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Real Time Implementation of Fuzzy Logic Based Direct Torque Control of Three Phase Induction Motor

Abstract. *Torque by means the space vector modulation (DTC-SVM) technique using a fuzzy logic controller and applied to the induction drive powered by a two-level inverter. Direct torque control (DTC) is used to achieve torque decoupling fuzzy regulation and space vector modulation in order to keep torque ripple and flux to a minimum. This paper uses a DTC-SVM method based on fuzzy logic controllers to overcome the limitation of DTC-SVM based PI controllers, such as sensitivity to machine parameter variation and external disturbance. In the end, the feasibility and effectiveness of the suggested methods are experimentally confirmed Validation with a real-time Matlab / Simulink program DSpace-based interface1104*

Streszczenie. *Moment obrotowy za pomocą techniki modulacji wektora przestrzennego (DTC-SVM) z wykorzystaniem sterownika logiki rozmytej i zastosowany do napędu indukcyjnego zasilanego przez dwupoziomowy falownik. Bezpośrednie sterowanie momentem obrotowym (DTC) służy do uzyskania rozmytej regulacji z odsprzęganiem momentu obrotowego i modulacji wektora przestrzennego w celu ograniczenia tętnienia i strumienia momentu obrotowego do minimum. W artykule wykorzystano metodę DTC-SVM opartą na sterownikach z logiką rozmytą w celu przezwyciężenia ograniczeń sterowników PI opartych na DTC-SVM, takich jak wrażliwość na zmiany parametrów maszyny i zakłócenia zewnętrzne. Ostatecznie wykonalność i skuteczność proponowanych metod jest potwierdzona eksperymentalnie Walidacja z programem czasu rzeczywistego Matlab / Simulink opartym na interfejsie DSpace1104 (**Implementacja w czasie rzeczywistym opartej na logice rozmytej bezpośredniej kontroli momentu obrotowego trójfazowego silnika indukcyjnego**)*

Keywords: dSpace1104 ; DTC-SVM ; fuzzy logic ; Induction motor;.
Słowa kluczowe:. dSpace1104; DTC-SVM ; logika rozmyta ; Silnik indukcyjny;

Introduction

The induction motor coupled to a frequency converter is the most used type of motor for applications where it is necessary to control the speed and movement of a load.

Because of its undeniable benefits (reliability and ease of design and maintenance, low cost, and, most all, the lack of the brush-collector assembly), the asynchronous machine is widely used, is the most used in industry, researchers never tire of improving its performance both on the asynchronous machine (IMs) and (PMSMs) are the most common AC machines. The induction machine has been increasingly successful for two decades by gradually replacing DC and synchronous machines in many industrial and transport applications.[1]-[2]

This success achieved by the induction machine is due to its robust design, which reduces maintenance costs by a relatively low cost compared to other electrical machines and also by increasing the computing capacity of the microprocessors to achieve high-performance control.

To get around the parametric adaptation problems raised by Takahashi and Depenbrock in 1985. The fundamental idea behind DTC is that stator voltage vectors should be chosen explicitly based on the changes in torque references and stator flux between the theoretical and actual values [3]-[9]

The current controllers, which are followed by an MLI comparator, are not utilized in DTC commands, and machine parameters are not used either, with the exception of the motor's Stator resistance.

As a result, the advantage of DTC is that it is less dependent on machine characteristics to provide a rapid torque response by pulse width when compared to torque control current controls for modulation and a simpler configuration. Several attempts are now being designed to improve the DTC instruction in terms of reducing torque and switching frequency of the Range inverter. [10]-[13]

The disadvantages of the Classic DTC strategy are also significant and most are derived from the fact that the switching frequency is highly variable

This can naturally raise problems of electromagnetic compatibility because it becomes difficult to guarantee the non-existence of harmonics at given frequencies.
On the other hand, the variations of the speed switching frequency and the torque from a few tens of Hz at low speed to a few khz at medium speed necessarily generates a high intensity audible noise which can be particularly annoying at low speed.

