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Adaptive Parameters Identification of a Permanent Magnet DC Motor

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ABSTRACT: This work shows a method ofadaptive parameters identification to determine the parameters of the model of a permanent magnet DC motor. The methodrequires high frequency signals to excite the system. The goal is for the identification process to take into account all modes of operation of the system. Experimental data illustrate the usefulness of the approach.

KEYWORDS: Parameters Identification, Control Systems.

I.INTRODUCTION

Among the several demands for automatic process control is the control of direct current (DC) motors, which is a necessary step in several industrial processes [1]. Many applications that require positioning control, variable speed, constant torque, fast acceleration and deceleration make use of DC motors due to their characteristics [2]. Often, the problem with controlling such engines is to determine the parameters of their dynamic model to design controllers that meet certain specifications for performance and accuracy. In this context, this paper recalls the methodology of adaptive parameters identification found in [3] to estimate the parameters of the dynamic model of a DC motor using an algorithm developed in MATLAB/Simulink software.

II.DC MOTOR DYNAMIC MODEL

The dynamic equations of a DC motor can be represented by an electric part and a mechanical part as shown in Equations (1) and (2), respectively. The variable $V_a$is the supply voltage, R_ae $L_a$are the resistance and the armature inductance, respectively,$I_a$is the armature current, $K_e$is an electric constant,ω is the angular velocity of the rotor,$J$is the inertia of the rotor,$B$is the viscous friction,$T_c$is the load torque and$K_t$is a torque constant.

$$\frac{d}{dt}I_a = -\frac{R_a}{L_a}I_a - \frac{K_e}{L_a}\omega + \frac{V_a}{L_a} \tag{1}$$

$$\frac{d}{dt}\omega = \frac{K_t}{J}I_a - \frac{B}{J}\omega + \frac{T_c}{J} \tag{2}$$

Considering the load torque as zero, the Equations (1) and (2) can be represented in state space model, as shown in Equation (3).

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$$\begin{bmatrix}\dot{I}_a\\ \dot{\omega}\end{bmatrix} = \begin{bmatrix}-\frac{R_a}{L_a} & -\frac{K_e}{L_a}\\ \frac{K_t}{J} & -\frac{B}{J}\end{bmatrix}\begin{bmatrix}I_a\\ \omega\end{bmatrix} + \begin{bmatrix}\frac{1}{L_a}\\ 0\end{bmatrix}V_a$$
$$\begin{bmatrix}y1\\ y2\end{bmatrix} = \begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix}\begin{bmatrix}I_a\\ \omega\end{bmatrix} + \begin{bmatrix}0\\ 0\end{bmatrix}V_a \quad (3)$$

III.ADAPTIVE PARAMETERS IDENTIFICATION

This technique for obtaining parameters of mathematical models was found in [3] and also used in the works [4] and [5]. For the understanding of the method, consider the system in Equation (4):

$$\dot{x}_i = \theta_i^T g_i(x,u), \qquad i = 1,\dots,n, \quad (4)$$

where$x = [x_1 \dots x_n]^T \in R^n$is the states vector,$u \in R^p$is the input signal,$\theta_i \in R^{n_i}, n_i \geq 0$is the unknown parameters vector and$g_i(.) \in R^{n_i}$is the functions vector. The method proposed in [3] specifies a parameters estimator given in Equation (5):

$$\dot{\hat{x}}_i(t) = \hat{\theta}_i^T g_i(x,u) - \lambda_i e_i, \quad (5)$$

where$\hat{\theta}_i \in R^n$is the estimated parameters vector, $\lambda_i > 0$ and$e_i = \hat{x}_i - x_i$is the error between the simulated and real responses. The adaptation law that describes the adjustment of the$\hat{\theta}_i$ parameter is given in Equation (6):

$$\dot{\hat{\theta}}_i = \dot{\emptyset}_i = -\gamma_i e_i g_i(x,u), \quad (6)$$

where$\gamma_i > 0$is the estimation adjustment of each parameter. The stability of the parameter estimator can be analyzed by defining an error parameter$\emptyset$, as shown in Equation (7):

$$\emptyset_i = \hat{\theta}_i - \theta_i, \quad (7)$$

and selecting a Lyapunuv quadratic function, such as the one presented in Equation (8):

$$V = \frac{1}{2}\sum_{i=1}^{n}\left[{e_i}^2 + \frac{{\emptyset_i}^T\emptyset_i}{\gamma_i}\right] \quad (8)$$

