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Optimization of 20kVA, 3-Phase Induction Motor using Genetic Algorithm

Abdulraheem T. [1], Asaolu G.O. [2], Oladele T.A. [3], Bamiduro H. A. [4], Ezeah J.U. [5]

Power Equipment and Electrical Machinery Development Institute, P.M.B 1029, Okene, Kogi State, Nigeria [1, 2,3,4,5]

ABSTRACT

This work optimizes the copper and iron losses in a 20kVA, 4 Pole, 3- phase, 50Hz squirrel cage inductor motor using genetic algorithm. Losses optimization selects the optimal values of the design variables which gives the least losses. Ten design variables were used in optimization process. The optimization was implemented using MATLAB software. The result shows that using the analytical method (without optimization), the losses was 710 W. But with the use of genetic algorithm to optimize the design, the losses were reduced to 642W. A comparison of these two methods shows a 9.6% decrease in losses with the use of optimization, resulting into an increase in efficiency.
Keywords : Genetic Algorithm, Losses, MATLAB, optimization, Squirrel Cage.

I. INTRODUCTION

The induction motor (IM) is without doubt the most used electrical motor and a great energy consumer. Three-phase induction motors consume 60% of industrial electricity and it takes considerable efforts to improve their efficiency. The vast majority of induction motor drives are used for heating, ventilation and air conditioning (HVAC) [1]. Squirrel cage Induction motor (SCIM) is the most widely used in industrial sector due to its low cost, simplicity and robustness. Improving efficiency in electric drives is important, mainly for economic saving and reduction of environmental pollution [2]. Therefore, the study of increasing energy saving in SCIM is very important as a small percentage increase in efficiency, will save huge amount of energy [3].

Losses minimization is one of the major goals of any manufacturer of induction motors. Losses in an IM constitute copper loss and iron or core loss in stator and rotor, mechanical loss and stray load loss. Iron loss and copper loss depend on the magnetic and electric loading of the machine and therefore, are controllable. The stray load loss depends mainly on the construction of the motor (type of stator and rotor slots, length of overhang, etc.) and also on the harmonics in the supply voltage. Usually, for a given motor and specified load, the sum of stray load loss and the mechanical loss (friction and windage) do not exceed 30% of the total losses and may be assumed to remain constant [4]. Because copper and iron losses contribute 70% of the total losses, hence, are the critical factors which decide the motor efficiency. Their values are different as the voltage and the load changes. During light load, the copper losses are less, whereas the majority of the total losses is core loss. Iron loss or core loss is the losses due to eddy currents and hysteresis. The core loss within a motor is determined by the choice of core material, the magnetic flux density at which the motor is operated and the operating frequency [3]. Maximum efficiency is obtained when copper losses and core losses become equal at any given torque and speed condition [3].

Optimization is finding a set of machine dimensions, materials, methods of assembly and so forth that constitute the best machine. In principle, it should be possible to figure out which machine is best and perhaps even to teach the computer program to seek out the optimal machine [5]. The conventional motor design using analytical method often times result in poor efficiency, low power factor and higher losses. This is because in the analytical motor design, design variables are manually selected but in computer based optimization, the design variables are automatically varied to find the optimal solution. Losses are the source of inefficiency in motors. Therefore, this works seeks to optimize the copper and iron losses in a 20kVA 4 Pole, 3- phase, 50Hz squirrel cage induction motor using Genetic Algorithm (GA) with the aid of MATLAB software.

Overview of Genetic Algorithm

In the most general sense, GA-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 [6]. GA is one of the efficient search methods based on the principle of natural selection. It has been successfully used as a tool for optimization of problems in broad fields such as engineering, economics and many other areas. It can provide approximate solutions for multivariable optimization problems. To apply GA appropriately, the problem must firstly be converted to a criterion function called “objective function”. This function represents the performance of the system. The GA consists of three main procedures, namely; selection, crossover, and mutation. Generally, at the first step, GA starts a random selection of population from the population set. Then the fitness evaluation is invoked. The retained population must pass the minimum requirement of the fitness evaluation while the rest is discarded. These retained members are then parented to produce offspring. All the parents and offspring have to go through the process of fitness evaluation again and only the strong ones are retained. These strong members are then used as replacements to the startup population. Following this, parenting reoccurs and the process is repeated until the fittest member or optimum solution is found [7]. The steps involved in the implementation of GA can be itemized as follows [8]:

i. Definition of parameters and objective function.
ii. Generation of first population in random manner from search space.
iii. Evaluation of populations using the objective functions and arrangement in order of merit.
iv. Testing of convergence. If satisfactory then stop, else continue.
v. Start reproduction process (selection, crossover and mutation).
vi. Form new generation of offspring and treat as new population. To continue the optimization, return to step 3.