In order to overcome the problem of switching frequency variation; related to the structure of conventional DTC control, we are going to study, control technique, based on SVM modulation.

The torque and flux ripples under steady state can be reduced by fuzzy logic switching controller[14]-[20]
In this research, a fuzzy logic controller for IM drives with space vector modulation is presented to address most of the limitations of standard DTCs and provide good control performance, such as low ripple level and quick dynamic with simplicity and robustness.

2. Model Presentation

In the stationary frame, the following is a description of the induction motor system:

(1) $$\dot{x} = f(x) + gV_{s\alpha\beta}$$

(2) $$x = \left[\, i_{s\alpha}\; i_{s\beta}\; \psi_{s\alpha}\; \psi_{s\beta} \right]$$

(3)
$$f(x) = \begin{bmatrix} -\frac{1}{\sigma L_s}(R_s + \frac{L_m^2}{L_r T_r}) & \omega_s & \frac{L_m}{\sigma L_s L_r T_r} & \frac{\omega L_m}{\sigma L_s L_r} \\ -\omega_s & -\frac{1}{\sigma L_s}(R_s + \frac{L_m^2}{L_r T_r}) & \frac{\omega L_m}{\sigma L_s L_r} & \frac{L_m}{\sigma L_s L_r T_r} \\ \frac{L_m}{T_r} & 0 & \frac{1}{T_r} & -\omega_s \\ 0 & \frac{L_m}{T_r} & -\omega_s & \frac{-1}{T_r} \end{bmatrix}$$

(4)

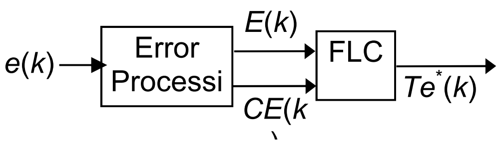
$$[B]=\begin{bmatrix} \frac{1}{\sigma L_s} & 0 \\ 0 & \frac{1}{\sigma L_s} \\ 0 & 0 \\ 0 & 0 \end{bmatrix}$$

where: $f(x)$ expresses the state variable x as a nonlinear function; $I_{s\alpha}, I_{s\beta}$ are the stator current components; $V_{s\alpha\beta}$ Represents the system-applicable control vector, that's represented in components of the stator voltage; $\psi_{s\alpha}, \psi_{s\beta}$: stator flux components; Rs, Rr : inductance of rotor and stator, respectively; Ls , Lr : inductance of stator and rotor, respectively; $\sigma = 1 - \frac{M_{sr}}{L_s L_r}$: Blondel's coefficient; Ts,Tr : The time constants for the stator and rotor; Msr is the mutual inductance of rotor-stators

3. Fuzzy Logic Controller Design

The most popular use of fuzzy logic is fuzzy control. Indeed, this method makes it possible to obtain an adjustment that is often very effective without having to do any modelling thorough Fuzzification, rule execution, and defuzzification are the three core modules of a fuzzy controller, which is a knowledge-based system. The fuzzy controller's main component is the rule base, which displays how the controller responds to each input condition. The rule is built on the selection of If-Then type rules:

$$R_j : If\ E(k) is\ A_j\ and\ CE(k)\ is\ B_j\ Then\ Te(k)\ is\ C_j, \quad j = 1..M$$



Fuzzy sets are : Bj, Aj and Cj

When NM (negative medium), NL (negative large), etc. defining fuzzy partition on the controller input space and CE(k) and E(k) are a scaled and normalized representation of the error e(k) the change in error ce(k) provided by:

(5)
$$E(k) = \text{ge}.e(k)$$
$$CE(k) = \text{gce}.ce(k)$$

where

(6)
$$e(k) = \Omega_m(k) - \Omega(k)$$
$$ce(k) = e(k) - e(k-1)$$

The membership function, which indicates the degree of membership of E(k) in the fuzzy set Aj, , introduces the sentence "E(k) is Aj " This is known as the fuzzification process. The membership feature's appearance is highly subjective and is determined by the user's selection. Trapezoidal and triangular shapes are commonly utilized for their simplicity. The rules are either derived from engineering expertise or generated automatically by an adjustment method.

