Identification of Induction Machine Electrical Parameters using Genetic Algorithms Optimization

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Abstract— **This paper introduces a new heuristic approach for identifying induction motor equivalent circuit parameters based on experimental transient measurements from a vector controlled Induction Motor (I.M.) drive and using an off line Genetic Algorithm (GA) routine with a linear machine model. The evaluation of the electrical motor parameters is achieved by minimizing the error between experimental responses (speed or current) measured on a motor drive and the respective ones obtained by a simulation model based on the same control structure as the experimental rig, but with varying electrical parameters. An accurate and fast estimation of the electrical motor parameters is so achieved. Results are verified through a comparison of speed, torque and line current responses between the experimental IM drive and a Matlab-Simulink model.**

Keywords— **Induction Motor Drives, Genetic Algorithms, System Identification, Vector Control**

I. Introduction

As it is well known, the method of vector control in an induction motor drive allows high performance control of torque and speed only if both the electrical and mechanical parameters of the machine are accurately known in all operating conditions [1]. It is clear that the precise knowledge of all IM parameters is very important for indirect rotor field oriented control (IRFO).

This is hard to achieve due to the variation of parameters with temperature, flux level and torque level.

There are many different ways to identify I.M. parameters. The most common traditional ways used to identify the resistance and inductance of both rotor and stator are the locked rotor, the no – load and the standstill frequency response test [3 – 5]. However these tests give a mix of parameters at different operating conditions, for example the locked rotor tests are performed with the machine core unsaturated and rated current thus giving different leakage inductances. Previous works have also discussed the estimation of the machine parameters at standstill [6 – 8]. The advantage of this test is that can be performed regardless the mechanical load of the machine and it is also achievable to apply an inverter to any induction machine for rotor flux oriented control even though both electrical and mechanical parameters are unknown [7]. It is also possible to integrate these types of tests within standard commissioning tests where these would be automatically performed rather than needing a trained engineer.

Analysis of dynamic systems can be classified as direct and inverse analysis. As an example of direct analysis (simulation) for dynamic systems is that we would like to predict the output response when the input and the system parameters are known. Alternatively, inverse analysis (identification) for dynamic systems aims to identify the system parameters when it's known the input and the output response. In this paper an inverse analysis is applied.

The motor used for this evaluation test is a 4 kW, 4 – pole I.M. A Matlab model was utilized within heuristic GA based identification routine.

GAs is a search technique used in many fields, like in computer science, to find accurate solutions to large optimization and search problems. The basic concept of GAs is to emulate evolution processes in natural system following the principles first laid down by Charles Darwin of survival of the fittest [9]. The advantage of GAs is that it is a very flexible and intuitive approach to optimization and presents a higher probability of not converging to local optima solutions compared to traditional gradient based methods. More recently, research work has appeared in the scientific literature about the use of GAs for control design in power Electronics and drives [10 - 11] and general structure identification [12]. The basic idea of this research work is that the evaluation of the electrical motor parameters can be achieved by minimizing, using a GAs approach, the error between the experimental response (speed or current) measured on the real motor drive and the respective one obtained by a Matlab-Simulink model implementing the same structure and control of the experimental rig, but with varying electrical parameters [13].

II. Description of the System

Figure 1 represents the experimental set-up. Measurements of experimental transient responses of speed and current from the vector controlled electrical drive test rig are stored and used as reference signals for the optimization. A fitness function based on the integral of the absolute error between these reference signals and the ones produced by the model are evaluated by the GAs intelligent search technique in order to home on the correct system electrical parameters.

A. *Experimental Induction Motor Drive*

In this study we are only focusing on the identification of electrical parameters.

