IDENTIFICATION OF TIME-VARYING ROTOR AND STATOR RESISTANCES OF INDUCTION MOTORS

G. Kenné[†*], T. Ahmed-Ali[‡], H. Nkwawo[§], and F. Lamnabhi-Lagarrigue[*]

[*]L2S, C.N.R.S–SUPELEC, Université Paris XI, 3 Rue Joliot Curie, 91190 Gif-sur-Yvette, France
fax: +33 (0)1 69 85 17 27
e-mail: {lamnabhi,kenne}@lss.supelec.fr
[†] Département de Génie Electrique, IUT-FV Bandjoun, Université de Dschang, Cameroun
[§]Département GEII, IUT, Université Paris XIII, 99 Avenue Jean Baptiste Clément 93430, France
e-mail: homere.nkwawo@iutv.univ-paris13.fr
[‡] ENSIETA, 2 Rue François Verny, 29806 Brest Cedex 9, France
e-mail: ahmedali@ensieta.fr

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Abstract

This paper deals with the identification of the stator and rotor resistances. The originality of this work is that it considers both rotor and stator resistances as time-varying parameters. Two schemes for the rotor resistance identification and one scheme for both stator and rotor resistances identification are outlined. The first and the third schemes use the measured stator current, voltage command and rotor speed while the second scheme uses only stator current and voltage commands. All schemes are based on the sliding mode observer and the convergence of the estimates to their true values does not required the persistence of excitation conditions to be satisfied by the input signal.

1 Introduction

This paper deals with the identification of stator and rotor resistances. The originality of this work is that both rotor and stator resistances are considered as time-varying parameters. It is well known in the literature that the rotor resistance is a parameter which largely varies during operation and it is crucial in the design of high performance induction motor control algorithms when flux measurements are not available. Rotor resistance may vary up to 100% and stator resistance up to 50% due to rotor and stator heating and can be hardly recovered using thermal models temperature sensors. Several works in this area exist in the literature, one can cite the work of [1] using a ninth order estimation algorithm which provides on-line exponentially convergent estimates of both rotor and stator resistances, when persistence of excitation conditions are satisfied and the stator currents integrals are bounded, on the basis of rotor speed, stator voltages, and stator currents measurements. Rotor flux is also asymptotically recovered. But the proposed algorithm always make an assumption that both stator and rotor resistances are constant during the estimation process. Moreover the identification schemes use the nominal values of stator and rotor resistances. Another result was proposed in [2] where the rotor resistance estimation scheme is outlined using least mean square and the adaptive algorithms in the transient state under the speed sensorless control of induction motor. Moreover, [3] used least squares identification techniques for the estimation of both electrical and mechanical parameters of an induction motor under slowly varying rotor speed. Recently, [4] proposed algorithms for the rotor and stator resistances estimation based on the model reference adaptive system (MRAS) approach. In this work, the fact that these parameters are time-varying is not investigated. The contribution of this paper is the extension of this work to the case of time-varying parameters by using the work of [7] and [8] which use sliding mode observer in the parametric identification schemes. In fact, it has been shown in [8] and [9] that, parametric identification scheme based on the variable structure provides better result than least square estimation technique. The remainder of the paper is organized as follow.

In the second Section, we describe the model of the induction motor. In the third one, we present a new scheme of the rotor resistance identification. We study two cases. In the first case, the rotor speed is supposed to be available while in the second case, it is neither measured nor estimated. In both cases, the stator current and voltage are measurable and the rotor resistance is time-varying. Another scheme for the stator and rotor resistances identification is presented in Section 4. This scheme used the measured stator current, voltage commands and rotor speed. Both stator and rotor resistances are time-varying. All designs are based on the sliding mode observer and the convergence of the estimates to their true values does not required the persistence of excitation conditions to be satisfied by the input signal. Section 5 is dedicated to the simulation results and section 6 concludes the paper.

