Using Genetic Algorithm Minimizing Length of Air-Gap and Losses along with Maximizing Efficiency for Optimization of Three Phase Induction Motor

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ABSTRACT:
Optimization of three-phase induction motor using Genetic Algorithm (GA) is displayed in the paper. Objective functions such as Air-Gap Length (Lg), SCL, RCL, SIL and efficiency are considered here along with their individual plotting after optimization have been presented. The intense non-linearity of the motor stated here have been observed in mathematical form and hence forth solved using MATLAB. To optimize performance of the Induction Motor the Genetic Algorithm method has been very useful for this purpose. MATLAB is very powerful software which has been used here effectively.

Keywords: *Air-Gap Length, Efficiency, GA, Induction Motor, RCL, SCL, SIL.*

I. INTRODUCTION

Induction motors have a wide range of applications in domestic and industrial purposes. Squirrel Cage Induction motor is the most widely used in industrial sector due to its low cost, simplicity and robustness. Most of the electrical energy is consumed by this motor, so a major concern becomes the minimization of the electrical energy used.

As per our literature survey several methods on multi-objective approaches for optimization have been uncounted. In this paper a 3-phase, 4 pole, 2238W Induction Motor has been optimized by GA and the results have been compared with the standard design results

The organization of the paper is as follows. In section II, the problem has been defined along with its design approach. The objective functions have been described in section III. In section IV a brief description of genetic algorithm has been given with its flow chart in section V. the section VI concludes with the results and discussion.

The performance of the machine is affected due to its non-linearity of the variables. The standard Non-linear programming (NLP) process becomes very inefficient and also expensive. One of the most evolved NLP technique is the Genetic Algorithm(GA) which has become important for design optimization of electrical machines. GA helps in finding the Global minimum in place of the local minimum, which may have different starting points and may not be near to the actual values. The aim of this paper is to ensure the optimum design of a three-phase Induction Motor considering the Air-Gap Length (Lg), and the stator winding temperature. The reduction in air-gap length and losses improves the efficiency of the machine as well as its power factor. The machine taken into consideration here is a 3-phase, 4pole, 2238 watt Squirrel Cage Induction Motor.[1]
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II. PROBLEM DEFINITION AND DESIGN APPROACHES.

Figure 1.presents the basic equivalent circuit model of the motor. This model is well known and easily understood by the engineers and has both less computational effort and good prediction accuracy. This figure shows the per phase representation of the balanced poly-phase induction machine in the frequency domain, having six elements or parameters. The parameters are as follows, Stator Resistance (R_1), Stator leakage reactance $(X\sigma_1)$,core-loss resistance (R_m), rotor leakage reactance $(X\sigma_2)$, magnetizing reactance $(X\sigma_m)$ and rotor resistance (R_2). The approach and methods used to calculate the motor performance are based on the works of [2].

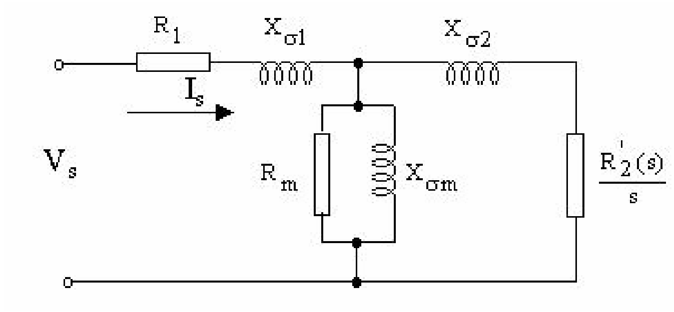

Figure 1: Equivalent circuit model of induction motor

For applying the NLP technique (GA), firstly an objective function has to be defined to evaluate how good each motor design is. A large subset of design variables are needed to be formulated to ensure physical feasibility of the motor, are included in the objective function.

III. THE OBJECTIVE FUNCTIONS FOR OPTIMIZATION USING GA.

A lot of attention is required for the design optimization of electric motors regarding the choice of objective functions that usually deals with the performance and economic features.

