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Application of genetic algorithms in parameters identification of asynchronous motor

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***Abstract*—The paper deals with methods of identification of the parameters of an induction motor model using genetic algorithms and propose that asynchronous motor parameters could be identificated based on genetic algorithm using data of induction motors during starting process. Methods and process are first presented to estimate all parameters of a asynchronous motor based on genetic algorithm, and then idengtification are actualized in the stator reference frame and rotor reference frame respectively. In the end, the identification in two reference frames are combined together, and the identification accuracy of all the parameters are improved a lot.**

***Keywords*—Genetic algorithm, asynchronous motor, parameters identification**

I. INTRODUCTION

Induction motor driver system has an important role in AC driver system field. It is well known that the methods of vector control and direct torque control in an induction motor drive allows high-performance control of torque and speed and it can be achieved only if both the electrical and mechanical parameters of the machine are accurately known in all operating conditions [1]. Even ordinary induction motor's frequency conversion driving using frequency converter also run on the premise that the parameters of the induction motor are known. However this is hard to achieve due to the variation of parameters at different machine operating points such as different loads, the temperature, flux level, torque level and the nonlinearities caused by skin effect and saturation [2].

Traditional ways were used to identify the parameters of induction motor by performing the locked - rotor and no -load tests [3–5]. The parameters achieved in this way are not enough precision to use. However it is hard to perform locked - rotor and no -load tests limited by field condition. Previous works have also discussed the estimation of the machine parameters in standstill [6-8]. The advantage of this test is that it can be implemented only adding software routine on the normal control implementation. It also gives effective estimation under any mechanical load [7]. In this method, however, the calculation and hardware are complicated [9].

Genetic algorithm (GA) is a search technique based on natural selection, which could be used to find solutions to optimization problems, either with or without restrictive conditions. GA is realized though repeated modification of a group of individuals with a single solution. In each step, GA randomly chooses an individual from the current population to reproduce and form the next generation. The same process is to be iterated, and the population is grandually "evolving" to a best solution. GA can be adopted in finding a solution to a wind range of optimization problems, such as discrete, non-differentiable, random or highly nonlinear objective functions, which are not proper or possible to be solved using standard optimization method. GA is of extremely high robustness and extensive applicability. The fact that GA is not resitricted by the nature of the problem to be solved unlocks the great potential in finding solutions in motor parameter identification.

This paper presents an accurate and fast method for evaluation of the electrical induction motor parameters using GA during starting process . The motor used for this evaluation test is a 4 kW, 4 - pole Induction motor

II. DESCIPTIONS ON GA-BASED PARAMETER IDENTIFICATION PROBLEM

Both the structure and the parameters of a system model can be identified with the help of GA. As the structure of an asynchronous motor model is given, it is only necessary to conduct parameter identification which is therefore being discussed in this paper.

The first issue to be solved in parameter identification with GA is to find a method to evaluate the parameters obtained, in other words to determine the fitness function of the GA. System identification is to, on the basis of measuring the input and output of the system to be identified, give an equivalent tracking system with the same structure as the system to be identified and with parameters to be determined. The evaluation of the system parameters is primarily to assess the closeness between the outputs of the equivalent tracking system and the system to be identified with the same input. The task of GA is to find the parameter which makes the two systems resemble each other as much as possible. Assume the dynamic math model of the system to be identified is defined as the following state equation:

$$\begin{cases} \dot{\mathbf{x}} = f(\boldsymbol{\theta}, \mathbf{x}, \mathbf{u}) \\ \mathbf{y} = \mathbf{C}\mathbf{x} \end{cases} \tag{1}$$

where, $\mathbf{x}$ is the state vector, $\mathbf{u}$ is the input vector, $\boldsymbol{\theta}$ is the parameter vector to be identified, $\mathbf{y}$ is the vector to be

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measured, and $\mathbf{C}$ is the constant array with proper order, then the equivalent tracking system can be expressed as

$$\begin{cases}\dot{\hat{\mathbf{x}}} = f(\hat{\boldsymbol{\theta}}, \hat{\mathbf{x}}, \mathbf{y}, \mathbf{u}) \\ \hat{\mathbf{y}} = \mathbf{C}\hat{\mathbf{x}}\end{cases} \tag{2}$$

where, $\hat{\mathbf{x}}$ is the state vector of the equivalent tracking system, $\hat{\boldsymbol{\theta}}$ is the estimated value of $\boldsymbol{\theta}$, and $\hat{\mathbf{y}}$ of $\mathbf{y}$. If the output error is defined as

