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Original scientific paper

ADAPTIVE CONTROL OF DC MOTOR WITHOUT IDENTIFICATION OF PARAMETERS

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Abstract. *Parameter identification is a major problem in industrial environments where it might be difficult or even impossible in some situations. Moreover, non-measurable and unknown variations of system parameters can affect the performance of conventional proportional-integral (PI) controllers. The concept of developing a controller that does not depend on the system parameters seems very interesting. Therefore, this paper deals with the experimental implementation of model reference adaptive control of a DC motor without identifying parameters. Adaptive control is considered an online solution to control a system without knowing system parameters since it can be adjusted automatically to maintain favorable tracking performance. The simulation and experimental results are presented to demonstrate the effectiveness of the proposed control method.*

Key words: *uncertainty of the identification, adaptive control, reference model, DC motor*

1. INTRODUCTION

Due to the simple structure of DC motors and their low cost, they have been widely used in electromechanical systems that require movement [1-18]. The DC motors are used in vehicles [2], Unmanned Underwater Vehicles [15-16-17], industrial tools [3], and robotic manipulators [4]. Moreover, they are perfect for many applications requiring an accurate operation and high precision [5], due to their inherent decoupling between torque and speed as well as their simple control [20].

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Nevertheless, the parameters identification of DC motor is very important to achieve speed control [19-20]. However, the uncertainty of the measuring devices (like Ammeter and voltmeter) and the bad use of the identification techniques [10-11] poses a real problem to calculate PI controller which is based on parameters of the DC motor. To get rid of these identification problems many researchers proposed complex algorithms to enhance the identification results like genetic algorithms [12-13-14]. Moreover, the performances of the conventional controllers can be affected by the unknown load dynamics, external disturbance, and parameters variations [22-23-24].

Therefore, the main contribution in this paper is to develop a control mode that is not based on the parameters of the system to be controlled to avoid identification problems. Moreover, this mode of control will save time by skipping parameter identification after maintenance or changing the DC motor in case of machine failure. Also this mode of control must be robust against online parametric variations.

Model reference adaptive control (MRAC) has been utilized to deal with these problems [6]. This mode of control has been used to deal with systems as a black box. To achieve or maintain a certain level of performance when the parameters of the process are either unknown and/or vary over time. Adaptive control can automatically adjust controllers during implementation (effect: reduction of adjustment time and improvement of performance) and can automatically determine the optimal parameters of the controllers in the various operating points of the process [7].

In this article, the implementation of model reference adaptive control (MRAC) on DC motor (sonelecRME_24245) without making the identification of its parameters is made using Dspace 1104 carte. In the beginning, a theoretical study is made where a control law is defined to calculate adaptive controller parameters, then adaptive control is simulated by Matlab Simulink to visualize motor speed and the MRAC parameters theta 1, theta 2, and theta 3, finally, the implementation of the adaptive control is done.

2. Functioning Principle of the Model Reference Adaptive Control

Adaptive control with reference model is simple to implement and used to date in practice. The adaptive control scheme with reference model was originally proposed by Whitaker [8] (1958), the first applications of this technique date back to the early 70s. MRAC does not depend on the system parameters but the system is forced to follow the desired reference model [7].

The diagram given in Fig. 1 represents the principle of functioning of adaptive control with a reference model, the difference between the output of the system (DC motor) and the output of the reference model is used by the adaptation mechanism which also receives other information to automatically adjust the controller parameters [7-21].

MIT rule and Lyapunov theory can be used to develop the adaptation mechanism, according to research the method Lyapunov is more effective than the MIT rule [25]. Moreover, the complicacy is reduced in the configuration of MRAC with the Lyapunov rule as compared to the MIT rule, so the physical realization for the system under consideration is comparatively more feasible with the Lyapunov theory [26-27].