The four objective functions considered here for the design optimization process of the three phase Induction Motor are as follows:[9,11,12]

a). Length of Air-Gap (to minimize),
b). Stator Copper Loss (to minimize).
c) Rotor Copper Loss(to minimize)
d)Stator Iron Loss(to minimize)
e)Efficiency(to maximize)
Consideration for the multi-objective approach and its formulations are as follows:

a) ***First Objective Function***: to minimize Air-Gap length.

$$Lg = 2\sqrt{\frac{D_1 L_1}{10^6}}$$

Where,D1= Bore Diameter in mm and L1= Stack Length in m.

b) ***Second Objective Function***: to minimize Stator Copper Loss.

$$SCL = 3 \times I_1^2 \times R_1$$

Where, I1= Phase current in ampere,
and R1= Stator resistance in ohms.

c) ***Third Objective Function***: to minimize Rotor Copper Loss.

$$RCL = \frac{\rho_2 \times S_r \times I_2^2}{A_b}\left(L_c + \frac{2D_{me}}{P}\right)$$

Where, ρ_2 =0.021(constant),
Sr = Number of Rotor Slots
I2=Rotor bar current in ampere(A),
Ab= Area of the bar,
Lc= Core Length in meter(m),
Dme= Mean end ring diameter in mm,

P= Number of Poles.

d) ***Fourth Objective Function***: to minimize Stator Iron Loss.

$$SIL = (W_{ts} \times W_{tkg}) + (W_{cs} \times W_{ckg})$$

Where, Wts = Stator Teeth weight,
Wtkg = Losses in stator tooth W/kg,
Wcs = Stator Core weight,
Wckg = Losses in Stator core W/kg.

e) ***Fifth Objective Function*** : to maximize efficiency

$$\eta = \frac{1000 \times P_{out}}{1000 \times P_{out} + (SCL + RCL + SIL + WF)} \times 100$$

Where, Pout= output power in watt
WF= windage and friction loss is 1% of output

The motor design variables here are :

1) Ampere Conductors(q)-------------------------x(1)
2) Average air-gap flux density(Bav)--- -------x(2)
3) Bore Diameter(D)------------------------------x(3)
4) Efficiency(η)----------------------------------x(4)
5) Power Factor(p.f.)-----------------------------x(5)
6) Stator winding current density(δ_1)---------x(6)
7) Stack length to pole pitch ratio (L/τ)------x(7)
8) Rotor winding current density(δ_2)---------x(8)
9) Ratio of slot height to slot width (Hs/Ws)--x(9)
10) Outer Diameter (D0)--------------------------x(10)
11) Height of core(Hc) ----------------------------x(11)
12) Maximum flux density in tooth(Btmax)--- x(12)
13) Maximum flux density in core(Bcmax)---- x(13)

IV. GENETIC ALGORITHM OVERVIEW

Selection

Selection is the process of choosing two parents from the population for crossing. After deciding on an encoding, the next step is to decide how to perform selection. According to Darwin's theory of evolution the best ones survive to create new offspring. Selection is a method that randomly picks chromosomes out of the population according to their evaluation function. The higher the fitness function, the more chance an individual has to be selected. Some of the selection methods are :

Crossover (Recombination)

Crossover is the process of taking two parent solutions and producing from them a child. After the selection (reproduction) process, the population is enriched with better individuals. Reproduction makes clones of good strings but does not create new ones.
Crossover operator is applied to the mating pool with the hope that it creates a better offspring.

Mutation

After crossover, the strings are subjected to mutation. Mutation is performed to one individual to produce a new version of it where some of the original genetic material has been randomly changed. Mutation prevents the algorithm to be trapped in a local minimum. Mutation plays the role of recovering the lost genetic materials as well as for randomly disturbing genetic information. It is an insurance policy against the irreversible loss of genetic material. Mutation has traditionally considered as a simple search operator. If crossover is supposed to exploit the current solution to find better ones, mutation is supposed to help for the exploration of the whole search space. Mutation is viewed as a background operator to maintain genetic diversity in the population. It introduces new genetic structures in the population by randomly modifying some of its building blocks. Mutation helps escape from local minima's trap and maintains diversity in the population.

Fitness Scaling

Fitness scaling is performed in order to avoid premature convergence and slow finishing. The various types of fitness scaling are: Linear scaling, σ-Truncation and Power law.