$$\mathbf{e} = \mathbf{y} - \hat{\mathbf{y}} \tag{3}$$

it is obvious that the value of $\mathbf{e}$ at a certain time point can relect the fitness of the estimated parameter to the system. Therefore, between the period from t_0 to t, the deviation between the outputs of the equivalent tracking system and the system to be identified can be expressed as the following performance index:

$$H(\boldsymbol{\theta}) = \int_{t_0}^{t} \mathbf{e}^T \mathbf{e} \tag{4}$$

GA is realized with the assistance of computer, and discrete form is to be adopted. Let the sampling number between the period from t_0 and t as N, it follows that

$$H(\boldsymbol{\theta}) = \sum_{k=0}^{N-1}\left\{\mathbf{e}^T(k)\mathbf{e}(k)\right\} = \sum_{k=0}^{N-1}\left\{[\mathbf{y}(k) - \hat{\mathbf{y}}(k)]^T[\mathbf{y}(k) - \hat{\mathbf{y}}(k)]\right\} \tag{5}$$

Define $H(\boldsymbol{\theta})$ as the objective function, and GA-based parameter identification problem can be described as a problem in the following form:

$$\min_{\boldsymbol{\theta}}\left\{H(\boldsymbol{\theta})\right\} \tag{6}$$

III. THE GENERAL STEPS OF GA APPLICATION IN DYNAMIC SYSTEM PARAMETER IDENTIFICATION

In order to apply GA in system parameter identification, the first and foremost is to determine the objective function used for parameter evaluation, as described in the last section. In addition, a series of operations and control parameters concerning the GA itself are to be determined according to the specific problem in question, as shown in the following:

1. Provide a mathematical description of the problem to be solved, and determine a proper objective function as the fitness function for the evaluation of estimated parameters.

2. Determine the number, sampling cycle, and acquisition method of data acquisition, and obtain input and output data of the system to be identified.

3. Determine the potential variation range of the parameters to be identified, and then determine parameter encoding length according to the variation range with the objective to ensure sufficient precision and to determine encoding plan.

4. Design GA operation method, and determine relevant control parameters, such as initial population size, crossover probability, and mutation probability, etc.

5. Write specific GA realization program.

6. Run the GA program, draw necessary visualized data graphs, obtain and decode the identification results.

7. Analyze the identification results.

IV. ASYNCHRONOUS MOTOR PARAMETER IDENTIFICATION UNDER STATOR COORDINATE SYSTEM

The state equation of three-phase asynchronous motor under stator coordinate system is

$$\begin{cases}\dot{i}_{s\alpha} = (-\frac{R_s}{L_\sigma} - \frac{L_s}{L_\sigma T_r})i_{s\alpha} - \omega_r i_{s\beta} + \frac{1}{L_\sigma T_r}\psi_{s\alpha} + \frac{1}{L_\sigma}(u_{s\alpha} + \omega_r \psi_{s\beta}) \\ \dot{i}_{s\beta} = \omega_r i_{s\alpha} + (-\frac{R_s}{L_\sigma} - \frac{L_s}{L_\sigma T_r})i_{s\beta} + \frac{1}{L_\sigma T_r}\psi_{s\beta} + \frac{1}{L_\sigma}(u_{s\beta} - \omega_r \psi_{s\alpha}) \\ \dot{\psi}_{s\alpha} = -R_s i_{s\alpha} + u_{s\alpha} \\ \dot{\psi}_{s\beta} = -R_s i_{s\beta} + u_{s\beta}\end{cases} \tag{7}$$

Denote the parameters to be identified as

$$\begin{cases}\theta_1^* = -\frac{R_s}{L_\sigma} - \frac{L_s}{L_\sigma T_r} \\ \theta_2^* = \frac{1}{L_\sigma T_r} \\ \theta_3^* = \frac{1}{L_\sigma} \\ \theta_4^* = -R_s\end{cases} \tag{8}$$

Let the sampling cycle as T_s, performing discretization to the above equation gives

$$\begin{cases}i_{s\alpha}(k+1) = i_{s\alpha}(k) + T_s\left\{\theta_1^* i_{s\alpha}(k) - \omega_r(k) i_{s\beta}(k) + \theta_2^* \psi_{s\alpha}(k) + \theta_3^*[u_{s\alpha}(k) + \omega_r(k)\psi_{s\beta}(k)]\right\} \\ i_{s\beta}(k+1) = i_{s\beta}(k) + T_s\left\{\omega_r(k) i_{s\alpha}(k) + \theta_1^* i_{s\beta}(k) + \theta_2^* \psi_{s\beta}(k) + \theta_3^*[u_{s\beta}(k) - \omega_r(k)\psi_{s\alpha}(k)]\right\} \\ \psi_{s\alpha}(k+1) = \psi_{s\alpha}(k) + T_s\left\{\theta_4^* i_{s\alpha}(k) + u_{s\alpha}(k)\right\} \\ \psi_{s\beta}(k+1) = \psi_{s\beta}(k) + T_s\left\{\theta_4^* i_{s\beta}(k) + u_{s\beta}(k)\right\}\end{cases} \tag{9}$$

