IDENTIFICATION BY HYBRID ALGORITHM APPLICATION TO THE IDENTIFICATION OF DYNAMICS PARAMATERS OF SYNCHRONOUS MACHINE

Jean Claude RAKOTOARISOA[a], Jean Nirinarison RAZAFINJAKA[b]

[a]Laboratoire d'Automatique, Ecole Supérieure Polytechnique, Diego Suarez, Madagascar
[b]Laboratoire d'Automatique, Ecole Supérieure Polytechnique, Diego Suarez, Madagascar

[a]rajeanclaud1976@yahoo.fr, [b]razafinjaka@yahoo.fr

ABSTRACT

This work treats the identification of the dynamic parameters of a synchronous machine using the test by symmetrical three-phased short circuit. The fitting of these parameters is carried out through the minimization of the quadratic errors between the short circuit currents measured and calculated.

. The approach of hybridization used in this work is the combination of the genetic algorithm (AG) and the algorithm of Levenberg-Marquardt (LM). The results of the optimization are validated first by comparing the parameters obtained by the approach adopted with those estimated with the graphic method of the IEEE standard then by the test of "voltage of reappearance".

Keywords: Identification, synchronous machine, Genetic Algorithm, Levenberg-Marquardt Algorithm

1. INTRODUCTION

The synchronous machine is used mainly for the generation of electrical energy. The dynamic behaviour of this machine is characterized by parameters which take into account the type of pole (smooth pole or projecting pole), the type of windings (with or without shock absorber) and the initial condition. These parameters are identified in the majority of cases by tests.

The reliable and precise determination of these parameters presents better latitude of optimization.

Various measurement techniques and procedures of estimation are used for this purpose. The graphic procedure to estimate the parameters using the short circuit test is well known like dynamic method. It requires the technical graphic for the construction of the envelope and the tangents of the currents of short circuit (IEEE Guide 1995). However, the manual construction of the tangents is not precise.

With the appearance of reliable algorithms of optimization, the idea of this article is to exploit them to optimize the quadratic errors between the measured values and those calculated of the short circuit currents of armature of the synchronous machine in order to identify its dynamic parameters. Various methods were used for this kind of problem. They can be subdivided in two groups: the first is the least square of which the algorithm of Levenberg-Marquardt is the most used. This algorithm converges quickly but its major disadvantage is the risk of convergence towards the local optima.

The second group is consisted by the method based on the evolution of an individual for example the set of the parameters. The genetic algorithm belongs to this group. The advantage of this group of optimization is the convergence towards the global minimum but it should be noted that it is slow because it requires several evaluations.

In this work, an approach of hybridization is used in order to exploit only the advantages of these two groups of algorithm. The principle of the approach consists in launching a global research with the genetic algorithm then to pass to local research with the algorithm of Levenberg-Marquardt in order to refine the result.

This article is organized as follows: first, the description of the test and the expressions of the currents induced at the moment of an abrupt three phased short circuit are detailed in the section 2. Then, a description of the algorithms, genetic algorithm and algorithm of Levenberg-Marquardt used for optimization are made in the section 3. The last section is devoted to the presentation of the results of identification and the comparison of these results between those obtained by using the method of estimate graphic. The article will be finished by a conclusion and prospect.

2. TEST IN THREE-PHASE SHORT-CIRCUIT SYMETRIQUE OF A SYNCHRONOUS MACHINE

2.1. Description of the experimental test

This test consists in applying a short circuit to the terminals of the stator phases from the no-load march of the machine and recording the evolution of the currents of the machine. It is often used to determine the dynamic parameters of the machine which are the time-constants and the transitory and sub transitory reactance. The test is applied on a standard synchronous machine LORENZO DL 1026 with projecting poles without shock absorber winding whose characteristics given by the manufacturer are shown by the following table:

Table 1: Characteristic of the machine

Power	1.1kVA
Nominal voltage	380V
Nominal current	1.67A
Factor of power	0.8AR
Frequency	50Hz
Number of poles	4

The following figure shows the assembly diagram:

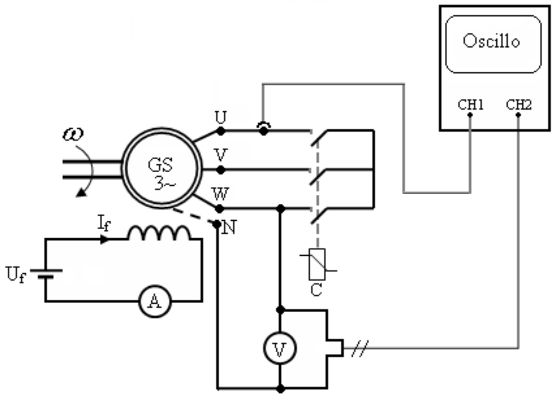

Figure 1: Assembly diagram of the test in abrupt three-phased short circuit

2.2. Expression of the current of short-circuit

The expression of the current in a phase at an abrupt three-phased short circuit on the stator without winding shock absorbers according to a no-load march is given (Amal 1979; Chatelain 1983):

$$
\begin{aligned}
i_a(t) = &-V_m\left(\frac{1}{x_d}\right)\cos(\omega_0 t+\varphi_0) \\
&-V_m\left(\frac{1}{x_d^{'}}-\frac{1}{x_d}\right)e^{\frac{-t}{T_d^{'}}}\cos(\omega_0 t+\varphi_0) \\
&-V_m\left(\frac{1}{x_d^{"}}-\frac{1}{x_d^{'}}\right)e^{\frac{-t}{T_d^{"}}}\cos(\omega_0 t+\varphi_0) \\
&+\frac{1}{2}V_m\left(\frac{1}{x_d^{"}}+\frac{1}{x_q^{"}}\right)e^{\frac{-t}{T_a}}\cos(\varphi_0) \\
&+\frac{1}{2}V_m\left(\frac{1}{x_d^{"}}-\frac{1}{x_q^{"}}\right)e^{\frac{-t}{T_a}}\cos(2\omega_0 t+\varphi_0)
\end{aligned} \quad (1)
$$

With,

x_d, $x_d^{'}$ *and* $x_d^{"}$: Reactances synchronous, transitory and sub transitory of the direct axis D.

$x_q^{"}$: The sub transitory reactance of the transverse axis Q.

$T_d^{'}$, $T_d^{"}$: Transitory and sub transitory time-constants corresponding to the direct axis D.

T_a : Time constant of the armature.

V_m : Maximum value of the voltage of armature before short circuit.

The current in the phases B and C is obtained while replacing respectively φ_0 by $(\varphi_0 - 2\pi/3)$ and $(\varphi_0 - 4\pi/3)$.

The examination of the expression of the current shows that it is the sum of five terms which are:

- A permanent sinusoidal term with pulsation ω_o whose amplitude is lowest than transient and sub transitory: $x_d^{"} < x_d^{'} < x_d$
- A deadened sinusoidal term (transitory) with pulsation ω_o whose damping coefficient is $\frac{1}{T_d^{'}}$, it is the transitory component of the current : $T_a < T_d^{'}$.
- A deadened sinusoidal term (sub transitory), with pulsation ω_o whose damping coefficient is $\frac{1}{T_d^{"}}$; this term decreases relatively quickly.
- A deadened aperiodic term whose damping coefficient is $\frac{1}{T_a}$, this damping is relatively fast $T_a < T_d^{'}$.
- A deadened sinusoidal term with pulsation $2\omega_o$; its amplitude is the lowest $x_d^{"} < ou \approx x_q^{"}$.