2 Model description

The dynamic model of an induction motor in stator reference frame is given by [5]

$$\frac{d}{dt}\Omega = \frac{3}{2}\frac{n_pM}{mL_r}i_s^TJ\lambda_r - \frac{\alpha}{m}\Omega - \frac{\tau_l}{m} \quad (1)$$

$$\frac{d}{dt}\lambda_r = (-\frac{R_r}{L_r}I + n_p\Omega J)\lambda_r + \frac{R_r}{L_r}Mi_s \quad (2)$$

$$\begin{aligned}
\frac{d}{dt}i_s &= -\frac{M}{\sigma L_s L_r}(-\frac{R_r}{L_r}I + n_p\Omega J)\lambda_r \\
&\quad -\frac{1}{\sigma L_s}(R_s + \frac{M^2 R_r}{L_r^2})i_s + \frac{1}{\sigma L_s}v_s \qquad (3)\\
I &= \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}, \qquad J = \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix}, \\
i_s &= \begin{pmatrix} i_{sd} \\ i_{sq} \end{pmatrix}, \quad v_s = \begin{pmatrix} v_{sd} \\ v_{sq} \end{pmatrix}, \quad \lambda_r = \begin{pmatrix} \lambda_{rd} \\ \lambda_{rq} \end{pmatrix},
\end{aligned}$$

where Ω, λ_r, R_r and L_r are respectively, rotor angular velocity, flux, resistance and inductance, v_s, i_s, R_s and L_s are respectively, stator command voltage, current, resistance and inductance, n_p is the number of poles pair, $\sigma = 1 - \frac{M^2}{L_s L_r}$ is the leakage parameter, M is the mutual inductance between stator and rotor winding, m is the moment of inertia of the rotor, α is the damping gain and τ_L is the external load torque.

In order to eliminate the unobservable flux, equations (2) and (3) are transformed by using an assumption which considers that the rotor speed changes significantly slower relative to the rotor flux and is considered as a constant parameter. By differentiating (3) and using (2), we obtain

$$\begin{aligned}
\frac{d^2}{dt^2}i_s &= (\alpha_1 I + \Omega\beta_1 J)\frac{d}{dt}i_s + (\alpha_2 I + \Omega\beta_2 J)i_s \\
&\quad +(\alpha_3 I + \Omega\beta_3 J)v_s + \alpha_4\frac{d}{dt}v_s \qquad (4)
\end{aligned}$$

$$\begin{aligned}
\text{where} \quad \alpha_1 &= -(\frac{R_s}{\sigma L_s} + \frac{R_r}{\sigma L_r}), \quad \beta_1 = n_p \\
\alpha_2 &= -\frac{R_s R_r}{\sigma L_s L_r}, \quad \beta_2 = \frac{n_p R_s}{\sigma L_s} \\
\alpha_3 &= \frac{R_r}{\sigma L_s L_r}, \quad \beta_3 = -\frac{n_p}{\sigma L_s}, \quad \alpha_4 = \frac{1}{\sigma L_s}
\end{aligned}$$

Equation (4) ([4]) can be transformed to

$$\frac{di_s}{dt} = a + \Omega b + \epsilon(t) \qquad (5)$$

where the functions a, b and $\epsilon(t)$ are defined as follows

$$\begin{aligned}
a &= (c + \alpha_1)i_{s1} + \alpha_2 i_{s0} + \alpha_3 v_{s0} + \alpha_4 v_{s1} \\
b &= J(\beta_1 i_{s1} + \beta_2 i_{s0} + \beta_3 v_{s0}) \\
\epsilon(t) &= \epsilon(t_0)\exp(-ct) \\
\text{and} \quad i_{s0} &= \frac{1}{s+c}i_s, \quad i_{s1} = \frac{s}{s+c}i_s \\
v_{s0} &= \frac{1}{s+c}v_s, \quad v_{s1} = \frac{s}{s+c}v_s
\end{aligned}$$

where s is the operator $\frac{d}{dt}$ and c is a strictly positive constant.
In the following analysis, it is assume that the stator current i_s, voltage command v_s, rotor speed Ω, and their time-derivatives are continuous and bounded.