Let $\hat{\theta}_1$, $\hat{\theta}_2$, $\hat{\theta}_3$ and $\hat{\theta}_4$ as the estimated value of θ_1^*, θ_2^*, θ_3^* and θ_4^* respectively, and then the following equivalent tracking system can be established:

$$\begin{cases}\hat{i}_{s\alpha}(k+1) = i_{s\alpha}(k) + T_s\left\{\hat{\theta}_1 i_{s\alpha}(k) - \omega_r(k) i_{s\beta}(k) + \hat{\theta}_2 \hat{\psi}_{s\alpha}(k) + \hat{\theta}_3[u_{s\alpha}(k) + \omega_r(k)\psi_{s\beta}(k)]\right\} \\ \hat{i}_{s\beta}(k+1) = i_{s\beta}(k) + T_s\left\{\omega_r(k) i_{s\alpha}(k) + \hat{\theta}_1 i_{s\beta}(k) + \hat{\theta}_2 \hat{\psi}_{s\beta}(k) + \hat{\theta}_3[u_{s\beta}(k) - \omega_r(k)\psi_{s\alpha}(k)]\right\} \\ \hat{\psi}_{s\alpha}(k+1) = \hat{\psi}_{s\alpha}(k) + T_s\left\{\hat{\theta}_4 i_{s\alpha}(k) + u_{s\alpha}(k)\right\} \\ \hat{\psi}_{s\beta}(k+1) = \hat{\psi}_{s\beta}(k) + T_s\left\{\hat{\theta}_4 i_{s\beta}(k) + u_{s\beta}(k)\right\}\end{cases} \tag{10}$$

Equations set (10) is actually a recursive estimated formulae of stator current. Once the initial values of stator flux linkage are given, let such values as the estimated initial values of stator flux linkage, namely $\hat{\psi}_{s\alpha}(0)$ and $\hat{\psi}_{s\beta}(0)$, combined with stator current data $i_{s\alpha}(k)$ and $i_{s\beta}(k)$, input stator voltage data $u_{s\alpha}(k)$ and $u_{s\beta}(k)$, as well as rotation speed $\omega_r(k)$ obtained during $t_0 \sim t_{N-1}$, the estimated value of stator current $\hat{i}_{s\alpha}(k)$ and $\hat{i}_{s\beta}(k)$ from t_2 on can be calculated. Then the fitness function can be defined as

$$H(\hat{\theta}_1,\hat{\theta}_2,\hat{\theta}_3,\hat{\theta}_4)=\sum_{k=2}^{N-1}\left\{[i_{s\alpha}(k)-\hat{i}_{s\alpha}(k)]^2+[i_{s\beta}(k)-\hat{i}_{s\beta}(k)]^2\right\} \quad (11)$$

And the problem is converted to find $\hat{\theta}_1$, $\hat{\theta}_2$, $\hat{\theta}_3$ and $\hat{\theta}_4$ to make $H(\hat{\theta}_1,\hat{\theta}_2,\hat{\theta}_3,\hat{\theta}_4)$ have a minimum value.

After the fitness function is determined, it is then to acquire the required data for the calculation of the fitness function. The more data collected, the better for the convergence of GA, however, excessive data would impose too much burden on the calculation. There is no special requirement on the selection of sampling cycle. Generally, the shorter the sampling cycle, the more precise the calculation, but it is equally worth noting that a too short cycle would sometimes render obvious increase of the relevance of the sampled data, resulting in ill-conditioned equations set. It shall be avoided. For industrial frequency powered motor system, the sampling cycle can be set as $T_s=5\times10^{-4}s$. If the number of data sampling points used for GA-based parameter identification each time is 300, then the time span of data sampling is 0.15 second; by the end of 7.5 industrial frequency cycles, the time is more or less in the same magnitude of the no-load start-up time of a general small or medium sized motor. If only single parameter check on the motor is required, instead of online tracking identification, then it is appropriate to conduct identification during the start-up process of the motor because the initial value of stator flux linkage can be deemed as zero under the circumstance. On the other hand, if this method is used to conduct online parameter tracking on the drive system of a motor, data collection and identification are to be carried out at a short enough interval (relative to the speed of parameter variation), and then use the identification result to compensate the motor parameters used for the drive. Continuous identification is also possible, but it would impose paramount burdens on the calculation, and higher requirement on CPU speed.