3. ALGORITHM OF OPTIMIZATION

As already mentioned in the introduction, the problem of identification becomes a problem of optimization through the minimization of the quadratic errors between the measured current and the current calculated by the expression (1). One leads then to the identification of the vector of parameters:

$$\theta^T = [T_a \ T_d^{'} \ T_d^{"} \ x_d \ x_d^{'} \ x_d^{"} \ x_q^{"} \ \omega_0 \ \varphi_0] \quad (2)$$

The value of V_m is determined by the initial conditions.

3.1. The Genetic algorithm

The structure of this algorithm (Ariba 2008) is given by the flow chart shown on Figure 2.

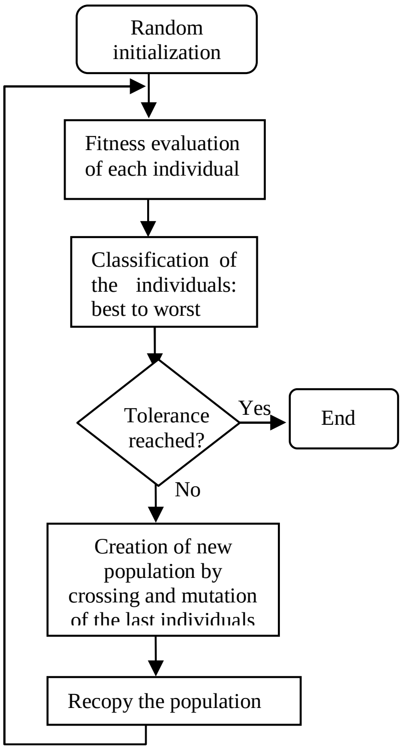

Figure 2: Structure of the genetic algorithm

This algorithm begins with the creation of the initial population individuals generated by random way and ends by converging to the best individual of the population corresponding to the solution of optimization. The passage of a generation through another is made by applying the mechanisms of evaluation, selection and modification until obtaining a stop criterion.

Each individual, called here chromosome, of the population is defined by a gene chain which corresponds to the various parameters to identify (see Figure 3).

T_a	T'_d	T''_d	x_d	x'_d	x''_d	x''_q	ω_0	φ_0

Figure 3: Representation of current chromosome.

To avoid the difficulties which can be raised on the binary coding and decoding of chromosome, the AG with real coding is used (Bontemps 1995). The values of the parameters are limited in an interval $[\theta_{\min}, \theta_{\max}]$. The principal reason to establish such limits is to make the process of research more effective by reducing its space.

The initial population is selected in a random way. That makes possible to begin research starting from various solutions of the space of research. The function of fitness defined by the equation (3) allotted to the algorithm is the sum of the quadratic errors between the digitized values of the measured current of phase and those calculated by the equation (1) by using the parameters of the evaluated chromosome.

$$Fit = \sum_{k=1}^{N} \left(I_m(k) - I_c(k)\right)^2 \quad (3)$$

The stochastic operators adopted by the algorithm are:

1. The selection by tournament which consists in taking randomly a sample of N individuals (2 at least) to each tournament. Then, the best of this sample is selected to be relative.
2. The crossing of the type $BLX-\alpha$. This type of crossing is applied parameter by parameter by using the following mechanism: x'_i is selected randomly in the interval $[\theta_{\min} + I\alpha, \theta_{\max} - I\alpha]$
   With:
   $\theta_{\min} = \min(x_i, y_i)$
   $\theta_{\max} = \max(x_i, y_i)$,
   $I = \theta_{\max} - \theta_{\min}$
   and α is a random number with $\alpha \in [0,1]$.
   x_i and y_i are of the same parameters row of two parents, x'_i the parameter of corresponding row of a child obtained.
   This type of crossing makes it possible to create diversity in the population and to move away from the risk of uniformity of the produced chromosomes (Bahloul and Ouali 2009). The rate of crossing is 90 %.
3. A uniform change applied with a probability of 1 %. It acts to modify a parameter by choosing a value in a way random defined by the constraints of the field.