3 Rotor resistance identification

In this section, we identify only the rotor resistance by using an estimator based on the sliding mode observer ([12]). We consider that the stator current and voltage are measurable and the rotor resistance is time-varying

$$R_r = R_{rn} + \Delta R_r \quad \text{with} \quad |\dot{R}_r| = |\Delta\dot{R}_r| \leq \mu,$$

where μ is a known positive constant. We also consider the both cases where the rotor speed is available or not. We can easily see that, by separating the terms containing R_r in equation (5), we obtain

$$\frac{di_s}{dt} = f_1 + R_r f_2 + \Omega J f_3 + \epsilon \qquad (6)$$

$$\begin{aligned}
\text{where} \quad f_1 &= (c + \rho_1)i_{s1} + \rho_2 v_{s1} \\
f_2 &= k_1 i_{s1} + k_2 i_{s0} + k_3 v_{s0} \\
f_3 &= \beta_1 i_{s1} + \beta_2 i_{s0} + \beta_3 v_{s0}
\end{aligned}$$

$$\begin{aligned}
\text{and} \quad \rho_1 &= -\frac{R_s}{\sigma L_s} \qquad \rho_2 = \frac{1}{\sigma L_s}, \\
\beta_1 &= n_p, \qquad \beta_2 = \frac{n_p R_s}{\sigma L_s}, \qquad \beta_3 = -\frac{n_p}{\sigma L_s}, \\
k_1 &= -\frac{1}{\sigma L_r}, \qquad k_2 = \frac{\rho_1}{L_r}, \qquad k_3 = \frac{\rho_2}{L_r}. \qquad (7)
\end{aligned}$$

3.1 Identification with the rotor speed available

Let us consider the following sliding observer

$$\frac{d\hat{i}_s}{dt} = f_1 + \hat{R}_{r1} f_2 + \Omega J f_3 + u_{is} \qquad (8)$$

where $u_{is} = -K_{is}\text{sign}(\hat{i}_s - i_s)$ is the input of the identifier, $\hat{i}_s$ is the adaptative observer and $\hat{R}_{r1}$ is the estimated value of the resistance R_{r1}. By defining $e_{is} = \hat{i}_s - i_s$, the observer error and $e_{r1} = \hat{R}_{r1} - R_r$, the parameter estimation error and by taking into account equations (6) and (8), one can obtain the following dynamic equation of the observer error

$$\dot{e}_{is} = e_{r1} f_2 + u_{is} - \epsilon. \qquad (9)$$

If the gain K_{is} of the input u_{is} is choosing such that

$$K_{is} > |e_{r1} f_2 - \epsilon|_{max}, \qquad (10)$$

with f_2, $\hat{R}_{r1}$ and ϵ bounded, a sliding regime occurs on the manifolds $\dot{e}_{is} = e_{is} = 0$ ([11]). From this, one can write

$$u_{iseq} = -e_{r1}\mathrm{f}_2 + \epsilon, \qquad (11)$$

where u_{iseq} is the equivalent control.
Remark: *From a practical point of view, it is not possible to implement u_{iseq}. We considered the average control as the approximation of u_{iseq} ([13]). This means that*

$$\begin{aligned}
\tau\frac{d}{dt}\bar{u}_{is} + \bar{u}_{is} &= u_{is} \\
\textit{or} \quad \bar{u}_{is} &= \frac{1}{1+\tau s}u_{is} \qquad (12)
\end{aligned}$$

where τ is a strictly positive constant that tends to zero. In others words, $u_{iseq} \approx \bar{u}_{is}$.
By taking into account (11), (12) and if the operation points of the motor are such that $|f_2|^2 \neq 0, \forall t \geq 0$, then one can deduce the following expression for the parameter estimation error

$$e_{r1} = \frac{-f_2^T u_{iseq}}{|f_2|^2} + \tilde{\epsilon} \tag{13}$$

$$\text{where} \quad \tilde{\epsilon} = \frac{f_2^T \epsilon}{|f_2|^2}.$$

Now let us consider the following rotor identifier

$$\dot{\hat{R}}_{r1} = -K_{r1}\text{sign}(-\frac{f_2^T u_{iseq}}{|f_2|^2}) \tag{14}$$

which can be rewritten as

$$\dot{\hat{R}}_{r1} = -K_{r1}\text{sign}(e_{r1} - \tilde{\epsilon}). \tag{15}$$

Therefore, the dynamic equation of the parameter error is

$$\dot{e}_{r1} = -K_{r1}\text{sign}(e_{r1} - \tilde{\epsilon}) - \dot{R}_{r1} \tag{16}$$