The time derivative of Equation (8) along the trajectories of Equations (5) and (6) is presented in Equation (9):

$$\dot{V} = \sum_{i=1}^{n}\left[-\lambda_i {e_i}^2\right] < 0, \quad (9)$$

itimpliesthat:

$$\lim_{t\to\infty} e_i(t) = 0, \qquad i = 1,\dots,n \quad (10)$$

The Equation (10) shows that the error$e_i(t)$between the real state and the estimated state will tend to zero over time. However, the asymptotic stability of the point $(e_i, \emptyset_i) = (0,0)fori = 1,\dots,n$cannot be concluded only with $\dot{V}$being

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negative. In practice, the convergence of $\emptyset_i(t)$to zero depends on the property of the excitation signal g_i (input signal $u(t)$). This property, called Pesistent Excitation (PE) is important for parameters identification.The objective of the PE condition is that the input signal $u(t)$is sufficient to excite all modes of the system under study. According to [3], the use of a signal $u(t)$that is sufficiently rich in different frequencies ensures that $g_i$satisfies the PE condition.

IV.APPLICATION OF THE METHOD IN A SECOND ORDER LINEAR SYSTEM

In order to use the methodology presented in [3] it was necessary to adapt Equations (5) and (6) to a second-order linear system that represents the behavior of a DC motor. Then consider the dynamic model of Equation (3) in the form of Equation (11):

$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\end{bmatrix} = \begin{bmatrix}-a_{11} & -a_{12}\\ a_{21} & -a_{22}\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix} + \begin{bmatrix}b\\ 0\end{bmatrix}u(t)$$
$$y = \begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix} + 0u(t), \quad (11)$$

where$x_1 = I_a$, $x_2 = \omega$, $a_{11} = \frac{R_a}{L_a}$, $a_{12} = \frac{K_e}{L_a}$, $a_{21} = \frac{K_t}{J}$, $a_{22} = \frac{B}{J}$ and$b = \frac{1}{L_a}$. In this way, Equation (5) must be rewritten as Equation (12) for the states $x_1$andx_2:

$$\dot{\hat{x}}_1(t) = -\hat{a}_{11}x_1(t) - \hat{a}_{12}x_2(t) + \hat{b}u(t) - \lambda_1 e_1(t)$$
$$\dot{\hat{x}}_2(t) = \hat{a}_{21}x_1(t) - \hat{a}_{22}x_2(t) - \lambda_2 e_2(t) \quad (12)$$

Therefore, the parameters $\hat{a}_{11}$, $\hat{a}_{12}$, $\hat{a}_{21}$, $\hat{a}_{22}$ and$\hat{b}$can be estimated as shown in Equation (13), from the adaptation law in Equation (6).

$$\begin{aligned}\dot{\hat{a}}_{11}(t) &= \gamma_{11}e_1(t)x_1(t),\\ \dot{\hat{a}}_{12}(t) &= \gamma_{12}e_1(t)x_2(t),\\ \dot{\hat{b}}(t) &= -\gamma_b e_1(t)u(t),\\ \dot{\hat{a}}_{21}(t) &= -\gamma_{21}e_2(t)x_1(t),\\ \dot{\hat{a}}_{22}(t) &= \gamma_{22}e_2(t)x_2(t),\end{aligned} \quad (13)$$

where$e_1(t)$ and$e_2(t)$are obtained by Equation (14):

$$\begin{aligned}e_1(t) &= \hat{x}_1(t) - x_1(t)\\ e_2(t) &= \hat{x}_2(t) - x_2(t)\end{aligned} \quad (14)$$

