algorithms and expert systems each with its advantages and use cases.

Table I.2 Shows a comparison between the performances of different improvement techniques of direct torque control [23].

TABLE I.2 : COMPARISON OF THE IMPROVEMENT TECHNIQUES OF DIRECT TORQUE CONTROL

Criterion	Conventional DTC	SVM based DTC	SMC based DTC	DTC-MPC	Fuzzy based DTC	ANN based DTC	GA based DTC
Torque dynamic response	Fast	Fast	Fast	Fast	Very fast	Very fast	Very fast
Torque and flux ripple	High	Low	Medium	Low	Very low	Very low	Medium
Current THD	More distortions	Less distortion	Less distortion	Less distortion	Less distortion	Less distortion	Less distortion
Switching frequency	Variable	Constant	Almost constant	Constant	Constant	Constant	Almost constant
Parameter sensitivity	Insensitive	Sensitive	Insensitive	Insensitive	Insensitive	Insensitive	Insensitive
Switching loss	High	Low	Medium	Low	Low	Low	Medium
Dynamic at low speed	Poor	Good	Good	Good	Very good	Very good	Very good
Algorithm complexity	Simple	Simple	Complex	Simple	More complex	More complex	Complex
Computation time	Low	Medium	High	Medium	High	High	Medium
Precession	Low	Medium	Medium	Medium	High	High	Medium
Regulation	Hysteresis	PI conventional	SMC controller	Hysteresis	FLC	ANN	GA-PI

I.5 DTC-SVM

Many studies investigated the possibility to associate space-vector modulation techniques with DTC in order to control the switching frequency, SVM being the most popular technique for the control of inverter switches. The controller calculates the required stator voltage vector and then it is realized by SVM technique. The main difference between the generic DTC and DTC-SVM is that DTC is based on instantaneous values whereas DTC-SVM methods are based on averaged value.

Several DTC-SVM methods have been addressed in literature, the simplest and most used is DTC-SVM with PI regulators, but others include schemes with predictive/dead-beat controllers, schemes based on fuzzy logic and/or neural networks [29].

The SVM technique uses eight sorts of different switch modes of inverter to control the stator flux to approach the reference flux circle. Eight switch modes correspond respectively to eight space voltage vectors that contain six active voltage vectors and two zero voltage vectors. The six active voltage vectors form the axes of a hexagon. The two zero voltage vectors are at the origin. The eight vectors are called the basic space vectors.

Figure I.4 represents the switch modes and voltage vectors.

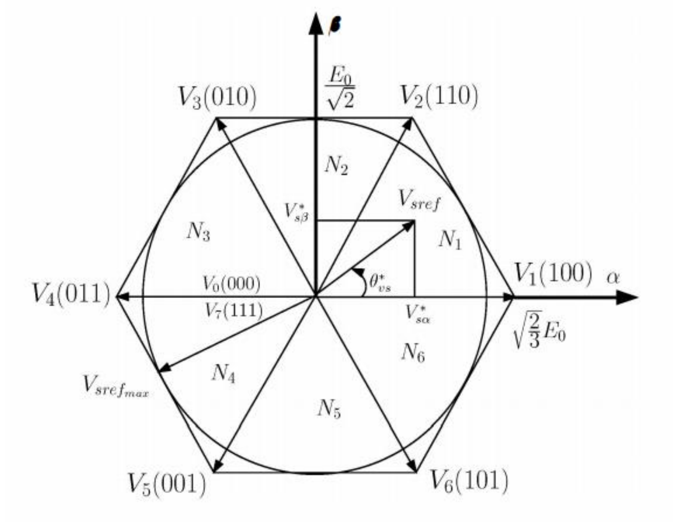

Figure I.4 : Basic switching vectors and sectors

In a PI controlled DTC-SVM IM, many structures exist : DTC-SVM scheme with closed-loop flux control where the rotor flux is assumed as a reference [30], DTC-SVM scheme with closed-loop torque control which was originally proposed for permanent magnet synchronous motor (PMSM), DTC-SVM scheme with closed-loop torque and flux control operating in polar coordinates and DTC-SVM scheme with closed-loop torque and flux control in stator flux coordinates.

