HYBRID METHOD USING GENETIC ALGORITHM FOR INDUCTION MOTOR DESIGN PROBLEM

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ABSTRACT- This paper describes the use of a new approach optimization procedure to determine the design of three phase electrical motors. The novelty 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. As the equations which calculate the iron losses make call to magnetic induction. From this point, the paper proposes to evaluate the B(H) characteristic by estimating the circuit's flux and the counting of excitation. Next, the optimal designs are analyzed by finite element method (F.E.M) and compared with results of another method which is genetics algorithms (GAs) optimisation technique, was done to demonstrate the validity of the proposed method. They reveal that the efficiency can be noticeably improved (+1.3%) by optimizing the machine parameters using (HGAs) techniques as well as by an appropriate parameters choice.

Keywords – Genetics algorithms (GAs), Gradient algorithm, Hybrid, Induction Motor, Efficiency.

1. INTRODUCTION

Recently, the induction motor comprises 95% of all motors utilized in machinery, and the operating efficiencies of these machines greatly impact the overall energy consumption in industry [1]. Current motors are produced with higher efficiency ratings than standard motors, but the decision to replace an existing motor focuses on the actual cost savings that depend on several key points such as operating efficiency, percentage of time at given loads. Owing to the importance of induction motors, this paper is aimed at contributing to energy saving efforts, more specifically in the field of low power induction motors. A contribution is kept in perspective by taking into consideration the energy saving potential during the motor design stage as well as during its operation. Every effort to save energy in motor application can be made by always attempting to use energy only as much as what needed during its operation. The best way is to exploit the saving potential during motor design, while at the same time taking into account its intended application. It can be achieved either through the improvement of motor design or through the reduction of its input electrical energy when the motor has already been built [1], [2].

Since, optimization technique are more and more combined with the electrical motor design, stimulated by the pressing demands of the motor market and applications. The task is to get a design optimizing an objective function as minimum material cost, minimum weight or an optimum performance feature of the motor as maximum efficiency [3]. Therefore, it is apt that achievement of a local optimized solution will result in loss of the global one when parameters are optimized with a deterministic algorithm. With the development of the modem mathematics, many scholars introduced the random approach into optimization algorithm and advanced some new and powerful algorithmic models for non linear problems. The (GAs) method, since firstly proposed by Holland, has been applied to many scientific areas, for instance, in engineering optimization and improvement problems, for energy calculations in atomic and molecular physics and in nonlinear fitting problems [4], [5].

Nowadays, 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. Although 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. 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 [6], [7], [8] and [9].

In this paper a comparison between the loss reduction problems by the stochastic technique which is called the genetic algorithm (GAs) also hybrid genetic algorithm (HGAs) The achieved results are discussed and analyzed [10].

2. INDUCTION MOTORS EFFICIENCY EVALUATION

The efficiency can be expressed in terms of output power ($P_{Mechanical}$) and the sum of losses ($\sum Losses$), input power ($P_{Electrical}$):

$$\eta = \frac{P_{Mechanical}}{P_{Electrical}} = \frac{P_{Mechanical}}{P_{Mechanical} + \sum Losses} \quad (1)$$

In order to determine the efficiency, several international standards exist. Basically, the difference between these standards exists in the way additional load or stray-load losses are dealt with. Either a fixed allowance is used, or they are calculated based on a mechanical output power measurement.

The Japanese JEC 37 standard simply neglects the additional load losses. In the IEEE 112-B standard, they are deduced by measuring the input and output power; the losses not covered by the 4 other loss terms - the stator and rotor copper losses, the iron losses and the friction and windage losses - are then supposed to be the additional load losses. In the IEC 60034-2 standard, these losses are estimated at 0.5% of the input power. The different way of dealing with the additional load losses is the reason why efficiency values obtained from different testing standards can differ by several percent [1].

2.1 Motor Losses

There are four different kinds of losses occurring in induction motors which are the following: electrical losses, magnetic losses, mechanical losses and stray-load losses. Those losses can be counted:

2.1.a Iron losses

The calculation of iron losses makes itself by numerous methods as: a simplified method; magnetization rate analysis method or by analytical method, [1], [11].

2.1.b Stray-load losses

These losses are very difficult to model and to quantify. Although, the stray-load losses were the theme of several studies and analysis, the phenomena that govern these losses are still under discussion, particularly from the measurement point of view. The standard IEEE 112-B defines these losses as the difference between the total measured losses and the conventional losses, [12].

2.1.c Copper losses

The third component of losses is Ohmic heading. The last is determined by a number of stator and rotor joule losses. The first are evaluated using the winding resistance measured in direct current and reported at the reference temperature. It depends on the machine insulation class. For this reason, it is independent by the real temperature reached during the load tests. As an example, for insulation class F an over temperature of 115°C has to be considered. The rotor joule losses are evaluated as the product of the rotor slip and the air gap transmitted power [1], [2].

2.2 Energy Efficient Motor

The vast majority motor manufacturers had provided a special category of product with increased efficiency and evidently higher price. However, questions raised about the application of energy efficient motors. Users of major industrial companies are frequently faced to the decision of buying more expensive motors; But with a feeling of uncertainty about the presumed economical advantages. It must be emphasised that a number of factors which may affect the motor efficiency include: power' supply quality, careful attention to harmonics, mechanical transmission and maintenance practices [1], [4].

Since, induction motors are the most commonly employed electrical machines in industry throughout the world today. Consequently, investment in the quality of motor that enables a reduction of its losses. Although a small percent is frequently neglected is usually a financial sound practice.