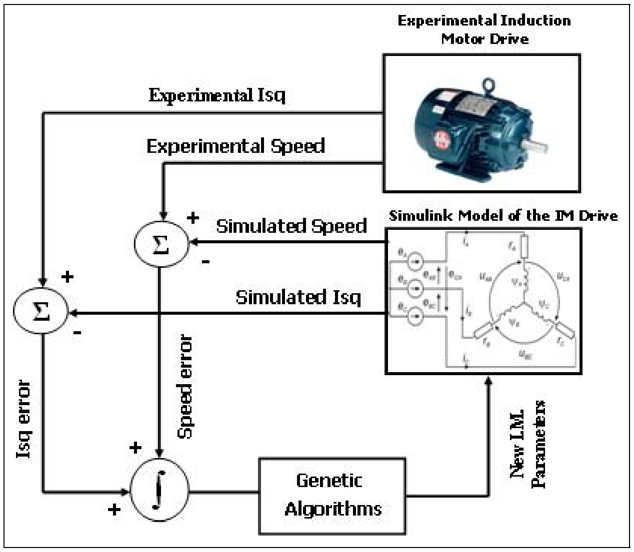

Fig. 1. Block diagram representing the experiment.

Nevertheless, the mechanical parameters (moment of inertia and friction) are identified experimentally using a free – wheeling deceleration test as described in [13].

Table I presents some of the most important characteristics from the Experimental vector controlled Induction Motor which are also used in the simulation model. The speed and current (Isq) transient responses used as reference signals in the GAs optimization are shown in Figs. 2. They represent the system response to a speed demand of 250 rad/sec.

B. *Simulated Induction Motor Drive*

The induction machine is modeled using a traditional dynamic model in abc reference frame where the vector control parameters are the same experimental ones shown in table 1 and the simulation is implemented in Matlab-Simulink.

TABLE I
EXPERIMENTAL VECTOR CONTROLLED IM PARAMETERS

Experimental vector controlled I.M. parameters			
Vector Control Parameters		*Induction Motor Parameters*	
Speed controller	Ksp = 0.6	Inertia J	0.152 Kgm^2
	Ksi = 5	Friction B	0.0147 Nms
Current controller	Kcp = 57.87	Stator Resistance	5.25 Ω
	Kci = 28050	Number of poles	4
Speed reference	250 rad/sec	Power	4 kW
Isd reference	4.9 A	Line voltage	415 V
Rotor time constant	0.1508	Frequency	50 Hz
Current limits	9A		
Voltage limits	1000V		

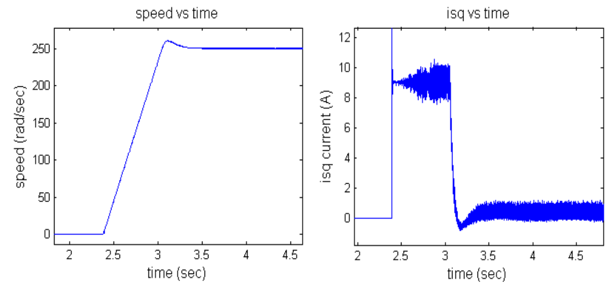

Fig. 2: Speed and current (Isq) response of the experimental I.M. drive

The simplified equivalent circuit of an induction machine is shown in the below Fig. 3.

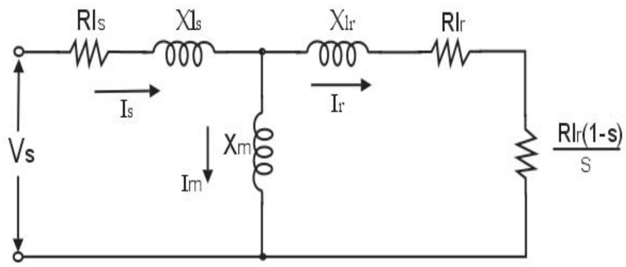

Fig. 3: Simplified equivalent circuit of an I.M

The equivalent circuit in steady state behavior of a three-phase Induction Motor can be represented by a combination of resistance and inductance from the stator and from those transferred from the rotor. So, from the equivalent circuit, the rotor current and the torque equations can be described in the equations below:

$$I_r = \frac{V_S}{\sqrt{\left(R_{ls}+\frac{R_{lr}}{s}\right)^2+(X_{ls}+X_{lr})^2}} \tag{1}$$

$$T = \frac{3R_r}{s\omega_e}\frac{p}{2}\frac{V_S^{\,2}}{\left[\left(R_{ls}+\frac{R_{lr}}{s}\right)^2+\left(X_{th}+X_{lr}\right)^2\right]} \tag{2}$$