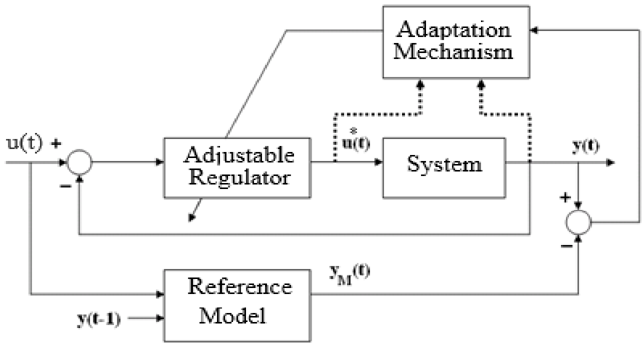

Fig. 1 Principle of functioning of model reference adaptive control

Model reference adaptive control contains two loops:

The internal loop is an ordinary feedback loop constituted by the process and the controller.

The external loop adjusts the controller parameters so that the tracking error e=y-ym is small.

3. Adaptive Controller Design

The problem of stability led several researchers in 1960 to consider the synthesis of adaptive controllers using stability theory like the second method of Lyapunov. The Lyapunov approach offers global stability properties for any restriction, either using the initial conditions of the error or the inputs of the system. The Lyapunov method is applied for the synthesis of the adaptive control with a reference model [9].

In the adaptive control, a Lyapunov function is determined and an adaptation mechanism is built to ensure that the tracking error e=y-ym converges to zero, the objective is to elaborate a control system that changes its parameters overtime to ensure that the tracking error converges to zero; it is about choosing a Lyoponov function, then chosing a control law that will decrease the derivative of this function.

3.1. State-space representation

System state space:

$$\begin{cases} \dot{x} = A_p x + B_p u = \begin{bmatrix} -(a+b) & -ab \\ 1 & 0 \end{bmatrix} x + \begin{bmatrix} 1 \\ 0 \end{bmatrix} u \\ y = C_p x = [1 \quad 0] x \end{cases} \tag{1}$$

reference model state space often defined from a technical specification or desired responses:

$$\begin{cases} \dot{x}_m = A_m x_m + B_m u_c = \begin{bmatrix} -2\zeta\omega & -\omega^2 \\ 1 & 0 \end{bmatrix} x + \begin{bmatrix} \omega^2 \\ 0 \end{bmatrix} u_c \\ y_m = C_m x_m = [1 \quad 0] x_m \end{cases} \tag{2}$$

3.2. Adaptive control law

The adaptive control law by state feedback is defined [7]:

$$\begin{cases} u = L_r u_c - Lx = \theta_3 u_c - \theta_1 x_1 - \theta_2 x_2 \\ L_r = [\theta_3] \text{ and } L = [\theta_1 \quad \theta_2] \end{cases} \tag{3}$$

The closed-loop system is:

$$\begin{cases} \dot{x} = (A_p - B_p L)x + B_p L_r u_c \\ \dot{x} = Ax + Bu_c \end{cases} \tag{4}$$

The matrices A, B, and C as a function of

$$\begin{cases} A(\theta) = A_p - B_p L = \begin{bmatrix} -(a+b)-\theta_1 & -ab-\theta_2 \\ 1 & 0 \end{bmatrix} \\ B(\theta) = B_p L_r = \begin{bmatrix} \theta_3 \\ 0 \end{bmatrix} \\ C = C_p = \begin{bmatrix} 0 & 1 \end{bmatrix} \end{cases} \tag{5}$$

Let us introduce the tracking error $e = x - x_m$ so:

$$\dot{e} = Ax + Bu_c - A_m x_m - B_m u_c = A_m e + (A - A_m)x + (B - B_m)u_c \tag{6}$$

This error tends to zero (0) if is stable

$$A(\theta) - A_m = 0 \quad and \quad B(\theta) - B_m = 0 \tag{7}$$

3.3. Unknown system parameters case

Let us define the Lyapunov function [7]:

$$V = e^T Pe + tr(A - A_m)^T Q_a (A - A_m) + tr(B - B_m)^T Q_b (B - B_m) \tag{8}$$