Proof of the convergence
In order to proof the convergence of the identifier (14), let us consider the following Lyapunov candidate function

$$V = \frac{1}{2}|e_{r1} - \tilde{\epsilon}|^2.$$

Then its time derivative along the solution of (16) is

$$\begin{aligned}
\dot{V} &= (e_{r1} - \tilde{\epsilon})(\dot{e}_{r1} - \dot{\tilde{\epsilon}}) \\
&= (e_{r1} - \tilde{\epsilon})(\dot{\hat{R}}_{r1} - \dot{R}_r - \dot{\tilde{\epsilon}}) \\
&= (-K_{r1}\text{sign}(e_{r1} - \tilde{\epsilon}) - \dot{R}_r - \dot{\tilde{\epsilon}})(e_{r1} - \tilde{\epsilon}) \\
&= -K_{r1}|e_{r1} - \tilde{\epsilon}| - (e_{r1} - \tilde{\epsilon})(\dot{R}_r + \dot{\tilde{\epsilon}})
\end{aligned}$$

From the fact that, $|\dot{R}_r| \leq \mu$, we deduce that

$$\dot{V} \leq -K_{r1}|e_{r1} - \tilde{\epsilon}| + \mu|e_{r1} - \tilde{\epsilon}| + |\dot{\tilde{\epsilon}}||e_{r1} - \tilde{\epsilon}|$$

$$\text{or} \quad \dot{V} \leq -(K_{r1} - \mu - |\dot{\tilde{\epsilon}}|)|e_{r1} - \tilde{\epsilon}|$$

Furthermore, since the stator and voltage commands are continuous and bounded, their filtered values and hence f_2 are bounded. Moreover, if the operating points of the motor are such that $|f_2(t)|^2 \neq 0, \forall t \geq 0$ with assumption (10) satisfied, then $|\tilde{\epsilon}|$ and hence $|\dot{\tilde{\epsilon}}|$ converge exponentially to zero (from the fact that $\epsilon(t) \in C^\infty$ and converges exponentially to zero).
Therefore, by choosing $K_{r1} > \mu$, we ensure that $|e_{r1} - \tilde{\epsilon}|$ and $|e_{r1}|$ converge asymptotically to zero and $\hat{R}_{r1} \to R_r$.

3.2 Identification with the rotor speed not available

This scheme is particularly interesting both economically and technically in speed sensorless control because measurement noise of the sensor can be avoided and the cost of the controller will be reduced. In this case, we also use equation (6) and we consider that the rotor speed is not available.
The term containing the rotor speed is eliminated by using the following property of the matrix operator J

$$x^T J x = 0, \quad \textit{for any given column vector } x.$$

If we multiply the two parts of equation (6) from the left by f_3^T, we obtain

$$f_3^T \frac{di_s}{dt} = f_3^T f_1 + R_r f_3^T f_2 + f_3^T \epsilon \tag{17}$$

Now let us consider the following change of variable

$$\Lambda = f_3^T - \frac{1}{2}\beta_1 |i_s|^2$$

Its time derivative is

$$\frac{d\Lambda}{dt} = g + R_r h + \bar{\epsilon} \tag{18}$$

$$\begin{aligned}
\text{where} \quad g &= (\beta_3 v_{s1} + (\beta_2 - c\beta_1) i_{s1})^T i_s + f_3^T f_1 \\
h &= f_3^T f_2 \\
\bar{\epsilon} &= f_3^T \epsilon
\end{aligned}$$

In order to identify the rotor resistance, we introduce the following sliding observer

$$\frac{d\hat{\Lambda}}{dt} = g + \hat{R}_{r2} h + u_\Lambda \tag{19}$$

where $u_\Lambda = -K_\Lambda \text{sign}(\hat{\Lambda} - \Lambda)$ is the control input of the identifier. By defining $e_\Lambda = \hat{\Lambda} - \Lambda$, the observer error and $e_{r2} = \hat{R}_{r2} - R_r$, the parameter estimation error, and by taking into account (18) and (19), one can derive the dynamic equation of the observer error as follow

$$\dot{e}_\Lambda = e_{r2} h + u_\Lambda - \bar{\epsilon} \tag{20}$$

From this, we can say that, if K_Λ is choosing such that

$$K_\Lambda > |e_{r2} h - \bar{\epsilon}|_{max} \tag{21}$$

with h and $\bar{\epsilon}$ bounded, the sliding regime occurs on the manifolds $\dot{e}_\Lambda = e_\Lambda = 0$ in finite time. Then we can write