Table I.3 gives a comparison between the three main control methods: FOC, DTC and DTC-SVM[29].

TABLE I.3 : ADVANTAGES AND DISADVANTAGES OF FOC, BASIC DTC AND DTC-SVM CONTROL METHODS

Control Methods	FOC	DTC	DTC-SVM
Advantages	-Constant switching frequency -Unipolar inverter output voltage -Low switching losses -Low sampling frequency -Current control loops	-Structure independent on rotor parameters, universal for IM and PMSM -Simple implementation of sensorless operation -No coordinate transformation -No current control loops	-Structure independent on rotor parameters, universal for IM and PMSM -Simple implementation of sensorless operation -No coordinate transformation -No current control loops -Constant switching frequency -Unipolar inverter output voltage -Low switching losses -Low sampling frequency
Disadvantages	-Coordinate transformation -Multiple control loops -Control structure dependent on rotor parameters	-Bipolar inverter output voltage -Variable switching frequency -High switching losses -High sampling frequency	-High CPU time -More complex

II FLUX ESTIMATORS

High-performance motor drives, such as field-oriented controlled and direct-torque controlled alternating current (AC) drive require accurate stator flux estimation. For AC machines, there exist two models for flux estimation, namely the voltage model and the current model. The current model estimation is known to be efficient in low and medium speed range, especially when combined with high-frequency injection-based estimation techniques. Nevertheless, the accuracy of the current model is highly dependent on the knowledge of the machine inductances. On the other hand, the voltage model, which consists of integrating the stator back-electromotive force (EMF) signal, is known for its good performance at medium and high speeds. The main advantage of the voltage model is its robustness against the machine parameters; it only requires the stator resistance, which can be quite accurately known in various applications [31].

In practice, the pure integration is prone to drift problems due to noises, measurement error, stator resistance uncertainty and unknown initial conditions. This limitation becomes more restrictive at low speed operation. Several solutions are reported in the literature.

A stator winding of an electric motor can be seen as a connection of a resistance R_s in series with a coil having time-varying inductance. The voltage equation can be written as:

$$v_s = R_s i_s + \frac{d\Phi_s}{dt} \tag{II.1}$$

Therefore, the stator flux vector can be estimated by integrating the back-EMF (e_s):

$$\Phi_s = \int (v_s - R_s i_s) = \int e_s \tag{II.2}$$

To ensure an accurate estimation, several algorithms have been reported in the literature. They can be summarized using the following general formulation:

$$\dot{\hat{\Phi}}_s = e_s + \omega_c(t)(\Phi_s^{cor} - \hat{\Phi}_s) \tag{II.3}$$

The generality of this structure lies in the choice of Φ_s^{cor}; depending on this choice different estimation algorithms can be derived. Particular algorithms are apparent. Choosing $\Phi_s^{cor} = \hat{\Phi}_s$ yields a pure integrator and choosing $\Phi_s^{cor} = 0$ results in a low-pass filter with a corner frequency ω_c.

II.1 Numerical integration

In discrete form equation I.5 can be implemented with the following formula:

$$u(k+1) = u(k) + \frac{T_s}{2}[x(k) + x(k+1)] \tag{II.4}$$

where T_s is the sampling time, u(k+1) and u(k) are present and previous outputs respectively and x(k+1) and x(k) are present and previous inputs respectively [1].

II.2 Low-pass filter (LPF)

A low-pass filter with fixed cutoff frequency can be represented in discrete form by:

$$u(k+1) = \frac{2 - \omega_c \times T_s}{2 + \omega_c \times T_s} u(k) + \frac{T_s}{2 + \omega_c \times T_s}[x(k) + x(k+1)] \tag{II.5}$$

Where $\omega_c = 2\pi f_c$ is the cut-off frequency of the LPF [32].

