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ADAPTIVE CONTROL OF STATOR CURRENTS FOR SELF-COMISSIONING OF INDUCTION MOTOR DRIVES

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This paper develops and experimentally substantiates a new algorithm to identify unknown parameters of induction motors during self-commissioning procedure. To guarantee asymptotic identification, we design an adaptive stator current controller using a stator flux observer. Allowed current references guarantee global exponential identification of three induction motor parameters as well as estimation of stator fluxes in both motionless and rotating motor operations. Overestimation of the stator fluxes is introduced to achieve global stability of parameters identification and flux estimation. An asymptotic stator current tracking is also ensured. Our experiments demonstrate that the proposed schemes guarantee identification and estimation accuracy with fast asymptotic convergence of errors to zero. The proposed procedure compliments the existing practical control schemes, and, consistent with vector controls including sensorless algorithms. References 17, figures 4.
Keywords: induction motor, identification, estimation.

Introduction. The self commissioning procedure is an important feature for induction motor (IM) drives where field-oriented control strategy is applied [1]. There are six unknown varying parameters of nonlinear lamped-parameter IM models, e.g., the stator and rotor resistances, stator and rotor inductances, magnetizing inductance, and moment of inertia. These parameters are used to realize vector control algorithms. Therefore, motor parameters should be known to implement controllers [1], [2]. The impact of parameter uncertainties and variations are studied in many publications, see [1] – [4] and references therein. It is well known that standard indirect field-oriented control with speed sensors is robustly stable with respect to variations of the rotor resistance [5]. The rotor resistance is the most critical parameter in closed-loop systems with IMs. To achieve optimal dynamic performance during speed and torque tracking, and, ensure energy conversion efficiency, rotor resistance and magnetizing inductance should be precisely known. Implementation of high-gain current control schemes in field-oriented algorithms allows one to reduce the effect of other parameter variations. Sensorless vector control algorithms are more sensitive to parameters' accuracy, and, one needs all electrical parameters including stator resistance [3].

A commonly used approaches to define the IM electric parameters are based on locked rotor and no-load tests [6]. These procedures do not provide required accuracy and have some limitations. Different parameter identification techniques have being developed since the 1980s, see an overview paper [7] and references in [8]. Two classes of identification schemes are [7]: an *on-line* approach, when the parameters are identified during normal operating conditions; an *off-line* approach, which may require special testing conditions.

The *on-line* techniques lead to the use of adaptive control schemes, allowing real-time controller reconfiguration. However, the identification problem if not all states are measured is a very complex task which remains an open theoretical problem. Knowledge of rotor resistance predefines correctness of field-orientation in majority of vector control systems. Further developments of adaptive control algorithms are still of a significant importance [9]. The knowledge of stator resistance is required to identify rotor resistance as well as to implement sensorless algorithms. An algorithm for real-time identification of stator and rotor resistances was proposed in [10], where the nine-order adaptive observer was synthesized. Different modifications of the least-square method to identify electric parameters were presented in [11], [12]. In [11], to obtain a linearly-parameterized estimation model, it is assumed that the speed varies slowly. Identification despite of varying angular velocity was performed in [12], where nonlinear least-square approach is used. Computationally, both solutions are quite complex, and, require significant processing capabilities for real-time implementation. A limited number of theoretically- and experimentally proven adaptive control algorithms with identification of a few parameters are available [13]. Simplification, design of adaptive controllers, performance improvements and practical implementation are very important issues.

The *off-line* methods are focused for self-commissioning of IM drives during initialization. They use different approaches [7]: parameter calculation from motor catalog data; parameter estimation based on steady-state motor models; frequency-domain parameter estimation; time-domain parameter estimation. In general, self-commissioning procedures require special testing conditions with free rotating rotor or motionless motor. The motionless tests present the recent trend, especially for sensorless controls.

The time-domain approaches are based on MRAS techniques, see [8], [14], [15] and references [80] – [100] in overview paper [7]. In [14], the standard hyperstability approach is applied assuming constant electromagnetic torque which should be known. An elegant solution, reported in [8], is based on parallel adaptive observer with non-minimum state-space presentation. The aforementioned approach provides an asymptotic estimation of motor parameters and fluxes under the standstill condition. Intensive simulations and experimental investigations demonstrate effectiveness of this observer. In general, application of MRAS techniques lead to different modifications of adaptive full-order observers [15].

The main goal of this paper is to develop a new algorithm for IM parameters identification for both standstill and free rotation operating conditions. Compared with existing solutions, we propose a new approach which is based on adaptive stator current regulation. This system structure with inner current loops is utilized in majority of vector controlled IM drives. A solution proposed, under suitable excitations, provides asymptotic stator fluxes estimations and three IM parameters (rotor resistance, stator/rotor and magnetizing inductances) identifications. Our experimentally-verified scheme guarantees fast convergence of motor parameters to their values. The proposed algorithm matches or exceeds many existing solutions, and, suits commercialized technologies.