$$e_{r2} h = -u_{\Lambda eq} + \bar{\epsilon} \tag{22}$$

where $u_{\Lambda eq}$ is the equivalent control approximated here as *in subsection (3.1).* If the operating points of the motor are such that $h \neq 0, \forall t \geq 0$, then the parameter estimation error is

$$e_{r2} = \frac{1}{h}(-u_{\Lambda eq} + \bar{\epsilon}). \tag{23}$$

Now let us consider the following rotor identifier

$$\dot{\hat{R}}_{r2} = -K_{r2}\text{sign}(-\frac{1}{h}u_{\Lambda eq}) = -K_{r2}\text{sign}(e_{r2} - \hat{\epsilon}) \tag{24}$$

$$\text{where} \quad \hat{\epsilon} = \frac{1}{h}\bar{\epsilon}.$$

By considering the Lyapunov candidate function

$$V = \frac{1}{2}|e_{r2} - \hat{\epsilon}|^2,$$

and if the operating points of the motor are such that $h \neq 0$, $\forall t \geq 0$, *with assumptions (21) satisfied, then* **the proof of the asymptotic convergence** *of* $\hat{R}_{r2} \rightarrow R_r$ *is similar to the above subsection.*

4 Rotor and stator resistances identification

In this section, we assume that the stator current and voltage command are measurable. We also consider that the rotor speed is available. We start by separating the terms containing R_r and R_s in equation (5). This leads to

$$\frac{di_s}{dt} = \tilde{f}_1 + R_s\tilde{f}_2 + R_r\tilde{f}_3 - \frac{R_sR_r}{\sigma L_s L_r} i_{s0} + \epsilon \qquad (25)$$

where

$$\begin{aligned}
\tilde{f}_1 &= ci_{s1} + \frac{1}{\sigma L_s}v_{s1} + n_p\Omega J(i_{s1} - \frac{1}{\sigma L_s}v_{s0}) \\
\tilde{f}_2 &= \frac{1}{\sigma L_s}(n_p\Omega J i_{s0} - i_{s1}) \\
\tilde{f}_3 &= \frac{1}{\sigma L_s L_r}v_{s0} - \frac{1}{\sigma L_r}i_{s1}
\end{aligned}$$

In order to identify the stator and rotor resistances, we use the following change of variables

$$\begin{aligned}
\lambda_1 &= i_{s0}^T J i_s \\
\lambda_2 &= \frac{1}{2} i_s^T i_s
\end{aligned}$$

This leads to

$$\begin{aligned}
\frac{d\lambda_1}{dt} &= g_1 + R_s h_{11} + R_r h_{12} + \epsilon_1 \\
\frac{d\lambda_2}{dt} &= g_2 + R_s h_{21} + R_r h_{22} + R_s R_r h_{23} + \epsilon_2 \qquad (26)
\end{aligned}$$

where

$$\begin{aligned}
g_1 &= i_{s0}^T J \tilde{f}_1 \qquad g_2 = i_s^T \tilde{f}_1 \\
h_{11} &= i_{s0}^T J \tilde{f}_2 \qquad h_{12} = i_{s0}^T J \tilde{f}_3 \\
h_{21} &= i_s^T \tilde{f}_2 \qquad h_{22} = i_s^T \tilde{f}_3 \qquad h_{23} = -\frac{1}{\sigma L_s L_r} i_s^T i_{s0} \\
\epsilon_1 &= i_{s0}^T J \epsilon \qquad \epsilon_2 = i_s^T \epsilon.
\end{aligned}$$

Now, let us consider the following sliding observer

$$\begin{aligned}
\frac{d\hat{\lambda}_1}{dt} &= -K_1\text{sign}(\hat{\lambda}_1 - \lambda_1) = -K_1\text{sign}(e_{\lambda_1}) \\
\frac{d\hat{\lambda}_2}{dt} &= -K_2\text{sign}(\hat{\lambda}_2 - \lambda_2) = -K_2\text{sign}(e_{\lambda_2}) \qquad (27)
\end{aligned}$$

