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Design Optimization of Induction Motor using Hybrid Genetic Algorithm "A Critical Analyze"

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Abstract

The aims of this paper is describes the procedure to determine the design of three phase electrical motors. The originality lies in combining a motor design program and employing a Hybrid Genetic Algorithm (HAGs) technique to obtain the maximum of objective function such as the motor efficiency. A method for evaluating the efficiency of induction motor is tested and applied on 2.2 kW experimental machines; the aforementioned is called equivalent circuit method (EC-M) and based on the analysis of the influence losses. After that, the optimal designs are analyzed by finite element method (FEM) and compared with results of another method which is genetic algorithms (GAs) optimisation technique, was done to demonstrate the validity of the proposed method.

Keywords

Genetics Algorithms, Hybrid, Induction Motor, Efficiency Evaluation, Element Method.

1. Introduction

Nowadays, improving efficiency of electric motors and its impact on energy savings are becoming a great challenge to researchers and manufacturers all over the world. Electric motors use more than half of all consumed electricity, with a typical range of 40-60 %, the lower and the upper limits are respectively for the developing and industrialised countries, [1, 2 and 3]. The industrial sector consume about 60-80 % and tertiary sector about 20-40%. Induction motors represent about 90% of the electric motors total consumption, as presented in, [3]. These statistical data on the electric motors park throughout the world show this topic as a leading research field on energy savings and underline the growing interest for improving electric driven systems, motors efficiencies in general and those of induction motors in particular. In fact, although that this type of energy conversion has a high efficiency relatively to the other types of conversion, so improving the motor efficiency by a few tenths of % for such machines, leads inevitably to a significant wide scale of energy savings.

In the last decades, new generation of motors are proposed on the world market and known as High Efficiency Motors (Hi-E.M) or as Energy Efficient Motors (E-E.Ms). These new types of motors are more expensive than classical ones, in the range of 20-40%, from larger to lower power range respectively. In general, most motor purchasers are interested by cheapest motors, instead of considering their characteristics and performances. The use of this new generation of electric motors and their dependence on the annual operating hours lead, especially, for heavy investments, to a quicker amortisement in some cases less than two years, [4].

At the moment, among the design trends in improving electrical machine performances we encounter the introduction of the artificial intelligence tools in optimizing the machine design parameters. This leads mainly to improve their efficiency, power to mass ratio and cost.

While genetic algorithms can rapidly locate the region in which the global optimum exists, they take a relatively long time to locate the exact local optimum in the region of convergence, [5]. A combination of a genetic algorithm and a local search method can speed up the search to locate the exact global optimum. In such a hybrid, applying a local search to the solutions that are guided by a genetic algorithm to the most promising region can accelerate convergence to the global optimum. The time needed to reach the global optimum can be further reduced if local search methods and local knowledge are used to accelerate locating the most promising search region in addition to locating the global optimum starting within its basin of attraction. Finally**,** his paper is a sort of comparison between the loss reduction problems by the stochastic technique which is called the genetic algorithm (GAs), also hybrid genetic algorithms (HGAs), [5, 6].

2. Induction Motors Efficiency Evaluation

The electric driven system efficiency depends on several factors such as: motor efficiency and control techniques, power system and distribution network qualities, system over sizing, mechanical transmission means, maintenance problems and practices, load management and operating cycles, [1-6]. To improve electric driven system efficiencies, different approaches are proposed. They mainly use variable speed drives, regulate and stabilise the electric power network, choose an optimal power size of the electric motors or improve their designs and efficiencies. The three first approaches are related to electric power network system, but the last ones are related to the motor design itself.

To evaluate efficiency ratio, many methods are proposed, as given in [1-4]: Name plate method, Slip method, Current method, Statistical method, Equivalent circuit method, Segregated losses method, Air-gap torque method, and the Shaft torque method. All these methods determine the efficiency according to the definition given by equation (1).

$$\eta = \frac{P_{out}}{P_{in}} = \frac{Shaft\ \ Output\ Power}{Electrical\ \ Input\ Power} \tag{1}$$

Electrical input power is measured directly, but motor shaft output power is evaluated by deducing calculated losses from the input power, and can be obtained directly or indirectly, in different ways. In the indirect case, which constitutes the most difficult task, losses have to be assessed, by a variety of normalized proposed methods. In fact, losses in rotating machines can be divided into three main groups:

- Electrical losses P_{Elect} ; - Magnetic losses P_{Mag} ; - Mechanical losses P_{Mec} ;

And a fourth group less important of some additional losses due to parasitic phenomena (leakage flux, non uniform current distribution, mechanical imperfection in the air-gap, and flux density distribution in the air-gap) is known as:

- Stray losses P_{Stray}.

It can be noticed, that electrical motor efficiency takes different values, depending on the experimental tests achieved and the precision apparatus used, and related to the standard adopted to determine this efficiency. The most used standards are the International Electro technical Commission (IEC-60034-2) and the new (IEC 61972), the National Electrical Manufacturers Association (NEMA-MG1) which is conform to the Institute of Electrical and Electronic Engineer (IEEE 112-B), and the Japanese Electro technical Committee (JEC-37). The Algerian manufacturer Electro-Industry (E.E-I) Azazga, uses the standard of the Deutschland Institute of Normalization (DIN) and VDE 0530, which are conform to the IEC 34-T2 standard.

Fig. 1, shows these discrepancies for the most employed standards and those used in Algeria, for a sample of 4 poles classical induction motors.

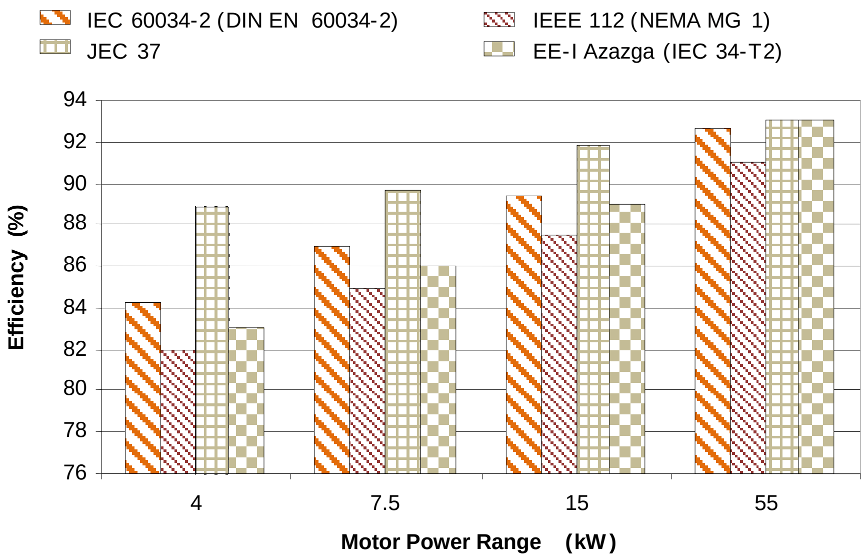

Fig. 1 Discrepancies on efficiency standards (4 poles machines), [1-4]

These discrepancies are about 2-4% for low power and about 1% for high power machines. It can be seen also that standards of IEEE 112-B, give the lower efficiencies, while the JEC-37, the higher ones. This means that tests and nameplate under the regulation of the IEEE 112-B standard are more stringent than the other ones. These differences are mainly due to the way how the stray losses are determined and accounted in the efficiency calculation. For the standard of the :

- IEEE 112 method B, calculates the stray losses for different loads, then linearises and corrects for the measurement imprecision in function of torque squared, as given in [5]. Now the torque can be measured with a high precision using the new generation of torque transducers;
- JEC 37 : neglects the stray losses, $P_{Stray} = 0$;
- IEC 60034-2 : is equivalent to the (DIN EN 60034-2) : which supposes that the stray losses have a constant ratio related to the input power : $P_{Stray}= 0.5\%$ Pin;
- New improved standard IEC 61972 determines : the stray losses by measurement or by fixed amount depending on the motor rating, [4, 5];

During the last decades, the trend on motor design was mainly focused on the reduction of both the power density ratio and cost, so giving smaller machines with lower costs. These aims have been partially reached to the detriment of a lower motor efficiency, so with a higher running cost. At the same time, electricity prices start to increase quickly and motor manufacturers have proposed a new generation of Energy-Efficient Motors (E-E.Ms) for high power range. Nowadays, consumers are being more aware and interested with the energy conservation and lower running cost, so needing high efficiency motors. As mentioned before, to improve motors efficiency two approaches can be adopted :

First, we have to act by an appropriate choice of the motor sizing, or by operating the motor in an efficient way, so using external intervention, [5].