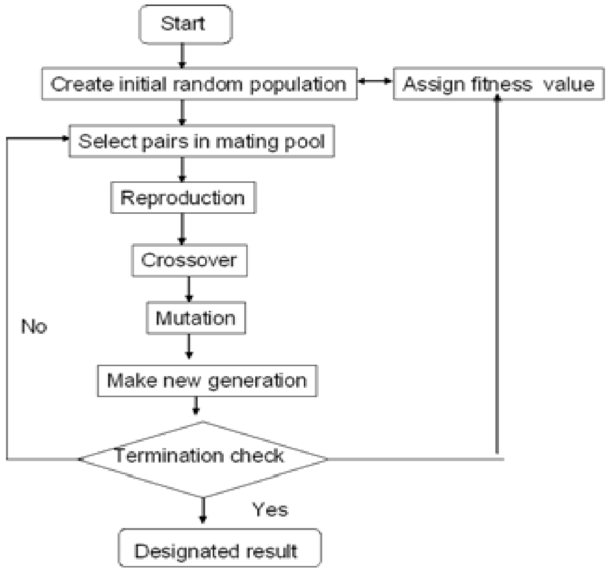


Figure 1. Genetic algorithm flow-charts [9].

II. METHODS AND MATERIAL

The main specifications of the squirrel cage induction motor are 20kVA, 415V, 3-phase, 50Hz, 4 pole and delta connected.

2.1 Optimization Variables

Variables used in the optimization problem formulation include, independent variables, dependent variables and design variables. Independent variables are independent of the design variables and require specification before the optimization process can begin. Dependent Variables are dependent on the design variables and will change throughout the optimization process [10]. Design variables are the primary parameters that determine that determines the performance or outcome of the optimization.

2.2 Independent Variable

Type of connection, Δ = Delta.
Supply frequency, f = 50Hz.
Number of phase, m = 3.
Supply voltage, V = 415V.
Phase voltage, V_{ph} = 415v
Power factor, p.f = 0.85

Number of poles, p = 4.
Stator winding factor, K_w = 0.955.
Specific magnetic loading B_{av} = 0.45 Wb/m^2.
Specific electric loading, Q = 23,000 A/m.
Number of slots per pole per phase, q = 3
Ratio of core length to pole pitch, K = 1
Pi, π = 22/7
Flux density of the stator core, B_{sc} =1.2 Wb/m^2
Stator current density, J_s = 4 A/mm^2
Current density of end ring, J_e = 7 A/mm^2.
Current density of rotor bar, J_b = 5 A/mm^2
Constant, k_1= 1.8
Constant, k_2 = 1.6
Constant, k_3 = 1.7
Flux density of the stator tooth, B_{st} = 1.6 Wb/m^2
Resistivity of copper, ρ_{cu} = 0.021 Ω/m and mm^2
Resistivity of copper, ρ_{fe} = 7.874 Ω/m and mm^2
Input power, Pin = 20kVA

2.3 Dependent Variable

Synchronous Speed in r.p.s, $N_s = (2 \times f) / p$ (1)

Mean turn length, $L_{mt} = 2L + [(2.3 \times \pi \times D)/p] + 0.24$ (2)

Outer Diameter, $Do = [(1.175 + 0.52 / p) \times D + 1.643 \times 10^{-2}]$ (3)

Flux per pole, $\phi = (\pi \times B_{av} \times D \times L) / p$ (4)

Area of core, $Ac = \phi / (2 \times B_{sc})$ (5)

Number of stator slots, $S_s = q \times m \times p$ (6)

Coil span, $C_s = S_s/p$ (7)

Number of stator turns, $N_{ph} = V_{ph} / (4.44 \times f \times \phi \times K_w)$ (8)

Stator current per phase, $Is = P_{in} \times 1000/(3 \times V_{ph})$ (9)

Number of rotor slots, $S_r = S_s - (2 \times p)$ (10)

End ring current, $I_e = S_r \times I_b/\pi \times p$ (11)

Rotor bar current, $I_b = 2 \times m \times Kw \times N_{ph} \times I_s \times p.f / Sr$ (12)

2.4 Design Variables

Stator bore diameter, $D = ((P_{in} \times p) / (Co \times k \times \pi \times N_s))^{(1/3)}$ (13)