From this, the dynamic equation of the observer errors will be as follows

$$\begin{aligned}
\dot{e_{\lambda_1}} &= -K_1\text{sign}(e_{\lambda_1}) - g_1 - R_s h_{11} - R_r h_{12} - \epsilon_1 \\
\dot{e_{\lambda_2}} &= -K_2\text{sign}(e_{\lambda_2}) - g_2 - R_s h_{21} - R_r h_{22} - R_s R_r h_{23} - \epsilon_2 \qquad (28)
\end{aligned}$$

By choosing the gains K_1, and K_2 such that

$$\begin{aligned}
K_1 &> |g_1 + R_s h_{11} + R_r h_{12} + \epsilon_1|_{max} \\
K_2 &> |g_2 + R_s h_{21} + R_r h_{22} + R_s R_r h_{23} + \epsilon_2|_{max}, \qquad (29)
\end{aligned}$$

a sliding regime occurs on the manifolds $\dot{e}_{\lambda_i} = e_{\lambda_i} = 0$, $i = 1, 2$ in finite time. This leads to

$$\begin{aligned}
\frac{d\hat{\lambda}_1}{dt} &= -K_1\text{sign}(e_{\lambda_1})_{eq} = u_{1eq} \\
\frac{d\hat{\lambda}_2}{dt} &= -K_2\text{sign}(e_{\lambda_2})_{eq} = u_{2eq} \qquad (30)
\end{aligned}$$

where u_{1eq} and u_{2eq} are the equivalent control inputs also approximated as *in subsection (3.1).* From the fact that ϵ_i converge to zero exponentially, we consider that the estimates of R_s and R_r verify the following equations

$$\begin{aligned}
u_{1eq} - g_1 &= \hat{R}_s h_{11} + \hat{R}_r h_{12} \\
u_{2eq} - g_2 &= \hat{R}_s h_{21} + \hat{R}_r h_{22} + \hat{R}_s \hat{R}_r h_{23} \qquad (31)
\end{aligned}$$

We suppose that system (31) is identifiable in the sense of the work of ([10]). This means that, there exits a unique solution $\hat{R}_s$ *and* $\hat{R}_r$ *satisfying system (31) for a given input-output behaviour* $\forall t \geq 0$. Therefore, the resolution of this system leads to the following identification laws for $\hat{R}_s$ and $\hat{R}_r$

$$\begin{aligned}
\hat{R}_s &= \frac{-B \pm \sqrt{\Delta}}{2A} \\
\hat{R}_r &= \frac{(u_{1eq} - g_1) - \hat{R}_s h_{11}}{h_{12}} \quad \text{for} \quad \hat{\lambda}_i = \lambda_i, i = 1, 2 \qquad (32)
\end{aligned}$$

where

$$\begin{aligned}
&A = h_{11}h_{23}, \qquad B = h_{11}h_{22} - h_{12}h_{21} - (u_{1eq} - g_1)h_{23}, \\
&C = (u_{2eq} - g_2)h_{12} - (u_{1eq} - g_1)h_{22}, \text{ and } \Delta = B^2 - 4AC
\end{aligned}$$

are the coefficients of the second order equation obtained and Δ its discriminant.
Equations (32) are the parameters identification laws of winding rotor induction motor. From this, we can have two cases:
First case $\Delta = 0$
The solution will be straightforward.
Second case $\Delta > 0$
In this case we can obtain two solutions. If one of them is negative, we consider the positive one. If both solutions are positive, we make an assumption which considers that the stator resistance bounds or nominal value should be known. This assumption is generally true because it is possible to measure the nominal value of the stator resistance independently by applying a dc voltage to the stator winding and then deriving the voltage to current ratio. A choice of the correct solution of $\hat{R}_s$ is therefore straightforward.