So:

$$\dot{V} = \frac{dV}{dt} = tr\begin{bmatrix} P\dot{e}e^T + Pe\dot{e}^T + \dot{A}^T Q_a (A - A_m) + \\ +(A - A_m)^T Q_a \dot{A} + \dot{B}^T Q_b (B - B_m) + (B - B_m)^T Q_b \dot{B} \end{bmatrix} \tag{9}$$

From (6) we can write:

$$\begin{cases} P\dot{e}e^T = P[A_m e + (A - A_m)x + (B - B_m)u_c]e^T \\ Pe\dot{e}^T = Pe[A_m e + (A - A_m)x + (B - B_m)u_c]^T \end{cases} \tag{10}$$

Let us put (10) into (9) and select the terms proportional to $(A - A_m)^T$ and $(B - B_m)^T$:

$$\begin{cases} 2tr[(A-A_m)^T Q_a \dot{A} + Pex^T] \\ 2tr[(B-B_m)^T Q_b \dot{B} + Peu_c^T] \end{cases} \tag{11}$$

Then its result:

$$\dot{V} = \frac{dV}{dt} = e^T PA_m e + e^T A_m^T Pe + 2tr[(A-A_m)^T Q_a \dot{A} + Pex^T] + \\ + 2tr[(B-B_m)^T Q_b \dot{B} + Peu_c^T] \tag{12}$$

parameters of the adaptation laws:
$$\begin{cases} Q_a \dot{A} + Pex^T = 0 \\ Q_b \dot{B} + Peu_c^T = 0 \end{cases} \tag{13}$$

while
$$\dot{V} = e^T (PA_m + A_m^T P)e \tag{14}$$

And: $\dot{V} = -e^T Pe \le 0$ let us put: $Q_a = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$ and $Q_b = 1$

then the parameter of the adaptation law result

$$\begin{cases} \dot{\theta}_1 = (p_{11}e_1 + p_{12}e_2)x_1 \\ \dot{\theta}_2 = (p_{11}e_1 + p_{12}e_2)x_2 \\ \dot{\theta}_3 = -(p_{11}e_1 + p_{12}e_2)u_c \end{cases} \tag{15}$$

4. SIMULATION BY MATLAB SIMULINK

The verification of the MRAC control on a DC machine is necessary, for this Matlab Simulink is used

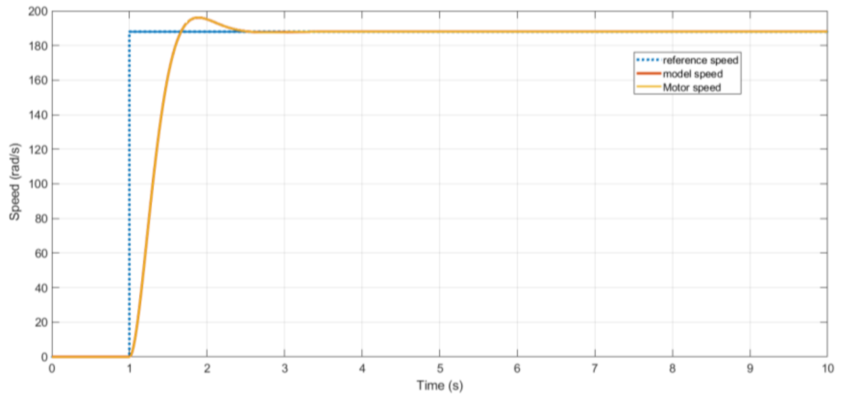

Fig. 2 Speed response (Matlab Simulink)

Table 1 Quantitative results of Speed response (Matlab Simulink)

	Rise time [s]	Peak time [s]	Settling time [s]	Overshoot [%]
Reference model speed	0.671	0.892	1.621	7%
DC motor speed	0.671	0.892	1.621	7%