The algorithm developed in MATLAB/Simulink to perform the adaptive parameters identification is shown in Figure 1. An identification box was created with three inputs: the applied signal$u(t)$, the armature current$x_1(t)$and the angular velocity of the rotor$x_2(t)$, as an output, the estimated values for parameters $\hat{a}_{11}$, $\hat{a}_{12}$, $\hat{a}_{21}$, $\hat{a}_{22}$ and$\hat{b}$are acquired. Inside the identification box was created a subroutine referring to Equations (12), (13) and (14) that are responsible for calculations of the parameters estimation.

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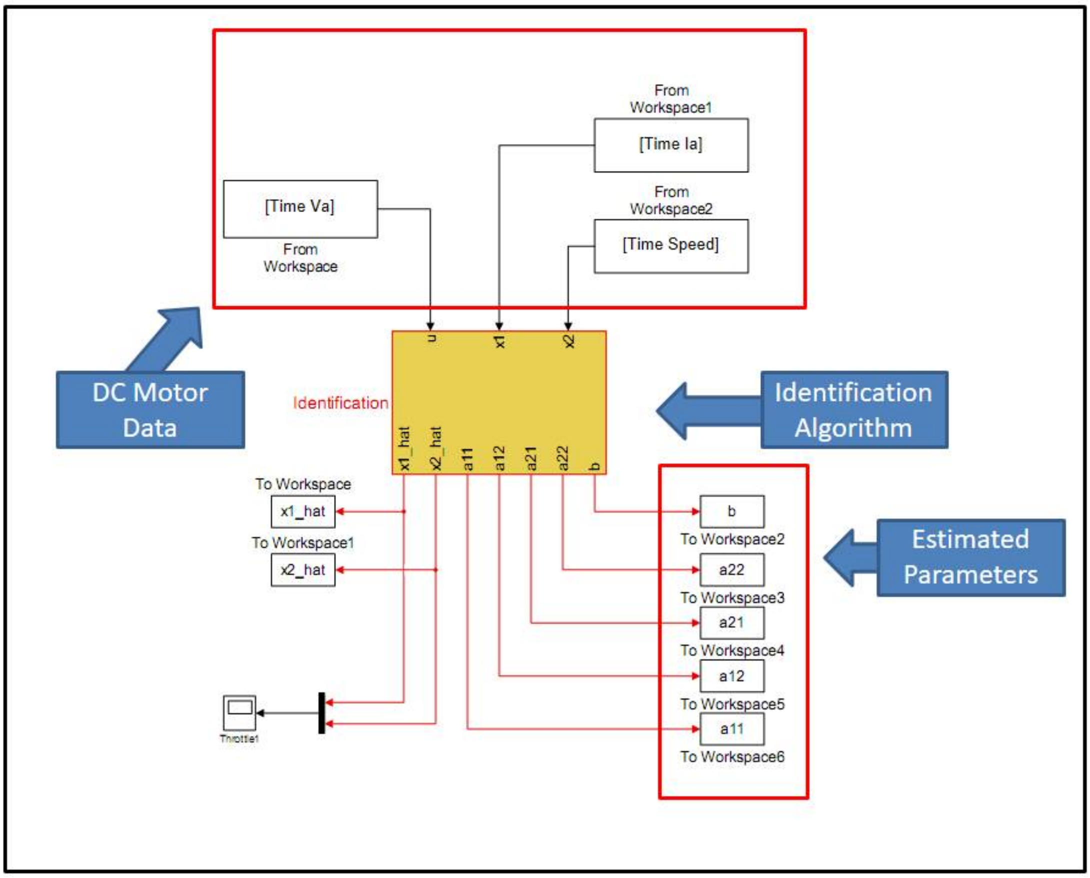

Figure 1: Algorithm for adaptive parameters identification.