The logical operators "and" and "Then" can be interpreted as a min or algebric object, and various defuzzification and inference methods can be used to get a crisp output result [20]-[25]. The crisp value of the controller output is: if the operators "and" and "then" are implemented as algebrics and the max-product inference and centroid defuzzification procedures are used.

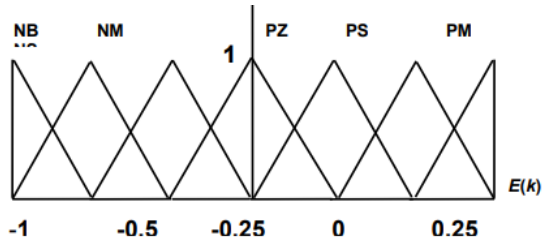
(7)
$$Te^*(k) = \frac{\sum_{j=1}^{M} m_{A_j}(E(k)).m_{B_j}(CE(k)).c_{0j}}{\sum_{j=1}^{M} m_{A_j}(E(k)).m_{B_j}(CE(k))}$$

where c0j is the middle of Fuzzy set Cj membership function, , such that . The equation above can be written as:

(8)
$$Te^*(k) = \sum_{j=1}^{M} m_j(k).c_{0j}$$

Where mj(k) is the uniform degree of j th rule contribution to controller performance

(9)
$$m_j(k) = \frac{m_{A_j}(E(k)).m_{B_j}(CE(k))}{\sum_{j=1}^{M} m_{A_j}(E(k)).m_{B_j}(CE(k))}$$



Fig/ 1. Membership

Fuzzy has seven input membership functions, and output is Negative Large (NL), Negative Medium(NM), Small Negativ(NS), Zero(Z), Positive Small(PS), Positive Medium(PM), and Large Positive(PL). Rules used in Fuzzy logic controller for DTC-SVM; Scheme appears in the Table 1.

Table 1. Fuzzy Logic Control Rules

ΔTe / ΔTe^*	NL	NM	NS	ZE	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	ZE
NM	NL	NL	NL	NM	NS	ZE	PS
PM	NL	NL	NM	NS	ZE	PS	PM
ZE	NL	NM	NS	ZE	PS	PM	PL
PS	NM	NS	ZE	PS	PM	PL	PL
PM	NS	ZE	PS	PM	PL	PL	PL
PL	ZE	PS	PM	PL	PL	PL	PL

4. SVM based direct torque control

The torque ripple caused by the hyteresis band is a key flaw with traditional DTC. Even so, also with reducing bandwidths, the torque is still significant due to hysteresis frequency uncontrollability . Additionally, very small bandwidth values increase the Speed Flipping inverter

5. Experimental results

The experimental tests will also check the control scheme proposed was performed in the dSpace 1104 board equipped laboratory. The experimental setup for implementation of the induction motor drive is basically as illustrated in Fig. 2 : 1: 1.1 kW squirrel cage with induction motor 2: Semikron converter with IGBT inverter and a rectifier. 3: sensor velocity 4: Dspace 1104 5. Computer desktop with control desk 6: Load control panel with magnetic powder 7: Voltages sensor 8:Current sensor 9: GW-INSTEK Numerical oscilloscope