What comes next is parameter coding. Let $\hat{R}_s$, $\hat{L}_s$, $\hat{L}_\sigma$ and $\hat{T}_r$ as the respective estimated value of stator resistance R_s, stator inductance L_s, leakage inductance L_σ and rotor time constant T_r, and then $\hat{\theta}_1$, $\hat{\theta}_2$, $\hat{\theta}_3$ and $\hat{\theta}_4$ are determined. On the other hand, $\hat{R}_s$, $\hat{L}_s$, $\hat{L}_\sigma$ and $\hat{T}_r$ can also be determined if the value of $\hat{\theta}_1$, $\hat{\theta}_2$, $\hat{\theta}_3$ and $\hat{\theta}_4$ are given. The two are equivalent. In the case of parameter identification on asynchronous motor by means of GA, coding can either be made on $\hat{\theta}_1$, $\hat{\theta}_2$, $\hat{\theta}_3$ and $\hat{\theta}_4$ or on $\hat{R}_s$, $\hat{L}_s$, $\hat{L}_\sigma$ and $\hat{T}_r$ directly. In order to identify the stator and rotor parameters of the motor directly, direct coding on $\hat{R}_s$, $\hat{L}_s$, $\hat{L}_\sigma$ and $\hat{T}_r$ is adopted. In this paper, motor parameters were coded in a direct fashion. Using double precision real-value coding in MATLAB, some of the parameters with relatively small value are magnified in order to make coded parameters in a same magnitude. The actual coding was conducted on $10\hat{L}_s$, $10\hat{T}_r$, $200\hat{L}_\sigma$ and $\hat{R}_s$. Conduct identification on a 4kw motor, set data sampling cycle as 0.0005 second, sample and acquire data with data sampling card 1202 during no-load start-up of the aforesaid 4kw motor. The genetic algorithm employs real-value coding. Select 300 for the size of initial population, [0, 20] for the range of initial population, N=500 for the point in the fitness function, optimize the data of this first 0.15 second at the initiation, and set 1,500 for the maximum number of generations. Table 1 gives the results of ten identifications.

TABLE I. THE RESULTS OF ASYNCHRONOUS MOTOR GA-BASED PARAMETER IDENTIFICATIONS UNDER STATOR COORDINATE SYSTEM

Coded parameters		$\hat{R}_s/\Omega$	$10\hat{L}_s/H$	$10\hat{T}_r/s$	$200\hat{L}_\sigma/H$
Real value		1.4000	1.4000	1.7500	1.9643
1	Identification result	1.40211	1.0049	1.00178	1.98548
	Relative error	0.1507%	-28.2214%	-42.7554	1.0782%
2	Identification result	1.40316	1.06738	1.07087	1.98967
	Relative error	0.2257%	-23.7586%	-38.8074%	1.2916
3	Identification result	1.40351	1.03599	1.0354	1.98942
	Relative error	0.2507%	-26.0007%	-40.8342%	1.2788%
4	Identification result	1.40394	1.07187	1.07496	1.99032
	Relative error	0.2814%	-23.4379%	-38.5737%	1.3246%
5	Identification result	1.40267	0.98039	0.97550	1.98679
	Relative error	0.1907%	-29.9721%	-44.2571%	1.1449%
6	Identification result	1.40272	0.94942	0.94048	1.98590
	Relative error	0.1943%	-32.1843%	-46.2583%	1.0996%
7	Identification result	1.40260	1.02862	1.02753	1.98867
	Relative error	0.1857%	-26.5271%	-41.2840%	1.2406%
8	Identification result	1.40280	1.20611	1.22384	1.99502
	Relative error	0.2000%	-13.8493%	-30.0663	1.5639%
9	Identification result	1.40259	0.94194	0.93169	1.98490
	Relative error	0.1850%	-32.7186%	-46.7606%	1.0487%
10	Identification result	1.40314	0.95641	0.94850	1.98665
	Relative error	0.2243%	-31.6850%	-45.8000%	1.1378%

The results of ten independent identifications under stator coordinate system have shown that the identification precision of stator resistance $\hat{R}_s$ and leakage inductance $\hat{L}_\sigma$ is relatively high, with less than 1% of margin of error at each identification of $\hat{R}_s$, and less than 3% of $\hat{L}_\sigma$, and that the identification of stator inductance $\hat{L}_s$ and rotor time constant $\hat{T}_r$ has a big and unacceptable margin of error. That is to say the motor equation is not sensitive to the variation of rotor parameters, which is understandable due to the fact that other than rotation speed, the data measured during the identification are stator voltage and stator current, both of which are more sensitive to stator parameters $\hat{R}_s$ and $\hat{L}_\sigma$, and $\hat{L}_\sigma$, in fact, is the total leakage inductance translated to the stator side, whereas $\hat{L}_s$, the stator inductance though, has its primary constitution in the mutual inductances of the coupled stator and rotor.