Second, by acting on the motor design, which means increasing the volume of the active material (Iron and Copper), using longer machines in order to keep the same slot design, selecting lower current density and a higher copper slot fill-factor, choosing new material with high magnetic performances (low iron losses), and optimizing the motor design according to its efficiency.

This paper describes the make use of a proper optimisation procedure to determine the design of an induction motor to get maximum efficiency. The method involved the use of a design method coupled to an optimisation technique such as, the (HAGs).

3. Optimization Techniques

Presently, research efforts have been made in order to invent novel optimization techniques for solving real life problems, which have the attributes of memory update and population-based search solutions. General-purpose optimization techniques such as hybrid genetic algorithm (HAGs), and Genetic Algorithms (GAs), have become standard optimization techniques which principal is:

3.1 Genetic Algorithms (GAs)

The genetic algorithm based optimization is a stochastic search method that involves the random generation of potential design solutions, then systematically evaluates, and refines the solutions until a stopping criterion is met. There are three fundamental operators involved in the search process of a genetic algorithm: selection, crossover, and mutation. The genetic algorithm implementation steps are, [5,7].

1 Parameter and objective function definition;
2 Random generation of the first population;
3 Population evaluation by objective function;
4 Convergence test. If satisfied then stop else continue;
5 Reproduction process launching (Selection, Crossover, Mutation);
6 Generation of new population by applying the following three genetic algorithm operators:
 -Selection; - Crossover; - Mutation.
7 Evaluation of all individuals of the new obtained population as described in section 6;
8 After each iteration the parameter search space is adjusted according to the local optimum solution;
9 Repetition of the subsequent sections from 1 to 8;

10 Ending the process whenever a prefixed number of generations or the best of the objective function imposed value has reached a satisfactory level. This last one is considered the most used termination criterion.

3.2 Simplex Method (SM)

The Simplex method is a robust nonlinear multi-dimensional optimization technique. The method does not require the derivation of the function to be optimization. A simplex is a geometrical figure consisting, in N dimensions, of (N+1) vertices. The Simplex method, start with initial simplex (N+1) points then through a transformations (reflection, contraction and extension), the initial simplex moves, expands and contracts, in such a way that it adapts itself to the function landscape and finally surrounds the optimum.

3.3 Hybrid Genetic Algorithm (HAGs)

A central goal of the research efforts in GAs is to find a form of algorithms that is robust and performs well across a variety of problems types.

Although genetic algorithms can rapidly locate the region in which the global optimum exists, they take a relatively long time to locate the exact optimum in the region of convergence. A combination of a GAs and a local search method can speed up the search to locate the exact global optimum. In such a hybrid, applying a local search to the solutions that are guided by a GAs to the most promising region can accelerate convergence to the global optimum, [8].

There are several ways to hybrid any systems, are based maintaining GAS enough modular program structure. this way, you only have to let it run until the genetic algorithm convergence therefore level then allowed the optimization procedure by the Simplex algorithm take over, taking for example 5% or 10% best individuals of the last generations. Several authors have proposed this technique (Bethke 1981, Bosworth foo and Zeigler 1972, Goldberg 1983), the idea is simple, interesting, and can be used to improve the final performance of gene exploration. A News hybrid approaches where the use of genetic operators improve the performance of existing heuristic methods are: Sequential Hybrid (S-H), Advanced Algorithms Genetics (A-GAS), [8, 9].

4. Improving Efficiency

The combination of a computer-aided design with artificial intelligent optimization techniques forms an important tool, especially on the engineering design process of high performances and costly systems. In the field of electrical machines, due to the complicated nature of the functions describing their performances, the optimization problem of such machines is a multivariable- constrained nonlinear problem. For optimizing the induction machine efficiency, computed design processes coupled to a genetic algorithm have been developed. The main steps of the design procedure for such motor are summarized in the flowchart of Fig.2, Including: Analytical model search; Optimization phase.

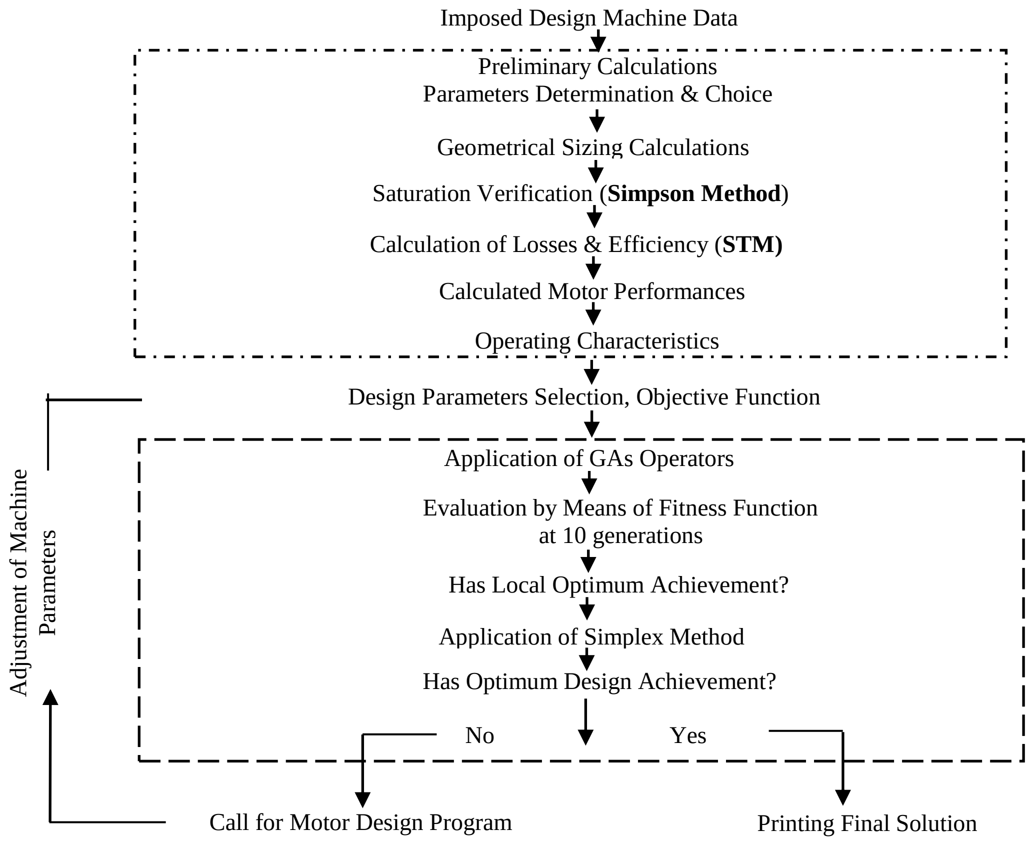

Fig. 2 Proposed optimizing efficiency method flowchart

The design procedure of electrical machine is based on Liwschitz method which can be summarized in three main stages: First, from the imposed machine design data, the measured geometrical dimensions and within linear interpolation of the normalized range curves. The used of Simpson method we intend to do is saturation test phase and accomplish the task of the optimization. Finding the optimized dimensions which characterized by the active volume given by the inner stator diameter and the core length of the machine. However, this lead to the parameters of the electrical equivalent circuit of the machine, [10]. Second, from the results of stage 1, the machine performances are evaluating in order to check or not the machine analytical model. Third, the Classical Direct Test Method (CDT-M) is used to provide the machine parameters.