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

3. OPTIMIZATION TECHNIQUES

Presently, research efforts have been made in order to invent new 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 Genetics Algorithms (GAs)

Genetic algorithms are search methods that employ processes found in natural biological evolution. These algorithms search or operate on a given population of potential solutions to find those that approach some specification or criteria. To do this, the algorithm applies the principle of survival of the fittest to find better and better approximations. At each generation, a new set of approximations is created by the process of selecting individual potential solutions (individuals) according to their level of fitness in the problem domain and breeding them together using operators borrowed from natural genetics. This process leads to the evolution of populations of individuals that are better suited to their environment than the individuals that they were created from, just as in natural adaptation [6], [7].

The (GAs) will generally include the three fundamental genetic operations of selection, crossover and mutation. These operations are used to modify the chosen solutions and select the most appropriate offspring to pass on to succeeding generations. (GAs) consider many points in the search space simultaneously and have been found to provide a rapid convergence to a near optimum solution in many types of problems; in other words, they usually exhibit a reduced chance of converging to local minima. (GAs) suffers from the problem of excessive complexity if used on problems that are too large [6], [8].

3.2 Hybrid Genetics 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 [8].

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 [9].

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 gradient 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. News hybrid approaches where the use of genetic operators improves the performance of existing heuristic methods are: Sequential Hybrid (S-H), Advanced Algorithms Genetics (A-GAs) [10].

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 Figure 1, Including:

A. Sizing phase; B. Optimization phase.

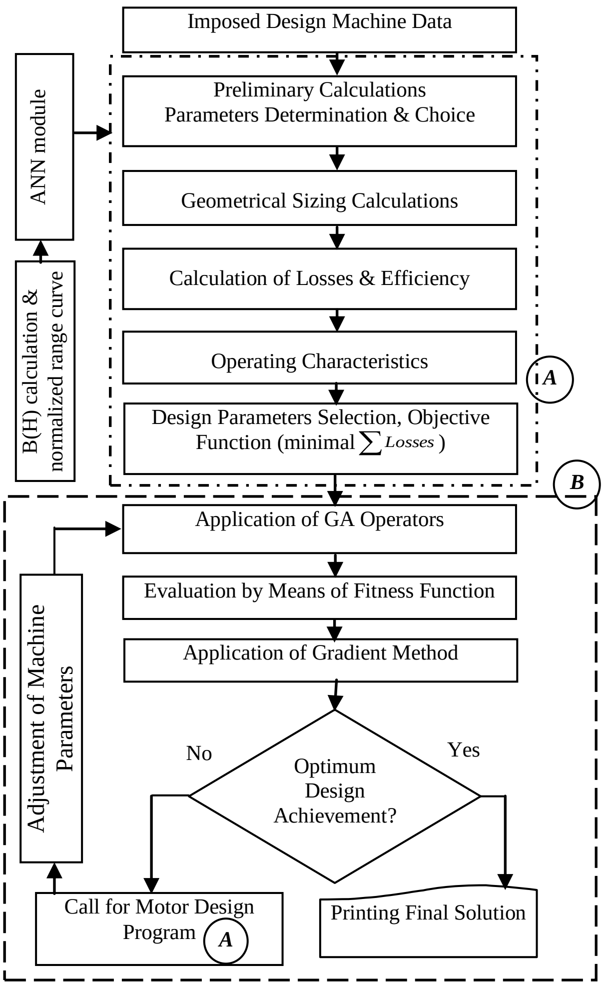

Figure 1. Proposed optimizing efficiency method flowchart

4.1 Analytical Design Procedure

The design procedure of electrical machine (DP-M) 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 Artificial Neural Network (ANN) interpolation of the normalized range curves. The type of ANN that we simulated is a multilayered network. Therefore, we use back propagation algorithm for its training. The in proposed method of optimization process which we intend to do is saturation test phase so that we can study the performances of the ANN and accomplish the task of the optimization. The entries are the B(H), saturation and form factors which mean that the number of entries of this network is equal to 4. Finding optimized dimensions which characterized by 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 [13], [14].

Second, from the results of stage1 the machine performances as evaluated in order to check or not the machine analytical model.

Third, the Name-Plate Method (NP-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.

4.1.1 B(H) Curve

Since, the major problem in iron losses calculation is the B(H) curve used. The latter proposes to use experimentally approach and the geometric sizes of the studied machine are carried on the Figure 2.

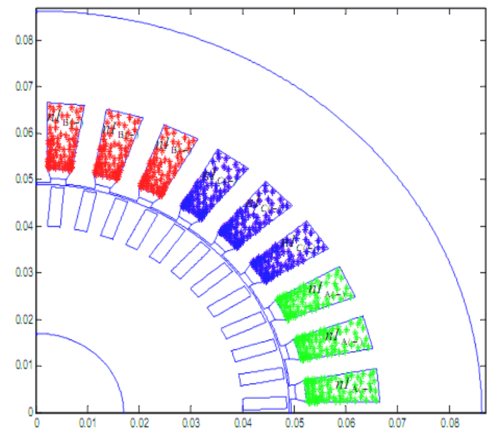

Figure 2. Induction motor cross section

One will be able to write therefore that the following relation is verified along a line [15].

$$\oint \vec{H}d\vec{L} = N_1\, I_1 = H\, L \tag{2}$$

At no-load test we can deduct:

$$H = \frac{N_1 \cdot I_0}{L} \tag{3}$$

The electromotive is given by:

$$E = V_0\, \frac{1}{1+\sigma_{H1}} \tag{4}$$

The back iron flux:

$$\phi_{Cul1} = \frac{\phi_{Tot}}{2} \Rightarrow \phi_{Tot} = 2\,\phi_{Cul1} \qquad (5)$$

Other side:

$$E = 4\,K_f\;f\;N_1\,K_{W1}\;\phi_{Tot} \qquad (6)$$

The stator back iron flux density is:

$$B_{Cul} = \frac{E}{2.4\,f\;N_1\,K_{W1}\,K_f\;l_{fe}\,E_{PCul1}} \qquad (7)$$

Where

I_0 No-load courant, L Field lines middle,
V_0 No-load voltage, σ_{H1} Heyland stator coefficient,
K_{W1} Winding coefficient, l_{fe} Magnetic length circuit,
K_f Form factors, E_{PCul1} Stator back iron thickness.