Asynchronous motor parameter identification under rotor coordinate system

In the last section, we has studied the identification under the stator coordinate system, and found that only stator resistance $\hat{R}_s$ and leakage inductance $\hat{L}_\sigma$ could be identified relatively precise. In order to identify the rotor parameters accurately, identification under the rotor coordinate system has been explored in this section.

The state equation of an asynchronous motor with stator current and rotor flux linkage as the state under rotor coordinate system is

$$\begin{cases} \dot{i}_{sd} = (-\frac{R_s}{\sigma L_s} - \frac{L_m^{\ 2}}{\sigma L_s L_r T_r}) i_{sd} + \omega_r i_{sq} + \frac{L_m}{\sigma L_s L_r T_r}\psi_{rd} + \frac{\omega_r L_m}{\sigma L_s L_r}\psi_{rq} + \frac{1}{\sigma L_s} u_{sd} \\ \dot{i}_{sq} = -\omega_r i_{sd} + (-\frac{R_s}{\sigma L_s} - \frac{L_m^{\ 2}}{\sigma L_s L_r T_r}) i_{sq} - \frac{\omega_r L_m}{\sigma L_s L_r}\psi_{rd} + \frac{L_m}{\sigma L_s L_r T_r}\psi_{rq} + \frac{1}{\sigma L_s} u_{sq} \\ \dot{\psi}_{rd} = \frac{L_m}{T_r} i_{sd} - \frac{1}{T_r}\psi_{rd} \\ \dot{\psi}_{rq} = \frac{L_m}{T_r} i_{sq} - \frac{1}{T_r}\psi_{rq} \end{cases} \tag{12}$$

Denote $L_\sigma = \sigma L_s$, and performing transformation to

$$\begin{cases} \psi'_{rd} = \frac{L_m}{L_r}\psi_{rd} \\ \psi'_{rq} = \frac{L_m}{L_r}\psi_{rq} \end{cases} \tag{13}$$

gives

$$\begin{cases} \dot{i}_{sd} = (-\frac{R_s}{L_\sigma} - \frac{L_s - L_\sigma}{L_\sigma T_r}) i_{sd} + \omega_r i_{sq} + \frac{1}{L_\sigma T_r}\psi'_{rd} + \frac{1}{L_\sigma}\omega_r \psi'_{rq} + \frac{1}{L_\sigma} u_{sd} \\ \dot{i}_{sq} = -\omega_r i_{sd} + (-\frac{R_s}{L_\sigma} - \frac{L_s - L_\sigma}{L_\sigma T_r}) i_{sq} - \frac{1}{L_\sigma}\omega_r \psi'_{rd} + \frac{1}{L_\sigma T_r}\psi'_{rq} + \frac{1}{L_\sigma} u_{sq} \\ \dot{\psi}'_{rd} = \frac{L_s - L_\sigma}{T_r} i_{sd} - \frac{1}{T_r}\psi'_{rd} \\ \dot{\psi}'_{rq} = \frac{L_s - L_\sigma}{T_r} i_{sq} - \frac{1}{T_r}\psi'_{rq} \end{cases} \tag{14}$$

where, the stator current and voltage under the rotor coordinate system are obtained from the following transforms respectively:

$$\begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix} = \begin{bmatrix} \cos\theta_r & \sin\theta_r \\ -\sin\theta_r & \cos\theta_r \end{bmatrix} \begin{bmatrix} i_{s\alpha} \\ i_{s\beta} \end{bmatrix} \tag{15}$$

$$\begin{bmatrix} u_{sd} \\ u_{sq} \end{bmatrix} = \begin{bmatrix} \cos\theta_r & \sin\theta_r \\ -\sin\theta_r & \cos\theta_r \end{bmatrix} \begin{bmatrix} u_{s\alpha} \\ u_{s\beta} \end{bmatrix} \tag{16}$$

Denote parameters to be identified as

$$\begin{cases} \lambda_1^{*} = -\frac{R_s}{L_\sigma} - \frac{L_s - L_\sigma}{L_\sigma T_r} \\ \lambda_2^{*} = \frac{1}{L_\sigma T_r} \\ \lambda_3^{*} = \frac{1}{L_\sigma} \\ \lambda_4^{*} = \frac{L_s - L_\sigma}{T_r} \\ \lambda_5^{*} = -\frac{1}{T_r} \end{cases} \tag{17}$$

