Acta Materialia Turcica

Volume 1, December 2017, Pages 35-39

Parameters Identification of the Three-phase Wound-rotor Induction Machine

M. GAICEANU[a,b,*], B. CODRES[a], R. BUHOSU[a,b]

[a] Dunarea de Jos University of Galati, Address, Galati-800008, Romania
[b] Integrated Energy Conversion Systems and Advanced Control of Complex Processes Research Center, Romania

Abstract:
In order to implement the adequate control of the wind turbine it is necessary to know the parameters of the electric generator. Due to the robustness, acquisition cost and maintenance, the three-phase wound-rotor asynchronous generator is used. The objective of this paper is to apply an identification method in order to find the electrical parameters (for both stator and rotor windings) of the three-phase asynchronous machine used as electric generator to be introduced for calculating the appropriate parameters of the control loops regulators. The most common identification method is the least squares one and it is used in this paper. The objective function is described, the identified parameters are chosen by minimization of the performance index. The synchronous reference frame based mathematical model of the induction machine (IM) is provided. Therefore, the vector control of the wind turbine is the most suitable control method. The Matlab implementation of the proposed method is presented in the paper. In order to show the performance of the used identification method, the real parameters values of the three-phase IM's are compared with the parameters obtained through the identification algorithm by using the proposed mathematical model of the IM. The validation of the proposed method has been achieved both by numerical simulation, and experimental results. Validation of the mathematical model is important for using in both for the hardware in the loop control (HIL) and for diagnosis purposes.
Keywords: Parameters Identification - Least Mean Squares - Wound Rotor.
DOI:

1. Introduction

There are off-line and on-line identification methods [1-6] of the electrical machines parameters. The necessary data can be obtained at standstill or at rotating operating regimes. The aim of the paper is to find the parameters of the wound rotor induction motor by using the least squares method [7,8], and to evaluate the performances of the applied identification method. The Matlab implementation of the proposed identification solution is shown [9].

2. Identification Problem

2.1. The *d, q* Mathematical Model of the Three-phase Wound Asynchronous Motor:

In order to proceed to the mathematical model of the IM some assumptions have been made: symmetrical windings powered from the symmetrical power source voltage rated magnetic flux, only fundamental harmonic is taken into consideration, constant air-gap. The mathematical model of the IM consists of the voltage, magnetic flux, torque and circular motion equations.

The adequate meanings of the used symbols are shown in the Table 1.

Table 1. The nomenclature of the used symbols.

Symbol	Nomenclature
ω_{sl}	slip angular speed;
i_{sd}, i_{sq}	longitudinal and transversal stator current components *d, q;*
u^*_{ds}, u^*_{qs}	(*d, q*) axes stator voltage components;
L_s, L_r	stator, rotor inductances;
L_m	mutual inductance;
T_L	rotor reduced equivalent load torque;
J	the equivalent inertia moment;
p	number of the pole pairs;
R_s, R_r	stator and rotor phase resistances;
ω_1	synchronous angular speed;
ω	rotor angular speed;
$\mathbf{u}_s$, $\mathbf{i}_s$, $\boldsymbol{\psi}_s$	voltage, current, flux stator space phasors;
$\mathbf{u}_r$, $\mathbf{i}_r$, $\boldsymbol{\psi}_r$	voltage, current, flux rotor space phasors;
Ψ_{ds}, Ψ_{qs}	the longitudinal and quadrature components of the stator flux;
Ψ_{dr}, Ψ_{qr}	the longitudinal and quadrature components of the rotor flux.

Corresponding Author E-mail: marian.gaiceanu@ugal.ro

The stator and rotor three-phase system Equations (1) are as follows:

$$\begin{cases} u_A(t) = R_s i_A(t) + \frac{d}{dt}\psi_A(t) \\ u_B(t) = R_s \cdot i_B(t) + \frac{d}{dt}\psi_B(t) \\ u_C(t) = R_s \cdot i_C(t) + \frac{d}{dt}\psi_C(t) \end{cases} \quad \begin{cases} u_a(t) = R_r i_a(t) + \frac{d}{dt}\psi_a(t) \\ u_b(t) = R_r \cdot i_b(t) + \frac{d}{dt}\psi_b(t) \\ u_c(t) = R_r \cdot i_c(t) + \frac{d}{dt}\psi_c(t) \end{cases} \tag{1}$$