II.3 Compensated LPF based flux estimation

[32] proposed a compensation technique to eliminate the phase and magnitude errors caused by the LPF based estimation. A diagram of the method is shown in Figure II.1.

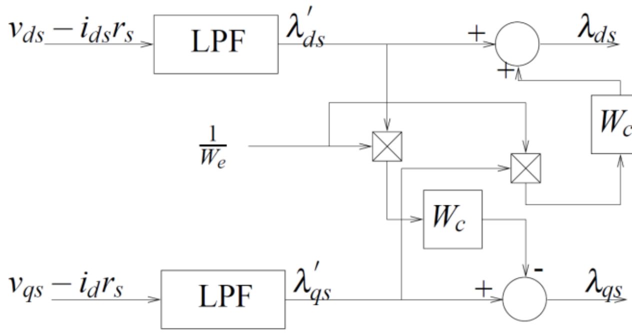

Figure II.1 : Block diagram of the Low-pass filter with stator flux compensation

The estimator's equation is:

$$\lambda_{ds} = \frac{\omega_c}{\omega_e}\lambda'_{qs} + \lambda'_{ds}$$
$$\lambda_{qs} = -\frac{\omega_c}{\omega_e}\lambda'_{ds} + \lambda'_{qs} \qquad \text{(II.6)}$$

Where ω_e is the operating frequency and λ_{ds} and λ_{qs} are the d,q components of the stator flux respectively.

II.4 Cascaded LPF based flux estimation

In [33], instead of using a single-stage filter where the time constant of the filter is large making the system response slow to decay the offset, cascaded low-pass filters with short filter time constants are used decreasing the time taken to decay the offset.

Figure II.2shows the block diagram of two cascaded LPFs where τ is time constant, G the gain and ω_e is the operating frequency. T and G are given by:

$$\tau = \frac{1}{\omega_e}\tan\left(\frac{pi}{2n}\right)$$
$$G = \frac{1}{\omega_e}\sqrt{[1 + (\tau\omega_e)^2]^n} \qquad \text{(II.7)}$$

With n the number of cascaded filters.

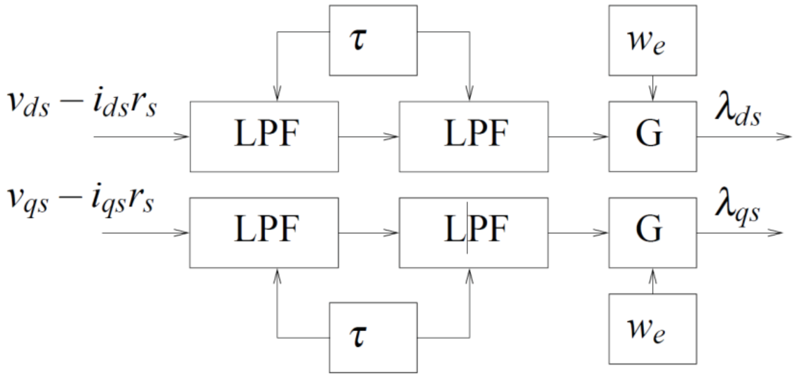

Figure II.2 : block diagram of two cascaded low-pass filters

II.5 High-pass Low-pass filter based flux estimation

[34] proposed using a low-pass filter to restrict the initial value error and using a high-pass filter to remove the offset input.

The structure of this estimator is shown in Figure II.3.

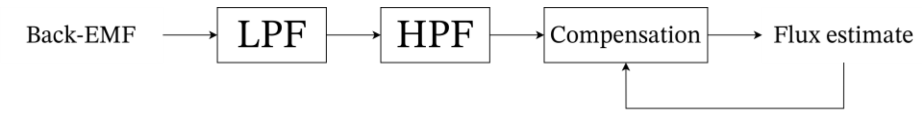

Figure II.3 : Structure of the LPF-HPF estimator

The cutoff frequency of the low-pass filter is set to $\omega_{c1} = k_1\omega_e$ and the cutoff frequency of the high pass filter set to $\omega_{c2} = k_2\omega_e$. The optimal coefficient k_1 is between 0.2 and 0.3, k_2 is generally set to $k_1/2$.