Identification Problem Statement. Assuming a linear magnetic system, the mathematic model of symmetric IM in the *stationary* reference frame is given by [1]

$$\dot\omega = (3L_m/2JL_2)p_n(\psi_{2a}i_b - \psi_{2b}i_a) - T_L/J, \qquad \dot i_a = -\left(R_1\sigma^{-1} + \alpha L_m\beta\right)i_a + \alpha\beta\psi_{2a} + \beta p_n\omega\psi_{2b} + \sigma^{-1}u_a,$$

$$\dot i_b = -\left(R_1\sigma^{-1} + \alpha L_m\beta\right)i_b + \alpha\beta\psi_{2b} - \beta p_n\omega\psi_{2a} + \sigma^{-1}u_b, \tag{1}$$

$$\dot\psi_{2a} = -\alpha\psi_{2a} - p_n\omega\psi_{2b} + \alpha L_m i_a, \qquad \dot\psi_{2b} = -\alpha\psi_{2b} + p_n\omega\psi_{2a} + \alpha L_m i_b,$$

where $\mathbf{i} = (i_a, i_b)^T$, $\boldsymbol{\psi}_2 = (\psi_{2a}, \psi_{2b})^T$ and $\mathbf{u} = (u_a, u_b)^T$ are the vectors of stator current, rotor flux linkage and stator voltage; ω is the angular velocity; R_1 is the stator resistance; J is the moment of inertia; T_L is the load torque; p_n is the number of pole pairs.

In (1) three positive constants σ, α and β are defined using the motor parameters as $\alpha = R_2/L_2$; $\sigma = L_1\left(1 - L_m^2/L_1L_2\right)$; $\beta = L_m/\sigma L_2$, where R_2 is the rotor resistance; L_1 and L_2 are the stator and rotor inductances; L_m is the magnetizing inductance. We need to identify five unknown parameters of IM models, e.g., the stator and rotor resistances R_1 and R_2, and, inductances L_1, L_2 and L_m.

The identification problem can be consistently simplified by applying the following practical and accurate postulates: (1) The numeric values of stator and rotor inductances are practically equal, $L_1 = L_2$; (2) The unknown parameters during identification are constant; (3) Stator resistance can be determined using the Ohm law when the dc voltages are applied to stator windings, e.g., if $u_a = \text{const}$ and $u_b = 0$, one has

$$\lim_{t\to\infty} i_a = u_a/R_1, \qquad \lim_{t\to\infty} i_b = 0. \tag{2}$$

Mathematically, the induction motor dynamics is described by five nonlinear differential equations (1). The stator currents and angular velocity are measured, while the flux linkages are not available for measurement. The derivatives of not measured flux linkages are unknown because there are unknown parameters in the right-hand sides of the flux equations in (1). Therefore, one cannot use the standard approaches of adaptive system theory. To overcome this problem, we use a concept proposed in [8]. We rewrite model (1) in the following form in order to avoid dependency of right side flux equations from unknown parameters

$$\dot\omega = \frac{1}{J}\left(\frac{3}{2}p_n(\psi_a i_b - \psi_b i_a) - T_L\right), \qquad \begin{pmatrix}\dot\psi_a\\ \dot\psi_b\end{pmatrix} = -R_1\begin{pmatrix}i_a\\ i_b\end{pmatrix} + \begin{pmatrix}u_a\\ u_b\end{pmatrix},$$

$$\begin{pmatrix} \dot{i}_a \\ \dot{i}_b \end{pmatrix} = -\begin{bmatrix} \left(R_1\sigma^{-1}+\rho\right) & p_n\omega \\ -p_n\omega & \left(R_1\sigma^{-1}+\rho\right) \end{bmatrix} \begin{pmatrix} i_a \\ i_b \end{pmatrix} + \sigma^{-1} \begin{bmatrix} \alpha & p_n\omega \\ -p_n\omega & \alpha \end{bmatrix} \begin{pmatrix} \psi_a \\ \psi_b \end{pmatrix} + \frac{1}{\sigma} \begin{pmatrix} u_a \\ u_b \end{pmatrix}, \qquad (3)$$

where $\boldsymbol{\psi} = \left(\psi_a, \psi_b\right)^T$ is the stator flux linkage vector; $\rho = \alpha L_m \beta + \alpha$.

The parameters identification is performed using four electromagnetic equations of motions without the *torsional-mechanical* differential equation in (3). We assume that the fed stator currents ensure bounded motion of IM states, and, persistency of excitation conditions is met.

Under this assumption we need to identify α, σ and ρ, which yield R_2, L_1, L_2 and L_m. Denoting the flux linkages estimates as $\hat{\boldsymbol{\psi}} = \left(\hat{\psi}_a, \hat{\psi}_b\right)^T$, the identification and estimations errors are $\tilde{\alpha} = \alpha - \hat{\alpha}$, $\tilde{\sigma} = \sigma - \hat{\sigma}$, $\tilde{\rho} = \rho - \hat{\rho}$, $\tilde{\psi} = \psi - \hat{\psi} = \left(\tilde{\psi}_a, \tilde{\psi}_b\right)^T$, where $\hat{\alpha}$, $\hat{\sigma}$ and $\hat{\rho}$ are the estimations of α, σ and ρ.

Let the bounded vector of current references $\mathbf{i}^* = \left(i_a^*, i_b^*\right)^T$ has the bounded first and second time derivatives. Under this assumption it is necessary to synthesize an adaptive current controller which guarantees:

O.1. Asymptotic current tracking, such that $\lim\limits_{t\to\infty}\left(\tilde{\mathbf{i}}\right) = 0$, $\tilde{\mathbf{i}} = \mathbf{i} - \mathbf{i}^*$.