Let the sampling cycle as T_s, performing discretization to equations (14) ~ (16) gives

$$\begin{cases} i_{sd}(k+1) = i_{sd}(k) + T_s\left\{\lambda_1^{*} i_{sd}(k) + \omega_r(k) i_{sq}(k) + \lambda_2^{*}\psi'_{rd}(k) + \lambda_3^{*}[u_{sd}(k) + \omega_r(k)\psi'_{rq}(k)]\right\} \\ i_{sq}(k+1) = i_{sq}(k) + T_s\left\{\lambda_1^{*} i_{sq}(k) - \omega_r(k) i_{sd}(k) + \lambda_2^{*}\psi'_{rq}(k) + \lambda_3^{*}[u_{sd}(k) - \omega_r(k)\psi'_{rd}(k)]\right\} \\ \psi'_{rd}(k+1) = \psi'_{rd}(k) + T_s\left\{\lambda_4^{*} i_{sd}(k) + \lambda_5^{*}\psi'_{rd}(k)\right\} \\ \psi'_{rq}(k+1) = \psi'_{rq}(k) + T_s\left\{\lambda_4^{*} i_{sq}(k) + \lambda_5^{*}\psi'_{rq}(k)\right\} \end{cases} \tag{18}$$

$$\begin{cases} i_{sd}(k) = i_{s\alpha}(k)\cos\theta_r(k) + i_{s\beta}(k)\sin\theta_r(k) \\ i_{sq}(k) = i_{s\beta}(k)\cos\theta_r(k) - i_{s\alpha}(k)\sin\theta_r(k) \\ u_{sd}(k) = u_{s\alpha}(k)\cos\theta_r(k) + u_{s\beta}(k)\sin\theta_r(k) \\ u_{sq}(k) = u_{s\beta}(k)\cos\theta_r(k) - u_{s\alpha}(k)\sin\theta_r(k) \\ \theta_r(k+1) = \theta_r(k) + T_s\omega_r(k) \end{cases} \tag{19}$$

Let $\hat{\lambda}_1$, $\hat{\lambda}_2$, $\hat{\lambda}_3$, $\hat{\lambda}_4$ and $\hat{\lambda}_5$ as the estimated value of λ_1^{*}, λ_2^{*}, λ_3^{*}, λ_4^{*} and λ_5^{*} respectively, and then the following equivalent tracking system can be established:

$$\begin{cases} \hat{i}_{sd}(k+1) = i_{sd}(k) + T_s\left\{\hat{\lambda}_1 i_{sd}(k) + \omega_r(k) i_{sq}(k) + \hat{\lambda}_2\hat{\psi}'_{rd}(k) + \hat{\lambda}_3[u_{sd}(k) + \omega_r(k)\hat{\psi}'_{rq}(k)]\right\} \\ \hat{i}_{sq}(k+1) = i_{sq}(k) + T_s\left\{\hat{\lambda}_1 i_{sq}(k) - \omega_r(k) i_{sd}(k) + \hat{\lambda}_2\hat{\psi}'_{rq}(k) + \hat{\lambda}_3[u_{sd}(k) - \omega_r(k)\hat{\psi}'_{rd}(k)]\right\} \\ \hat{\psi}'_{rd}(k+1) = \hat{\psi}'_{rd}(k) + T_s\left\{\hat{\lambda}_4 i_{sd}(k) + \hat{\lambda}_5\hat{\psi}'_{rd}(k)\right\} \\ \hat{\psi}'_{rq}(k+1) = \hat{\psi}'_{rq}(k) + T_s\left\{\hat{\lambda}_4 i_{sq}(k) + \hat{\lambda}_5\hat{\psi}'_{rq}(k)\right\} \end{cases} \tag{20}$$

Define the fitness function as

$$H(\hat{\lambda}_1, \hat{\lambda}_2, \hat{\lambda}_3, \hat{\lambda}_4, \hat{\lambda}_5) = \sum_{k=2}^{N-1}\left\{[i_{sd}(k) - \hat{i}_{sd}(k)]^2 + [i_{sq}(k) - \hat{i}_{sq}(k)]^2\right\} \tag{21}$$