3.2. Algorithm of Levenberg-Marquardt

The function cost defined by the equation (4) used is in the algorithm is the sum of the quadratic errors between the digitized values of the measured current of phase and those calculated by the equation (1) by using the parameters defined in the equation (2).

$$J(\theta) = \sum_{k=1}^{N} \left(I_m^k - I_c^k(\theta)\right)^2 \quad (4)$$

This algorithm works by starting from the best parameters found by the genetic algorithm and ends in convergence towards the best parameters corresponding to the solution of the problem optimization. The formula updating the parameters is given by:

$$\theta^{k+1} = \theta^k - \left(H(\theta^k) + \mu_{k+1} I\right)^{-1} \nabla J(\theta^k) \quad (5)$$

Where $H(\theta^k)$ is the Hessian matrix of the function cost J, I is the matrix identity, and where μ_{k+1} is a scalar called step. For small step values μ_{k+1}, this method approaches the Newton one (Dennis and More 1977) while for great step values, the method tends towards the gradient simple one (More 1977). By judiciously choosing the step value during the algorithm, it is then possible to avoid preliminary implementation like method of simple gradient to approach the minimum.

The calculation of the reverse of the matrix $[H(\theta^k) + \mu_{k+1} I]$ can be done by methods of direct inversion. Nevertheless, taking into account the function cost considered in (4), it is preferable to implement a method of iterative inversion, founded by the following property: being given four matrixes A, B, C and D.

$$(A + BCD)^{-1} = A^{-1} - A^{-1}B\left(C^{-1} + DA^{-1}B\right)^{-1} DA^{-1} \qquad (6)$$

The expression of the Hessian matrix is as followed:

$$H\left(\theta^k\right) = \sum_{n=1}^{N} \left(\frac{\partial e_n}{\partial \theta^k}\right)\left(\frac{\partial e_n}{\partial \theta^k}\right)^T + \sum_{n=1}^{N} \frac{\partial^2 e_n}{\partial \theta^k \left(\partial \theta^k\right)^T} e_n \qquad (7)$$

Where $e_n = y_n^p - y_n$ is the prediction error.

Neglecting the second term in the relation (7), which is proportional to the error, the following approximation of the Hessian matrix is obtained:

$$H\left(\theta^k\right) = \tilde{H}\left(\theta^k\right) = \sum_{n=1}^{N} \left(\frac{\partial e_n}{\partial \theta^k}\right)\left(\frac{\partial e_n}{\partial \theta^k}\right)^T \qquad (8)$$

This approximate Hessian matrix obeys to the formula of following recurrence:

$$\tilde{H}^n = \tilde{H}^{n-1} + X^n \left(X^n\right)^T$$
$$\text{with} \quad X^n = \frac{\partial e_n}{\partial \theta^k} = \frac{\partial y_n}{\partial \theta^k}, \quad n = 1, \ldots, N \qquad (9)$$

By fixing like initial value $\tilde{H}^0 = \mu_k I$, the following expression is obtained: $\tilde{H}^N = \tilde{H} + \mu_k I$

Using the lemma of inversion stated previously with $A = \tilde{H}^{n-1}$, $B = X^n$, $C = I$, $D = \left(X^n\right)^T$, it is possible to write:

$$\left(\tilde{H}^n\right)^{-1} = \left(\tilde{H}^{n-1}\right)^{-1} - \frac{\left(\tilde{H}^{n-1}\right)^{-1} X^n \left(X^n\right)^T \left(\tilde{H}^{n-1}\right)^{-1}}{I + \left(X^n\right)^T \left(\tilde{H}^{n-1}\right)^{-1} X^n} \qquad (10)$$

It is then possible to calculate the reverse of the matrix repeatedly $\tilde{H}^N = \tilde{H} + \mu_k I$

Let us note that this method of approximate calculation of the reverse of the matrix rises from the approximation (9), which is valid only for low error values of prediction e_n, and thus for the values of θ near the optimal value. The field of validity of the Newtonian approximation, extended a priori by the addition of the term $\mu_k I$ in the formula (7) is finally restricted to be able to effectively calculate the reverse of this increased Hessian matrix.