V.EXCITATION SIGNAL DETERMINATION

In order for the parameters to converge, it is necessary to satisfy the PE condition by exciting all modes of system operation. A linearly swept frequency cosine, also known as chirp, given by Equation (15) was then chosen for $u(t)$.

$$u(t) = A\cos(2\pi f_i(t)t), \tag{15}$$

where:

$$f_i(t) = f_o + \beta t, \quad \beta = \frac{(f_1 - f_o)}{t_1}, \tag{16}$$

where$A$is the signal amplitude, $f_0$is the cosine initial frequency, $f_1$is the cosine final frequency and$t_1$is the final instant of time.Figures 2a and 2b show, respectively, an example of the chirp signal and its frequency spectrum obtained by Fast Fourier Transform(FFT), for$A$ = 12, f_0 = 1 Hz, f_1 = 10 Hz andt_1 = 10 s. The use of this signal can achieve a very large range of frequencies for the operation of the DC motor.

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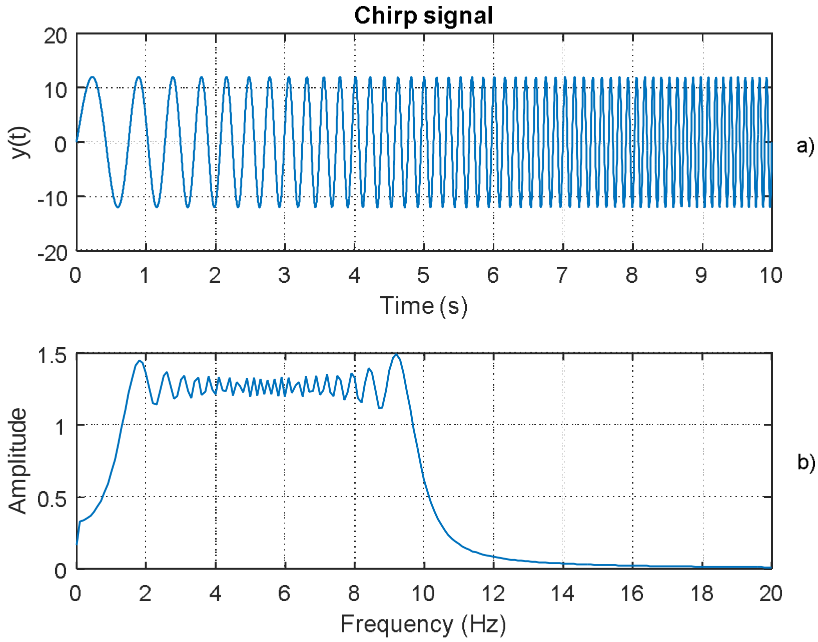

Figure 2: (a) Chirp signal. (b) Frequency spectrum (FFT).

According to [6], for linear systems, the convergence of the estimation of m parameters requires at least $m/2$sines or cosines in the excitation signal $u(t)$. In this way, as it is desired to determine five parameters: $\hat{a}_{11}$, $\hat{a}_{12}$, $\hat{a}_{21}$, $\hat{a}_{22}$ and$\hat{b}$, the signal used will be the sum of three chirp signals and their configurations are shown in Table 1.

Signal	Amplitude (V)	f_0 (Hz)	f_1 (Hz)	t_1 (s)
Chirp 1	4	1	25	1200
Chirp 2	4	1	15	1200
Chirp 3	4	1	11	1200

Table 1: Configuration of the three chirp signals.

The advantage of using the chirp is that the frequency of its signal varies over time within a chosen range, so the excitation signal will be richer than using cosines.The resulting signal was then applied to the DC motor and its current $I_a(t)$and its velocity$\omega(t)$were measured. Afterwards, the acquired data were used into the adaptive parameters identification program shown in Figure 1 and the results were obtained.