And then the problem is converted to find $\hat{\lambda}_1$, $\hat{\lambda}_2$, $\hat{\lambda}_3$, $\hat{\lambda}_4$ and $\hat{\lambda}_5$ to make $H(\hat{\lambda}_1, \hat{\lambda}_2, \hat{\lambda}_3, \hat{\lambda}_4, \hat{\lambda}_5)$ have a minimum value. In the case of parameter identification on asynchronous motor by means of GA, coding can also be made on $\hat{\lambda}_1$, $\hat{\lambda}_2$, $\hat{\lambda}_3$, $\hat{\lambda}_4$ and $\hat{\lambda}_5$. Using double precision real-value coding in MATLAB, some of the parameters with relatively small value are magnified in order to make coded parameters in a same magnitude. The actual coding is conducted on $10\hat{L}_s$, $10\hat{T}_r$, $200\hat{L}_\sigma$ and $\hat{R}_s$. Conduct identification on the same set of data of a 4kw motor. The genetic algorithm employs real-value coding. Select 500 for the size of initial population, [0, 20] for the range of initial population, N=300 for the point in the fitness function, optimize the data of this first 0.15 second at the initiation, and set 1,500 for the maximum number of generations. Table 2 gives the results of ten identifications.

TABLE II. THE RESULTS OF ASYNCHRONOUS MOTOR GA-BASED PARAMETER IDENTIFICATIONS UNDER ROTOR COORDINATE SYSTEM

Coded parameters		$\hat{R}_s/\Omega$	$10\hat{L}_s/H$	$10\hat{T}_r/s$	$200\hat{L}_\sigma/H$
Real value		1.4000	1.4000	1.7500	1.9643
1	Identification result	1.63039	1.25681	1.70687	1.98231
	Relative error	16.4564%	-10.2279%	-2.4646%	0.9169%
2	Identification result	1.63245	1.21869	1.65663	1.98060
	Relative error	16.6036%	-12.9507%	-5.3354%	0.8298%
3	Identification result	1.62969	1.21247	1.64290	1.98113
	Relative error	16.4064%	-13.3950%	-6.1200%	0.8568%
4	Identification result	1.63478	1.17329	1.58842	1.97869
	Relative error	16.7700%	-16.1936%	-9.2331%	0.7326%
5	Identification result	1.62729	1.21397	1.64235	1.98103
	Relative error	16.2350%	-13.2879%	-6.1514%	0.8517%
6	Identification result	1.62809	1.21219	1.64012	1.98049
	Relative error	16.2921%	-13.4150%	-6.2789%	0.8242%
7	Identification result	1.62953	1.21673	1.64924	1.98061
	Relative error	16.3950%	-13.0907%	-5.7577%	0.8303%
8	Identification result	1.63323	1.20409	1.63555	1.98122
	Relative error	16.6593%	-13.9936%	-6.5400	0.8614%
9	Identification result	1.63019	1.21201	1.64336	1.98085
	Relative error	16.4421%	-13.4279%	-6.0937%	0.8425
10	Identification result	1.62981	1.21067	1.640743	1.98017
	Relative error	16.4150%	-13.5236%	-6.2433%	0.8079%

The results of ten independent identifications under rotor coordinate system have shown that compared with the identification under stator coordinate system, the identification precision of rotor time constant $\hat{T}_r$ has increased significantly, with a margin of error within 10%, and the identification precision of stator inductance $\hat{L}_s$ also has a significant increase, whereas there is no obvious change of leakage inductance $\hat{L}_\sigma$ which maintains a considerably high identification precision. But there has been a remarkable decline of the identification precision of stator resistance $\hat{R}_s$, with a margin of error up to 17%.

V. METHOD TO IMPROVE THE PRECISION OF GA-BASED ASYNCHRONOUS MOTOR PARAMETER IDENTIFICATION

There are both advantages and disadvantages in both identification methods, one under stator coordinate system and the other under rotor coordinate system. The simplest method to improve motor parameter identification precision, obviously, is to conduct two independent identifications under stator coordinate system and under rotor coordinate system, with stator resistance identified under stator coordinate system, and other parameters under rotor coordinate system.