The expression of the flux density takes the following shape:

$$B_{Zd} = \frac{\frac{1}{1+\sigma_{H1}} \cdot V_0}{4 \cdot f \cdot N_1 \cdot K_{W1} \cdot K_f \cdot S_{z1}} \qquad (8)$$

And

$$S_{z1} = \tau_{z1}\;l_{fe}\,\frac{Z_1}{2p} \qquad (9)$$

S_{z1} Stator teeth section,
τ_{z1} Stator teeth step, $\frac{Z_1}{2p}$ Pole teeth number.

The B(H) figure obtained from the laboratory as shown in Figure 3 compared with standard curve, [14].

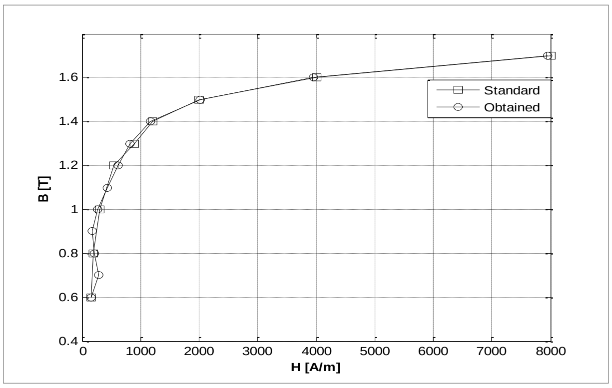

Figure 3. Experimental B(H) curve

The use an experimental B(H) curve and equivalent circuit method (EC-M). Among the obtained results are the machine equivalent circuit parameters as depicted in Figure 4.

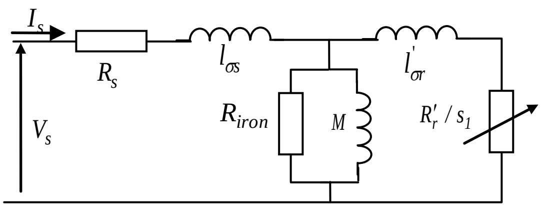

Figure 4. Induction motor equivalent circuit on the stator side

Where

I_s Phase stator current,
V_s Stator phase voltage, s_1 Slip.

Its parameters: stator resistance (R_s), stator leakage reactance ($l_{\sigma s}$), magnetizing reactance (M), core-losses resistance (R_{iron},) rotor leakage reactance ($l'_{\sigma r}$), and rotor resistance referred to the stator side (R'_r). It allows the representation and assessment of the machine efficiency at any load [5], [14] and [15].

4.1.2 Machine Name-Plate Method (NP-M)

This method allows to estimating of motor parameters by using the motor plate information. The main equations are summarized as follows [16], [17]:

$$\sigma = \frac{1-\cos\varphi}{1+\cos\varphi} \qquad (10)$$

$$T_r = \frac{1}{\omega_r}\sqrt{\frac{1}{\sqrt{\sigma}}} \qquad (11)$$

$$l_{\sigma s} = \frac{V_s\sqrt{\sigma}}{I_s\omega_s} \qquad (12)$$

$$M = L'_r = l_{\sigma s}\,\frac{1-\sigma}{\sigma} \qquad (13)$$

$$L_s = M + l_{\sigma s} \qquad (14)$$

$$R'_r = \frac{L'_r}{T_r} \qquad (15)$$

Where

R_s Satator resistance can be measured on line,
σ Leakage coefficient, T_r Rotor time constant,
L_s, L'_r Total stator and rotor inductances,
ω_r Rotor current frequency, $\cos\varphi$ Power factor.

The above identification methods applied on a 2.2 kW radial flux induction machine using a laboratory test-rig. Then the measured geometrical dimensions are included on the developed motor design program. The investigation results of the analysed machine parameter identification methods are reported in Table 1.

Parameters	(DP-M)	(NP-M)
R'_r (Ω)	2.67717	2.1647
$l'_{\sigma r}$ (H)	0.01286	0.0284
$l_{\sigma s}$ (H)	0.01208	0.0232
R_s (Ω)	3.158	3.5
M (H)	0.20952	0.1704

Table 1. Induction motor parameter comparison of identification methods

4.1.3 Results Analysis

The studied identification methods are applied to the tested induction motor. The obtained results from a developed program, under MATLAB environment are summarized in Table 1. It can be stated that the determined machine parameters from two methods are relatively close to each other, accepted the values of R_s and R'_r. This mainly is justified by the temperature effect consideration.

The presented study is concretized by establishing three motor characteristics $I_s = f(s_1), C_e = f(s_1)$ and efficiency $\eta = f(s_1)$ is drawn as depicted in Figures 5, 6 and 7 respectively. These figures are zoomed by data cursor so as to highlight the performance in the normal operating load rang.