4. RESULTS AND DISCUSSIONS

4.1. Experimentation

The alternator is actuated at its nominal speed by an engine with D.C. current of 3kW, under a tension of excitation reduced not to run up against property damages due to electromechanical constraints.

This also makes it possible to avoid erroneous results bus in the zone of saturation the parameters change values.

The maximum tension at the boundaries of the winding before the short circuit is of $E_m = 312\sqrt{2}$ [V]. The following curve shows the recorded current:

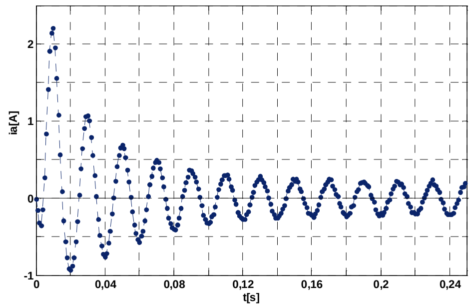

Figure 4: Current of three-phase short-circuit

The oscilloscope used has an interface making possible to record in a PC the discrete values of the current. These discrete values are then used to feed the program of optimization to identify the parameters of the machine. Figure 5 (resp. Figure 6) shows the evolution of the average quadratic error between the estimated current and the current measured during cycle of optimization by AG (resp. Hybrid Algorithm).

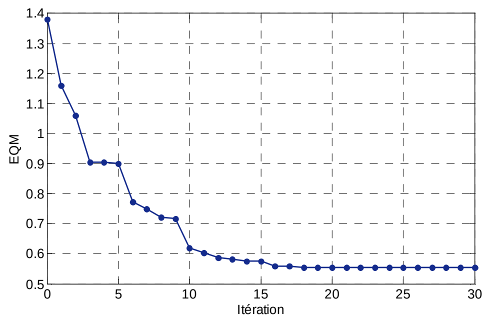

Figure 5: Evolution of the global error (AG)

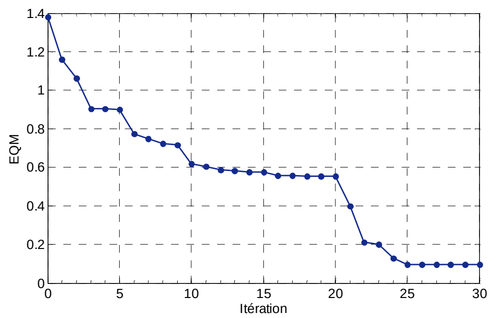

Figure 6: Evolution of global error (Hybrid)

It is noted that convergence is ensured in both cases. The use of AG alone gives a global error approximately 0.5 at the end of 20 iterations (Figure 5). This error is still reduced by continuing optimization with the algorithm of LM. One obtains a final error of 0.1 in 30 iterations (Figure 6). These results justify the adopted approach.