A genetic algorithm is a problem solving method that uses genetics as its model of problem solving. It's a search technique to find approximate solutions to optimization and search problems. GA handles a population of possible solutions. Each solution is represented through a chromosome, which is just an abstract representation. For GAs to find a best optimum solution, it is necessary to perform certain operations over these individuals. The process starts by generating an initial population of chromosomes. [10]

This first population must offer a wide diversity of genetic materials. The gene pool should be as large as possible so that any solution of the search space can be engendered. Then, the GA loops over an iteration process to make the population evolve. Each iteration consists of selection, reproduction, evaluation and replacement.

In the most general sense, GA-based optimization is a stochastic search method that involves the random generation of potential design solutions and then systematically

evaluates and refines the solutions until a stopping criterion is met. There are three fundamental operators involved in thesearch process of a genetic algorithm: selection, crossover, and mutation. The genetic algorithm implementation steps are shown as follows:

The genetic algorithm implementation steps are shown as follows:

Step 1: Define parameter and objective function (Initializing)

Step 2: Generate first population at random

Step 3: Evaluate population by objective function

Step 4: Test convergence. If satisfied stop, else continue.

Step 5: Start reproduction process (Selection, Crossover, and Mutation)

Step 6: New generation. To continue the optimization, return to step 3.

V. DESIGN OPTIMIZATION BY GA

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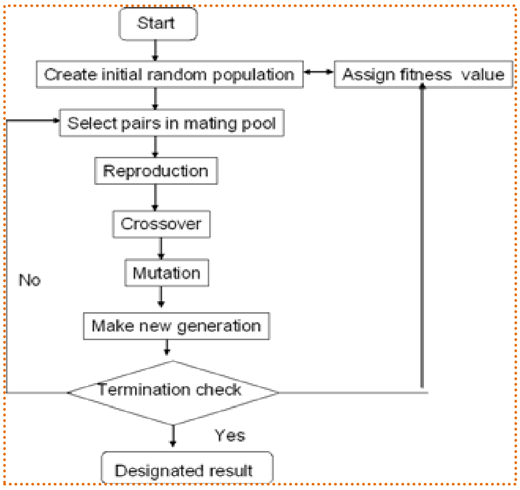

Figure 2: Flow Chart for Design Optimization

Here, the figure 2. Shows the design optimization procedure flowchart. The blocks contain a number of sub-routines. The program execution namely the initial motor design variables, number of generations, population size, crossover-rate, mutation rate and fitness scaling. The user dependent factors are the population size, number of generations, crossover-rate and mutation rate.

The penalty function consisting of each design variable and penalty limits, which can be varied within its domain. The design variables of both stator and rotor is calculated. This in turn is followed by optimization process such as selection, crossover, mutation and specification of the lower and upper bounds.

The design is evaluated for every individual of a population. After the optimum design is reached the algorithm ends after testing the specified convergence. Now the performance analysis for the proposed design can be viewed. If optimization are satisfied, then the design optimization process must be stopped, else continue the GA process of optimization.

VI. RESULTS AND DISCUSSION

Comparison of performance of GA based design with normal design, shows that normal design has high air-gap length, losses and low efficiency. This is because in normal design procedure the design parameters are selected manually whereas, in GA method the design parameters are automatically varied to find the optimal solution. So, the optimally designed motor has lower air-gap length and losses are reduced which in turn improves power factor a great extent. Hence there is significant increase in the efficiency due to the reduction in losses. The Table 1.Shows the comparison of the normal design procedure with the proposed method.

Table 1. Proposed Design results compared with conventional design results.