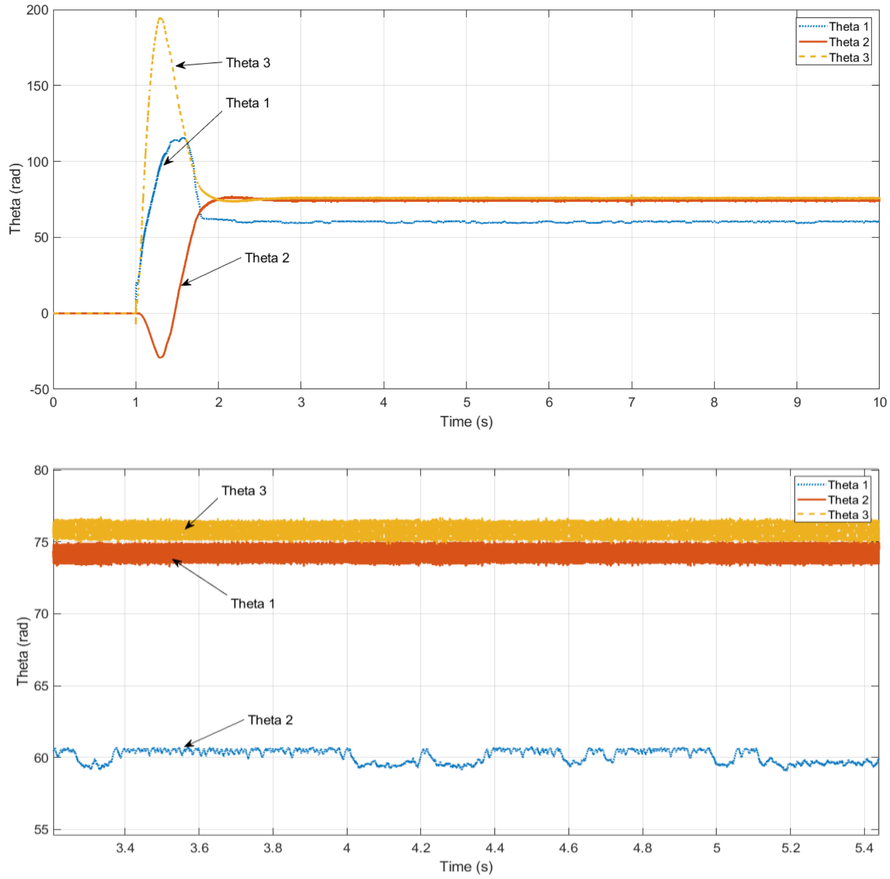

Fig. 3 Theta 1, 2 and 3 responses (Matlab Simulink)

Table 2 Quantitative results of Theta 1, 2, and 3 response

	Adaptation time [s]	Peak time [s]	Settling value [rad]	Peak value [rad]	Oscillation after settling time per second [rad/s]
Theta 1	1 to 2s	1.574	60.06	115.8	$1.62/10^{-5}$
Theta 2	1 to 2s	1.293	73.47	-29.26	$1.72/10^{-5}$
Theta 3	1 to 2s	1.302	75.82	194.5	$1.33/10^{-1}$

Fig. 2 and Table 1 show that the motor follows perfectly the imposed reference speed because it is forced to follow the reference model, the system responds very quickly with a response time less than 1.621s and an overshoot of less than 7% with no steady errors.

The adaptations parameters of the state feedback control (theta 1, theta 2 and theta 3) are given in Fig. 3, and in more details in Table 2. These parameters converge towards their nominal values. It can be noticed that the adaptation parameters change in the Transient State from t=1s to t=2s, to stabilize at almost fixed values in the steady-state, the value of theta 1 increases to the value of 115.8 rad at 1.574 s to drop to its nominal value 60.06, the same for theta 3 which reaches the value of 194.5 rad at 1.302s then decreased to a stabilization value of 75.82 rad, but theta 2 decreases to -29.26 rad at 1.293 then increase to a steady value 73.47, oscillation is remarked after steady values of Theta 1, 2, and 3.