5 Simulation results

Efficiency of the proposed identifiers has been verified by simulation in MATLAB/SIMULINK environments. Motor parameters nominal values ([4]) used in the simulation are given as

follow.
$R_{sn} = 0.11\Omega$, $R_{rn} = 0.0187\Omega$, $M = 0.000804H$, $L_r = 0.0011H$, $L_s = 0.0011H$, $n_p = 6$, $\tau_L = 4$, $m = 0.5$, $\alpha = 0.7$.
We consider that

$$\begin{aligned} R_{r,s} &= R_{\{r,s\}0} + at \qquad \text{if} \quad t \le t_1 \\ R_{r,s} &= R_{\{r,s\}n} + f(t) \qquad \text{if} \quad t \ge t_1 \end{aligned}$$

where $R_{\{r,s\}0}$ is the initial value of the resistance, a is a positive constant and $f(t)$ represents square, chirp or sinusoidal signals.
The magnitudes of the variations of the reference time-varying rotor and stator resistances are respectively 10% and 20% of the nominal values while initials values are 20% of the nominal values. All the schemes work well in both cases of slowly and constant rotor speed.
Fig. 1 and Fig. 2 show the results of the identification of the time-varying parameter R_r with respectively zero and 0.03 initial values and function $f(t)$ being square signal.
Fig. 3 and Fig. 4 show the results of the identification of the time-varying parameters R_r with initial values equal respectively to zero and 0.03 and function $f(t)$ being chirp signal.
Fig. 5 shows the identification of the time-varying parameter R_r in the case where the rotor speed is not available with function $f(t)$ being chirp signal.
Fig. 6 and Fig. 7 show the identification of both stator and rotor resistances by considering the function $f(t)$ as sinusoidal signal.
The parameters of the identifier of the rotor resistance in the first case are $c = 10, K_{r1} = 0.3, K_{is} = 500$. In the second case $c = 10, K_{r2} = 4, K_\Lambda = 12000$. For the identification of both stator and rotor resistances, the parameters of the simulations are $c = 10, K_1 = 1000, K_2 = 3000$.
Moreover, the approximation of the equivalent control has been performed using first order low-pass filter with $\tau = 1ms$ and the functions $\text{sign}(X)$ are replaced by a saturation function $\frac{X}{|X|+0.01}$ ([6])
From the simulations results, one can easily see that the proposed identifiers is suitable for time-varying parameters as rotor and stator resistances. In all cases, the estimates values of the resistances converge to the true values within a very short time.

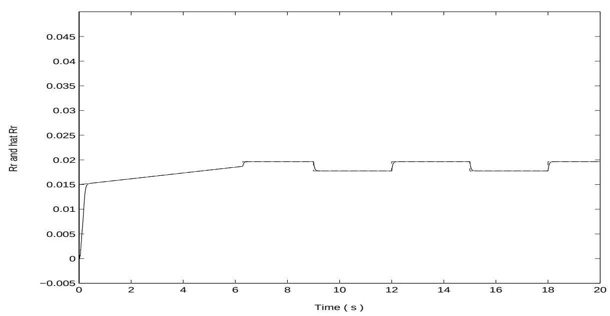

Figure 1: R_r and its estimate $\hat{R}_r$ with measured rotor speed, zero initial condition and $f(t)$ being square signal

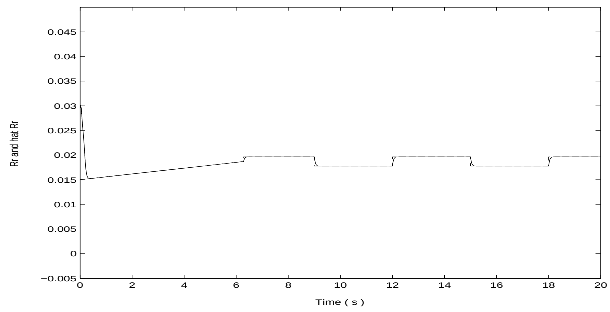

Figure 2: R_r and its estimate $\hat{R}_r$ with measured rotor speed, initial condition 0.03 and $f(t)$ being square signal

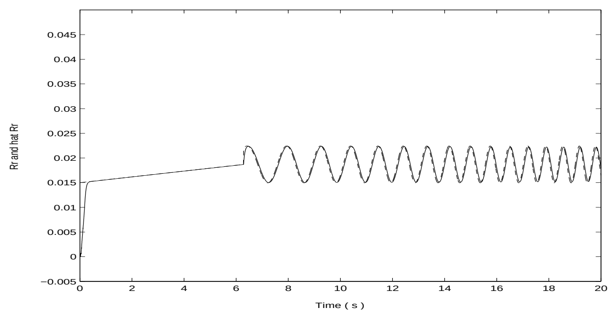

Figure 3: R_r and its estimate $\hat{R}_r$ with measured rotor speed, zero initial condition and $f(t)$ being chirp signal