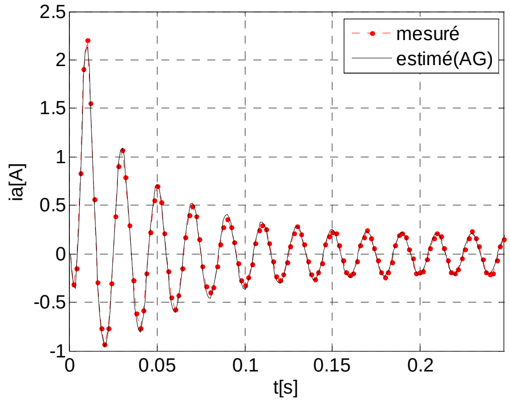

Figure 7: Estimation of the current phase $i_a(t)$ by AG

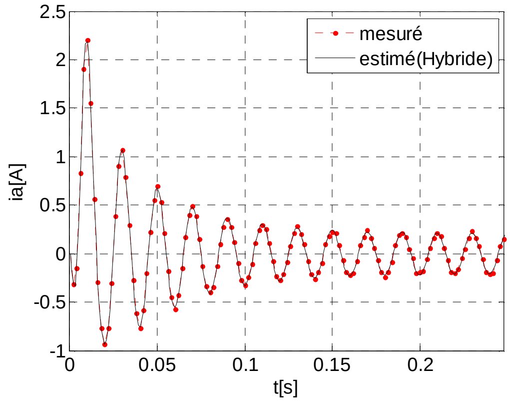

Figure 8: Estimation of the current phase $i_a(t)$ by hybrid algorithm.

Figure 7 (resp. Figure 8) shows the estimation between the measured current and the current estimated by AG (resp. Hybrid Algorithm). It is noted that these two methods offer a good estimate as well in transient state as in steady operation. The superiority of the hybrid algorithm is shown in comparison of the global errors presented in Figure 5 and Figure 6.

4.3. Comparison

To evaluate the parameters identified by the method suggested a comparison with those estimated by AG and detailed graphic method (IEEE Guide 1995; Rakotoarinoro 1999) is presented in the following table:

Table 2: Comparison of the parameters

	AG	Hybrid	Graphic
$T_a[ms]$	10.15	10.15	10
$T'_d[ms]$	44.21	38.72	38
$T''_d[ms]$	38.92	35.16	38
$x_d[\Omega]$	218.45	209.87	210
$x'_d[\Omega]$	24.88	26.31	23.3
$x''_d[\Omega]$	24.59	23.40	23.3
$x''_q[\Omega]$	120.9	102.03	98
$\omega_0[rad.s^{-1}]$	314.46	314.18	314.16
$\varphi_0[rad]$	0.0001	0.0001	0

For a synchronous machine without shock absorbers, the sub transitory and transient parameters (reactances and time-constants) are supposed to be identical during a graphic estimate. However, in reality, there is a light difference. This difference is shown well by the adopted approach. It is important to notice that the vector of parameters which is obtained with the suggested approach is only one average vector of parameters i.e. it is the vector which corresponds to the best compromise to represent the machine in its operation.

4.3 Experimental validation

To check the parameters identified by the hybrid algorithm proposed, it is useful to proceed a phase of experimental validation. For that, one carried out under test known as "of tension of reappearance" (Lessenne, Notelet and Seguier 1981). The alternator is initially in three-phase short-circuit, one opens the short-circuit by the intermediary of the three poles switch C (Figure 1) and one records the curve of re-establishment of current.

The simplified expression of this tension, for a synchronous machine without shock absorbers is (Rakotoarinoro 1999) :

$$V_a = V_m\left(1-\left(1-\frac{x'_d}{x_d}\right)e^{\frac{-t}{T'_{d0}}}\right)\sin(\omega t+\varphi) \qquad (11)$$

With $T'_{d0} = T'_d \dfrac{x_d}{x'_d}$

The following curve shows the evolution of this tension of reappearance:

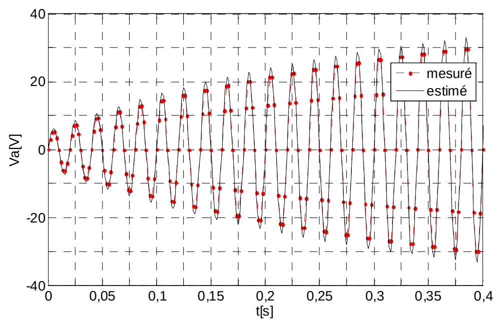

Figure 9: Voltage waveform of reappearance

According to Figure 9, the tension of reappearance curve simulated by using the parameters identified with hybrid algorithm follows well the experimental one. That increases the certainty with the suggested method.