The Nameplate data of the examined motor were: P=4 kW, U=415 V, Δ connection, I=8.4 A, n= 1420 rpm. Using the traditional Induction Machine parameters identification based on “no–load” and “locked rotor” tests [3–5] the following electrical parameters can be obtained: Stator resistance Rs=5.25Ω, Rotor Resistance Rr= 5.19 Ω, Magnetizing inductance Lm=0.571H, Stator leakage inductance Lls=0.01816 H and Rotor leakage inductance Llr = 0.01816H. In the following these values will be referred as “standard parameters”. A Comparison between modeled and measured time responses is shown in the below in Fig. 4, Fig. 5 and Fig. 6. As it can be noted there is an evident mismatch between the modeled and experimental responses indicating a difference between the experimental and estimated parameters.

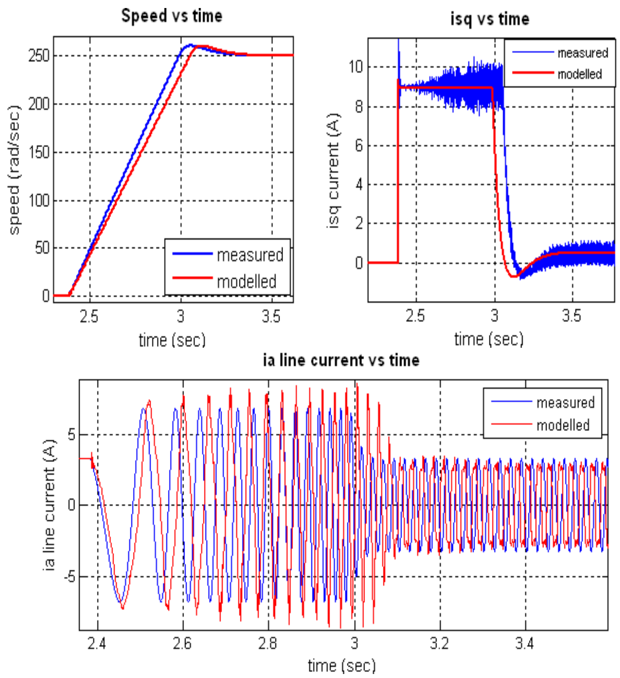

Fig. 4: Measured and modeled Speed, Isq current and phase a line current responses: no load and standard parameters.