III Advanced motor control

Intelligent Control includes all control techniques other than scalar and vector controls like artificial intelligence-based techniques including artificial neural networks and fuzzy-logic based controllers, sliding modes and predictive control.

III.1 AI Based Control

Artificial intelligence (AI) and Biologically-inspired techniques, particularly the neural networks, are recently having significant impact on power electronics and electric drives. Neural networks have created a new and advancing frontier in power electronics, which is already a complex and multidisciplinary technology that is going through dynamic evolution in the recent years [35].

These include neural network-based controllers that feed the input signals to a trained neural network which outputs the control states for the inverter, fuzzy logic which is based on the principles introduced by ZADEH in his 1965 paper [36], but they also include other biologically-inspired techniques like genetic algorithms and brain emotional learning which is inspired by the limbic system of mammalian brain and emotional learning based action selection [35].

Some papers combine different intelligent control methods like fuzzy-neural networks [37].

III.2 Predictive Control

Predictive control predicts the changes in the dependent variable of the modeled system that will be caused by the change in the independent variable. The predictive control techniques are typically classified into dead beat control, hysteresis and trajectory-based control and model predictive control [22].

Dead-beat control makes the error signals go to zero in the next sampling instant. In hysteresis and trajectory-based control, an optimization criterion is used to keep the controlled variables within the band. Model predictive control method combines the use of PI control and the predictive model of the system for the improvement of both steady state and dynamic response of the system, it's block diagram is shown in Figure III.1.

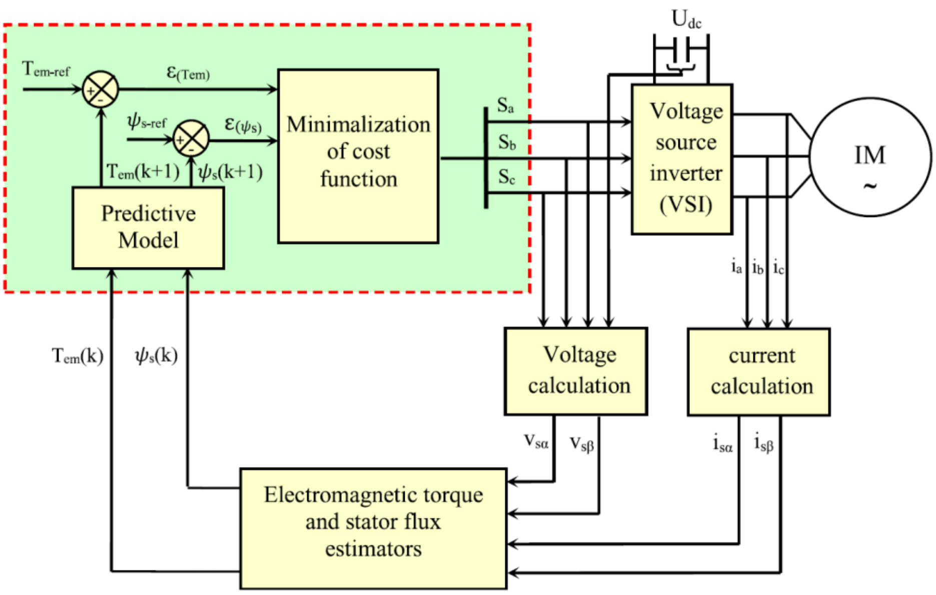

Figure III.1 : Model predictive Torque Control block diagram

The advantages of this technique are: the use of online optimization technique, switching tables are not used, switching losses are reduced and it features an improved steady state and dynamic response. However, it requires a tedious tuning work [22].