The modern electric drives suppose the implementation of the vector control. In this respect, the appropriate space phasors for the stator current, voltage and flux (2) are considered:

$$\begin{cases} \mathbf{u}_s = \frac{2}{3}\left[u_A(t) + \mathbf{a}u_B(t) + \mathbf{a}^2 u_c(t)\right] \\ \mathbf{i}_s = \frac{2}{3}\left[i_A(t) + \underline{\mathbf{a}} i_B(t) + \mathbf{a}^2 i_c(t)\right] \\ \boldsymbol{\psi}_s = \frac{2}{3}\left[\psi_A(t) + \mathbf{a}\psi_B(t) + \mathbf{a}^2 \psi_c(t)\right] \end{cases} \tag{2}$$

Taken into account the (d, q) components, defined into a two-phase stator reference frame system, of the above mentioned stator space phasors, and similar rotor space vectors, by separating the real part from the imaginary part the (d, q) stator voltage model (3) is provided:

$$\begin{cases} u_{ds} = R_s \cdot i_{ds} + \frac{d}{dt}\psi_{ds} - \omega_1 \psi_{qs} \\ u_{qs} = R_s \cdot i_{qs} + \frac{d}{dt}\psi_{qs} + \omega_1 \psi_{ds} \\ u_{dr} = R_r i_{dr} + \frac{d}{dt}\psi_{dr} - (\omega_1 - \omega)\psi_{qr} \\ u_{qr} = R_r i_{qr} + \frac{d}{dt}\psi_{qr} + (\omega_1 - \omega)\psi_{dr} \end{cases} \tag{3}$$

Replacing the below mentioned (d, q) components flux equations (4)

$$\begin{cases} \psi_{ds} = L_s i_{ds} + L_m i_{dr} \\ \psi_{qs} = L_s i_{qs} + L_m i_{qr} \\ \psi_{dr} = L_r i_{dr} + L_m i_{ds} \\ \psi_{qr} = L_r i_{qr} + L_m i_{qs} \end{cases} \tag{4}$$

into the stator and rotor (d, q) components (3), the final stator and rotor (d, q) voltage components (5) are obtained:

$$\begin{cases} u_{ds} = R_s \cdot i_{ds} - \omega_1\left(L_s i_{qs} + L_m i_{qr}\right) + \frac{d}{dt}\left(L_s i_{ds} + L_m i_{dr}\right) \\ u_{qs} = R_s \cdot i_{qs} - \omega_1\left(L_s i_{ds} + L_m i_{dr}\right) + \frac{d}{dt}\left(L_s i_{qs} + L_m i_{qr}\right) \\ u_{dr} = R_r \cdot i_{dr} - (\omega_1 - \omega)\left(L_r i_{qr} + L_m i_{qs}\right) + \frac{d}{dt}\left(L_r i_{dr} + L_m i_{ds}\right) \\ u_{qr} = R_r \cdot i_{qr} + (\omega_1 - \omega)\left(L_r i_{dr} + L_m i_{ds}\right) + \frac{d}{dt}\left(L_r i_{qr} + L_m i_{qs}\right) \end{cases} \tag{5}$$

The electromagnetic torque is invariant to the system reference frame (6):

$$T_e = \frac{3}{2} p \,\mathrm{Im}\left\{\underline{\boldsymbol{\psi}}_{s\lambda} \cdot \mathbf{i}^*_{s\lambda}\right\} = \frac{3}{2} p \,\mathrm{Im}\left[\underline{\boldsymbol{\psi}}_{r\lambda} \cdot \mathbf{i}^*_{r\lambda}\right] = \frac{3}{2} p L_m \left(i_{dr} i_{qs} - i_{qr} i_{ds}\right) \tag{6}$$

The circular motion dynamic Equation (7) is:

$$\frac{d\omega}{dt} = \frac{p}{J} \cdot \left(m - m_s\right) \tag{7}$$

2.2. Least Mean Squares Identification Method:

Suppose that the set of N observations has been collected.