This procedure is applied on a three phase squirrel cage induction motor ELPROM, type A0-112 M-2B3T-11, 2.2 kW, Δ/Y 220/380 V, 9.2/5.3 A, Cosφ=0.82, 1425 trs/mn and 22 kG.

4.1 Geometrical Parametric Identification (GPI-M)

The imposed machine data such as the mechanical power (P_m), stator voltage, stator phase current and slip (s_1) are introduced as inputs for the main developed program. The program calculates according to a set of experimental curves the normalized values of the power factor $(\cos\varphi)$ and efficiency (η); the inner stator diameter (D) and the core length (l_i); the magnetic and electric variables, [10].

A. Calculation of stator resistance

The stator turn number by phase (N_1) and the stator resistance (R_s) are expressed by:

$$N_1 = \frac{V_s \cdot \left(\frac{1}{1+\sigma_{H1}} \right)}{4 \cdot \pi \cdot f_1 \cdot K_{W1} \cdot \phi} \tag{2}$$

$$R_s = \rho \cdot \frac{L_{tot}}{S} \tag{3}$$

Where:

k_{W1}	Total stator winding coefficient;	f_1	Supply frequency;
σ_{H1}	Heyland stator coefficient;	S	Conductor cross section area;
L_{tot}	Total conductor length per phase.		

B. Calculation of the leakage reactance

- **Total stator leakage reactance**

The stator leakage inductance is deduced from the total stator leakage reactance as follows:

$$l_{\sigma s} = \frac{X_{\sigma 1}}{\omega} = 4 \cdot \pi \cdot f_1 \frac{N_1^2}{\omega \cdot p} \cdot \left(\Lambda_{\sigma b1} + \Lambda_{\sigma z1} + \Lambda_{\sigma d1} \right) \tag{4}$$

- **Total rotor leakage reactance**

The rotor leakage inductance is expressed as follows.

$$l_{\sigma r} = \frac{X_{\sigma 2}}{\omega} = 4 \cdot \pi \cdot \frac{f_1}{\omega 2 p} \cdot \left(\Lambda_{\sigma b2} + \Lambda_{\sigma z2} + \Lambda_{\sigma d2} \right) \tag{5}$$

Where:

$\Lambda_{\sigma b1}, \Lambda_{\sigma b2}$ End coil permeances of stator and rotor;

$\Lambda_{\sigma d1}, \Lambda_{\sigma d2}$ Differential permeances of stator and rotor;

$\Lambda_{\sigma z1}, \Lambda_{\sigma z2}$ Permeances of stator and rotor slot.

C. *Assessment of the losses*

- Copper losses

In the Stator: The copper losses in the stator coils (P_{cu1}) are given by:

$$P_{cu1} = m_1 \cdot R_s \cdot I_s^2 \tag{6}$$

In the Rotor: The copper losses in the secondary (P_{cu2}) are:

$$P_{cu2} = m_2 \cdot R_2 \cdot I_2^2 \tag{7}$$

$$R_2 = R_{bar} + \frac{2 \cdot R_{ring}}{4 \cdot \sin^2 \dfrac{\pi \cdot p}{Z_2}} \tag{8}$$

The equivalent phase resistance $R_r^{'}$ refereed to the stator side is:

$$R_r^{'} = \left(\frac{m_1}{m_2}\right) \cdot \left(\frac{N_1}{N_2} \cdot \frac{K_{W1}}{K_{W2}}\right)^2 \cdot R_2 \tag{9}$$

Where

R_{bar}, R_{ring} Bar and ring resistances; R_2, Z_2 Rotor resistance; Bar number;

K_{W2} Total rotor winding coefficient; N_1, N_2 Stator and rotor turns by phase;

m_1, m_2 Stator and rotor phase number.

- Iron losses

The sum of the losses (p_{H+W}) in one iron kg is given by:

$$p_{H+W} = K_H \cdot f \cdot B^2 \cdot 10^{-2} + K_W \cdot \left(S_t \cdot f_1 \cdot \hat{B}\right)^2 \cdot 10^2 \tag{10}$$

The constants K_H, K_W for the different materials are given by normalized rang.

$\hat{B}$ Peak air gap flux dens; S_t Metal sheet thickness.

- Mechanical losses

These losses are taken into account with rubbings due to the rotation of the mobile part of the machine, and they are estimated according to the speed [5, 7].

D. Determination of no-load parameters

The stator no-load current (I_o) comprises the magnetizing current (I_{mo}) and load losses one (I_{oa}).

$$I_0 = I_{m0} + I_{oa} \tag{11}$$

$$I_{mo} = \frac{p \cdot F_{mmtot}}{0.9 m_1 K_{W1} N_1} \qquad I_{0a} = \frac{P_{\sup} + P_{ft+vt}}{m_1 \cdot V_s} \tag{12}$$

$$\cos\varphi_o = \frac{I_{ao}}{I_o} \tag{13}$$

The no-load reactive power (Q_0) is:

$$Q_o = 3 \cdot V_s \cdot I_0 \cdot \sin\varphi_0 \tag{14}$$

Where:

P_{ft+vt}	Rubbing and ventilation losses;	φ_0	Phase angle at no-load.
F_{mmtot}	Total magneto motive force calculated according Simpson method;	P_{sup}	Supplementary losses;

Therefore, the total stator inductance (L_s) is determined as follows:

$$L_s = \frac{Q_0}{3 \cdot \omega_s \cdot I_0^2} = \frac{3 \cdot V_s \cdot I_0 \cdot \sin\varphi_0}{3 \cdot \omega_s \cdot I_0^2} \tag{15}$$

After having determined (L_s) and $(l_{\sigma s})$, the mutual inductance is expressed by:

$$M = L_s - l_{\sigma s} \tag{16}$$

And the total rotor inductance referred to the stator side $(L_r^{'})$ is determined:

$$L_r^{'} = M + l_{\sigma r}^{'} \tag{17}$$

Finally the efficiency is:

$$\eta = \frac{P_m}{P_m + \sum Losses} \tag{18}$$

4.2 Classical Direct Test Identification Method (CDT-M)

This method is based on two tests that used terminal measurements: a no-load test at rated voltage and a short-circuit at reduced voltage. It permits the parameter determination of induction motor equivalent circuit referred to the stator side by neglecting the rotor leakage inductance.

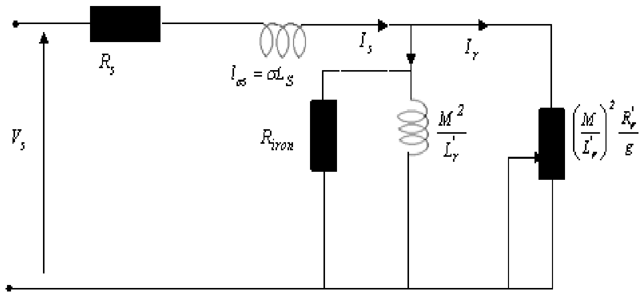

Fig. 3 Induction motor equivalent circuit on the stator side

The unknown parameters to be found by this method when solving the following equations are L_s, M and R_r' while the winding Ohmic resistance R_s can be obtained by a DC volt-drop test, [11]. The active (p) and reactive (Q) powers are measured and use to evaluated the equivalent impedance of each test. The core losses represented by the equivalent magnetizing resistance (R_{iron}) as well as the mechanical losses are deduced from the measured active power.

$$\begin{cases} R_{eq0} = P_0 \cdot \dfrac{V_0^2}{P_0^2 + Q_0^2} \\ X_{eq0} = Q_0 \cdot \dfrac{V_0^2}{P_0^2 + Q_0^2} \end{cases} \tag{19}$$

The equivalent resistance R_{eq0} and X_{eq0} reactance of the schematic circuit at no-load are:

$$\begin{cases} R_{eq0} = R_s + R_{iron} \dfrac{(M\omega)^2}{R_{iron}{}^2 + (M\omega)^2} \\ X_{eq0} = l_{\sigma s}\omega + M\omega \dfrac{R_{fe}{}^2}{R_{iron}{}^2 + (M\omega)^2} \end{cases} \tag{20}$$

The short-circuit test was carried out at a reduced stator voltage and locked rotor. The current, in this case, is only limited by the motor internal impedance that will be determined in a way of the no-load test.