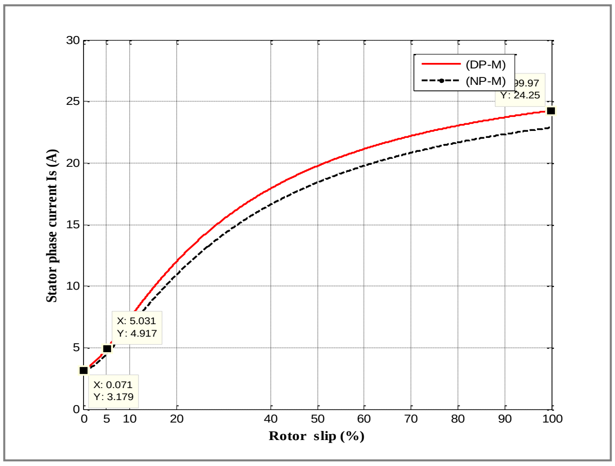

Figure 5. Stator phase current versus rotor slip

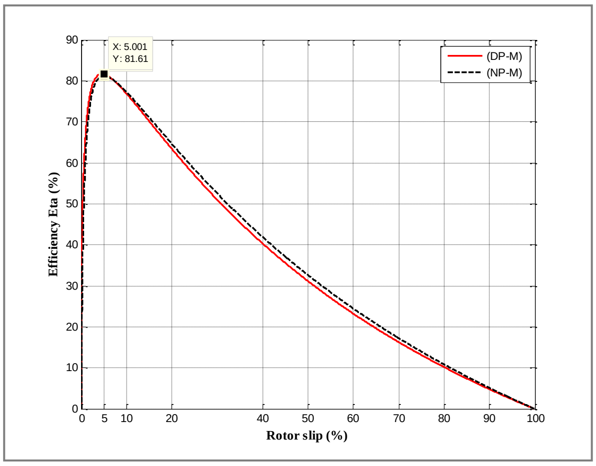

Figure 6. Efficiency versus rotor slip

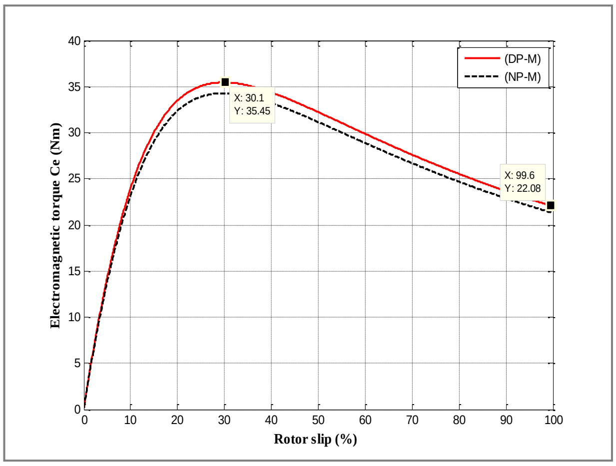

Figure 7. Electromagnetic torque versus rotor slip

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 (DP-M) and (NP-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.

It can be concluded that the analytical model is in good correlation and it can be accepted for optimization phase.

4.2 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.

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	$12 \le h_{t1} \le 18$
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	$21 \le M \le 23$
Stator slot / Rotor bar number	36/48	
Stator turns per phase N_1	220	
Stator no-load current I_0 (A)	3.142	
Starting current I_{1cc} (A)	24.25	
Nominal torque T_n (Nm)	14.25	
Starting torque T_{sta} (Nm)	22.04	
Maximal torque T_{max} (Nm)	35.45	
Efficiency data base (%)	82	
Efficiency calculated (%)	81.15	

Table 2. Design variables and their limit values for an experimental B(H) curve

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.

Parameters	Solutions with HAGs	Solutions with GAs
Inner stator diameter (mm)	103.3	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

Table 3. Design parameter values obtained after optimization

In Figure 8, 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.

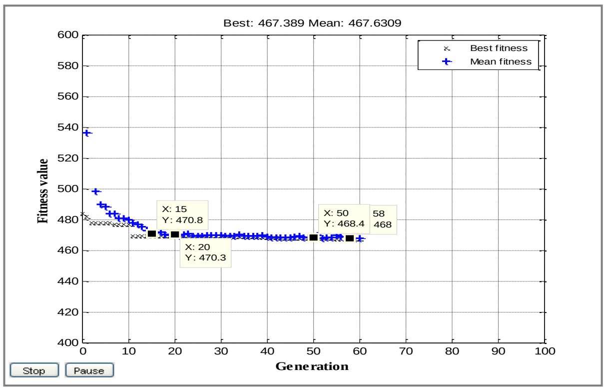

Figure 8. Evolution of (GAs) average and best fitness Functions

According to the results in Figure 9, 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 [18].

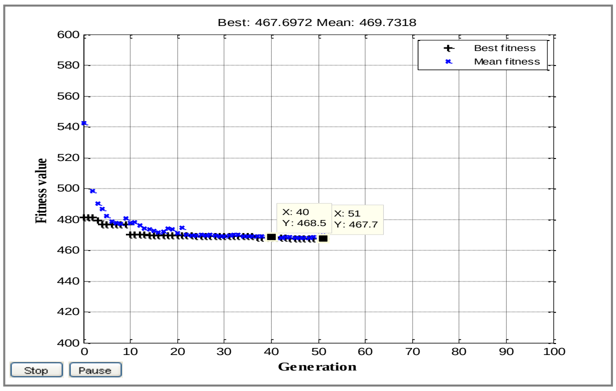

Figure 9. Evolution of (HAGs) average and best fitness functions

The best-yielded results machine which reported in Table 4 and Figures 10 to 12. The latter, depict examples of performance characteristics of standard and optimum design.