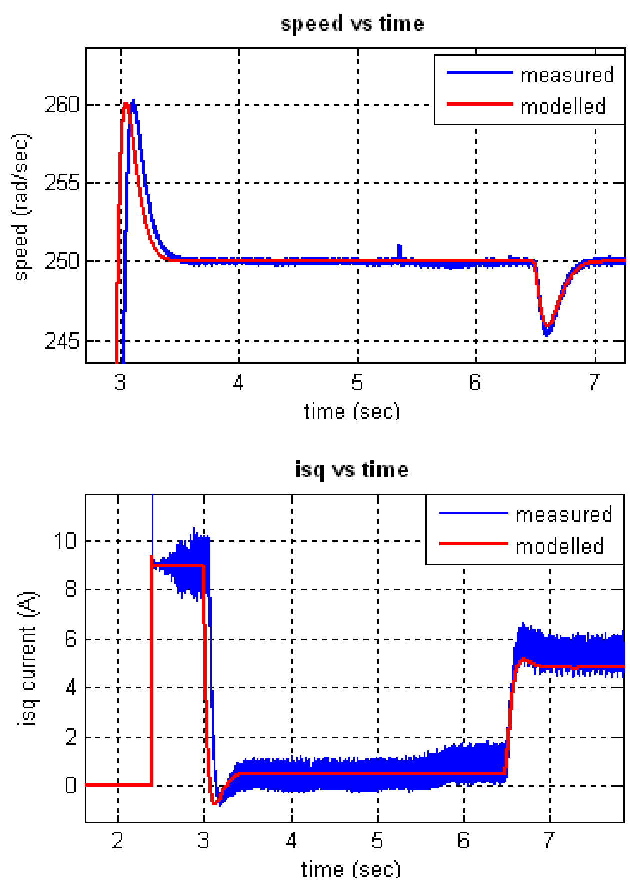

Fig. 5: Measured and modeled Speed, Isq current responses: with load and standard parameters.

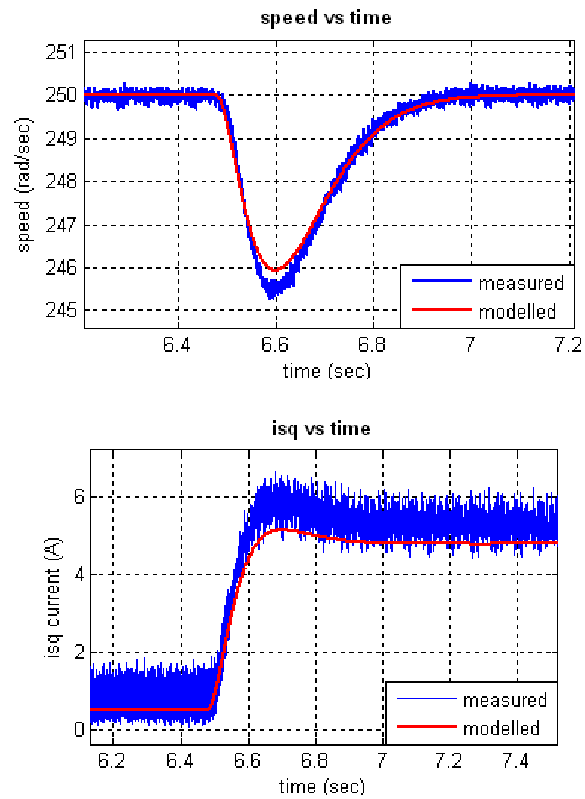

Fig. 6: Zoom of Speed and current response of in Fig. 5 at the time that the load is applied

The below Fig. 7 represents the speed error between the experimental and modeled response by using standard parameters that are calculated using the traditional methods. It can be seen, the error appears during the speed response transient period.

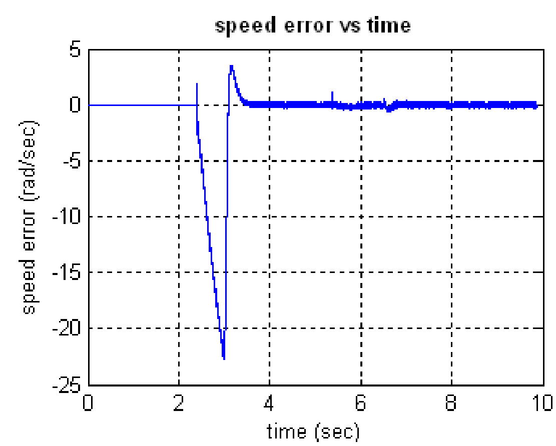

Fig. 7: Speed error between measured and modeled speed response

III. GAs Experimental Parameters Identification

The diagram shown in Fig. 8 explains in details the GAs identification procedure. The fitness function plays an important role to the GA optimization procedure as it measures the quality of the represented solution. The fitness function is always problem dependent. An ideal fitness function connects closely with the algorithm's goal and yet may be evaluated quickly because usually a genetic algorithm must be repeated many times in order to

achieve the desirable result and the speed of execution might be a very important factor.

In some cases, it is even hard to define a fitness function, so an interactive genetic algorithm is used that uses human evaluation. In our problem, the fitness function is used is the sum of the integral of the absolute value on both the speed and Isq current error as shown in (3):

$$FF = \int \left(\left| speed\ error \right| + \left| Isq \text{ current error} \right| \right) \qquad (3)$$

where, "speed error" is the difference between the reference speed response of the experimental induction motor drive and that of the Simulink model. Similarly, "Isq current error" is equal to the difference between the reference current Isq and the one derived from the Simulink model.