The equivalent resistance R_{eqcc} and X_{eqcc} reactance at rated voltage:

$$\begin{cases} R_{eqcc} = P_{cc} \cdot \dfrac{V_n^2}{P_{cc}^2 + Q_{cc}^2} \\ X_{eqcc} = Q_{cc} \cdot \dfrac{V_n^2}{P_{cc}^2 + Q_{cc}^2} \end{cases} \tag{21}$$

$$\begin{cases} R_{eqcc} = R_s + R_f \dfrac{(M\omega)^2}{R_f^{\ 2} + (M\omega)^2} \\ X_{eqcc} = l_{\sigma s}\omega + M\omega \dfrac{R_f^{\ 2}}{R_f^{\ 2} + (M\omega)^2} \end{cases} \tag{22}$$

Where:

$$R_f = \frac{R_{iron} \cdot R'_r}{R_{iron} + R'_r} \tag{23}$$

4.3 Results Analysis

The above identification methods applied on a 2.2 kW radial flux induction machine using a laboratory test-rig. Then the measured geometrical dimensions (en mm) which carried on the Fig. 4 are included on the developed motor design program. The investigation results are reported in Table 1.

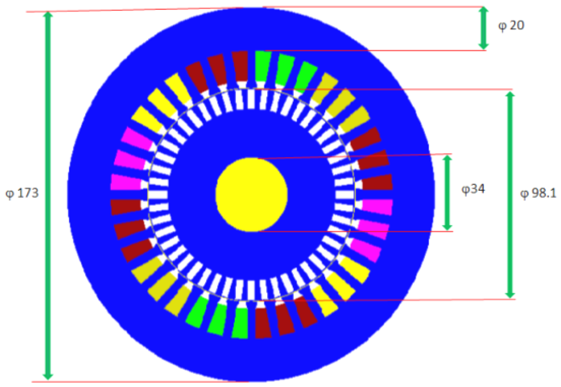

Fig. 4 Induction motor cross section

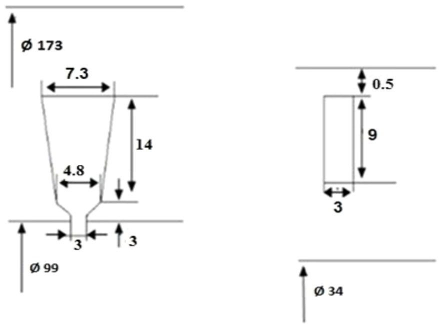

Fig. 5 Stator and rotor slot dimensions en (mm)

Table 1. Induction motor parameter comparison of identification methods

Parameters	**(GPI-M)**	**(CDT-M)**
$R'_r\ (\Omega)$	2.67717	2.1647
$l'_{\sigma r}\ (H)$	0.01286	0
$l_{\sigma s}\ (H)$	0.01208	0.0232
$R_s\ (\Omega)$	3.158	3.5
$M\ (H)$	0.20952	0.1704

According to the results which are summarized in Table 1, it can be declared that the determined machine parameters from two methods are relatively close to each other, excepted the values of R_s and $l'_{\sigma r}$. This mainly be justified by the temperature effect consideration for the first one and it is zero by assumption for second one.

Used equivalent circuit method (EC-M), The presented study is concretized by establishing three motor characteristics $I_s = f(s_1)$, $T_e = f(s_1)$ and efficiency $\eta = f(s_1)$ are drawn as depicted in Fig. 6, 7 and 8 respectively. These figures are zoomed by data cursor so as to highlight the performance in the normal operating load rang for classical direct test identification method (CDT-M) and geometrical parametric identification method (GPI-M)

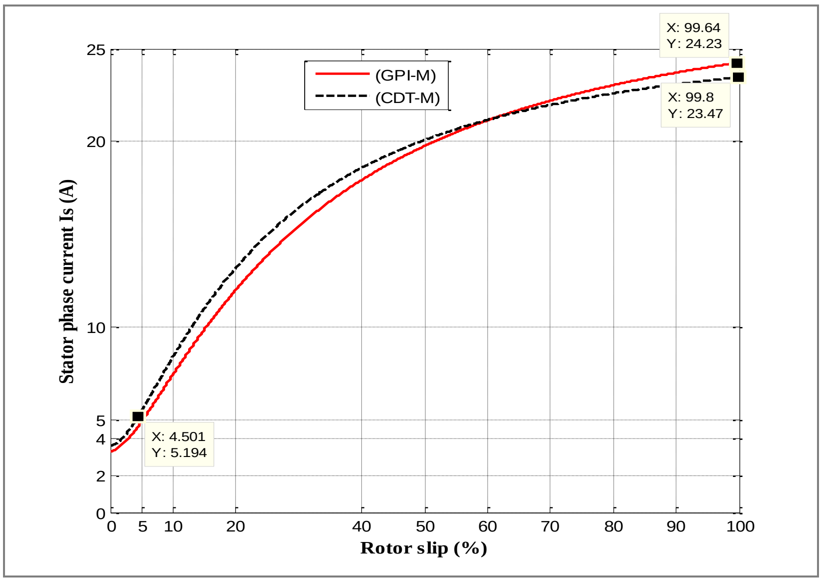

Fig. 6 Stator phase current versus rotor slip

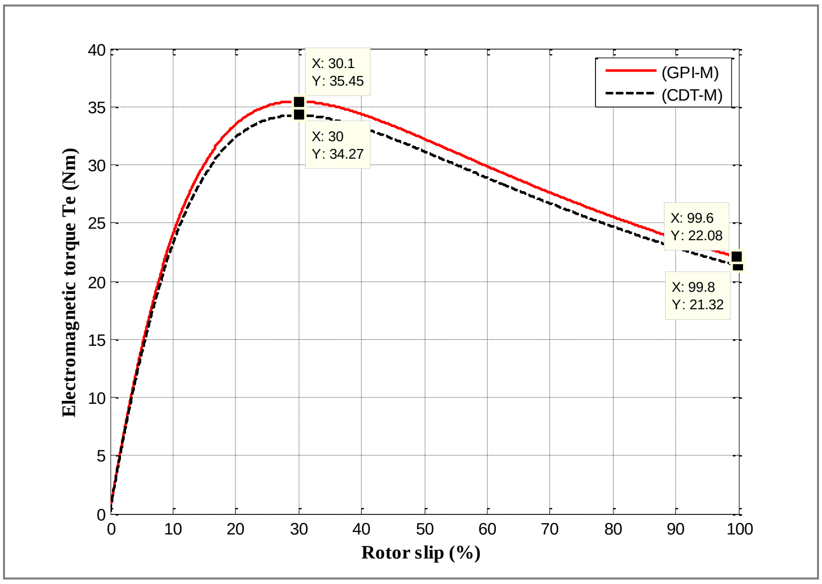

Fig. 7 Electromagnetic torque versus rotor slip

Analysis of the figures show that the plotted motor characteristic are relatively close to each other particularly at low slip values (i.e. up to 5%). As the slip rises from 10% to the starting point, the curve of (GPI-M) and (CDT-M) ones tend to loose this closeness although a tight closeness kept by the first method from one hand and by the second ones on the other hand.