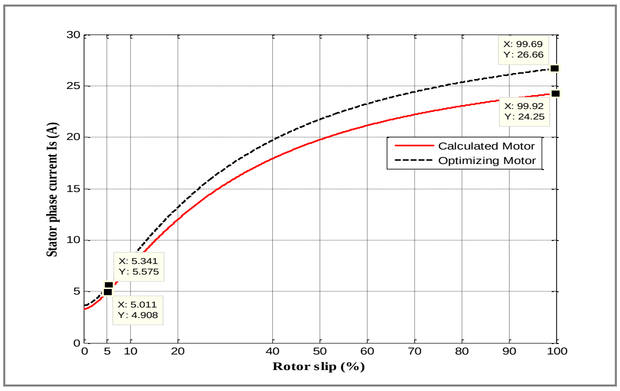

Figure 10. Stator phase current versus rotor slip

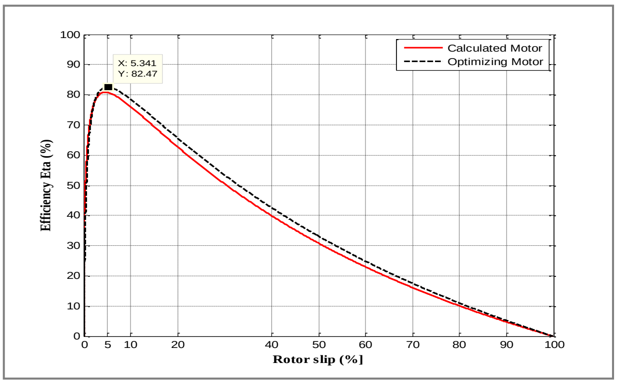

Figure 11. Efficiency versus rotor slip

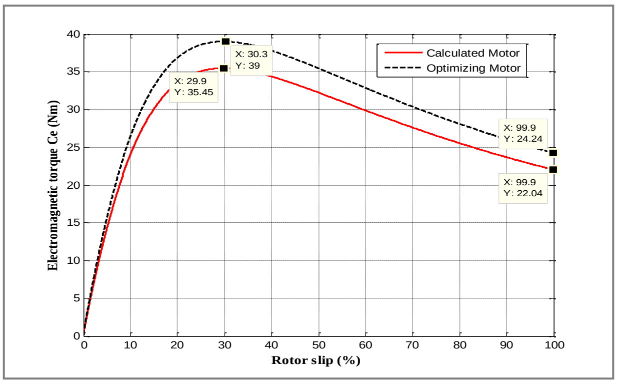

Figure 12. Electromagnetic torque versus rotor slip

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

Table 4. Comparison of calculated and optimizing results

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.

4.2.1 Dynamical Performances Analysis

The dynamic performance of an AC machine is somehow complex due to the coupling effect between the stator and rotor parameters which vary with rotor position. This can be simplified by using the d-q axis theory; as a result the time-varying parameters are eliminated. The dynamical model of induction machine used is represented by a fourth order state space model for the electric part and by a second order system for the mechanical part of the machine. Meanwhile the electrical variables and parameters are given in Table 1.

The simulation analysis of these three-induction motor was performed using SIMULINK blocks and power system blocks within SIMULINK toolbox under MATLAB environment. Within the block diagrams the induction motor is represented by the according block which models electric and mechanical dynamics and the three phase sources.

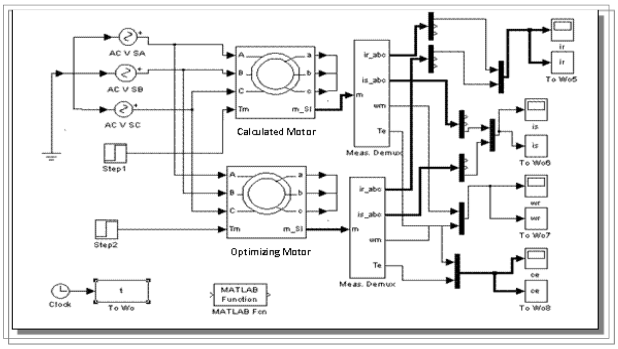

Figure 13. Block diagram of dynamical performances analysis

In the first test, the machines will be fed during three phase source Figure 13 to simulate the starting phase of the two motor (calculated and optimizing) under full load conditions, and then, by varying the load in order to analyze the electromagnetic torque versus time in this hard condition. It can be seen from Figure 14 ($T_r = 23.5\ Nm,\ 26\ Nm$) for the calculated and optimizing motors respectively. However, this last one presents slightly better starting capabilities.

In the second test, these machines will be fed from three phase source in an open-loop speed control system to simulate the starting under the same conditions of test 1. Then after 0.35s the load torque is stepped to the maximum values in order to check the pull-out torque. It can see from Figure 15 that the optimizing motor presents slightly better overloading capabilities.