O.2. Asymptotic stator flux linkages estimation, such that $\lim\limits_{t\to\infty}\left(\tilde{\boldsymbol{\psi}}\right) = 0$.

O.3. Asymptotic identification of the unknown parameters α, σ, ρ, such that $\lim\limits_{t\to\infty}\left(\tilde{\alpha}, \tilde{\sigma}, \tilde{\rho}\right) = 0$.

Adaptive Controller Design. We design an adaptive current controller using stator flux observer in the following form

$$\begin{aligned} &\dot{\hat{\psi}}_a = -R_1 i_a + u_a + k_\psi \tilde{i}_a, \qquad \dot{\hat{\psi}}_b = -R_1 i_b + u_b + k_\psi \tilde{i}_b, \\ &u_a = R_1 i_a^* - \hat{\alpha}\hat{\psi}_a - p_n\omega\hat{\psi}_b + \hat{\sigma}\left(\hat{\rho} i_a^* + p_n\omega i_b + \dot{i}_a^* - k_i \tilde{i}_a\right) - p_n\omega\hat{\tilde{\psi}}_b, \\ &u_b = R_1 i_b^* - \hat{\alpha}\hat{\psi}_b + p_n\omega\hat{\psi}_a + \hat{\sigma}\left(\hat{\rho} i_b^* - p_n\omega i_a + \dot{i}_b^* - k_i \tilde{i}_b\right) + p_n\omega\hat{\tilde{\psi}}_a, \end{aligned} \qquad (2)$$

where $k_\psi > 0$ and $k_i > 0$ are the tuning coefficients.

In the adaptive current controller, the additional vector of auxiliary variables $\hat{\tilde{\boldsymbol{\psi}}} = \left(\hat{\tilde{\psi}}_\alpha, \hat{\tilde{\psi}}_b\right)^T$ is used. The stator flux overestimation with $\hat{\tilde{\boldsymbol{\psi}}} = \left(\hat{\tilde{\psi}}_\alpha, \hat{\tilde{\psi}}_b\right)^T$ is required to guarantee global stability of stator current regulation. The corresponding estimation error vector is $\tilde{\tilde{\boldsymbol{\psi}}} = \tilde{\boldsymbol{\psi}} - \hat{\tilde{\boldsymbol{\psi}}}$.

From (3) and (2), the current tracking and flux estimation error dynamics is

$$\begin{pmatrix} \dot{\hat{\tilde{\psi}}}_a \\ \dot{\hat{\tilde{\psi}}}_b \end{pmatrix} = -k_\psi \begin{pmatrix} \tilde{i}_a \\ \tilde{i}_b \end{pmatrix},$$

$$\begin{pmatrix} \dot{\tilde{i}}_a \\ \dot{\tilde{i}}_b \end{pmatrix} = \begin{pmatrix} -\left(R_1\sigma^{-1}+\rho+k_i\right) & 0 \\ 0 & -\left(R_1\sigma^{-1}+\rho+k_i\right) \end{pmatrix} \begin{pmatrix} \tilde{i}_a \\ \tilde{i}_b \end{pmatrix} + \begin{bmatrix} \frac{\alpha}{\sigma} & 0 & \frac{\hat{\psi}_a}{\sigma} & -\frac{\phi_a}{\sigma} & -i_a^* & 0 & \frac{p_n\omega}{\sigma} \\ 0 & \frac{\alpha}{\sigma} & \frac{\hat{\psi}_b}{\sigma} & -\frac{\phi_b}{\sigma} & -i_b^* & -\frac{p_n\omega}{\sigma} & 0 \end{bmatrix} \tilde{\mathbf{x}} \triangleq \qquad (5)$$

$$\triangleq \mathbf{A}\tilde{\mathbf{i}} + \mathbf{W}(t)\mathbf{D}^{-1}\tilde{\mathbf{x}},$$

$$\phi_a = \hat{\rho} i_a^* + p_n\omega i_b - k_i \tilde{i}_a + \dot{i}_a^*, \qquad \phi_b = \hat{\rho} i_b^* - p_n\omega i_a - k_i \tilde{i}_b + \dot{i}_b^*, \qquad \tilde{\mathbf{x}} = \left(\tilde{\psi}_a, \tilde{\psi}_b, \tilde{\alpha}, \tilde{\sigma}, \tilde{\rho}, \tilde{\tilde{\psi}}_a, \tilde{\tilde{\psi}}_b\right)^T,$$

where $\mathbf{A} = \begin{bmatrix} -\left(R_1\sigma^{-1}+\rho+k_i\right) & 0 \\ 0 & -\left(R_1\sigma^{-1}+\rho+k_i\right) \end{bmatrix}$; $\mathbf{W}(t) = \begin{bmatrix} 1 & 0 & \hat{\psi}_a & -\phi_a & -i_a^* & 0 & p_n\omega \\ 0 & 1 & \hat{\psi}_b & -\phi_b & -i_b^* & -p_n\omega & 0 \end{bmatrix}$ is the regression matrix; $\mathbf{D} = \mathrm{diag}\left[\sigma/\alpha, \sigma/\alpha, \sigma, \sigma, 1, \sigma, \sigma\right] > 0$, $\mathbf{D} \in \mathbb{R}^{7x7}$.