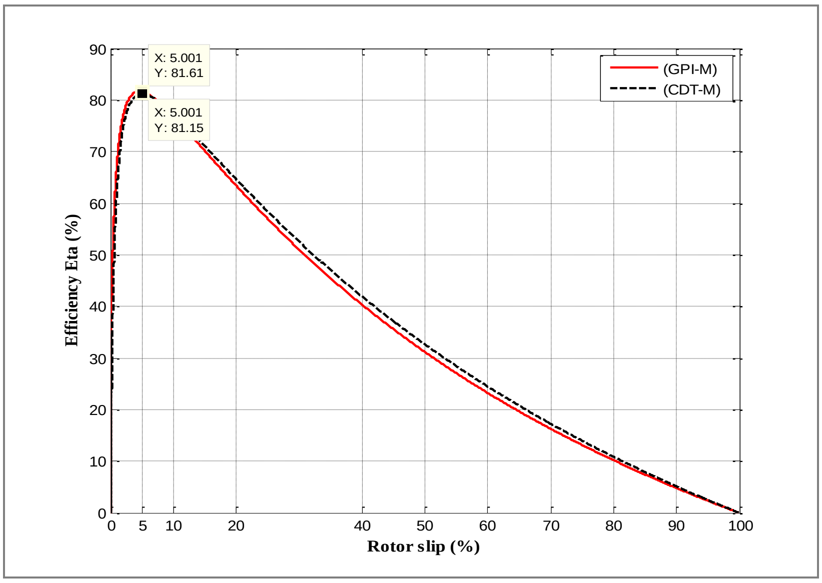

Fig. 8 Efficiency versus rotor slip

In fact, it can be concluded that the analytical model developed using the Liwschitz method is in good correlation and it can be accepted for optimization phase.

4.4 Optimization Phase

In order to obtain an acceptable design, Table 2 summarized the design program results and the practical domains for the design parameters. Within case presented here, eight design parameters some of which are used in literature and affect induction motor's first order basic geometry is chosen. So, the efficiency (motor losses) is selected as main objective function and the weight of motor is selected as a constraint of optimization.

Table 2. Design variables and their limit values

Variables	**Initial value**	**Search region**
Inner stator diameter (mm)	98	$95 \le D \le 104$
Geometric report	1.25	$0.75 \le \lambda \le 1.75$
Stator slot height (mm)	17	$13 \le h_{t1} \le 18$
Back iron thickness (mm)	20	$16 \le h_{j1} \le 22$
Air-gap length (mm)	0.33	$0.3 \le \delta \le 0.5$
Stator tooth flux density (T)	1.543	$1.3 \le B_{t1} \le 1.7$
Rotor tooth flux density (T)	1.582	$1.4 \le B_{t2} \le 1.8$
Machine weight (kG)	22.60	$21 \le M \le 23$

4.4.1 Mains Results

Table 3 shows and compares the values for the eight design parameters of the HAGs with those GAs techniques. Accordingly, the HAGs algorithm has returned an acceptable solution which is indicated by a good value for the objective with no constraint violation.

Table 3. Optimization results

Parameters	**Solutions with**	
	HAGs	**GAs**
Inner stator diameter (mm)	103.2	102
Geometric report	1.497	1.5
Stator slot height (mm)	14	14.9
Back iron thickness (mm)	18	16.9
Air-gap length (mm)	0.3057	0.35
Stator tooth flux density (T)	1.469	1.55
Rotor tooth flux density (T)	1.523	1.65
Machine weight (kG)	21.801	22.69
Optimized efficiency η_{Opt} (%)	82.48	82.48

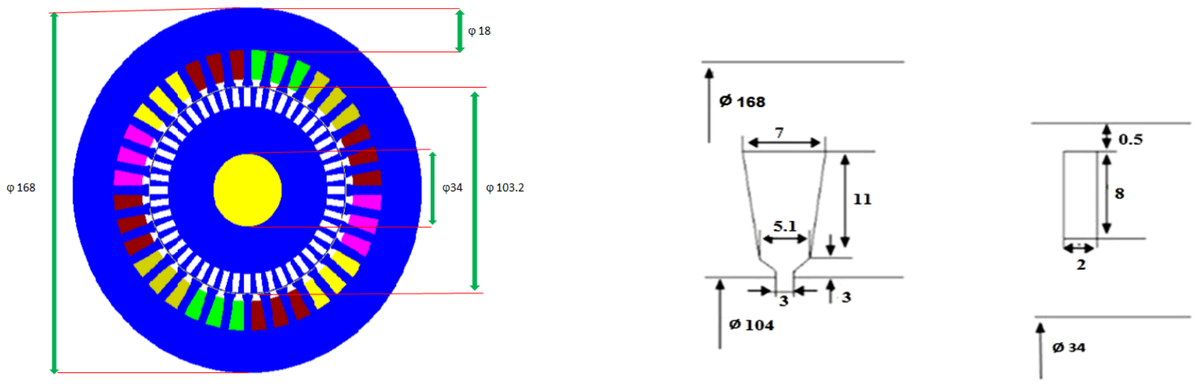

Fig. 9 Optimizing motor geometrical dimensions en (mm)

In Fig. 10, the best and average in the population, as a function of the generation number, are shown. The optimal solution is achieved at the 60 generations and the data of the best motor are reported in Table 3. It has also optimized motor the air-gap assume their minimum, but the maximum of machine weight is reached and other parameters are optimized value with respect to their prefixed rang.

According to the results in Fig. 11, the algorithm has returned an acceptable solution every time (50 generation), which is indicated by a good value for objective (82.48%) with no constraint violations. On the other hand**,** it can be said that HAGs is suitable for motor design and can reach successful designs with lower cost, [5].

The results of the best-yielded machine as reported in Table 4 and Fig. 12 to 14. The latter, depict examples of performance characteristics of standard and optimum design.