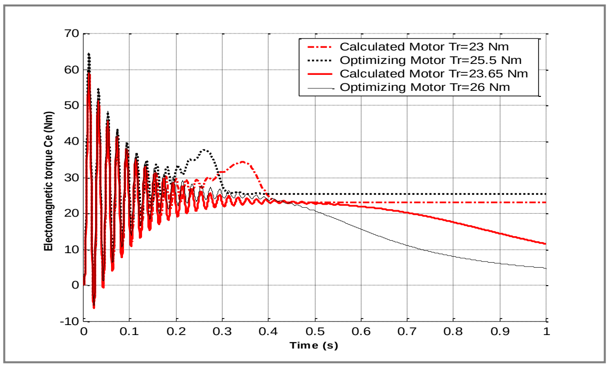

Figure 14. Electromagnetic torque versus time

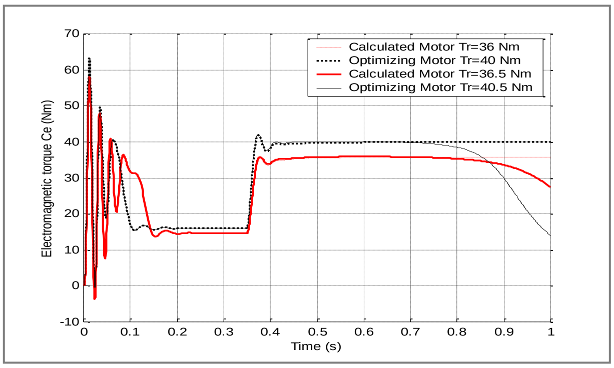

Figure 15. Electromagnetic torque versus time

4.2.2 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. (F.E.A) is the practical application of the finite element method (F.E.M), which is used by engineers and scientist to mathematically model and numerically solve very complex structural problems [9].

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. (F.E) 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 as carried in Figures 16 and 17. This model applies to devices which have voltage sources varies over time and $\frac{\partial B}{\partial t} \neq 0$ 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:

$$rot(v.rot\vec{A}) + j\omega\sigma\vec{A} = \vec{j} \qquad (16)$$

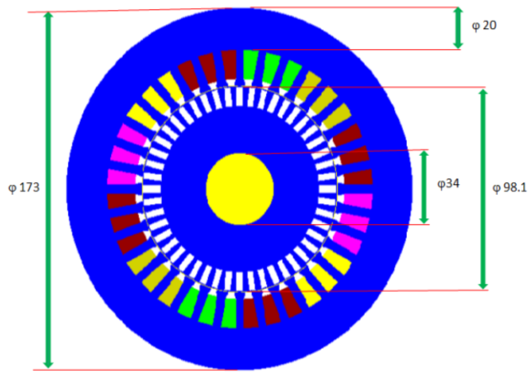

Figure 16. Calculated motor geometrical

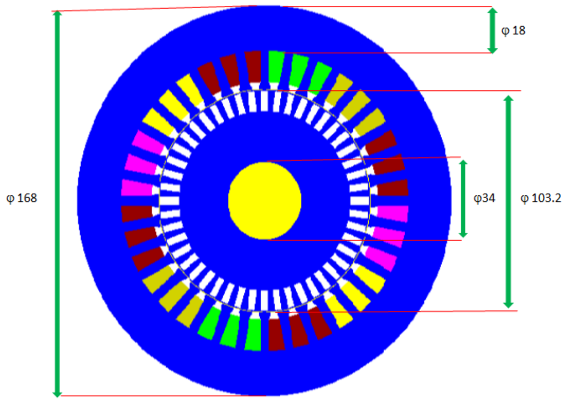

Figure 17. Optimizing motor geometrical

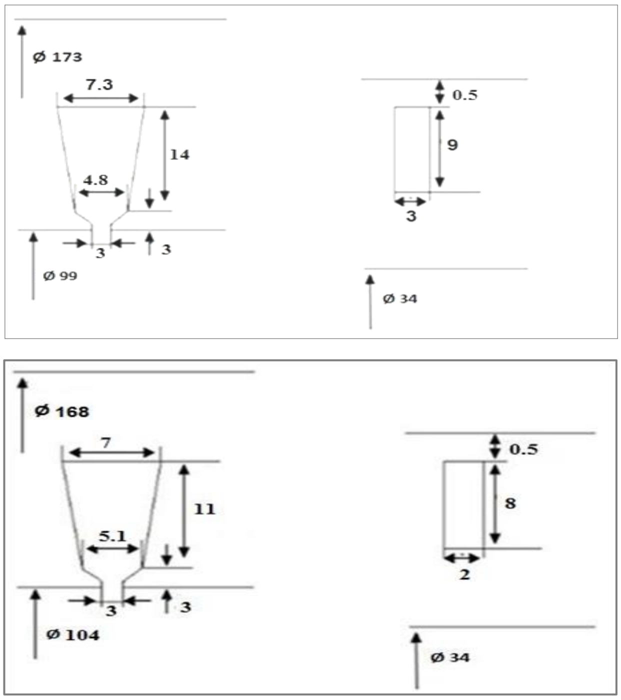

Figure 18. Stator and rotor slot dimensions

Used Flux-2D program, flux distribution in different parts of the magnetic circuit was investigated and the results are illustrated in Figure 19 for the calculated motor and in Figure 20 for the optimizing one. On the other side Figures 21 and 22 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.