VI.RESULTS AND DISCUSSION

After importing the $I_a(t)$, $\omega(t)$, and$u(t)$data to the program developed in MATLAB/Simulink, the values of the parameters were obtained as shown in Figure 3.Each parameter was determined by the average of the last 20 seconds of estimation as shown in Table 2.The eigenvalues of the identified dynamic model areα_1 = -32.3327 and α_2 = -696.8720.

$\hat{a}_{11}$	$\hat{a}_{12}$	$\hat{a}_{21}$	$\hat{a}_{22}$	$\hat{b}$
729.0764	1.9203	1.1685e+04	0.1282	66.4774

Table 2: Parametersidentified.

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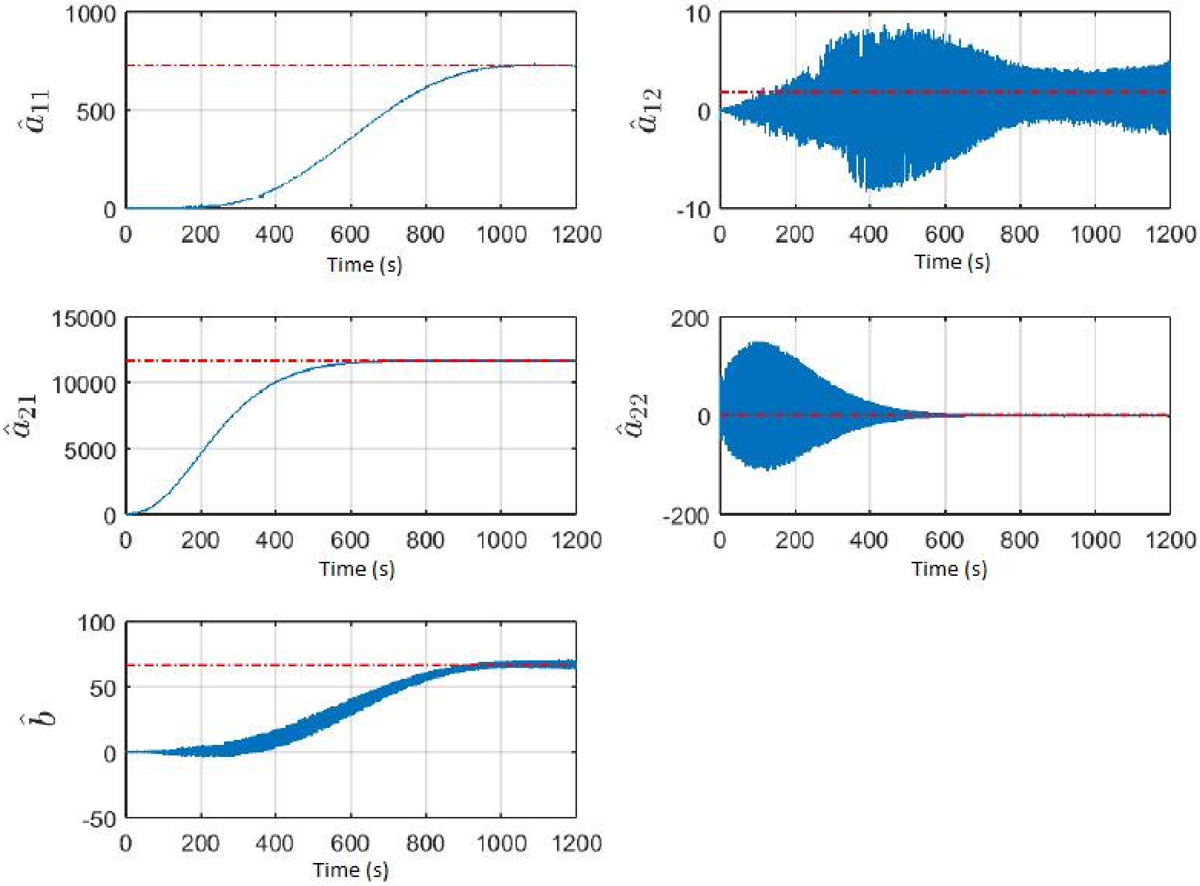

Figure 3: Parameters estimation results.

