
ABSTRACT

In this work, Genetic Algorithm (GA) has been used as an optimization technique to minimise the losses in an induction machine. It was been observed that the GAs locate the global optimum region faster than the conventional direct search optimization techniques. In this paper, the concept of GA was used as an optimization technique to minimize the losses in an electric machine thereby improving on the efficiency. The result shows an improvement in the machine's efficiency from 90.3% to 94.3%.

KEYWORDS: *Genetic Algorithm, Optimization, Losses, Performance.*

INTRODUCTION

Optimization entails finding an alternative with the most cost effective or highest achievable performance under the given constraints, by maximizing desired factors and minimizing undesired ones. In comparison, maximization means trying to attain the highest or maximum result or outcome with regard to cost or expense (5). Optimization of induction motor design is one of the important aspects in electrical engineering design. The induction motor design optimization problem is formulated in mathematical terms as a nonlinear programming problem. The optimal design of an induction motor for minimum loss (copper & iron only) is taken to minimize the loss (copper & iron only) of the motor. The problem consists of an objective loss (copper & iron only) function which is minimized. The motor design procedure consists of a system of non-linear equations as our objective function as well as corresponding constraints (2). The research in this study has applied loss (copper & iron only) optimization in the design of three phase induction motor with single objective.

OVERVIEW OF GENETIC ALGORITHM

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 GA 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. 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 process which consist of selection, reproduction, evaluation and replacement. Genetic Algorithm (GA) was used in the optimization process, it mimic the principles of Natural Genetics and Natural selection to constitute search and optimization procedure. The idea was that, if nature's power to produce from a randomly created population, a population with individuals that are better to fit the environment could be reflected upon the algorithm, that algorithm could be used to solve complex problems. 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 (3)evaluates and refines the solutions until a stopping criterion is met(1). There are three fundamental operators involved in the search process of a genetic algorithm: selection, crossover, and mutation (4).

METHODOLOGY

The Objective function, Constraints as well as the Test files were coded using MATLAB mfile environment. Fig 1 has also shown the flow chart that was used to achieve the purpose.

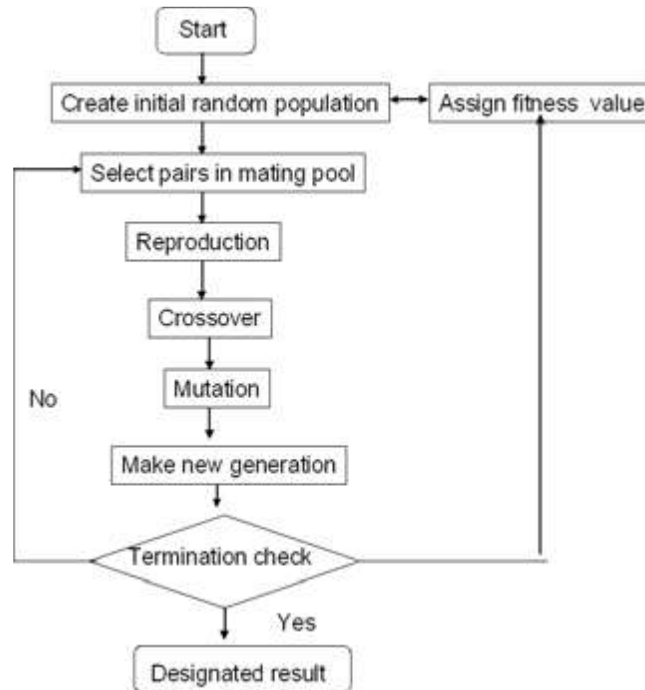


Fig. 1: Flowchart of Genetic Algorithm

Derivation of the objective function

The losses of a three phase induction motor were used as the objective function.

The losses considered were as follow:

1. Copper Loss
1. Stator Copper Loss
2. Rotor Copper Loss
3. Iron Loss
1. Stator Iron Loss

Stator Copper Loss (P_{st})

$$P_{st} = mI_s^2 r_s, \text{ but } r = \rho l/a$$

$$r_s = \frac{\rho_{cu} l_{mt} N_{ph}}{a_{cu}} \quad \text{Also, } J_s = \frac{I_s}{a_{cu}}$$

$$r_s = \frac{\rho_{cu} l_{mt} N_{ph} J_s}{I_s}$$

$$P_{st} = \frac{m \rho_{cu} I_s^2 N_{ph} J_s l_{mt}}{I_s}$$

$$P_{st} = m \rho_{cu} N_{ph} J_s I_s l_{mt} \quad (1)$$

Rotor Copper Loss (P_{rt})

$$P_{rt} = \text{Rotor bar loss } (P_b) + \text{End ring loss } (P_e)$$

Rotor bar loss (P_b)

$$P_b = I_b^2 r_b S_r$$

$$\begin{aligned}
 P_b &= \frac{\rho_{cu} l_b}{a_b} & a_b &= \frac{l_b}{J_b} \\
 r_b &= \frac{\rho_{cu} l_b J_b}{I_b} \\
 P_b &= \frac{l_b^2 \rho_{cu} J_b S_r}{I_b} \\
 P_b &= \rho_{cu} l_b J_b S_r I_b
 \end{aligned} \tag{2}$$