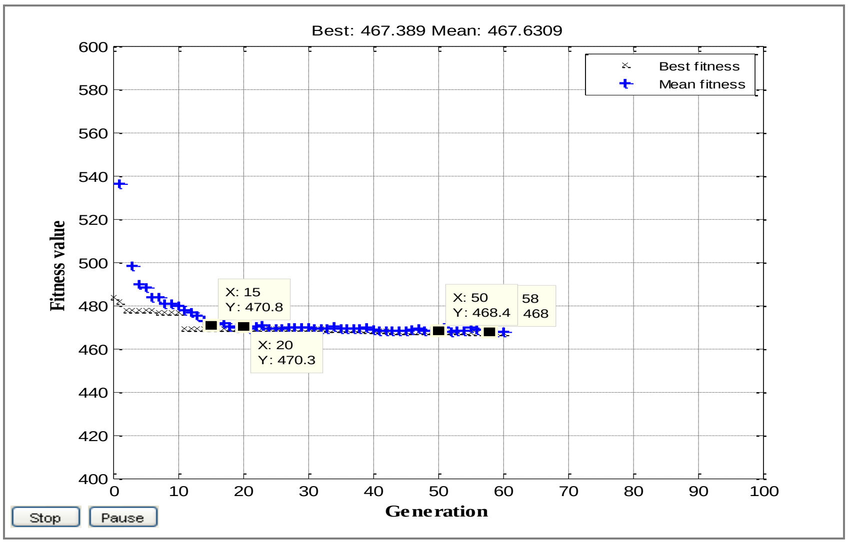

Fig. 10 Evolution of GAS average and best fitness functions

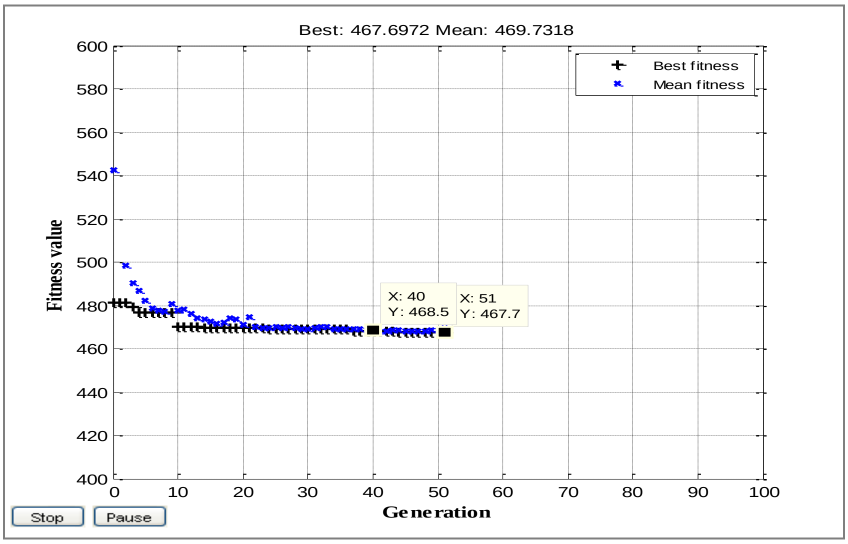

Fig. 11 Evolution of HAGs average and best fitness functions

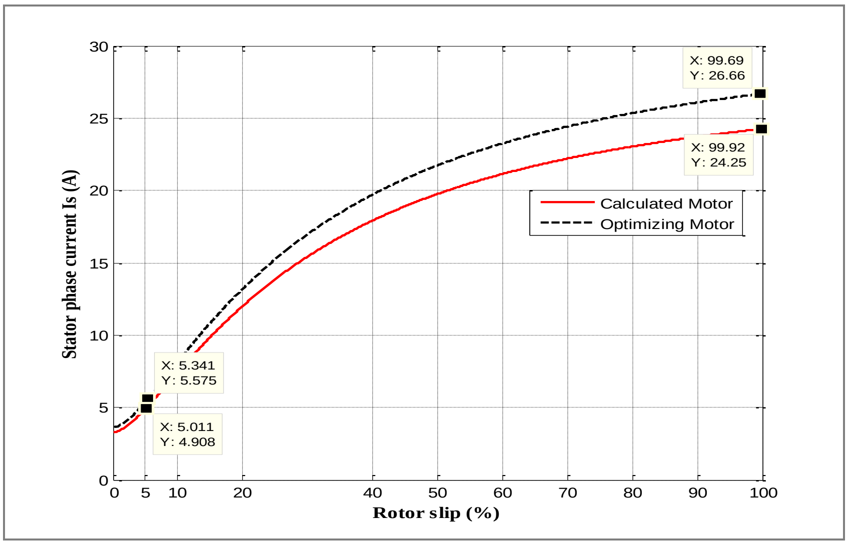

Fig. 12 Stator phase current versus rotor slip

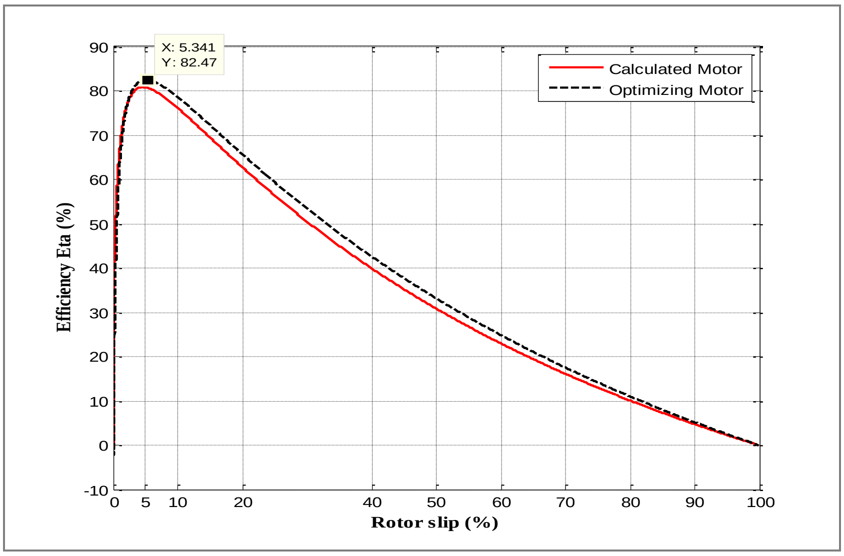

Fig. 13 Efficiency versus rotor slip

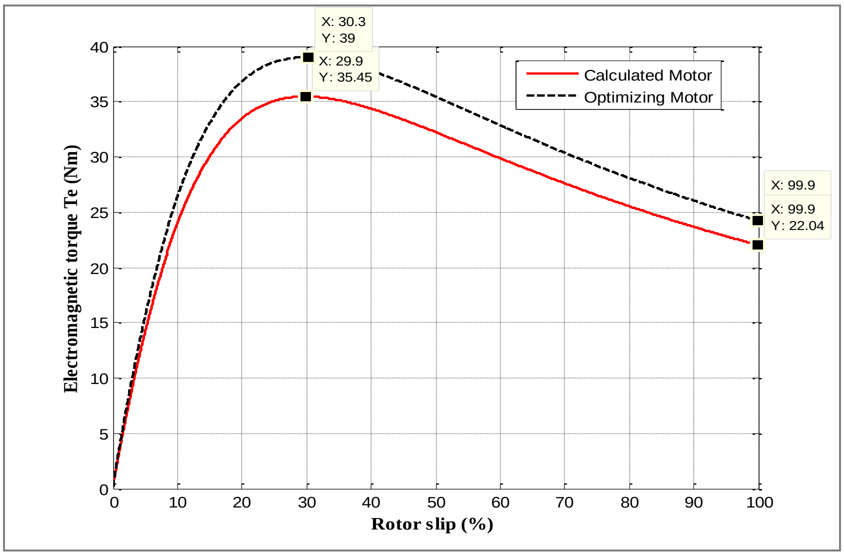

Fig. 14 Electromagnetic torque versus rotor slip

Table 4. Specified performances

Motor parameters	**Calculated motor**	**Optimizing motor**
Starting current I_{1cc} (A)	24.25	26.66
At no load I_0 (A)	3.142	3.6
Nominal current	4.91	5.57
Efficiency η (%)	81.15	82.48
Rated T_{star}/T_n	22.04/ 14.25	24.74/ 16.45
Rated T_{max}/T_n	35.45/ 14.25	39/ 16.45
Motor total weight (kG)	22.60	21.801

According to obtained results, while achieving performance improvements, the efficiency of the motor is increased by about (1.3%). This difference correspond to approximately (30 W) at full load which is important. From one point, starting torque and pullout are desirably increased ($\approx 2.7Nm$). From the other point, a small decrease in motor total weight is observed from the results. Therefore, it can be said that HAGs is suitable for motor design and can reach successful designs with lower weight, higher torque, and higher efficiency than the standard motor meanwhile satisfying almost every constraint.

4.4.2 Finite Element Analysis (F.E.A)

F.E.A is the modeling of systems in a virtual environment, for the purpose of finding and solving potential structural or performance issues. FEA is the practical application of the finite element method (FEM), which is used by engineers and scientist to mathematically model and numerically solve very complex structural problems, [12].

A finite element model comprises a system of points, called “nodes”, which form the shape of the design. Connected to these nodes are the finite elements themselves which form the finite element mesh and contain the material and structural properties of the model, defining how it will react to certain conditions. The density of the finite element mesh may vary throughout the material, depending on the anticipated change in stress levels of a particular area. FE models can be created using one-dimensional (1D beam), two-dimensional (2D shell) or three-dimensional (3D solid) elements. Another phase of design procedure, in this paper F.E.A. is used to analyze the flux distribution and to check some performances of the machine in a magneto-dynamic model under no-load operating conditions. From the program results, the geometrical model of these machines are implemented and used in the Flux-2D program. This model applies to devices which have voltage sources varies over time and $\frac{\partial \vec{B}}{\partial t} \neq 0$, and that assumes the current density is sinusoidal in steady state. Thereby RMS current value is obtaining. Finally this mode can be used in equivalent circuit machine study. The system to be solved is:

$$r\vec{ot}(v.r\vec{ot}\vec{A}) + j\omega\sigma\vec{A} = \vec{j} \tag{24}$$

Flux distribution in different parts of the magnetic circuit was investigated, and the results are illustrated in Fig. 15 for the calculated motor and in Fig. 16 for the optimizing one. Fig. 17 and 18 present the flux density for these two machines respectively, and show clearly the lower degree of saturation concerning the second, which is considerate an advantage for this motors type.