It is clear that this is a minimization problem, whereby the accuracy of the identification of the electrical motor parameters improves as the fitness function (FF) approaches zero.

As previously mentioned the unknown electrical parameters of the motor are the rotor resistance (Rr), the magnetizing inductance (Lm), the leakage inductance of the stator (Lls) and of the rotor (Llr). Given a wide range of industrial I.M. (of similar rating) the bounds for the GA search were considered in a way to create intervals which encompasses most practical parameter values (4):

$$\begin{gathered} 1\ \Omega \le R_R \le 10\ \Omega \\ 0.1\ \text{H} \le L_m \le 1\ \text{H} \\ 0.005\ \text{H} \le L_{ls} \le 0.1\ \text{H} \\ 0.005\ \text{H} \le L_{lr} \le 0.1\ \text{H} \end{gathered} \qquad (4)$$

It has been found by experience that, above all in identification problems, it would be desirable that the GA routine could restrict the parameters search ranges during its optimization. In order to minimize the bounds of the electrical parameters, an identification strategy involving a search space reduction method (SSRM) is proposed. The aim of this method is to increase the accuracy and reliability of identification by reducing the search space during the algorithm operation. The idea is to reduce the search space for those parameters that converge quickly and thus reduce convergence time [12].

In order to achieve this, a specified number of shorter initial runs is performed by the algorithm and the different results stored by the program; mean "m_i" and standard deviation "σ_i" are then estimated for each parameter to identify. Generally, the number of runs should be chosen as a compromise between the estimation accuracy of mean and standard deviation and the total optimization time. At the end of these initial runs the search space is redefined for each parameter according to (5):

$$\text{Bounds parameter i} = m_i \pm W\sigma_I \qquad (5)$$

where W, width of the window, defines how much the search space is reduced, but it has to ensure that the new bounds are not wider than the original limits. Practically it is found that a value of window width of about 4 gives good performance for all parameters. Five initial runs are performed in this case using a traditional genetic algorithm with elitist selection. The obtained results are shown in table II.

From the results it can be seen that all runs produce similar parameters estimations except for the stator inductance. The optimization routine applies then the search space reduction method (SSRM) in order to estimate the new bounds for the parameters. From equation (5) it can be found that the new limits for the electrical parameters are given as in (6). The GAs optimization settings selected are shown in table III. Finally, applying the last wider genetic algorithms optimization including the new parameters bounds we obtain the final estimation of our I.M. electrical parameters shown in table IV.

$$\begin{gathered} 4.0672\ \Omega \le R_R \le 4.1920\ \Omega \\ 0.54188\ \text{H} \le L_m \le 0.54979\ \text{H} \\ 0.01354\ \text{H} \le L_{ls} \le 0.06010\ \text{H} \\ 0.05556\ \text{H} \le L_{lr} \le 0.05595\ \text{H} \end{gathered} \qquad (6)$$