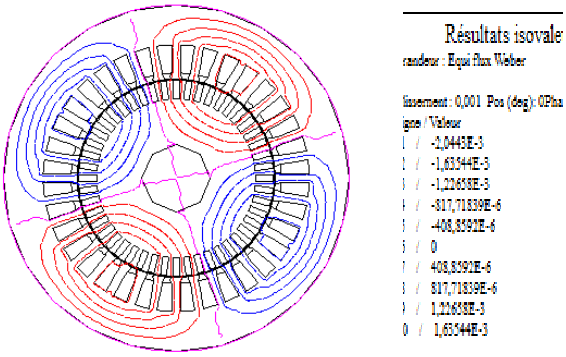

Figure 19. Flux distribution calculated motor

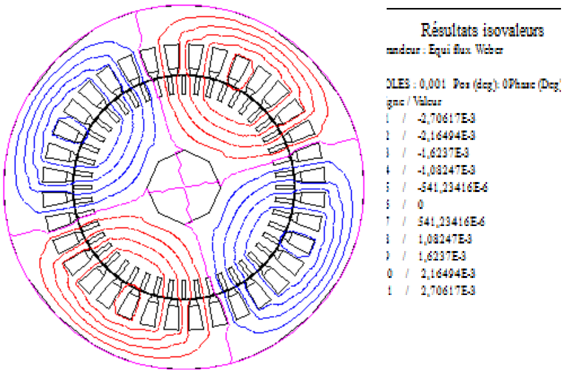

Figure 20. Flux distribution optimized motor

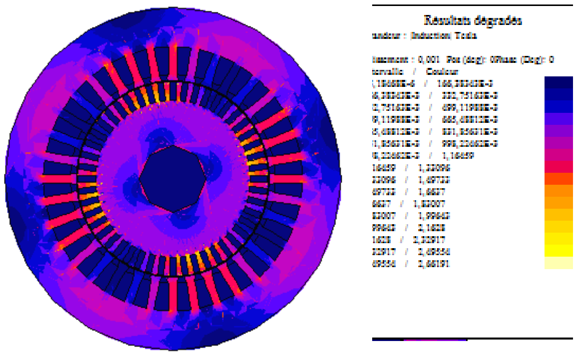

Figure 21. Flux density distribution calculated motor

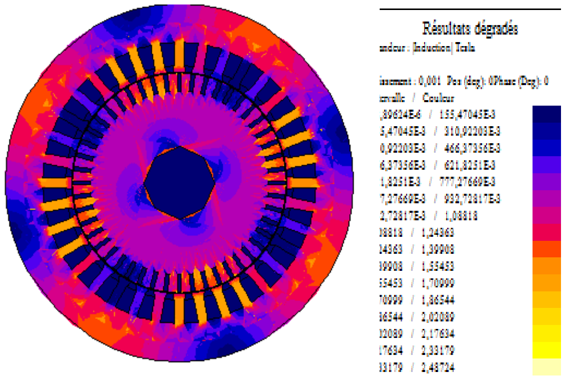

Figure 22. Flux density distribution optimized motor

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 is large compared to the stator motor at starting in no-load conditions; this is illustrated by Figures 23 and 24.

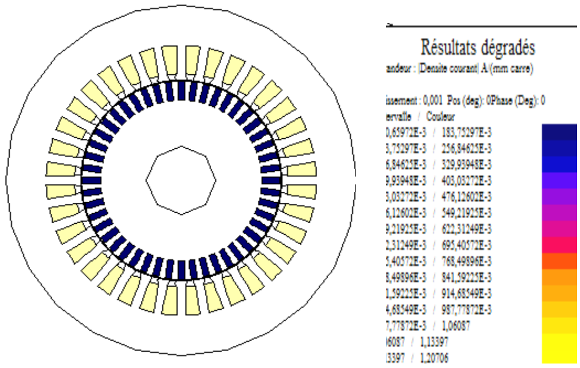

Figure 23. Current density distribution calculated motor

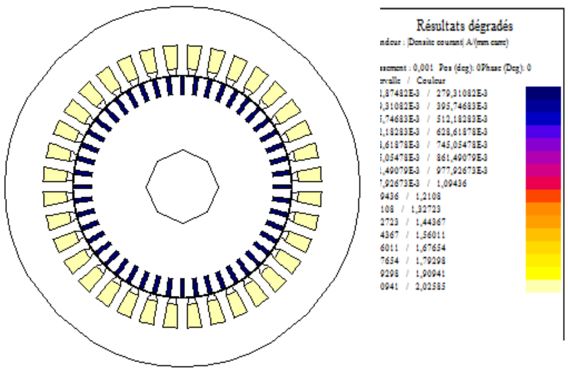

Figure 24. Current density distribution optimized motor

Through the Figures 25 and 26, the simulation results under full load conditions, we can note for the two machines, the presence of two pairs of poles. It is clear the flux is high for optimized motor and 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.

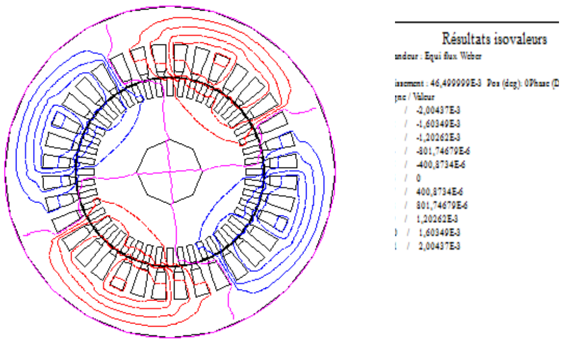

Figure 25. Flux distribution calculated motor under full load conditions

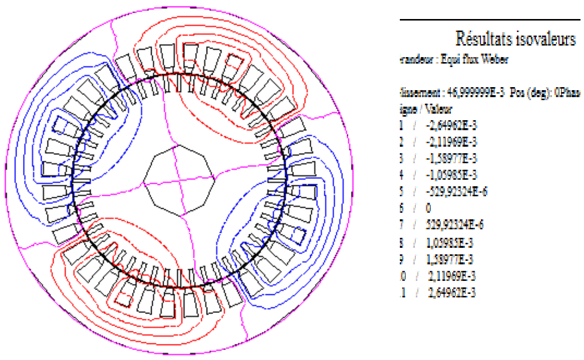

Figure 26. Flux distribution optimizing motor under full load conditions

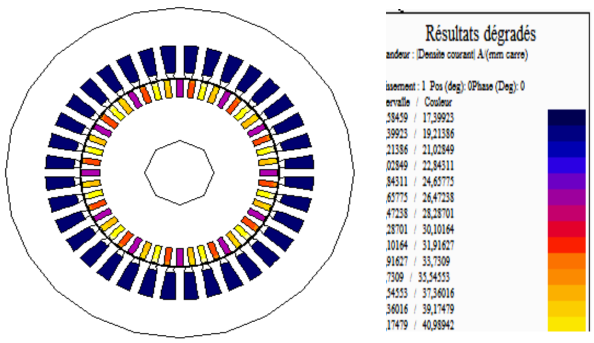

Figure 27. Current density distribution calculated motor under starting conditions