If there are m parameters (8) of the mathematical model:

$$\bar{\theta} = [\bar{\theta}_1, \quad \dots, \quad \bar{\theta}_m]^T \tag{8}$$

The mathematical model is a linear combination between the observations and the parameters of the model $\bar{\theta}$, φ(t) being the polynomial regression $y(t)$, can be written as (9):

$$y(t) = \varphi^T(t)\bar{\theta} + \bar{v}(t) \tag{9}$$

Based on the N data observations, least-squares estimate $\hat{\theta}$ (10) of the real set of parameters $\hat{\theta}$ is given by:

$$\hat{\theta} = \arg \min_{\bar{\theta}} J(\bar{\theta}); \quad J(\bar{\theta}) = \sum_{t=1}^{N}\left[y(t) - \varphi^T(t)\bar{\theta}\right]^2 \tag{10}$$

where $J(\bar{\theta}) = \sum_{t=1}^{N} v(t)^2 = \bar{\mathbf{v}}^T \bar{\mathbf{v}}$, $\bar{\mathbf{v}} = y(t) - \varphi^T(t)\bar{\theta}$ - the sum of the square errors is the performance criterion. In order to estimate the model parameters, the performance criterion must be minimized by differentiating the criterion J versus parameter and equating with zero, the normal equations for the estimation problem are obtained.

$$\varphi^T(t)y(t) = \varphi^T(t)\varphi(t)\bar{\theta} \tag{11}$$

Taking into consideration that the rank $\varphi(t)$=m, m being the number of the parameters, $\varphi^T(t)\varphi(t)$ is invertible. In this way, the unique estimates $\hat{\theta}$ (12) of system parameters $\bar{\theta}$ is obtained by using least squares estimated method:

$$\hat{\theta} = \left[\sum_{t=1}^{N}\varphi^T(t)\varphi(t)\right]^{-1} \sum_{t=1}^{N}\varphi^T(t)y(t). \tag{12}$$

Therefore, the estimates (12) can be written in the equivalent form (13):

Corresponding Author E-mail: marian.gaiceanu@ugal.ro

$$\hat{\theta} = \left[\Phi^T \Phi\right]^{-1} \Phi^T Y, \qquad (13)$$

where the observation vector (14) and the regression matrix (14):

$$\begin{aligned} Y &= \left[y(1) \;\; \dots \;\; y(N)\right]^T, \\ \Phi &= \left[\varphi(1) \;\; \dots \;\; \varphi(N)\right]^T. \end{aligned} \qquad (14)$$

For the wound three-phase asynchronous machine the following electrical signals could be measured: the supply voltage $U_s = u_{ds} + ju_{qs}$, the stator currents $I_s = i_{ds} + ji_{qs}$, the rotor currents $I_r = i_{dr} + ji_{qr}$, the stator frequency ω_1 and the angular rotor speed $\omega = p\Omega$.

Taken into consideration that the voltage equations comprise all the unknown parameters of the wound three-phase asynchronous machine, the steady state model can be used. As the control input the (*d*, *q*) stator voltage components are considered. For *N* data observations, the input vector consists of the (*d*, *q*) stator and rotor voltage components, i.e. the control vector (15):

$$Y = \left[y(1) \;\; \dots \;\; y(N)\right]^T \Rightarrow Y = \left[u_{ds}(1) \;\; u_{qs}(1) \;\; 0 \;\; 0 \;\; \dots \;\; u_{ds}(N) \;\; u_{qs}(N) \;\; 0 \;\; 0\right]^T \qquad (15)$$

The unknown parameter vector (16) should be estimated is as follows:

$$\theta^T = \left[R_s \quad R_r \quad L_s \quad L_r \quad L_m\right] \qquad (16)$$

The regression matrix (17):

$$\Phi = \begin{bmatrix} \varphi(1) \\ \dots \\ \varphi(N) \end{bmatrix}, \qquad (17)$$

consists of the sampled regression submatrix at each instant (18):

$$\varphi(1) = \begin{bmatrix} I_{ds}(1) & 0 & -\omega_1 I_{qs}(1) & 0 & -\omega_1 I_{qr}(1) \\ I_{qs}(1) & 0 & -\omega_1 I_{ds}(1) & 0 & -\omega_1 I_{dr}(1) \\ 0 & I_{dr}(1) & 0 & -(\omega_1 - \omega) I_{qr}(1) & -(\omega_1 - \omega) I_{qs}(1) \\ 0 & I_{qr}(1) & 0 & (\omega_1 - \omega) I_{dr}(1) & (\omega_1 - \omega) I_{ds}(1) \end{bmatrix} \qquad (18)$$