5. CONCLUSION

A method of optimization hybrid combining the genetic algorithm (AG) and the algorithm of Levenberg-Marquardt (LM) was implemented in this article.
The objective was to minimize the quadratic errors between measured and estimated of short circuited currents.

In their work, Bahloul et al. (Bahloul 2009) proposed the identification of the dynamic parameters of a synchronous machine by using only the genetic algorithm. They arrived at notable results. However, the combination of this algorithm with the Levenberg-Marquardt one led to finer results on by the way of the global errors.

The approach of hybridization adopted in this work makes possible to find the parameters dynamic of a machine synchronous using the test in short-circuit, independently of the initial parameters. The space of research of the parameters is given to help the algorithm to find quickly the optimum.

The approach suggested is tempting and offers a very interesting alternative compared to the traditional methods, which require "to start" near the optimal vector and whose behaviour is dubious in front of the local minima.

The comparison between the measured current and the current estimated by simulation makes it possible to validate the method. Indeed, there is agreement of the results as well in transient state as in steady operation showing the precision of the given parameters. This proves the performance and the robustness of the adopted method of optimization.

This work gives multiple possibilities of research that it is interesting to dig. First of all with regard to the genetic algorithm, it would be interesting to compare our approach with that where the change of individuals is fixed not by probability but by sizes of under population. Then concerning the choice of the moment when the algorithm of Levenberg-Marquardt takes over in its turn, it would be interesting to exploit the evolution of each parameter.

Finally, it was said that the suggested method combines the genetic algorithm and the Levenberg-Marquardt one. Here, it is noted that the number of iterations Ni is approximately equal to two for three times the number of parameters Np. The identification is started with AG and after 18 iterations; the commutation to the LM algorithm is made. It would be useful to find a relation between Ni and Np.

REFERENCES

IEEE Guide, 1995. *Test Procedures for Synchronous Machines*, IEEE Std 115

Amail, P., 1979, Régime transitoire et stabilité des machines à courant alternatif, *EDF Division technique générale.*

Chatelain, J., 1983, Machines Electriques. *Traité d'Electricité, Vol. X.* ed. Georgi

Ben Ariba, H., 2008, *Apports à la résolution de problèmes pour le dispatching des réseaux d'énergie électrique*, Thesis (Doctorat). ENIS University.

Bontemps, C., 1995, *Principes Mathématiques et Utilisations des Algorithmes Génétiques*. Extract of course.

Bahloul W., Ouali M., 2009, Identification des paramètres dynamiques de la machine synchrone par algorithme génétique. *IREC'09* (Sousse, Tunisia)

Dennis, J.E., More, J.J. Holland, M., 1977. Quasi-Newton methods, motivation and theory. *SIAM Review, Vol. 19, No. 1,* pp. 46-89.

More, J.J., 1977. The Levenberg-Marquardt Algorithm: Implementation and Theory. *Lecture Notes in Mathematics,* ed. Springer Verlag. pp.105-116.

Rakotoarinoro, R.C., 1999. *Contribution à l'étude du comportement des machines synchrones de réseau en régimes transitoires*. Thesis (DEA) ESP-University of Diego Suarez.

Lessenne, J., Notelet, F., Seguier, G., 1981. Introduction à l'électrotechnique approfondie. *Technique de documentation.* Paris.

AUTHORS BIOGRAPHY

Razafinjaka N. Jean. Born in 1956. Doctor Engineer. He works now in the Laboratory of Automatic, Polytechnic Higher School of Diego Suarez, Madagascar. His field of research relate to the advanced commands applied to electric and electromechanical systems.

Rakotoarisoa A. Jean Claude. Born in 1976. Holder of DEA. He works at the laboratory of Automatic and currently prepares his doctorate in collaboration with the University of Paris 8. His theme consists of research on the identification of a mechanical micro system using different algorithms and their combination.