5. Adaptive Control Implementation

To implement the adaptive control, the combination between Matlab Simulink to build the MRAC control and ControlDesk to control the Dspace 1104 is used. The Dspace 1104 board generates a PWM signal to control the 4 quadrant chopper that will drive the DC motor. The feedback is done by the incremental encode (GI355). Fig. 4, represent the Implementation adaptive control diagram on the DC motor:

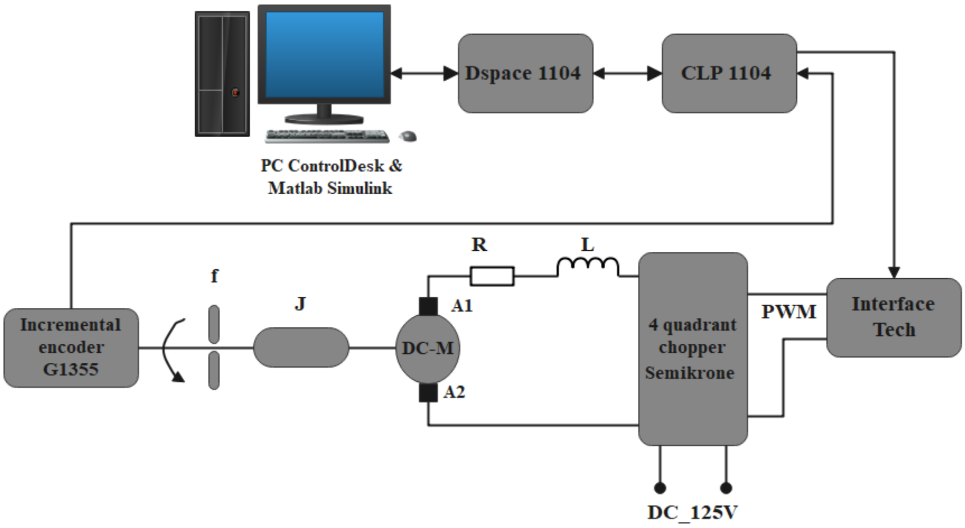

Fig. 4 Implementation adaptive control diagram on DCM

5.1. Four quadrant chopper power circuit

DC motor is excited by its stator at a fixed voltage 125 V and supplied by its rotor by variable voltage via the 4 quadrant chopper, isolation is assured by Tech isolator that also prevents the closing of T1 and T2, or T3 and T4, at the same time, then it secures the circuit against short circuits. Fig. 5 illustrates the four-quadrant chopper drive DC motor utilized:

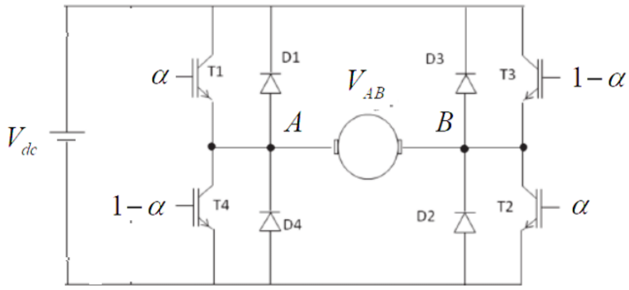

Fig. 5 Four quadrant chopper drive DC motor

To deduce α to control the switches $T_{1,2,3,4}$ it is necessary to calculate V_{AB}

$$V_A = \alpha V_{dc} \quad and \quad V_B = (1-\alpha)V_{dc} \tag{16}$$

As result
$$V_{AB} = (2\alpha - 1)V_{dc} \quad so \quad \alpha = \frac{1}{2}\left(\frac{V_{AB}}{V_{dc}} + 1\right) \tag{17}$$