3. Numerical Results

The database is formed by a several experimental results, taken from different steady states operating regimes for different loads. In order to obtain the electrical angular velocity, $\omega = p\Omega$, the rotor speed measurement Ω is necessary. The obtained parameters through least squares method are compared with the real parameters values of the wound asynchronous motor. The real parameters (19) consist of the stator and rotor resistances, and inductances, adding the magnetizing inductance:

ry= [R1 R2 L1 L2 L12] (19)

The known values of the real parameters vector are (20):

ryr =[1.70;2.55;0.136;0.136;0.127] (20)

By knowing the used testing frequency of the supplied voltages, the electrical pulsation of the voltage input (21) can be obtained:

w1=2*pi*f1 (21)

The following [8x1] acquisition vector is considered: [U_{d1} U_{q1} I_{d1} I_{q1} I_{d2} I_{q2} omega w_1].

The **v** vector consists of 20 samples obtained at different levels of the supplied voltages. Based on it, the regression matrix is obtained. By applying adequately the Matlab function LSQNONNEG, the unknown parameter vector, **rye**, is identified (22):

rye =[1.6402 2.6011 0.1374 0.1374 0.1288] (22)

The 3D graphic representation indicates that based on the 20 samples values (x axis), the 5 parameters are identified (y axis) at the appropriate value (shown on z axis) (Figure 1).

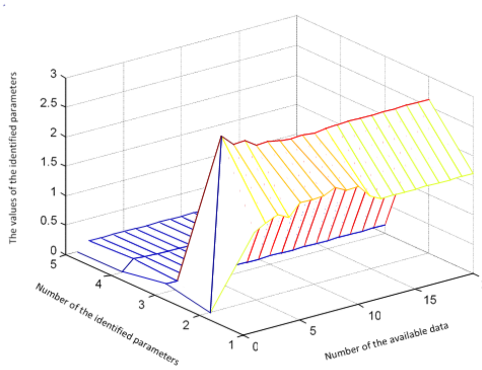

Figure 1. The identified parameters of the wound asynchronous motor: R1 R2 L1 L2 L12. 3D graphic representation.

By comparing the real values with the identified ones the identification error could be obtained for each of the identified parameter (Figures 2-6). In the Figure 7 the error functions of the identified electrical parameters of the three-phase wound-rotor induction machine are shown.

Corresponding Author E-mail: marian.gaiceanu@ugal.ro

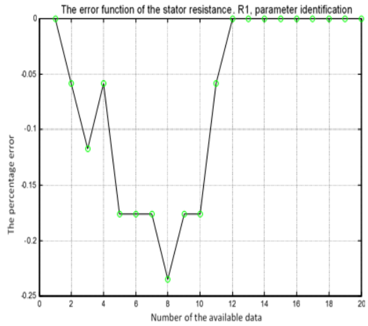

Figure 2. The error of estimation of the stator resistance.

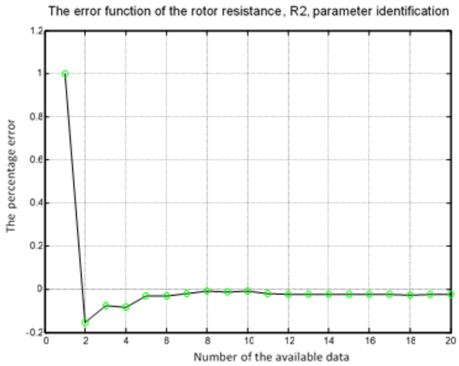

Figure 3. The error of estimation of the rotor resistance.

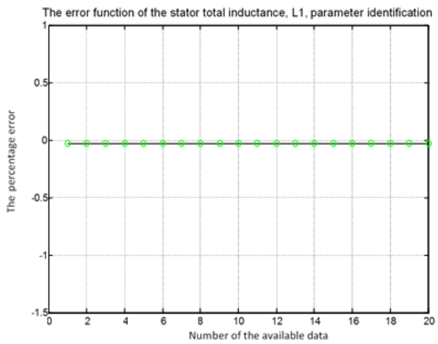

Figure 4. The error of estimation of the stator total inductance.

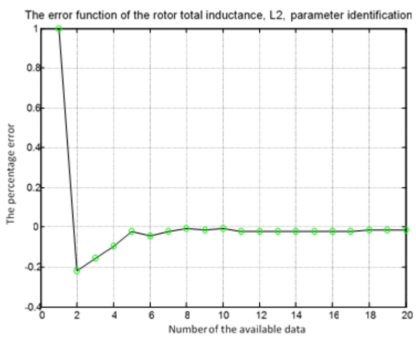

Figure 5. The error of estimation of the rotor total inductance.