To design our identification algorithm, consider the following positive-definite function

$$V=\frac{1}{2}\left[(\tilde{i}_a^{\,2}+\tilde{i}_b^{\,2})+k_\psi^{-1}\frac{\alpha}{\sigma}(\tilde{\psi}_a^2+\tilde{\psi}_b^2)+\gamma_\psi^{-1}\frac{1}{\sigma}(\tilde{\tilde{\psi}}_a^2+\tilde{\tilde{\psi}}_b^2)+\gamma_\alpha^{-1}\frac{1}{\sigma}\tilde{\alpha}^2+\gamma_\sigma^{-1}\frac{1}{\sigma}\tilde{\sigma}^2+\gamma_\rho^{-1}\tilde{\rho}^2\right], \qquad (6)$$

The total derivative of (6) along the trajectories of (5) is given by

$$\begin{aligned}\dot{V}=&-(\frac{R_1}{\sigma}+\rho+k_i)\tilde{i}_a^2+\frac{1}{\sigma}p_n\omega\tilde{\tilde{\psi}}_b\tilde{i}_a+\frac{\tilde{\alpha}}{\sigma}\hat{\psi}_a\tilde{i}_a-\tilde{\rho}i_a^*\tilde{i}_a-\frac{\tilde{\sigma}}{\sigma}\phi_a\tilde{i}_a-\\&-(\frac{R_1}{\sigma}+\rho+k_i)\tilde{i}_b^2-\frac{1}{\sigma}p_n\omega\tilde{\tilde{\psi}}_a\tilde{i}_b+\frac{\tilde{\alpha}}{\sigma}\hat{\psi}_b\tilde{i}_b-\tilde{\rho}i_b^*\tilde{i}_b-\frac{\tilde{\sigma}}{\sigma}\phi_b\tilde{i}_b+\\&+\gamma_\alpha^{-1}\frac{1}{\sigma}\dot{\tilde{\alpha}}\tilde{\alpha}+\gamma_\sigma^{-1}\frac{\tilde{\sigma}}{\sigma}\dot{\tilde{\sigma}}+\gamma_\rho^{-1}\dot{\tilde{\rho}}\tilde{\rho}+\gamma_\psi^{-1}\frac{1}{\sigma}\dot{\tilde{\tilde{\psi}}}_a\tilde{\tilde{\psi}}_a+\gamma_\psi^{-1}\frac{1}{\sigma}\dot{\tilde{\tilde{\psi}}}_b\tilde{\tilde{\psi}}_b.\end{aligned} \qquad (7)$$

From (7) the identification and estimation algorithm is expressed as

$$\begin{aligned}&\dot{\hat{\alpha}}=-\dot{\tilde{\alpha}}=\gamma_\alpha\left(\hat{\psi}_a\tilde{i}_a+\hat{\psi}_b\tilde{i}_b\right),\quad \dot{\hat{\sigma}}=-\dot{\tilde{\sigma}}=-\gamma_\sigma\left(\phi_a\tilde{i}_a+\phi_b\tilde{i}_b\right),\quad \dot{\hat{\rho}}=-\dot{\tilde{\rho}}=-\gamma_\rho\left(\tilde{i}_a i_a^*+\tilde{i}_b i_b^*\right),\\&\dot{\hat{\tilde{\psi}}}_a=\dot{\hat{\psi}}_a-\dot{\tilde{\tilde{\psi}}}_a=-k_\psi\tilde{i}_a-\gamma_\psi p_n\omega\tilde{i}_b,\qquad \dot{\hat{\tilde{\psi}}}_b=\dot{\hat{\psi}}_b-\dot{\tilde{\tilde{\psi}}}_b=-k_\psi\tilde{i}_b+\gamma_\psi p_n\omega\tilde{i}_a.\end{aligned} \qquad (8)$$

From (7) and (8), one obtains

$$\dot{V}=-\left(R_1\sigma^{-1}+\rho+k_i\right)\left(\tilde{i}_a^2+\tilde{i}_b^2\right). \qquad (9)$$

Hence, the positive-definite V, given by (6), is a Lyapunov function.

From (6) and (9), it follows that $\tilde{\mathbf{i}}$ and $\tilde{\mathbf{x}}$ are bounded. Therefore for bounded $\mathbf{u}$, $\mathbf{i}$, $\boldsymbol{\psi}$ and ω, estimates $\hat{\mathbf{i}}$, $\hat{\boldsymbol{\psi}}$, $\hat{\alpha}$, $\hat{\sigma}$, $\hat{\rho}$, $\hat{\tilde{\boldsymbol{\psi}}}$ are also bounded because the conditions imposed on a Lyapunov pair are satisfied. Furthermore, $\mathbf{W}(t)$ in (5), and, the total derivative $\dot{\tilde{\mathbf{i}}}$, are also bounded.