TABLE III. THE RESULTS OF ASYNCHRONOUS MOTOR GA-BASED PARAMETER IDENTIFICATIONS UNDER ROTOR COORDINATE SYSTEM

Coded parameters		R_s/Ω	$10\hat{L}_s/H$	$10\hat{T}_r/s$	$200\hat{L}_\sigma/H$
Real value		(known)	1.4000	1.7500	1.9643
1	Identification result	1.40211	1.46121	1.69882	1.97823
	Relative error	0.1507%	+4.3721%	-2.9246%	+0.7092%
2	Identification result	1.40316	1.4549	1.69189	1.97827
	Relative error	0.2257%	+3.9214%	-3.3206%	+0.7266%
3	Identification result	1.40351	1.46093	1.69684	1.97851
	Relative error	0.2507%	+4.3521%	-3.0377%	+0.7234%
4	Identification result	1.40394	1.46889	1.70961	1.97894
	Relative error	0.2814%	+4.9207%	-2.3080%	+0.7453%
5	Identification result	1.40267	1.4630	1.70209	1.97813
	Relative error	0.1907%	+4.5000%	-2.7377%	+0.7041%
6	Identification result	1.40272	1.45273	1.68907	1.97787
	Relative error	0.1943%	+3.7664%	-3.4817%	+0.6908%
7	Identification result	1.40260	1.45565	1.69189	1.97797
	Relative error	0.1857%	+3.9750%	-3.3206%	+0.6959%
8	Identification result	1.40280	1.46755	1.70725	1.97778
	Relative error	0.2000%	+4.8250%	-2.4429%	+0.6862%
9	Identification result	1.40259	1.45083	1.68642	1.97823
	Relative error	0.1850%	+3.6307%	-3.6331%	+0.7092%
10	Identification result	1.40314	1.46231	1.70107	1.97804
	Relative error	0.2243%	+4.4507%	-2.7960%	+0.6995%

Under rotor coordinate system, the identification precision of stator resistance $\hat{R}_s$ is the lowest among all other parameters. It is, however, considerably high under stator coordinate system. In order to further improve the identification precision of the motor parameters, the identification process is to be carried in two steps: step 1, conduct identification on all four parameters of the motor under stator coordinate system in accordance with the method stated in Reference 3; step 2, use the stator resistance identified in step 1 as a known factor, and conduct identification on 3 other motor parameters under rotor coordinate system. Actually, the first step identification has already been finished. Now we identify the other three parameters under rotor coordinate system with the stator resistance identification result as given parameter. Table 3 shows the corresponding identification results (R_s is given). The genetic algorithm employs real-value coding. Select 500 for the size of initial population, [0, 20] for the range of initial population, N=300 for the point in the fitness function, optimize the data of this first 0.15 second at the initiation, and set 1,500 for the maximum number of generations.

The identification results has shown that after the 2-step identification method has been employed in the GA-based parameter identification, the margin of error of all parameters identified is within 5%, and that of the stator resistance $\hat{R}_s$ and leakage inductance $\hat{L}_\sigma$ is even with 1%. It can be clearly seen that high identification precision of all parameters is not possible by independent GA-based parameter identification, neither under stator coordinate system nor under rotor coordinate system, but if the identifications under the two coordinate systems are combined together, all parameters can be identified accurately.

VI. CONCLUSIONS

This paper proposes to conduct parameter identification during the start-up process of a motor by means of GA. These ways are researched and contrasted. GA is of extremely high robustness and extensive applicability. The result shows that when identified under the stator coordinate system, the identification accuracy of stator resistance and total leakage inductance is relatively high while that of the rotor time constant and stator inductance is relatively low: whereas when identified under the rotor coordinate system, the identification accuracy of leakage inductance, rotor time constant and stator inductance is relatively high while that of the stator resistance declines significantly. If the identifications under the two coordinate systems are combined, given the stator resistance obtained under the stator coordinate system, other parameters can be identified under the rotor coordinate system, resulting in great improvement on the identification accuracy of all parameters.

REFERENCES

[1] w. Leonard: “Control of Electrical Drives”, Springer 1997.

[2] Marin Despalatovic, martin Jadric, Bozo Terzic, “Identification of Induction Motor Parameters from Free Acceleration and Deceleration Tests”, AUTOMATICA 46(2005) 3 – 4, 123 – 128.

[3] Charles Kingsley, Stephen D. Umans, “Electric Machinery”, Sixth Edition.

[4] Austin Hughes, “Electric Motors and Drives”, Third Edition 2006. .

[5] G.R. Slemon, A. Straughen, “Electric Machines” .

[6] J.R. Willis, G. J. Brock, and J. S. Edmonds, “Derivation of induction motor models from standstill frequency response tests”, IEEE Trans. Energy Conv. Vol. 4, pp. 608 – 613, Dec 1989. .

[7] J. – K. Seok, S – I. Moon, and S. – K. Sul, “Induction parameter identification using pwm inverter at standstill”, IEEE Trans. Energy Conv. Vol. 12, pp. 127 – 132, June 1997. .

[8] L. A. de S. Ribeiro, C. B. Jacobina, and A. M. N. Lima, “The influence of the slip and the speed in the parameter estimation of induction machines”, in Proc. PESC Conf. Rec., June 1997, pp. 1068 – 1074. .

[9] H.S. Choi and S.K. Sul, “Automatic commissioning for vector controlled ac motors using Walsh functions,” IEEE Ind. Applicat. Soc. Annu. Meeting, pp. 1284-1289, 1999.