6. IMPLEMENTATION RESULT

Fig. 6 represents the actual motor speed response (rad/s) realized by the Dspace 1104 card (Matlab from ControlDesk). Fig. 6a shows that the motor follows the speed reference because in reality it is forced to follow the reference model. At the beginning we drive the motor at the speed of 160 rad/s, then we break our motor, then the motor turns to the opposite direction at the speed -100 rad/sec, and finally we return to the nominal speed in the positive rotation direction. Adaptive control changes the parameters of the adaptation mechanism each time the speed of rotation is changing without knowing the parameters of the machine. Fig. 6b, a close-up view of the speed response, and Table 3 show that the time response in real-time is less than 1.272s and the overshoot is less than 12.17% with no steady errors, while the time responses of the reference model are less than 1.621s and the overshoot is less than 7 %. Fig. 6c, a closer view of the response, shows small measurement disturbance.

The comparison of the simulation and implementation results with other studies demonstrate that MRAC control with the Lyapunov method is more robust than MRAC control with MIT rules, MRAC control with MIT rules is very sensitive with changes in the amplitude of the reference signal and may become oscillatory for larger values of reference input [28]. However, the result of simulation and implementation of our study demonstrates that MRAC control with Lyapunov method is more robust even against for larger values of reference input (100, 160 rad/s). Moreover, beyond a certain limit the performance of the system becomes very poor for MRAC control with MIT rules and stability cannot be determined [29], but our study proves that MRAC control with the Lyapunov method is very stable with the change of reference input.