Table 3 shows the configurations used for the estimation.

λ_1	λ_2	γ_{11}	γ_{12}	γ_{21}	γ_{22}	γ_b
1000	1000	18000	14000	100	100	18000

Table 3: Identification configurations.

Three validation signals shown in Figures 4, 5 and 6 were applied to the real motor and the simulated model, being the step signal, sinusoidal signal and triangular signal, respectively. Table 4 shows the results of the comparisons between the curves obtained experimentally and the curves obtained through the simulation, using the Normalized Root-Mean-Square Error (NRMSE).

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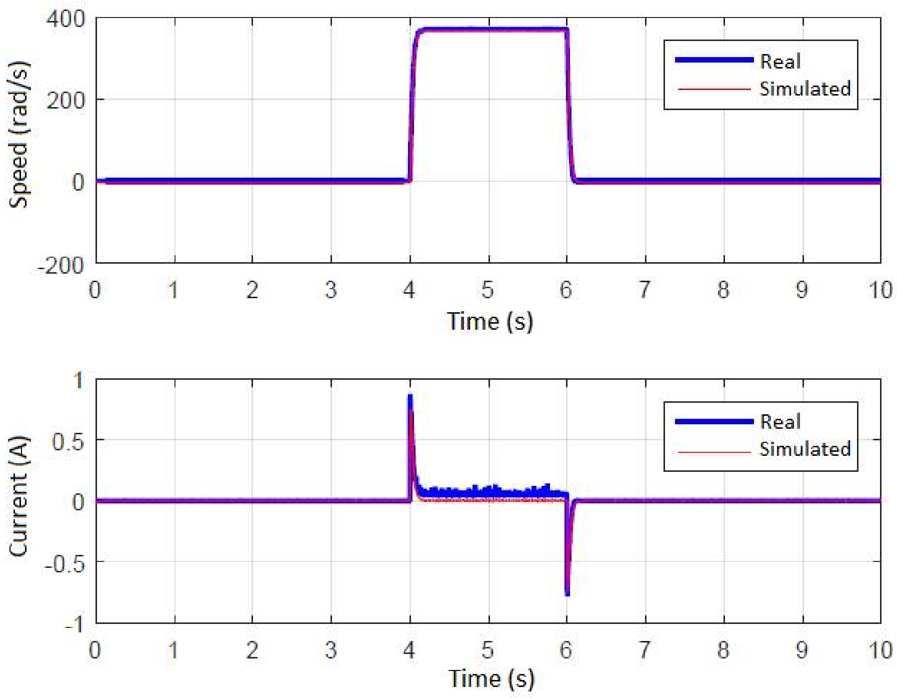

Figure 4: Validation with step signal.