Stator core length, $L = (K \times \pi \times D)/p$ (14)

Length of bar, $L_b = L + 0.065$ (15)

Depth of stator core, $d_{sc} = Ac/ (0.9 \times L)$ (16)

Depth of stator slot, $d_{ss} = (Do - D - 2d_{sc})/2$ (17)

Tooth width, $W_t = \phi / (1.7 \times Cs \times 0.9 \times L)$ (18)

Rotor diameter, $D_r = D - 2L_g$ (19)

Diameter of end ring, $D_e = D - 0.04$ (20)

Slot pitch, $S_p = \pi \times D/S_s$ (21)

Length of air gap, $Lg = [0.2 + (2(DL)^{1/2}]/1000$ (22)

2.5 Objective Function

This is the major factor(s) that determines the performance or outcome of the physical system, such as losses, costs, weight, efficiency, etc. The objective function for this design optimization is power losses (Iron and copper losses only). The power losses P, can be expressed as [9]:

$$P = m\rho_{cu}N_{ph}J_sI_sL_{mt} + \rho_{cu}(L_bJ_bS_rI_b + 2\pi I_eJ_eD_e) + \rho_{fe}\big[w_td_{ss}Ls_sK_1f^{K_2}B_{st}^{K_3} + \pi Ld_{sc}K_1f^{K_2}B_{sc}^{K_3}(D + 2d_{ss} + d_{sc})\big] \quad (23)$$

2.6 Constraints

During the course of optimization when variables undergo incrementing or decrementing, they should also be constrained to be within practical ranges [11]. The optimization can be subjected to both equality and inequality constraints. The following constraints were imposed on the SCIM design optimization.

i. $D \leq (P_{in} \times p/Co \times \pi \times k \times N_s)^{1/3}$
ii. $\pi \times D \times N_s \leq 30$
iii. $L \leq k \times \pi \times D/p$

iv. $L + 0.065 \leq L_b$
v. $d_{sc} \leq Ac/Ls$
vi. $d_{ss} \leq (D_o\text{-}D\text{-}2d_{sc})/2$
vii. $L_g \leq [0.2+2(DL)^{1/2}]/1000$
viii. $D_r \leq D\text{- }2 \times L_g$
ix. $S_p \leq \pi \times D/S_s$
x. $D_e = D - 0.04$

2.7 Bounds Limit of the design variables

The design variables can be restricted to certain limits by specifying the lower limit and upper limit. Table1 shows Bound limits that were set for the design variable as shown in.

Table 1.Upper and Lower Bounds For The Design Variables

Design variable	**D**	**L**	**L_b**	**d_{ss}**	**d_{sc}**	**W_t**	**D_r**	**D_e**	**S_p**	**L_g**
Upper Limit	0.230	0.200	0.250	0.007	0.050	0.008	0.230	0.210	0.020	0.00059
Lower Limit	0.180	0.160	0.210	0.003	0.020	0.004	0.170	0.170	0.015	0.00055