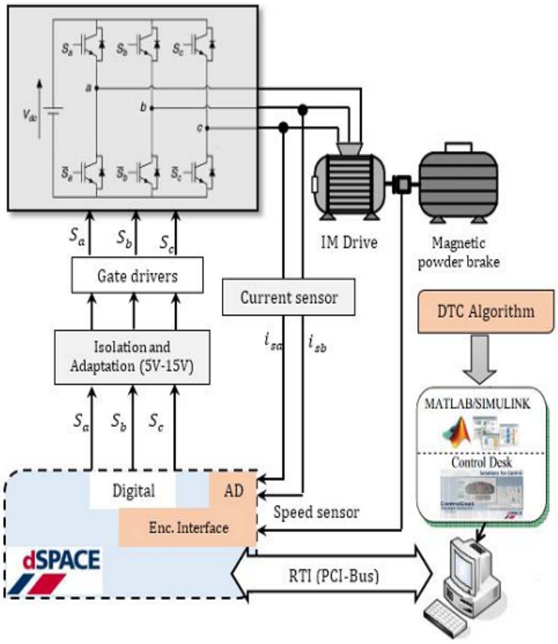


Fig..2 presentation of experimental setup

Fig. 3. Showing the experimental setup

The figures below display different operating conditions for induction motors, such as steady state, load activity ... etc. Fig.4 presents the experimental results of induction motor response at start-up and during load application. Figure 6 shows the stator flux with low ripples and follows its 1Wb reference. the use of DTC-SVM with fuzzy controller shows the rapidity of the flux response with a perfect continuation of its reference

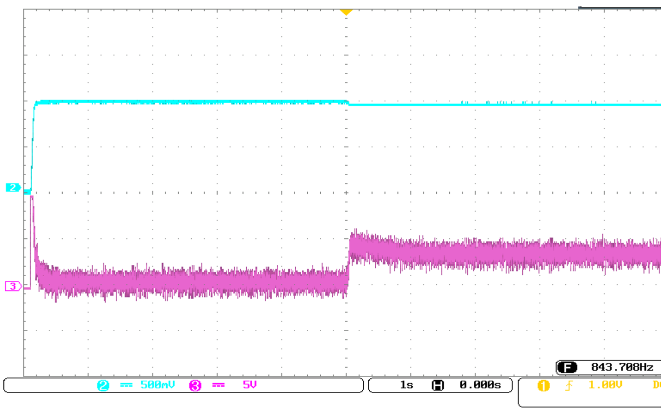


Fig. 4. Responses to speed and torque during starting and then load operation

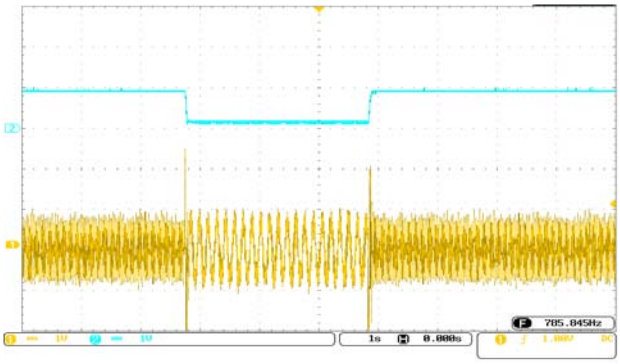


Fig. 5 . Speed(rpm) and Stator phase current isa (A)

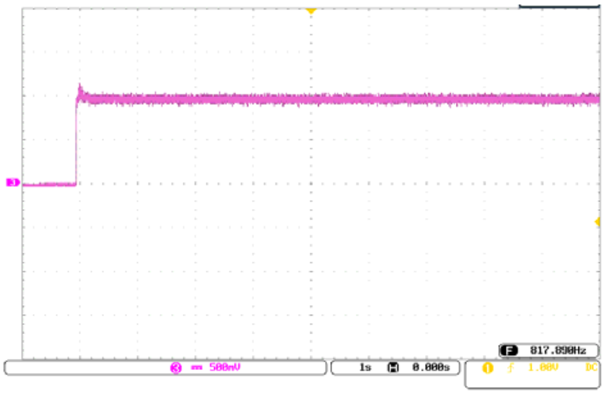


Fig. 6. magnitude of stator flux (Wb)