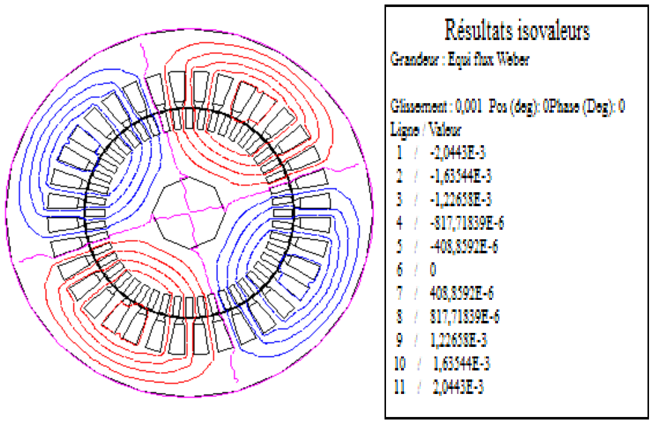

Fig. 15 Flux distribution calculated motor

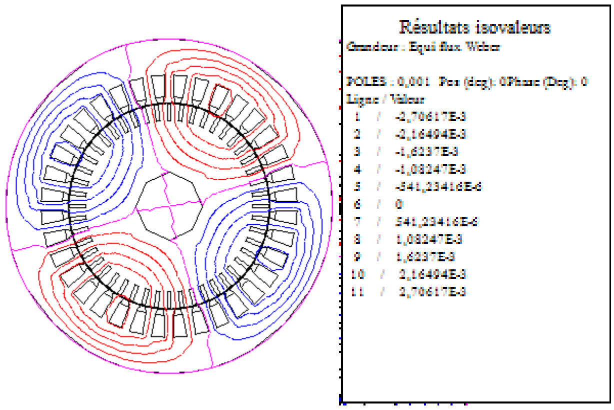

Fig. 16 Flux distribution optimized motor

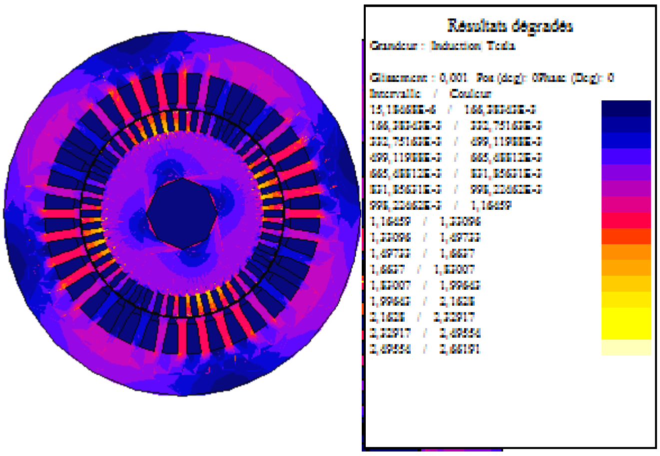

Fig. 17 Flux density distribution calculated motor

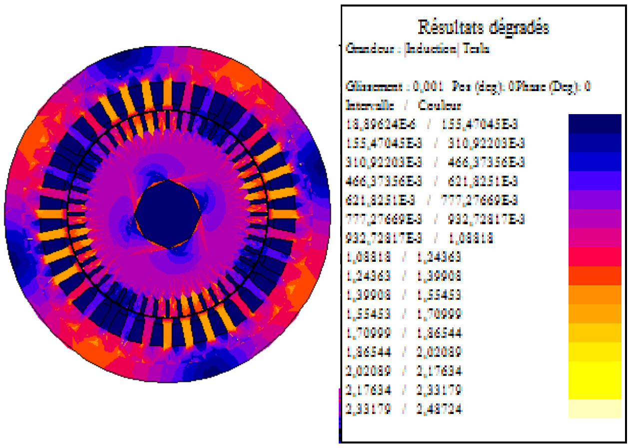

Fig. 18 Flux density distribution optimized motor

In addition finite element method can be used for the calculation of skin effect in the rotor bars of induction motors, and current density distribution in rotor and stator motor at starting in no-load conditions this is illustrated by Fig. 19 and 20.

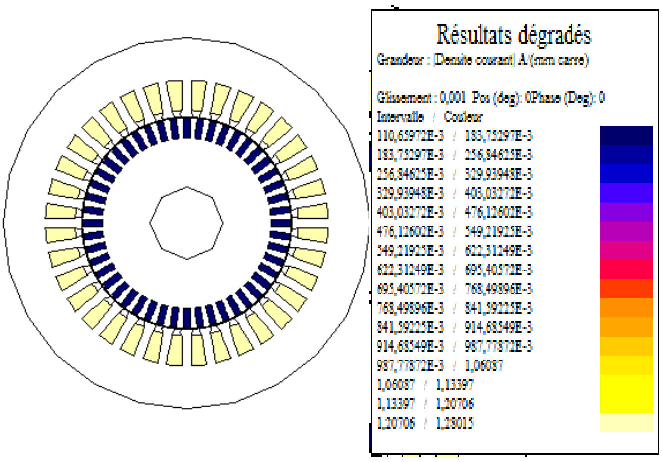

Fig. 19 Current density distribution calculated motor

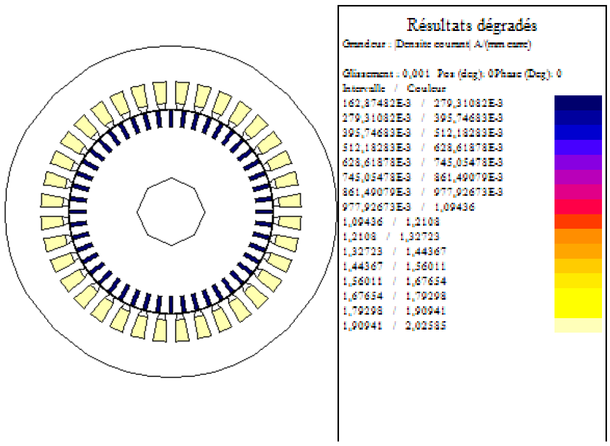

Fig. 20 Current density distribution optimized motor

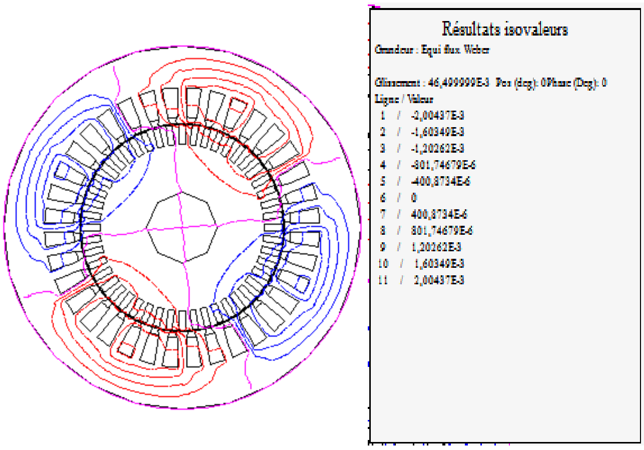

Fig. 21 Flux distribution calculated motor under full load conditions

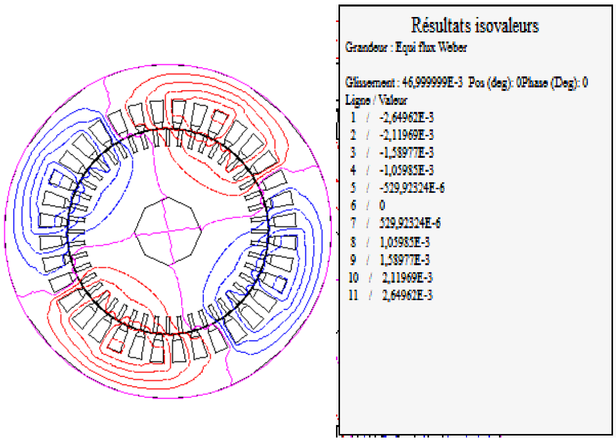

Fig. 22 Flux distribution Optimizing motor under full load conditions

Through the Fig. 21 and 22 we can note for the two machines, the presence of two pairs of poles. Flux distribution is almost symmetrical with poles axes respect. So the lines flow between the stator and the rotor are slightly deflected in the direction rotation of rotor.