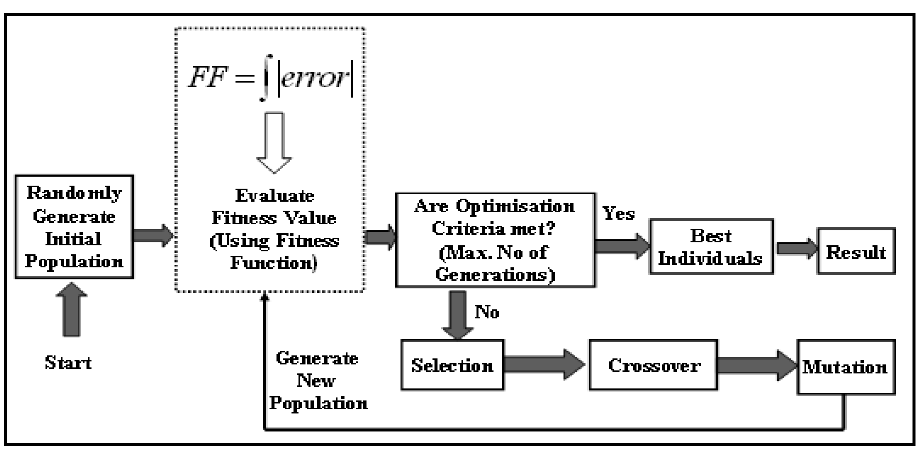

Fig. 8: Block diagram representing the GAs routine

TABLE II
GENETIC ALGORITHM ESTIMATED MOTOR PARAMETERS IN THE INITIAL RUNS

Electrical Parameters	1st run	2nd run	3rd run	4th run	5th run
Rotor Resistance (Rr)	4.1111 Ω	4.1111 Ω	4.1375 Ω	4.1397 Ω	4.1488 Ω
Magnetizing Inductance (Lm)	0.5476 H	0.5462 H	0.5453 H	0.5453 H	0.5448 H
Leakage inductance of stator (Lls)	0.0568 H	0.0250 H	0.0429 H	0.0297 H	0.0297 H
Leakage inductance of rotor (Llr)	0.0557 H	0.0557 H	0.0558 H	0.0558 H	0.0558 H
Best Objective Value	0.9032	0.8794	0.8524	0.8511	0.8457

TABLE III
GENETIC ALGORITHM CHARACTERISTICS

GAs parameters		
Generation Gap		0.9
Crossover rate		0.85
Mutation rate		0.15
Initial runs	Maximum Generations	25
	Number of Individuals	20
Final run	Maximum Generations	50
	Number of Individuals	40

TABLE IV
FINAL GENETIC ALGORITHM ESTIMATED MOTOR PARAMETERS

Electrical Parameters	
Rotor Resistance (Rr)	4.1636 Ω
Magnetizing Inductance (Lm)	0.5435 H
Leakage inductance of stator (Lls)	0.0291 H
Leakage inductance of rotor (Llr)	0.0556 H
Best Objective Value	0.8325

From table II and IV can be noted that the new SSRM method gives very good reliable identification results in a reasonable time. It can also be seen that the best objective value in table IV is smaller compared to a standard GA and so the identification accuracy has also been improved.

A comparison of speed, torque and *ia* line current responses between the experimental induction motor drive performance and the Simulink model using the new GA estimated parameters are shown in Fig. 9.

The same results, but in the case in which a 15.5 Nm load torque is applied are shown in Fig. 10 and Fig. 11.