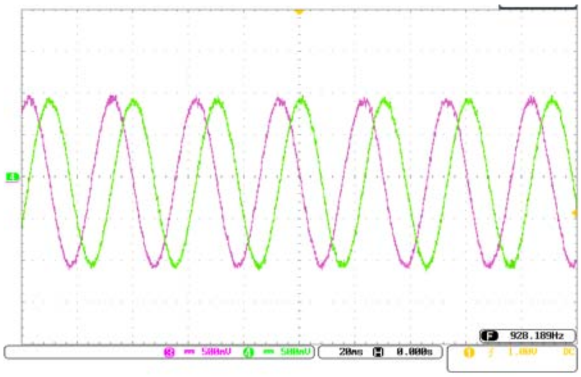


Fig. 7. stator flux response

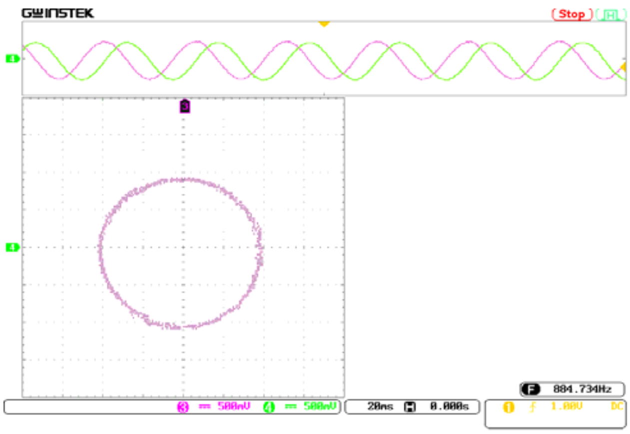


Fig. 8. Stator flux circular trajectory (ψsα, ψsβ)

In Fig 7, the flux components in the trajectory have the same strong waveform and degree of ripples. Fig.9 shows variable speed in various regions (1000 rpm-800rpm-600rpm-400rpm-200 rpm)

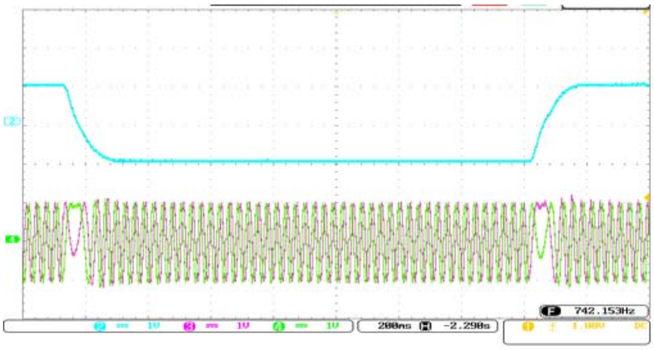


Fig. 9. Speed response with trapezoidal reference while direction reverses

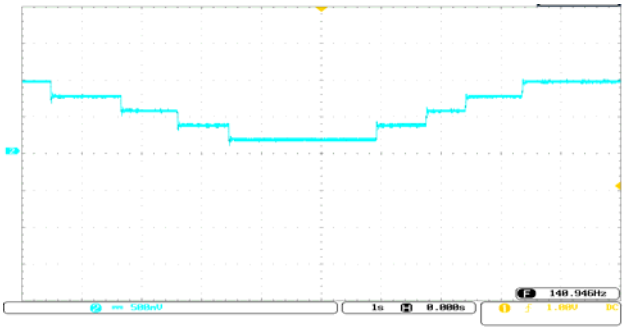


Fig. 10. Benchmark speed trajectory: speeds measured in various regions (1000 rpm-800rpm-600rpm-400rpm-200rpm)

7. Appendix

The parameters of experimental test bench are:
P= 1.1kw , Vs = 220/380 V , I=4.4 A, Msr= 0.4957 H, p=2 , f=0.002 SI, f=0.002 SI, J = 0.01240 kg.m2 Rs = 6.750 Ω, Rr = 6.210 Ω, Ls = 0.51920H , Lr =0.51920H

8. Conclusion

In this work, the direct torque control technique based on fuzzy controller was investigated. Constant switching frequency is used in this technique, which lowers inverter switching losses and harmonics in torque and flux. It also illustrates that by selecting an output voltage vector, the experimental results indicate that the fuzzy SVM-DTC may reduce flux and torque ripples.

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