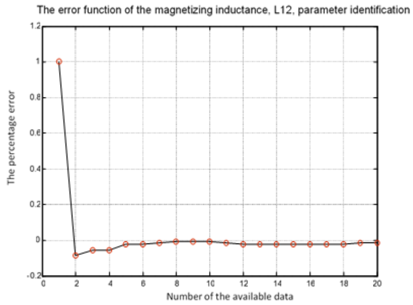

Figure 6. The error of estimation of the magnetizing inductance.

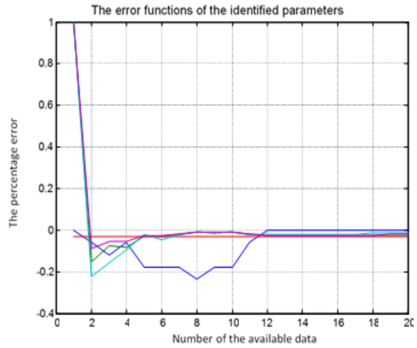

Figure 7. The error functions of the identified electrical parameters.

4. Conclusions

The identification of the electric parameters of the wound three-phase induction machine by using least squares method is developed and validated in this paper. Taken into account the symmetry of the magnetic and electric circuits of the three-phase wound asynchronous motor the (*d, q*) model is taken into account. Therefore, a reduced order of the regression matrix is considered. The identification problem formulation is done in globally way, such that the method could be applied to all types of electrical machines: DC or AC machines. The most advantage of using this identification method is that the necessary data is obtained at rotating operating conditions under different loads, and does not need the operation at locked rotor or no-load.

Acknowledgements

This work was supported by a grant of the Romanian National Authority for Scientific Research, CNDI– UEFISCDI, project number PN-II-PT-PCCA-2011-3.2-1680.

References

[1] M. Wang, C. Xian, Y. Hui, “Induction motor vector control parameters off-line identification technology”, Transaction of China Electrotech-

Corresponding Author E-mail: marian.gaiceanu@ugal.ro

nical Society, 21, 2006, 90-96.

[2] X. Zhan, G.Zeng, J. Liu,Q. Wang, S. Ou, “A Review on Parameters Identification Methods for Asynchronous Motor”, International Journal of Advanced Computer Science and Applications, Vol. 6, 1, 2015, 104-109.
Doi: 10.14569/IJACSA.2015.060115

[3] V. Verma, M. J. Hossain, T. Saha, C. Chakraborty, “Performance of MRAS Based Speed Estimators for Grid Connected Doubly fed Induction Machines during Voltage Dips, ” Power and Energy Society General Meeting, 2012, IEEE.
Doi: 10.1109/pesgm.2012.6345006

[4] D. C. Huynh, M. W. Dunnigan, "Parameter estimation of an induction machine using a dynamic particle swarm optimization algorithm," in Industrial Electronics (ISIE), 2010 IEEE International Symposium on, 2010, 1414-1419.
Doi: 10.1109/isie.2010.5637818

[5] F. Gonzalez-Longatt, et al., "Induction Generator Model Parameter Estimation using Improved Particle Swarm Optimization and On-Line Response to a Change in Frequency," in Proc. IEEE PES GM, Detroit, USA, 2011.
Doi: 10.1109/PES.2011.6039373

[6] J.L. Rueda, F.M. Gonzalez-Longatt and I. Erlich, 2015. “Online estimation of equivalent model for cluster of induction generators: a MVMO-based approach”. 12th Intelligent Systems Applications to Power Systems Conference and Debate (ISAP), Porto, Portugal, 11th-16th September 2015.

[7] C. Cai and G. Chen. “A study on parameter estimation of induction motor using least square method”. Hubei: Journal of Wuhan Institute of Chemical technology, 2003, 25 (2).

[8] R. Fang and H. Ma. “Classification of Induction Machine Rotor Faults Based on Least Square Support Vector Machine”. Transaction of China electrotechnical society, 2006, 21(5).

[9] M. Gaiceanu, “Conception and control implementation of power converters-electrical machines systems”. Applications. Galati University Press Publishing House, Galati, 2014, pp.195.

Corresponding Author E-mail: marian.gaiceanu@ugal.ro