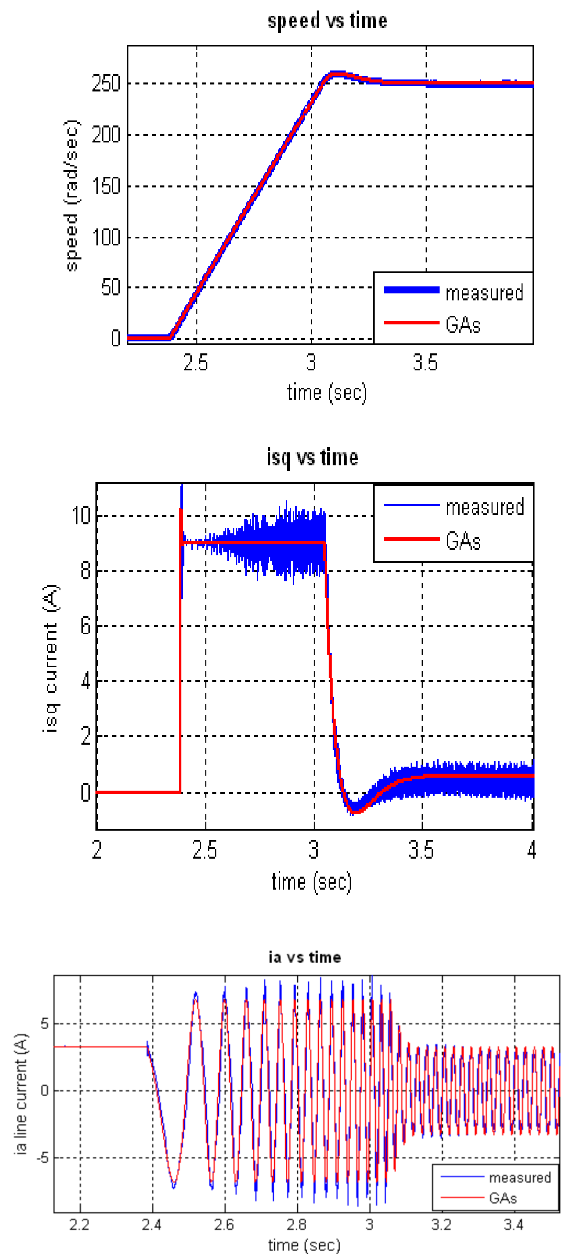

Fig. 9: Simulated system behaviors with the new GA evaluated machines electrical parameters against the experimental ones in the no-load condition

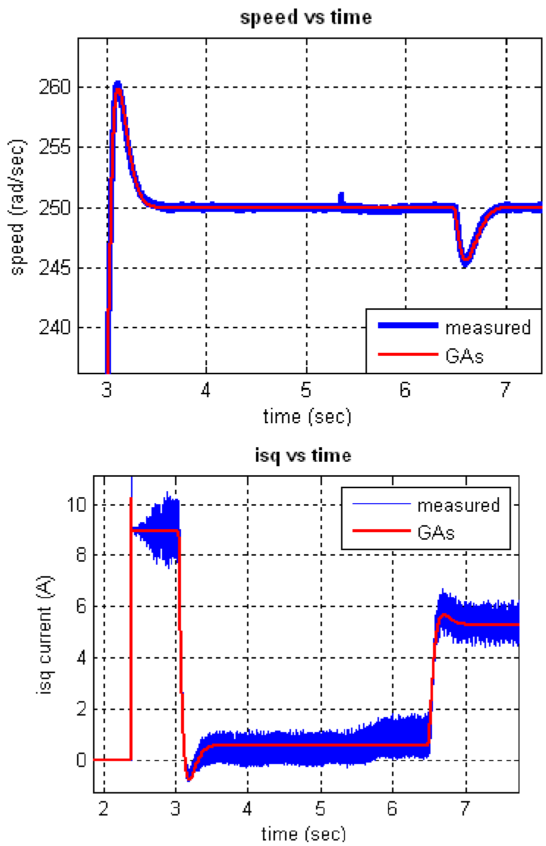

Fig. 10: Simulated system behaviors with the new GA evaluated machines electrical parameters against the experimental ones in with a load torque of 15.5 Nm

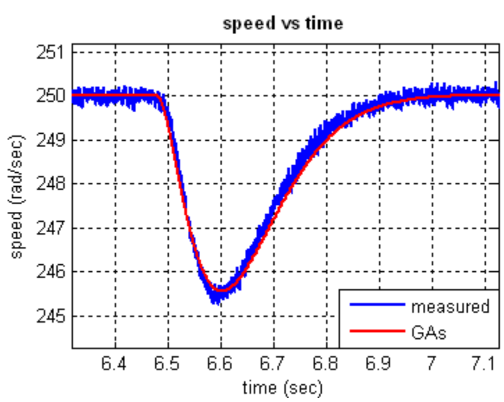

Fig. 12 represents the speed error between the experimental and modeled response behavior with the new GA evaluated electrical parameters.

Fig. 13 shows the difference between the errors from both Fig. 7 and Fig. 12. It can be obviously seen that GAs give us less speed error compared with traditional methods, which means more accurate and reliable identified electrical parameters.

It can be clearly noticed that the system dynamic behavior simulated using the new proposed GA parameters estimation parameters obtained are perfectly matching the experimental measures and show a significant improvement compared with the model obtained using the traditional identification methods.