Serial No:	Description	Conventional Design	Proposed Design
1)	Ampere Conductor	24,000	23,778
2)	Average air gap flux density(wb/m^2)	0.737	0.439
3)	Bore Diameter (D) in mm	0.075	0.105
4)	Efficiency(η)	83.906	94.0904
5)	Power Factor(p.f)	0.824	0.96777
6)	Stator winding current density (A/mm^2)	4	4.002
7)	Ratio of stack length to pole pitch	1.894	1.967
8)	Rotor winding current density (A/mm^2)	4	4.002
9)	Ratio of slot height to slot width	3.001	3.0039
10)	Outer Diameter in mm	0.112	0.119
11)	Core Height (Hc)	2.001	2.007
12)	Maximum flux density in tooth (Btmax)	1.301	1.601
13)	Maximum flux density in core (Bcmax)	1.200	1.292

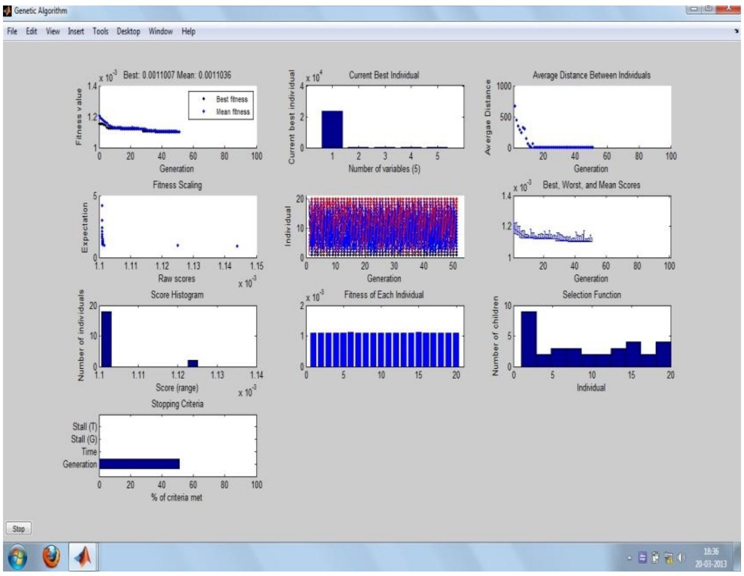

Figure 3: Air-Gap Length Optimization By GA

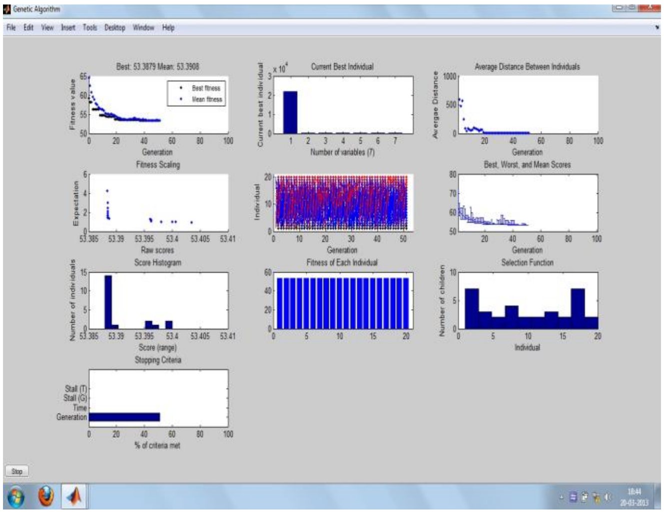

Figure 4: Stator Copper Loss