Due to $\int_0^t \dot{V}d\tau=-\left[V(t)-V(0)\right]\left(R_1/\sigma+\rho+k_i\right)^{-1}\le V(0)\left(R_1/\sigma+\rho+k_i\right)^{-1}$, a square-integrable $\tilde{\mathbf{i}}(t)$ is bounded, with the bounded total derivative. Applying the Barbalat's Lemma [16], we have $\lim_{t\to\infty}\tilde{\mathbf{i}}=0$.

From (5) and (8), the errors dynamics is described as

$$\dot{\tilde{\mathbf{i}}}=\mathbf{A}\tilde{\mathbf{i}}+\mathbf{W}(t)\mathbf{D}^{-1}\tilde{\mathbf{x}},\qquad \dot{\tilde{\mathbf{x}}}=-\boldsymbol{\Gamma}\mathbf{W}(t)^T\mathbf{P}\tilde{\mathbf{i}}. \qquad (10)$$

where $\boldsymbol{\Gamma}=\mathrm{diag}\left[k_\psi,k_\psi,\gamma_\alpha,\gamma_\sigma,\gamma_\rho,\gamma_\psi,\gamma_\psi\right]>0$, $\boldsymbol{\Gamma}\in|^{7x7}$. $\mathbf{P}=\mathrm{diag}[1,1]$, $\mathbf{P}=\mathbf{I}\in|^{2x2}$.

If persistency of excitation conditions is satisfying, for a mapping $\mathbf{W}$ we have

$$\int_t^{t+T}\mathbf{W}(\tau)\mathbf{W}^T(\tau)d\tau>0,\qquad T>0,\qquad \forall t\ge 0. \qquad (11)$$

As $\dot{\mathbf{W}}(t)$ is bounded, an equilibrium $\left(\tilde{\mathbf{i}},\tilde{\mathbf{x}}\right)^T=0$ of [14] is globally exponentially stable [15]. Therefore, objectives O.1 – O.3 are guaranteed. Correspondingly, asymptotic current regulation, asymptotic flux estimation and identification of unknown α, σ, ρ were achieved.

A set of equations (2), (8) provides the resulting equations for adaptive current controller and observer. From the estimated values $\hat{\alpha}$, $\hat{\sigma}$, $\hat{\rho}$, derived with the predetermined R_1, the parameters $L=L_1=L_2$, L_m and R_2 are given as $\hat{L}=\hat{\rho}\hat{\sigma}/\hat{\alpha}$, $\hat{L}_m=\sqrt{\hat{L}\left(\hat{L}-\hat{\sigma}\right)}$, $\hat{R}_2=\hat{\alpha}\hat{L}$.

Experimental Studies. The experiments are carried out using the Rapid Prototyping Station (RPS) at the National Technical University of Ukraine. As shown in Fig. 1, the RPS includes: (1) Induction motor with rated power 2.2 kW (four-pole, 380 V, 5 A, 157 rad/sec, 15 Nm, 50 Hz) and a loading induction motor which operates in a torque control mode; (2) 20 A and 380 V three-phase PWM controlled inverter, operated at 10 kHz switching frequency; (3) DSP TMS320C32 controller which performs data acquisition, implements control algorithms with programmable tracing of selected variables; (4) Personal computer for processing, programming, interactive oscilloscope, data acquisition, etc. The motor speed is measured by a 1024 pulse/revolution optical encoder. The sampling time is 200 μsec. To verify the identification algorithm (2)–(8), we set the zero initial conditions for the estimates of unknown parameters. This represents the most challenging case. For the adaptive controller, we assign $k_\psi=10$, $k_i=100$, $\gamma_\alpha=120$, $\gamma_\sigma=0.0001$, $\gamma_\rho=100$ and $\gamma_\psi=1$.

The experimental evolutions of the stator currents $i_a(t)$, $i_b(t)$, stator voltages u_a and u_b, flux estimates $\hat{\psi}_a, \hat{\psi}_b$ as well as current tracking and parameter identification errors are reported in Fig. 2. During $t \in [0;\ 1.1]$ sec, the induction motor operates as a motionless single-phase machine with $i_b^* = 0$ and $u_b = 0$. At t=1.1 sec, we apply i_b^*, and, motor rotates. The identification is performed for motionless and rotating motor. As it follows from Fig. 2, asymptotic current tracking, accurate identification is accomplished within ~3 sec.

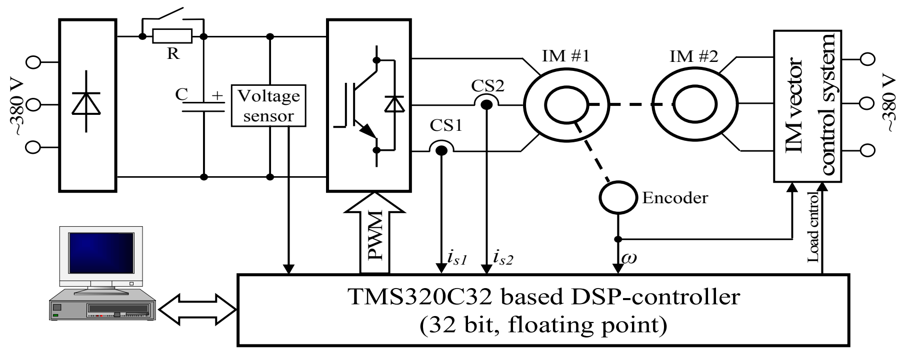

Fig. 1

The experimental studies are compared with the simulation results. Fig. 3 provides the errors evolution for the current, estimated flux and *characterizing* motor parameters $\tilde{\alpha}$, $\tilde{\sigma}$ and $\tilde{\rho}$. We analyze experimental results, given in Fig. 2, and, numeric studies as reported in Fig. 3. The documented findings illustrate precise correspondence, accuracy and matching. The reported results justify and substantiate our fundamental findings, analytic results, numerical studies and experimentally-justified practical identification technology.