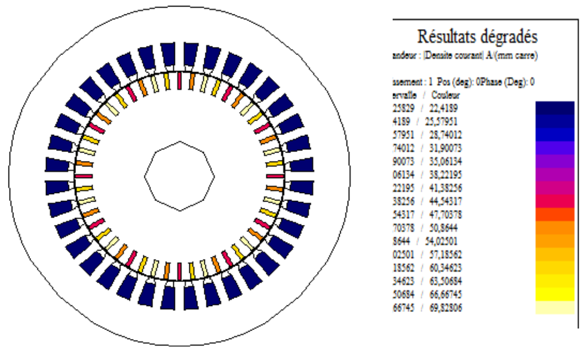

Figure 28. Current density distribution optimizing motor under starting conditions

We also note the distribution of induction is quasi-symmetrical, and that the current in the startup bar is superior to the nominal operation for the optimizing motor. This is another advantage for high efficiency machines as shows in the Figures 27 and 28.

Finally, as the results of this finite element method analyze. Two representative torque curves for the 2.2kW motors as shown in Figures 29 and 30. 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.

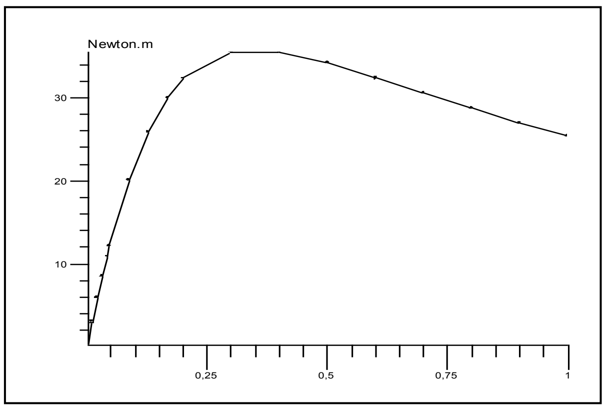

Figure 29. Electromagnetic torque versus rotor slip calculated motor

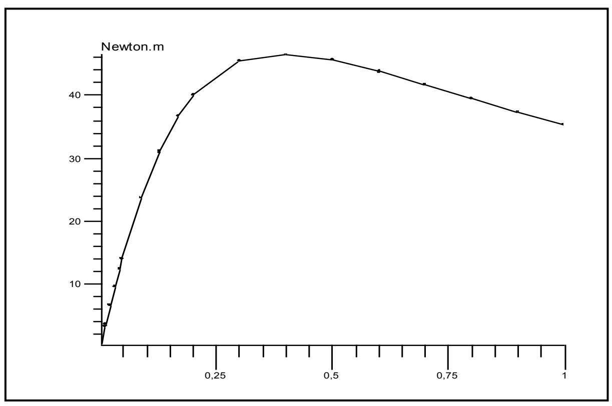

Figure 30. Electromagnetic torque versus rotor slip optimizing motor

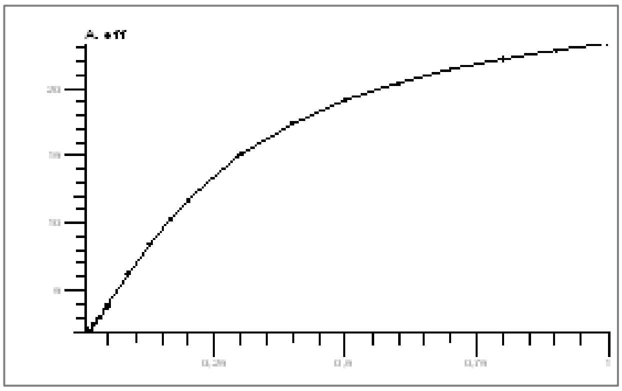

Figure 31. Stator phase current versus rotor slip calculated motor

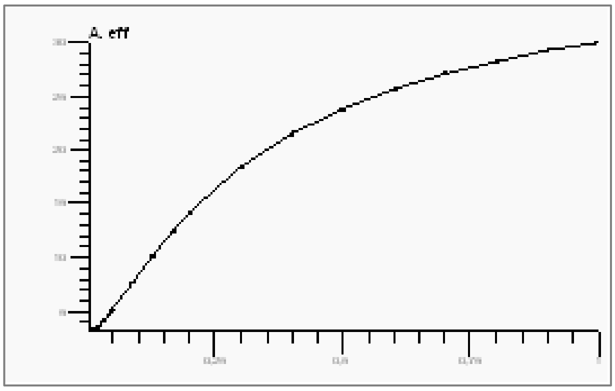

Figure 32. Stator phase current versus rotor slip optimizing motor

It can be seen from Figures 31 and 32 an example of performances characteristic of calculated and the optimum design is the stator phase current as function of the slip, a significant increase in the starting current of the optimizing motor is show. 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. Indeed Table 5 give also a comparison performance, they greatly affect the quality of the results.

Table .5 Comparisons of the data base and simulation results

Motor parameters	Data base	Optimizing motor	F.E.A
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	25.40/12.3
Rated T_{max} / T_n	35/ 15	39/16.45	35.54/12.3
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 simulations. For further verification, the optimal designs are analyzed by finite element method (F.E.M). 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.

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