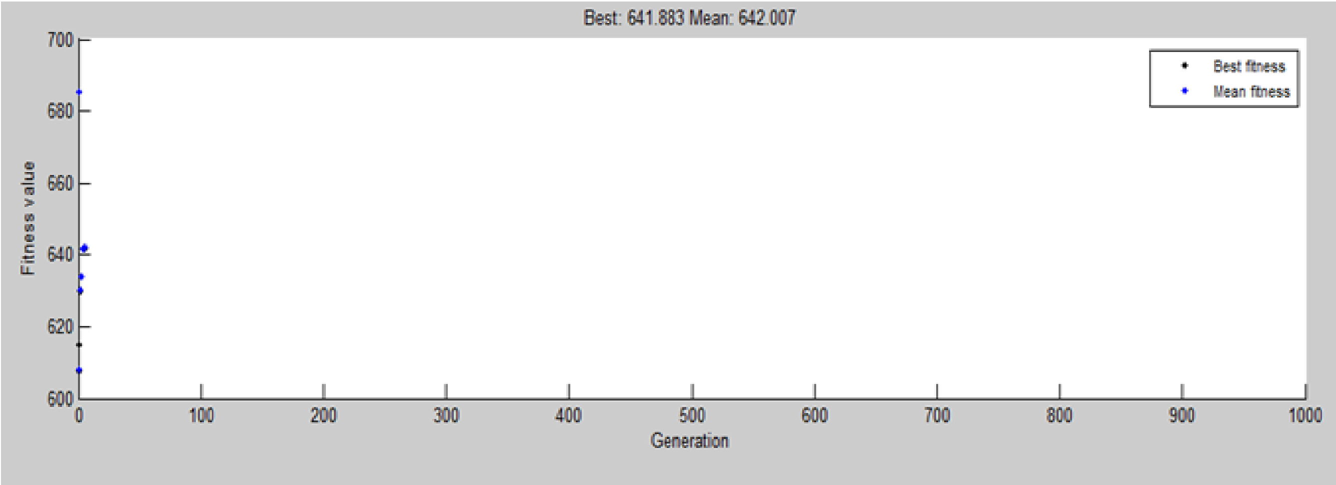
2.8 Implementation

The GA optimization of the SCIM design was implemented using MATLAB software. The optimization program was run severally until the best value was obtained. At each run of the program, a value was return with no constraint or bound violation

III. RESULTS AND DISCUSSION

Table 2. Values of unoptimized (analytical) and optimized design variables

Design variable	**D**	**L**	**L_b**	**d_{ss}**	**d_{sc}**	**W_t**	**D_r**	**D_e**	**S_p**	**L_g**
unoptimized value	0.201	0.165	0.230	0.005	0.004	0.006	0.208	0.189	0.015	0.00057
Optimized value	0.206	0.160	0.225	0.003	0.020	0.004	0.170	0.185	0.015	0.00058



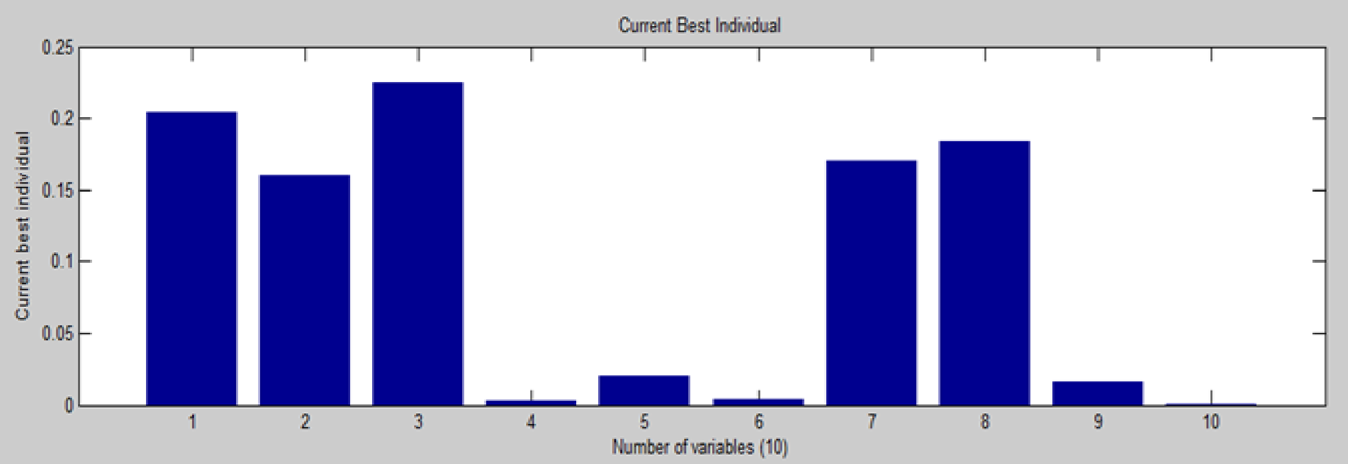


Figure 2. Graphical representation of the design variables and power losses optimization result.

Table 2 and figure 2 present the result obtained from the optimization of the 20kVA induction motor. Table 2 shows the values of the design variables obtained using the analytical (unoptimized) method and GA optimization technique. It can be observed that there are little variations between the values obtained from the two methods. Figure 2 shows a graphical description of the optimized value of the design variables and power losses. The analytically calculated value of the power losses gives 710W. But with the use of GA to optimize, the losses were reduced to 642W. This shows a decrease in losses by 68W (9.6%), leading to an improvement in efficiency.

IV. CONCLUSION

A 20kVA, 415V, 3-phase squirrel cage induction motor has been optimized successfully using genetic algorithm with losses as objective function. The optimal values of the design variables obtained resulted in losses reduction (by 9.6%). This shows that with the use of genetic algorithm for optimization, better efficiency can be achieved, using the optimal values of the design parameters. Induction motor manufacturers that use computer optimization for design are more likely to roll out products with better performance.

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