Sensorless control with identifyed parameters. To validate our results, we test sensorless vector control of IM [17] using parameters identified. Fig. 4 documents the evolution of the angular velocity errors, as well as the torque component of the stator current i_q during speed reference tracking with the final speed values of 1.5 rad/sec (1% of rated speed, Fig.4a) and 50 rad/sec (30% of rated speed, Fig. 4b). The speed reference is applied at t=0.6 sec. At $t \in [1;1,5]$ sec, the motor is loaded with the rated load torque T_L=15 Nm. Very good dynamic and steady state performances as well as excellent capabilities are guaranteed in an expanded operating envelope, e.g., low angular velocity and up to rated loads. An overall effectiveness and practicality of the proposed identification algorithm in sensorless vector control scheme are substantiated.

Conclusions. We synthesized and analyzed a robust identification algorithm with estimation of not measured stator flux linkages to identify IM parameters for self-commissioning procedure during drive initialization. The seven-order adaptive current tracking control algorithm is designed. Specific current references guarantee global exponential identification of three induction motor parameters, as well as estimation of the stator fluxes for motionless and free rotation motor operations conditions. Overestimation of fluxes is required to achieve global convergence.

Experimental results in identification of motor parameters substantiate the proposed identification technology. The use of identified parameters in sensorless vector control experimentally proved the effectiveness and suitability of the proposed identification scheme. Our findings are of a particular interest for high-performance systems, including sensorless vector controls. Robust, near-real-time and fast convergence of unknown varying parameters to the actual values leads to design of superior systems which ensure optimal performance and capabilities.

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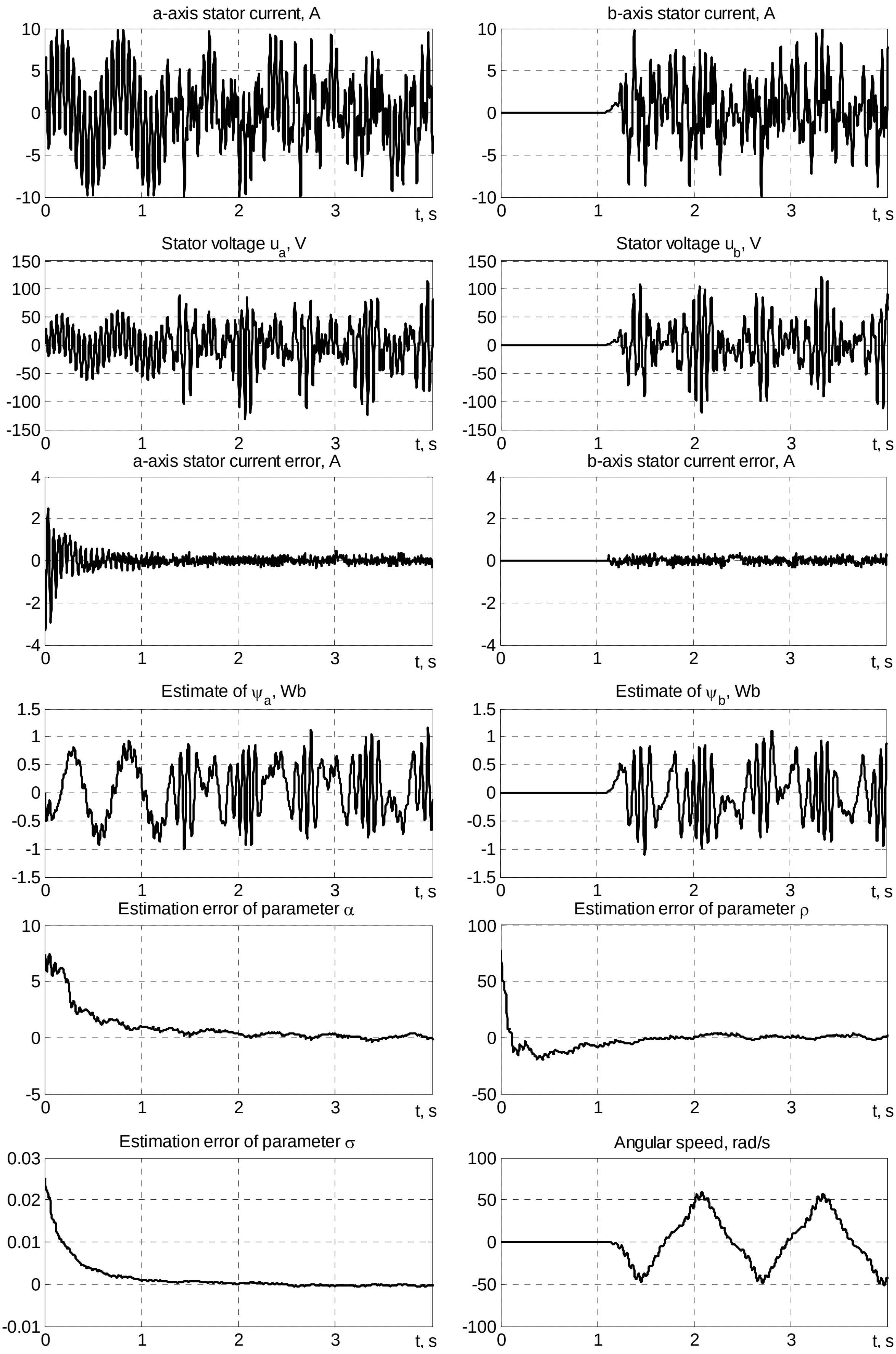
a-axis stator current, A
b-axis stator current, A
Stator voltage u_a, V
Stator voltage u_b, V
a-axis stator current error, A
b-axis stator current error, A
Estimate of ψ_a, Wb
Estimate of ψ_b, Wb
Estimation error of parameter α
Estimation error of parameter ρ
Estimation error of parameter σ
Angular speed, rad/s
t, s