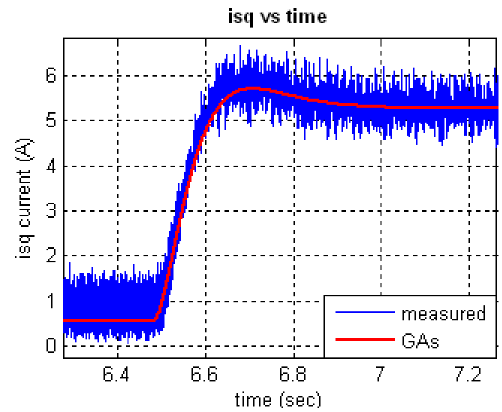

Fig. 11: Zoom of speed and current response of in Fig. 10 at the time that the load is applied

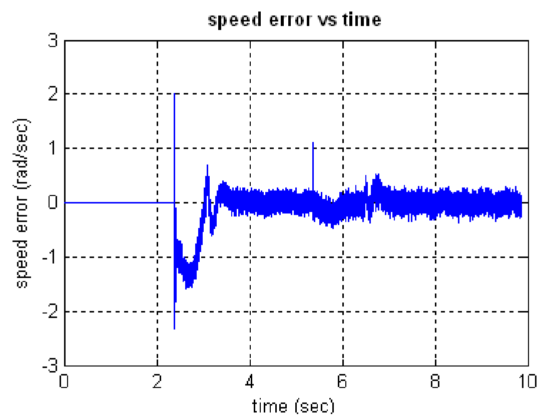

Fig. 12: Speed error between measured and GAs speed response

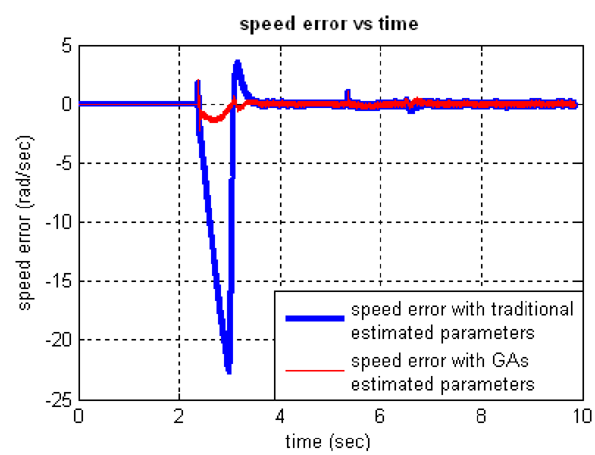

Fig. 13: Difference between errors from Fig. 7 and Fig. 12

It is to be noticed that in this paper, it is assumed that the machine resistances remain constant since the tests simulation is kept to a maximum value of 10 seconds and so the temperature variation will not affect the value of the resistance. Table V also shows the error introduced by traditional estimation methods.

TABLE V
COMPARISON BETWEEN THE NEW GENETIC ALGORITHM ESTIMATED MOTOR PARAMETERS AND THE TRADITIONAL ONES

	Traditional Methods	GAs	%error
Rotor Resistance (Rr)	5.19 Ω	4.1636 Ω	19.7
Magnetizing Inductance (Lm)	0.571 H	0.5435 H	4.8
Leakage inductance of stator (Lls)	0.01816 H	0.0291 H	60.24
Leakage inductance of rotor (Llr)	0.01816 H	0.0556 H	206.16

IV. CONCLUSION

This paper has presented a novel Induction Machine electrical parameters estimation method in a motor drive based on a Genetic Algorithm heuristic optimization approach, a simulation model and experimental transient measurements. Based on both the simulation and experimental measured results it is concluded that the use of the proposed strategy is an effective and reliable method for induction motor parameter identification and for accurately modelling the behavior of the drive system. Significant improvements in terms of identification accuracy and reasonable time are also achieved using the SSRM method. This method gives also the basis for an optimized and high performance control design.

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