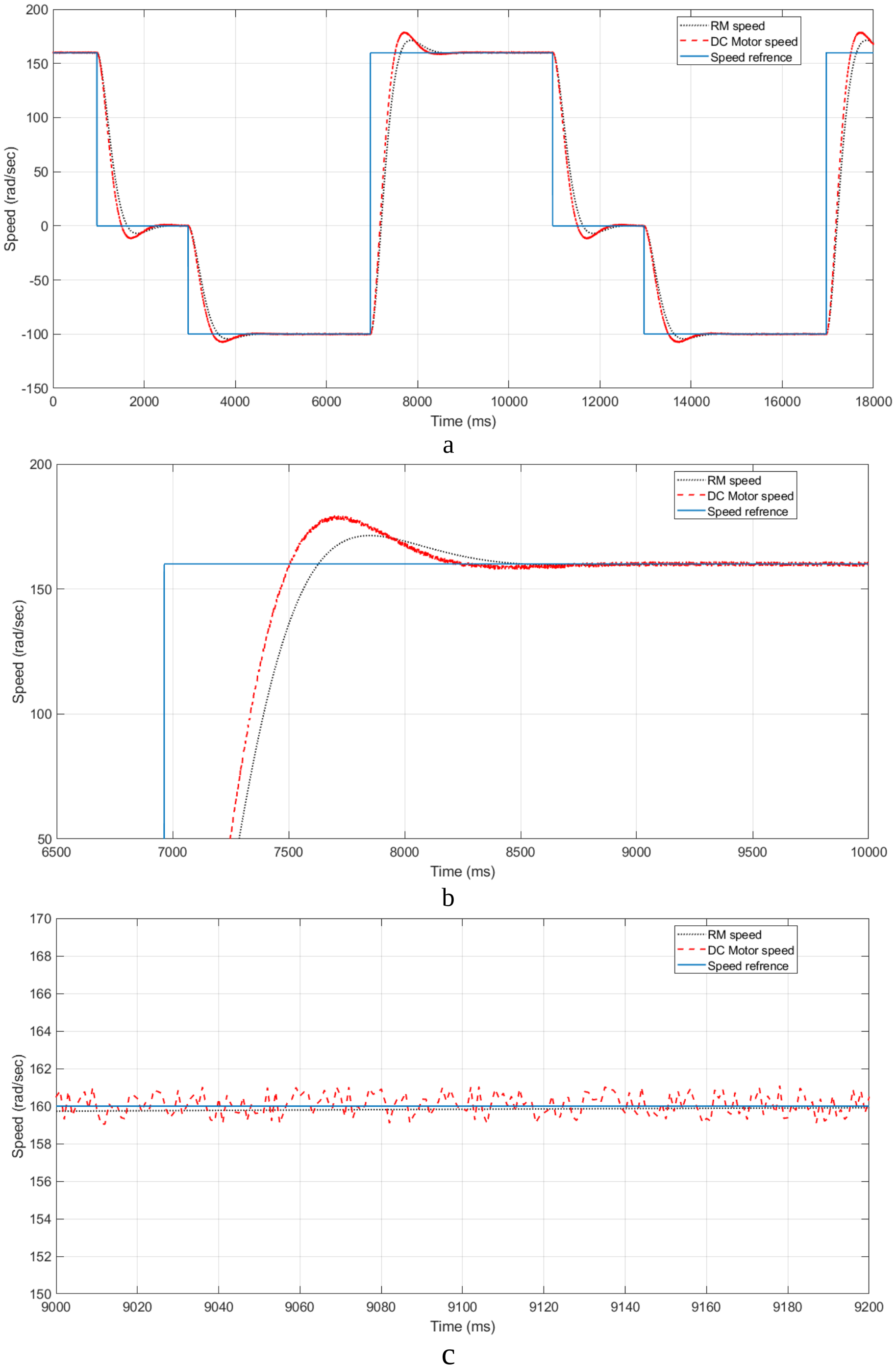

Fig. 6 Motor speed response (rad/s) (Matlab from ControlDesk)

Table 3 Experimental results of speed values

	Rise time [s]	Peak time [s]	Settling time [s]	Overshoot [%]
DC motor speed	0.544	0.743	1.272	12.17 %
Reference model speed	0.671	0.892	1.621	7 %

7. Conclusion

In this study, the adaptive control with reference model has been validated via computer simulations and experimentally implemented in real-time using the Dspeace 1104 controller board.

Model reference adaptive control proves that controlling an electrical machine especially a DC motor can be accomplished without the need for parameter identification. a major problem in an industrial environment where identification can be difficult or impossible. The results have shown good performance and an excellent speed DC motor response, and the implementation results showed no overshoot and no steady-state error. Adaptive control changes control parameters in real-time to ensure reference speed tracking by following the reference model.

The next step is to test this control mode on several similar electric machines in the industry without making the parameters identification which takes a lot of time and creates a lot of uncertainty problems, or after doing maintenance of the machine without redoing the identification, then implement this mode of control on the most commonly used machine (asynchronous squirrel-cage machine).

8. Materials Used List

The material used is available at the ICEPS (Intelligent Control et Electrical Power System) laboratory http://www.univ-sba.dz/fge/index.php/fr/recherches

Dspace 1104 (code 382508)

DC motor Hampden DM-100A sonelecRME_24245 Serial NO 10545 (125Volt 3.5 Amp 1800 RPM)

Incremental encoder GI355 (1024 impulsions)

Measurement card for Dspace utech

Analog/Digital Conversion Interface for Dspace

two-level inverter Semikron ref Semiteach IGBT SKM50GB used as a chopper

9. Nomenclature

x, y	system state and output vector
u	system input (or control) vector
A_p	system state (or system) matrix
B_p	system input matrix
C_p	system output matrix
x_m, y_m	reference model state and output vector
u_c	reference model input (or control) vector

A_m	reference model state (or system) matrix
B_m	reference model input matrix
C_m	reference model output matrix
a, b	system poles
ζ, ω	damping and pulsation of the reference model
θ_1, θ_2, θ_3	adaptive control parameters
e	tracking error
V	Lyapunov function
P, Q_a	2×2 Matrix
Q_b	1×1 Matrix
tr	Trace of a matrix
V_A, V_B, V_{dc}, V_{AB}	A, B, DC, AB voltage

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