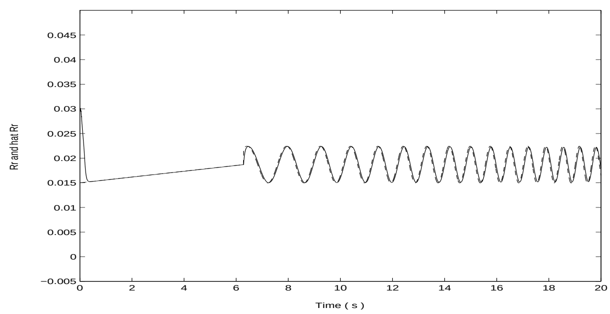

Figure 4: R_r and its estimate $\hat{R}_r$ with measured rotor speed, initial condition 0.03 and $f(t)$ being chirp signal

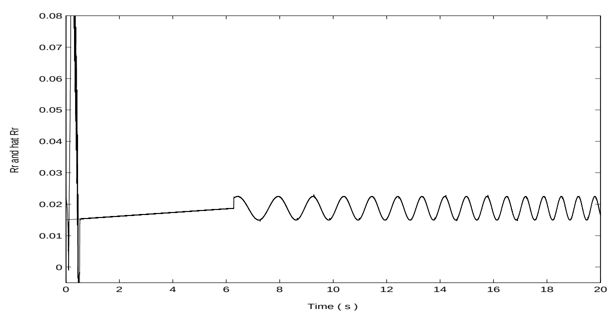

Figure 5: R_r and its estimate $\hat{R}_r$ with rotor speed neither measured nor estimated and $f(t)$ being chirp signal

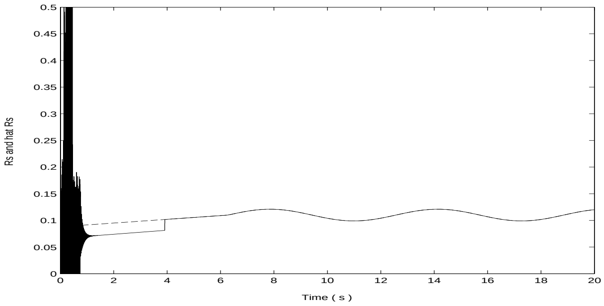

Figure 6: R_s and its estimate $\hat{R}_s$ with measured rotor speed and $f(t)$ being sinusoidal signal

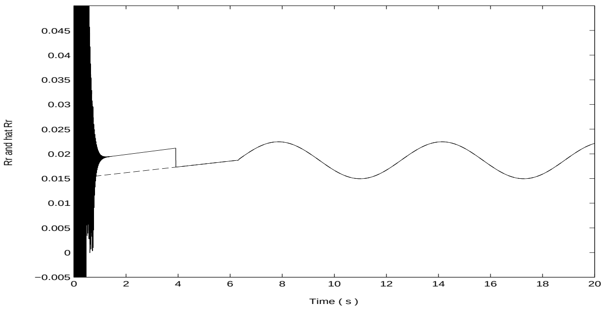

Figure 7: R_r and its estimate $\hat{R}_r$ with measured rotor speed and $f(t)$ being sinusoidal signal

6 Conclusion

In this paper, two schemes for the rotor resistance identification and one scheme for both stator and rotor resistances identification has been designed. The first and the third schemes use the measured stator current, voltage commands and rotor speed while the second scheme uses only stator current and voltage commands. The designs are based on the sliding mode observer and the convergence of the estimates to their true values does not required the persistence of excitation conditions to be satisfied by the input signal. The originality of this work is that it considers both rotor and stator resistances as time-varying and that the schemes proposed are easily implementable. This feature distinguishes the proposed identifier from the known ones.
The simplified dynamic model of the induction motor used in this work depends on the parameter c. Further work is under way to derive the validity condition of this model and hence the choice of this parameter c. Further more, real-time implementations deserves to be realized in order to verify the effectiveness of the proposed schemes with respect to the sensor noise, discretization effects, and modeling inaccuracies.

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