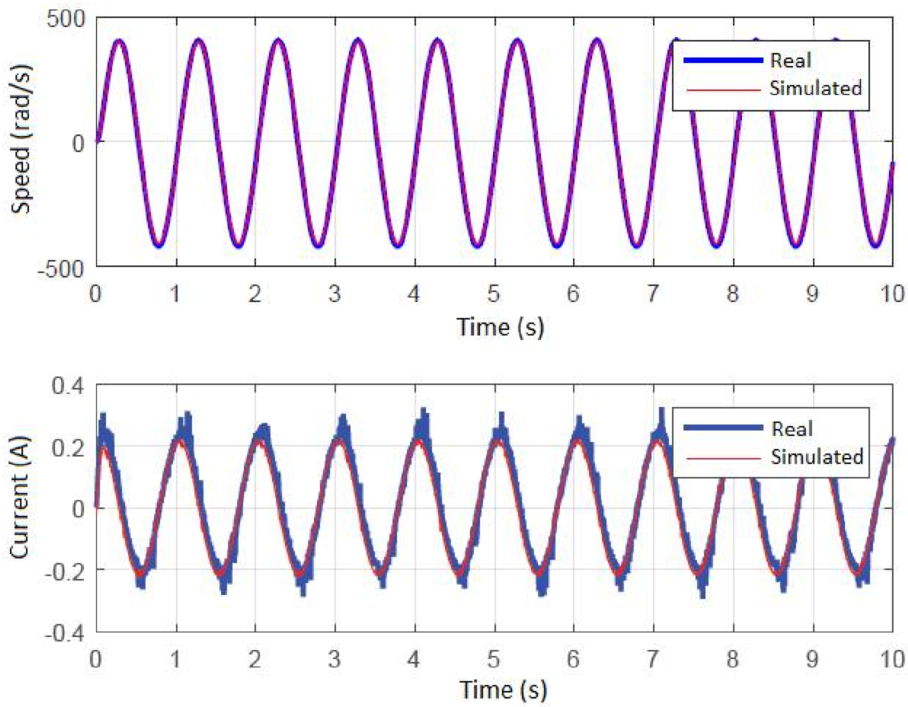

Figure 5: Validation with sinusoidal signal.

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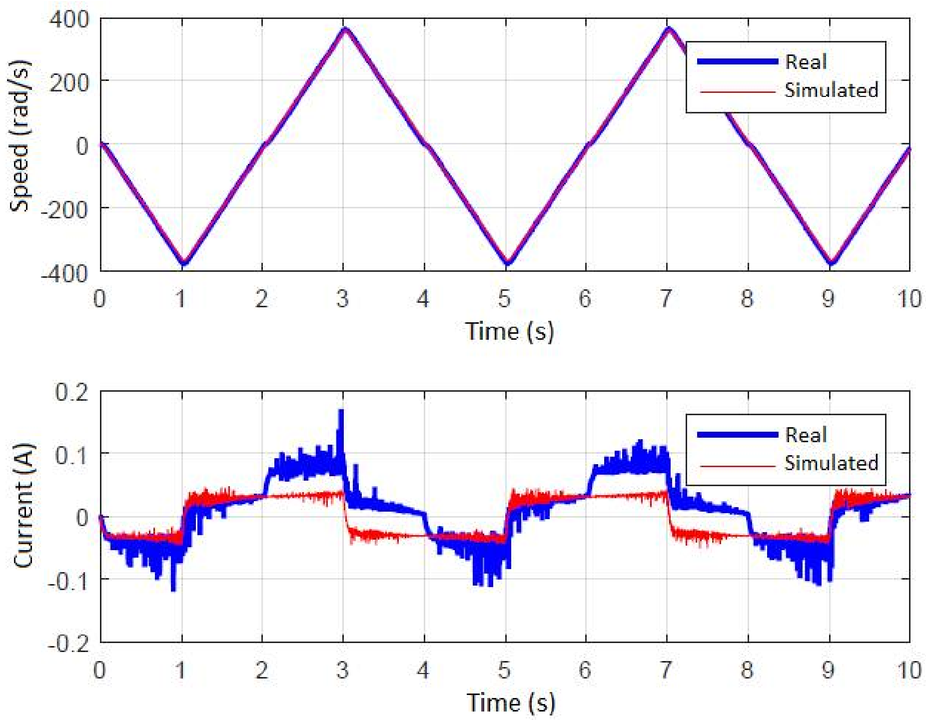

Figure 6: Validation with triangular signal.

Signal	NRMSE (%)	
	Velocity	Current
Step	96.7076	49.8470
Sinusoidal	97.3685	77.7452
Triangular	97.4794	30.7889

Table 4: Comparison between the real and simulated curves.

X.CONCLUSION

In this work, the adaptive parameters identification method was applied to determine the parameters of the dynamic model of a DC motor. It was verified through the results that the identified model proved to be efficient.

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