End rings loss (P_e)

$$\begin{aligned}
 P_e &= 2I_e^2 r_e \\
 r_e &= \frac{\rho_{cu} l_e}{a_e} \\
 l_e &= \text{mean length of current path in the end ring} = \text{circumference of the end ring} \\
 l_e &= \pi D_e \\
 P_e &= \frac{2I_e^2 \rho_{cu} \pi D_e}{a_e} \\
 a_e &= \frac{l_e}{J_e} \\
 P_e &= 2\pi \rho_{cu} J_e I_e D_e
 \end{aligned} \tag{3}$$

Rotor Copper Loss (P_{rt}) = P_b + P_e

$$\begin{aligned}
 P_{rt} &= \rho_{cu} l_b J_b S_r I_b + 2\pi \rho_{cu} I_e J_e D_e \\
 P_{rt} &= \rho_{cu} (l_b J_b S_r I_b + 2\pi I_e J_e D_e)
 \end{aligned} \tag{4}$$

Now,

Total Copper Loss (P_{cu}) = P_{st} + P_{rt} i.e. equation 1 + equation 2

$$P_{cu} = m \rho_{cu} N_{ph} J_s I_s l_{mt} + \rho_{cu} (l_b J_b S_r I_b + 2\pi I_e J_e D_e) \tag{5}$$

Stator Iron Loss, (P_{fe})

$$P_{fe} = \rho_{fe} (V_t K_1 f^{K_2} B_{st}^{K_3} + V_c K_1 f^{K_2} B_{sc}^{K_3})$$

Where,

V_t = volume of teeth,

V_c = Volume of core.

$$V_t = w_t d_{ss} l_s$$

$$V_c = \frac{\pi l}{4} (D_o^2 - [D + 2d_{ss}]^2)$$

But,

$$D_o = D + 2d_{ss} + 2d_{sc}$$

$$\text{Hence, } D + 2d_{ss} = D_o - 2d_{sc}$$

$$V_c = \frac{\pi l}{4} (D_o^2 - (D_o - 2d_{sc})^2)$$

$$V_c = \frac{\pi l}{4} (4D_o d_{sc} - 4d_{sc}^2)$$

$$V_c = \pi l d_{sc} (D_o - d_{sc})$$

$$\text{Recall; } D_o = D + 2d_{ss} + 2d_{sc}$$

Therefore,

$$V_c = \pi l d_{sc} (D + 2d_{sc} + d_{ss})$$

Substituting V_t and V_c into the expression for stator iron loss, we have;

$$P_{fe} = \rho_{fe} [w_t d_{ss} l_s K_1 f^{K_2} B_{st}^{K_3} + \pi l d_{sc} (D + 2d_{ss} + d_{sc}) K_1 f^{K_2} B_{sc}^{K_3}] \tag{6}$$

Finally, Total Losses (P) = Total Copper Loss (P_{cu}) + Total Iron Loss (P_{fe}) i.e. Equation 5 + Equation 6.

$$\begin{aligned}
 P &= m \rho_{cu} N_{ph} J_s I_s l_{mt} + \rho_{cu} (l_b J_b S_r I_b + 2\pi I_e J_e D_e) \\
 &\quad + \rho_{fe} [w_t d_{ss} l_s K_1 f^{K_2} B_{st}^{K_3} + \pi l d_{sc} K_1 f^{K_2} B_{sc}^{K_3} (D + 2d_{ss} + d_{sc})]
 \end{aligned}$$

Variables optimized

Eight variables were selected and optimized; the variables are shown in the table below:

Description	Independent variables	Initial Values
Bore Diameter (D)	X ₁	0.1406
Axial Length(L)	X ₂	0.1104
Length of Rotor Bar(l _b)	X ₃	0.1304
Depth of Stator Slot (d _{ss})	X ₄	0.0092
Depth of Stator Core (d _{sc})	X ₅	0.0205
Stator tooth Width (W _t)	X ₆	0.0032
Rotor Diameter (D _r)	X ₇	0.1397
Diameter of End Ring (D _e)	X ₈	0.1265

Constraints

Both inequality and equality constraints were imposed on the design. The imposed constraints are as follow:

1. Inequality constraints

- $D \leq (P_{in} \times p / C_o \pi k n_s)^{1/3}$
- $L \leq k \pi D / p$
- $L + 0.02 \leq L_b$
- $d_{ss} \leq (D_o - D - 2d_{ss}) / 2$
- $d_{sc} \leq A_c / L$
- $W_t \leq \phi / (1.7 C_s L_i)$
- $D_r \leq D - 2l_g$

2. Equality constraint

- $D_e = 0.9D$

Bound Limits

The bounds used for the design are shown in the tabular form below:

Lower	0.10	0.10	0.10	0.007	0.02	0.003	0.10	0.10
Bound(LB)								
Upper	0.17	0.30	0.14	0.010	0.03	0.004	0.20	0.13
Bound(UB)								

DISCUSSION OF RESULTS

The optimized result from the GA is as shown in the table below:

Variables	X ₁	X ₂	X ₃	X ₄	X ₅	X ₆	X ₇	X ₈
Values	0.1274	0.1000	0.1200	0.0071	0.0201	0.0030	0.1001	0.1146

Optimized Losses = 285.3060W

Running the GA Test m-file several times, a better set of variables(X₁ to X₈) as shown above can be obtained which results to minimization of losses, keeping correct sets of bounds and constraints.

CONCLUSION

It can be seen that with GA involves random generation of potential design solutions and then systematically evaluates and refining of solutions until a stopping criterion is met that performance of the machine is enhanced thus optimized as the losses (copper and iron only) is reduced from 487.0652W to 285.3060W. Hence, leading to an increase in efficiency from 90.3% to 94.3%.

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