III.3 Sensorless Control

In recent years, the application of sensorless AC motor drives is expanding in areas ranging from industrial applications to household electrical appliances. The advantages of sensorless motor drives include lower cost, increased reliability, reduced hardware complexity, better noise immunity and less maintenance requirements.

Sensorless Control aims at removing the need for a mechanical position/speed sensor in a vector control system, this increases the reliability of drive systems and reduces cost and complexity [38].

Figure III.2 show the block diagram of a typical IM vector control system where the speed and flux are estimated through an observer.

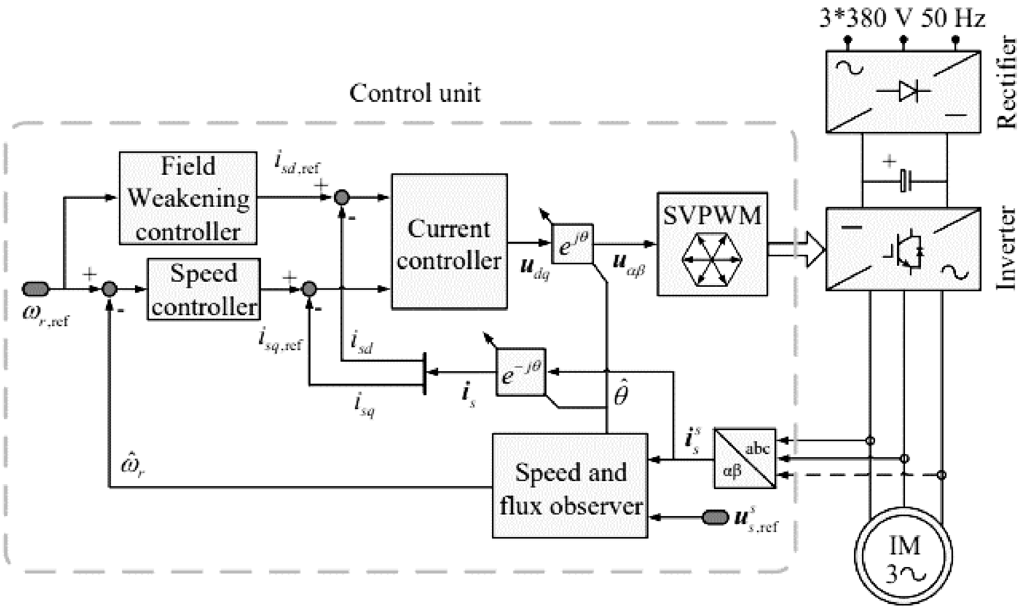

Figure III.2 : Block diagram of typical IM vector control System

A lot of researches have been done on flux and speed observer of IM sensorless drive system, mainly includes: low frequency signal injection method [39], high frequency signal injection method [40] and model reference adaptive system (MRAS) [41], full order flux observer [42], reduced order observer [43], sliding mode observer [44], neural network [45], and Kalman filter [46]. These methods can be classified into two categories:

- Signal injection-based flux and speed observer which works by injecting a signal and uses rotor slot harmonic and leakage inductance to extract the rotor position information.

- IM model-based flux and speed observer which works by first establishing the mathematical model of the IM and then estimating the rotor flux and rotor speed.

GENERAL CONCLUSION

In this thesis, a state-of-the-art review was presented on the main control methods for induction machines as well as more advanced control methods.

V/f constant is the least complex control method, it doesn't rely on any motor parameters. It can be implemented in an open-loop or closed-loop setting. Vector control algorithms try to emulate the functioning of a DC motor, they are heavily reliant on motor parameters and often very complex. DTC control requires only the knowledge of stator resistance but directly controls the torque and flux of the motor. DTC-SVM introduces the Space Vector Modulation to DTC to reduce torque ripple, current distortion and fix the switching frequency.

A review on different flux estimation techniques was given.

In recent years, more advanced techniques are being introduced to motor control algorithms, especially fuzzy logic controllers and artificial neural networks, especially for regulators and estimators.

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