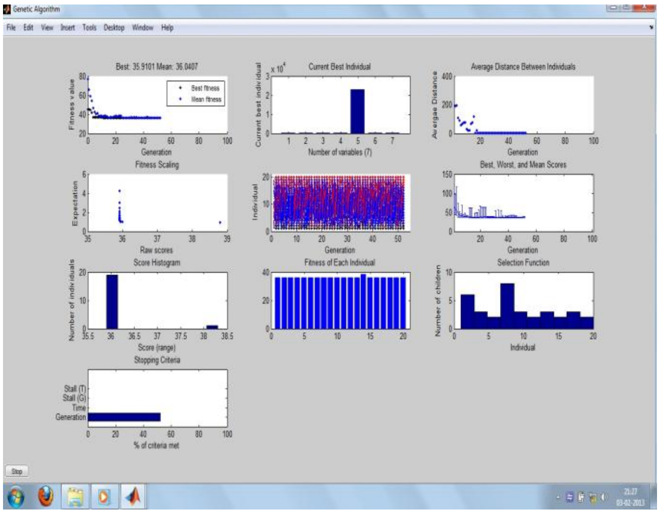

Figure 5: Rotor Copper Loss

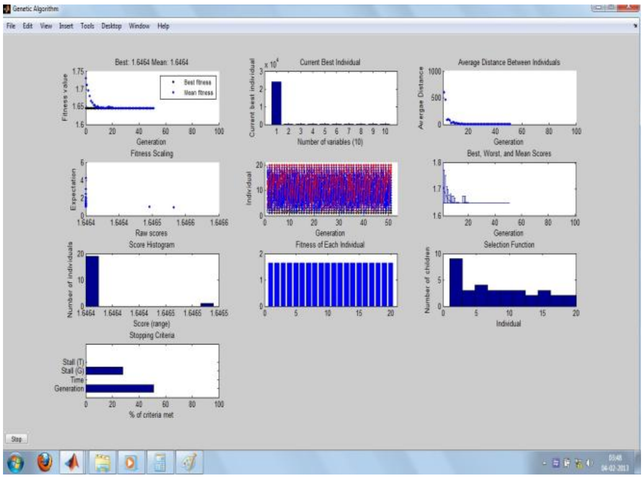

Figure 6: Stator Iron Loss

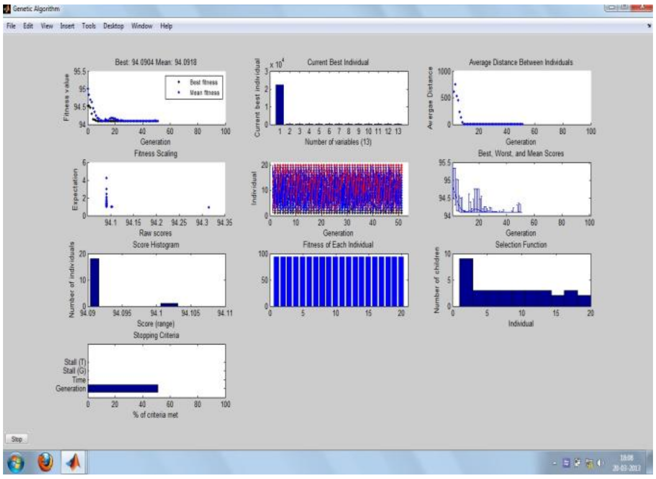

Figure 7: Efficiency

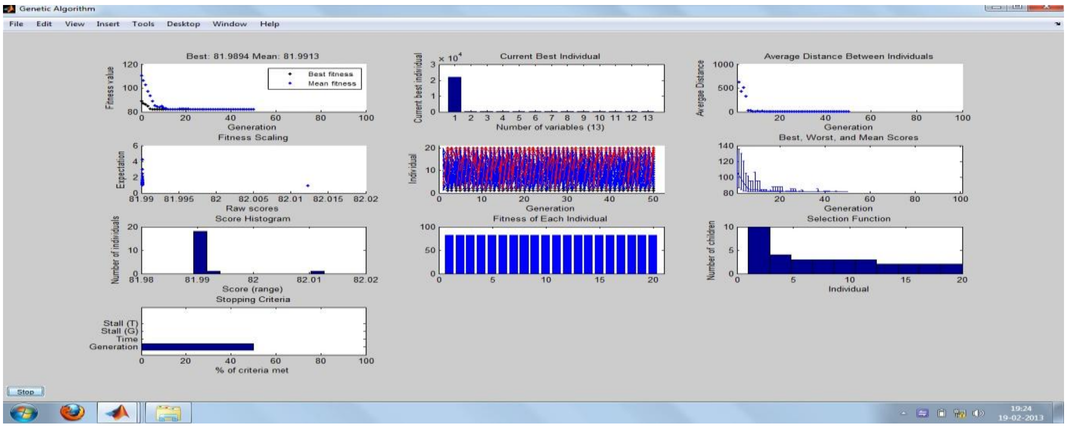

Figure 8: Total Optimization Graph

VII. CONCLUSION

A unique NLP technique known as GA was applied to the design process for optimization to occur. The results above shows the output performance of the motor optimized by GA process proves to be far better than the conventional procedure. The normal design has been compared with the proposed design of 3-phase squirrel cage Induction Motor both having the same ratings. Matlab is powerful design and simulation software which has been used here.

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