Fig. 2

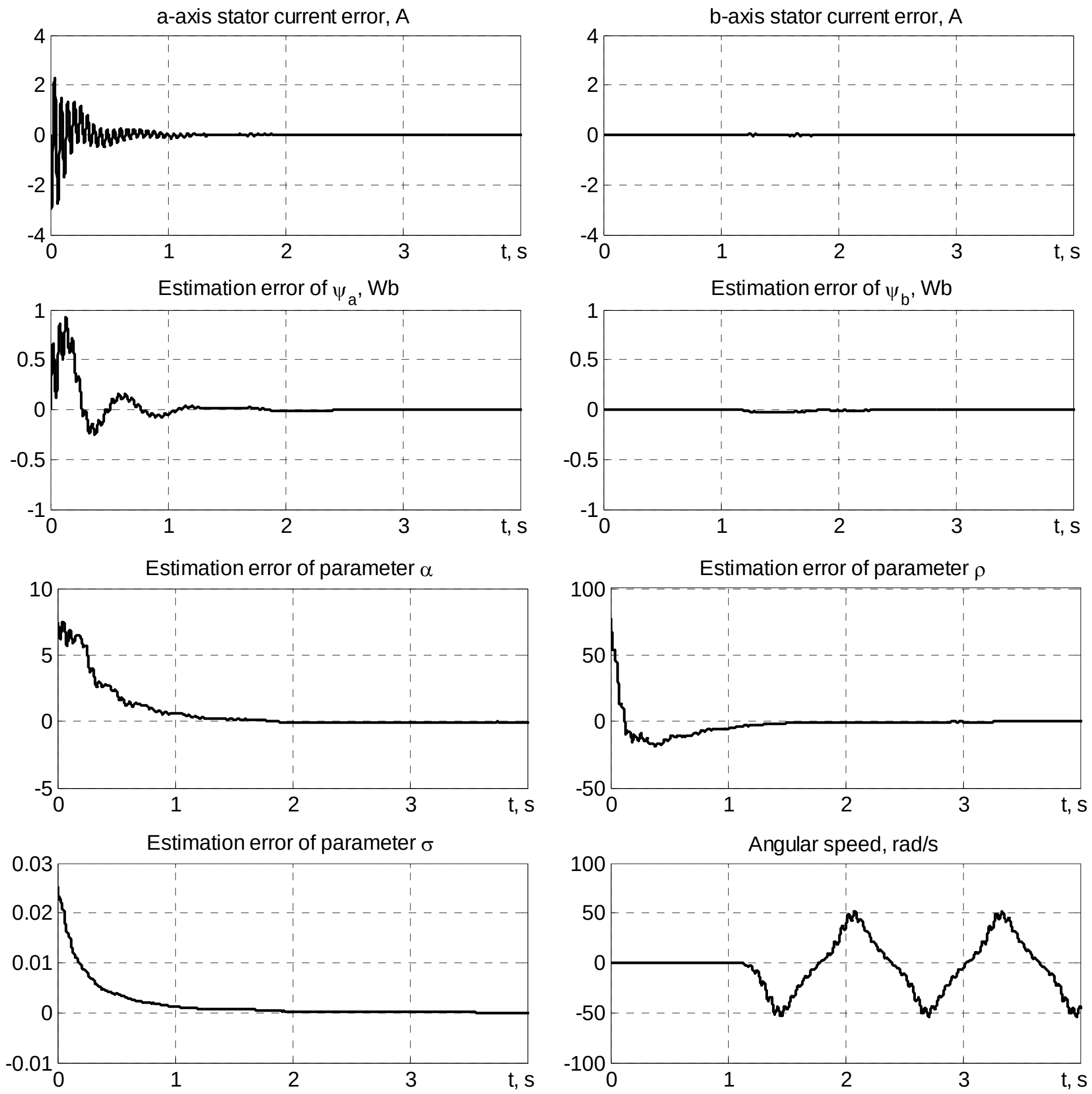
a-axis stator current error, A
b-axis stator current error, A
Estimation error of ψ_a, Wb
Estimation error of ψ_b, Wb
Estimation error of parameter α
Estimation error of parameter ρ
Estimation error of parameter σ
Angular speed, rad/s
t, s