The distribution of induction is also quasi-symmetrical. And that the current in the startup bar is superior to the nominal operation for the optimizing motor, this is confirmed by the following Figures.

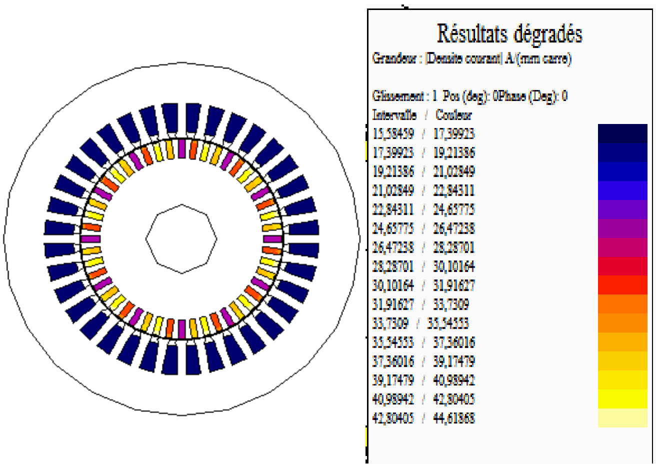

Fig. 23 Current density distribution calculated motor under starting conditions

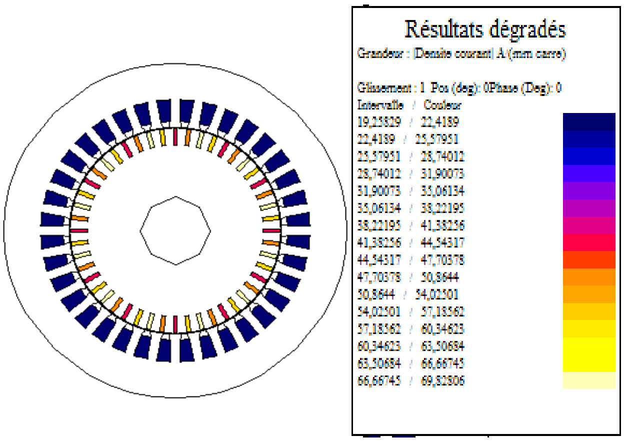

Fig. 24 Current density distribution optimizing motor under starting conditions

Finally, as the results of this finite element method analyze. Two representative torque curves for the 2.2kW motors as shown in Fig. 25. One curve is for a standard motor while the other is a high efficiency. It can be noted that the high efficiency motor maintains its high torque-slip rang as compared with the standard motor. However, there is no trend to have the high efficiency machine grouped together apart from the standard efficiency machines. Further insight into this issue can be gained concerned the starting and maximum torque values.

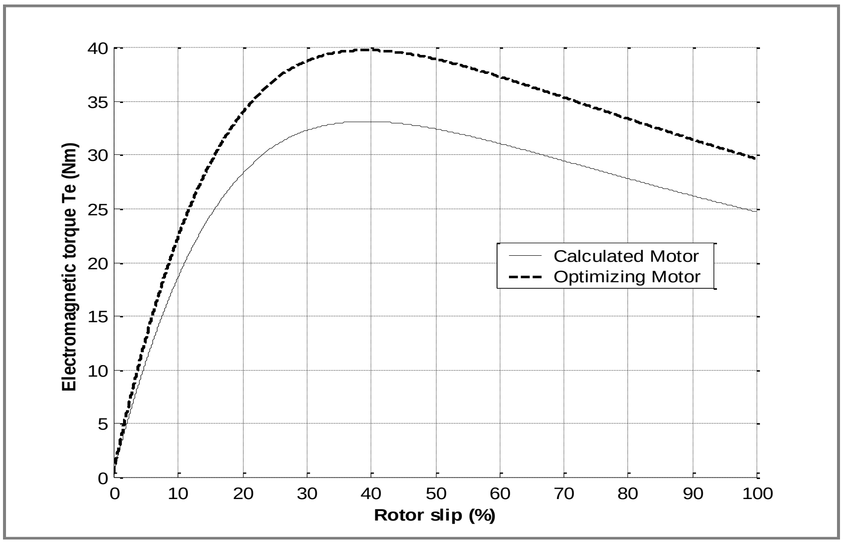

Fig. 25 Electromagnetic torque versus rotor slip

It can be seen from Fig. 26 an example of performance characteristics of calculated and the optimum design is the stator phase current as function of the slip, show a significant increase in the starting current of the optimizing motor. We also note the no load current they were actually lower, the last item is justified by air gap current which is called magnetising current. Has a direct effect on the saturation factor, its only significant impact is associated with power factor improvement.

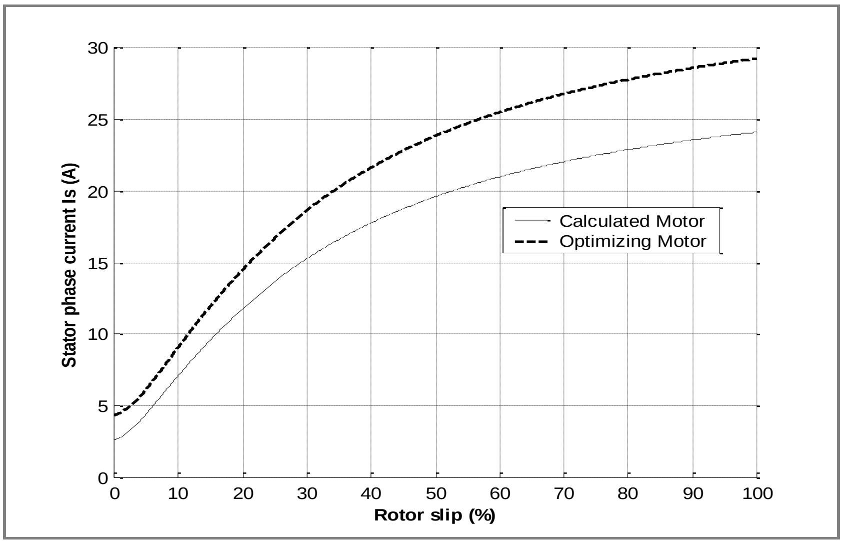

Fig. 26 Stator phase current versus rotor slip

Table 5 give also a comparison performance, they greatly affect the quality of the results.

Table. 5 Comparison of the data base and simulation results

Motor parameters	Data base	Optimizing motor	FEA
Starting current I_{1cc} (A)	25	26.66	28
At no load I_0 (A)	3	3.6	3.27
Nominal current	5.3	5.57	4.8
Efficiency η (%)	82	82.48	-----
Rated T_{star} / T_n	22/ 15	24.74/ 16.45	29/12.3
Rated T_{max} / T_n	35/ 15	39/ 16.45	39/12.3
Motor total weight (kG)	22	21.801	--------

5. Conclusion

This paper presents a Hybrid Genetic Algorithm (HAGs) and a new application of it for solving the induction motor design problem. For solving this problem, numerical results on a machine type ELPROM, type A0-112 M-2B3T-11 2.2kW system demonstrate the feasibility and effectiveness of the proposed method, and the comparison at AGs technical shows its validity.

The performance of the proposed approach is demonstrated with MATLAB. For further verification, the optimal designs are analyzed by finite element method (FE). The achieved results of this investigation have clearly demonstrated that the machine efficiency can be improved by this optimization procedure. Such achievement can be considered of a great interest since it results in a paramount of energy saving and consequently an important reduction on the energy running cost.

6. References

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