Fig. 3

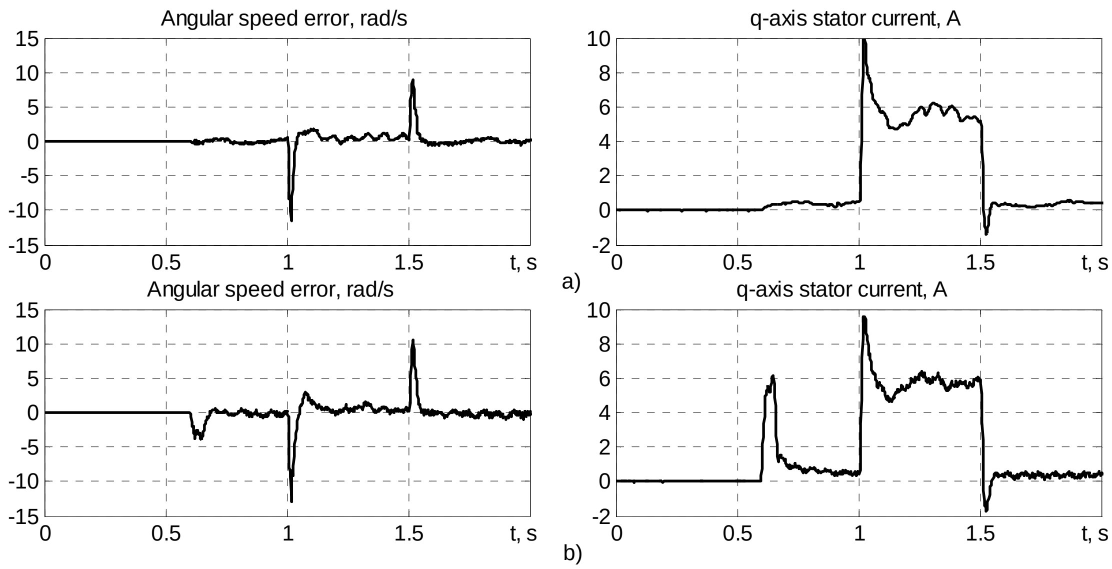
Angular speed error, rad/s
q-axis stator current, A
t, s
a)
Angular speed error, rad/s
q-axis stator current, A
t, s
b)

Fig. 4

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АДАПТИВНОЕ РЕГУЛИРОВАНИЕ ТОКОВ СТАТОРА ДЛЯ ПРОЦЕДУР САМОНАСТРОЙКИ АСИНХРОННЫХ ЭЛЕКТРОПРИВОДОВ

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В работе синтезирован и экспериментально проверен новый алгоритм идентификации неизвестных параметров асинхронного двигателя для процедур самонастройки электроприводов. С целью обеспечения асимптотической идентификации параметров разработан адаптивный регулятор токов статора, основанный на наблюдателе потокосцепления статора, в который для обеспечения свойств глобальной экспоненциальной устойчивости введен вектор избыточных оценок. Использование специально сформированных заданных траекторий токов статора гарантирует глобальную экспоненциальную идентификацию трех параметров асинхронного двигателя и оценивание вектора потокосцепления статора, как при неподвижном, так и при свободно вращающемся роторе. Проведенное экспериментальное тестирование синтезированного алгоритма демонстрирует высокую точность идентификации параметров, а также высокую скорость сходимости ошибок в ноль, которые не уступают существующим в промышленных решениях. Предложенная процедура идентификации может использоваться для настройки систем векторного управления, в том числе и бездатчиковых. Библ. 17, рис. 4.

Ключевые слова: асинхронный двигатель, идентификация, оценивание.

АДАПТИВНЕ РЕГУЛЮВАННЯ СТРУМІВ СТАТОРА ДЛЯ ПРОЦЕДУР САМОНАЛАШТУВАННЯ АСИНХРОННИХ ЕЛЕКТРОПРИВОДІВ

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У роботі синтезовано і експериментально перевірено новий алгоритм ідентифікації невідомих параметрів асинхронного двигуна для процедур самоналаштування електроприводів. З метою забезпечення асимптотичної ідентифікації параметрів розроблено адаптивний регулятор струмів статора, заснований на спостерігачі потокозчеплення статора, в який для забезпечення властивостей глобальної експоненційної стійкості введено вектор надлишкових оцінок. Використання спеціально сформованих заданих траєкторій струмів статора гарантує глобальну експоненційну ідентифікацію трьох параметрів асинхронного двигуна і оцінювання вектора потокозчеплення статора як при нерухомому двигуні, так і такому, що вільно обертається. Проведене експериментальне тестування синтезованого алгоритму демонструє високу точність ідентифікації параметрів, а також високу швидкість сходимості похибок в нуль, які не поступаються існуючим в промислових рішеннях. Запропонована процедура ідентифікації може використовуватися для налаштування систем векторного керування, в тому числі і бездавачевих. Бібл. 10, рис. 4.

Ключові слова: асинхронний двигун, ідентифікація, оцінювання.

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