International Journal on Recent and Innovation Trends in Computing and Communication
ISSN: 2321-8169 Volume: 11 Issue: 8
***Article Received:** 20 May 2023 **Revised:** 28 May 2023 **Accepted:** 16 August 2023*

Design Optimization of Electric Motor (Induction Motor)Using Genetic Algorithm

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Abstract— Various three phase Induction Motors are extensively used in domestic, commercialand industrial applications. One such induction motor is the Squirrel Cage type which is characterized by its simplicity, robustness and low cost. Hence, squirrel cage motors are extensively used in the industrial sector. However these motors consume large quantities of power. The reduction in electric energy consumption in squirrel cage motors through a better motor design is an attractive option. Optimization of the electromagnetic devices requires consideration of discrete and continuous variables and discontinuities in the search space.

Keywords— *Soft Magnetic Materials, Efficiency.*

1. GENETIC ALGORITHM :

Genetic Algorithm (GA) is recognized as a potent tool to optimize the design of electrical machinery. One of the important advantages of the GA over the standard NLP techniques is that it finds the global minimum, instead of a local minimum, without the need for the startingpoints to be close to the actual values. Attaining the derivative function is an added advantage to the For example, when dealing with real measurements involving noisy values, the power factor and efficiency improvement are mainly considered. The present thesis, it is suggested that further contribution towards the optimum design of a three phase induction motor for a given power factor and efficiency can be improved by manipulating the five objective functions namely Stator Copper Loss (SCL), Rotor Copper Loss (RCL), Stator Iron Losses (SIL), Full Load Efficiency (FLE) and Full Load Power Factor (PF). The GA having the feature of a unique search was then used for the optimization processes. A design package has been developed using MATLAB1.7 specifically for a three-phase SCIM. The optimal design of statorwinding to improve the motor power factor and efficiency in a wide load range is proposed using GA. This algorithm is a population-based search algorithm characterized as conceptually simple, easy to implement and computationally efficient. An approach with minimum parameters are incorporated in the proposed algorithm to handle the constraints effectively.
In the present research, 2.2 kW and 7.5 kW, 400V, 50 Hz, 4-pole, three phase, multiflux stator winding Squirrel Cage Induction Motors have been designed for optimal power factor and efficiency. The results are compared with that of the conventional design.

2. OBJECTIVE FUNCTIONS:

The objective function for the optimized design of a single winding induction motor requires consideration of both economic and performance aspects. Hence, the following five contradictory objective functions are chosen.
Minimize stator copper loss

a. Minimize rotor copper loss
b. Minimize stator iron losses
c. Maximize the efficiency
d. Maximize the power factor

This problem is represented by a multi-objective optimization approach. The mathematicalexpressions of the Multi-Objectives are given below,

a. The stator copper loss is optimized using the equation (1),

$$SCL = 3I_{ph}^2(R_s)$$

Where,
Iph - Phase Current in Amperes Rs - Stator Resistance in Ohms

b. The rotor copper loss is optimized using the equation (2),

$$W_{RCL} = \frac{\rho_r S_2 I_b^2}{a_b}(L_r + \frac{2D_e}{p}) \quad (2)$$

Where,
r - Resistivity of the winding (0.021- 2)
S2 - Number of rotor slots
Ib - Rotor bar current in amperes

De -Mean end ring diameter in millimeters (mm)Lr - Length

of the rotor core in meters
P - Number of poles
ab- area of the each rotor bar in mm

c. The stator iron loss is optimized using the equation (3),

SIL Wt Wtk Wc Wck (3)
Where,
Wt - Weight of the stator teeth in kg Wc - Weight of the stator core in kg
Wtk - Losses in stator tooth portion W/kg Wck - Losses in stator core W/kg

d. Full load efficiency is determined using the equation (4),

$$\eta = \frac{1000P_o}{1000P_o + W_{SCL} + W_{RCL} + W_{SIL} + W_F} \times 100 \quad (4)$$

Where,
P0 - Output Power in kW
WSCL - Stator Copper Loss in watts WRCL - Rotor Copper Loss in watts WSIL - Stator Iron Losses in watts WF - Frictional losses in watts

e. Full load power factor is found using the equation (5),

$$PF = \frac{R_s + G_4}{\sqrt{\{(R_s + G_4)^2 + (x_5 + G_5)^2\}}} \quad (5)$$

Where,
RS - Stator Resistance in ohms
x5 - Average air gap flux density (wb/m2) G4, G5 - Magnetizing constants

The GA-based optimization is a stochastic search method that involves the random generation of potential design solutions and the systematic evaluation and refinement of the solutions till a defined criterion is met. The three fundamental operators involved in the search process of a Genetic Algorithm are selection, crossover and mutation. The GA implementation steps are presented next.
Step 1: Initialize the defining parameters and the objective functionStep 2: Generate the first population at random
Step 3: Evaluate the population by objective function
Step 4: Test for convergence; if satisfied stop, else continue

Step 5: Start the selection, crossover and the reproduction processes Step 6: New generation. To continue, return to step 3. The Genetic
Algorithm is composed of the following three operators, namely,

$$P_j = \frac{F(X_i)}{\sum_i F(X_i)} \quad (6)$$

Where,
Pj is the selection probability F(X*i*) is the objective function

3. DESIGN OF 2.2 KW INDUCTION MOTOR USING GENETIC ALGORITHM

A design approach for a 2.2 kW induction motor is presented. The equivalent circuit model of the motor is shown in the Figure 1.1. A flow chart for design optimisation using Genetic Algorithm is shown in the Figure 1.2. The model is popular and well understood among engineers and, despite its shortcomings, offers a reasonably good prediction accuracy with modest computational effort. This model is basically a per phase representation of a balanced polyphase induction machine in the frequency domain, comprising of six elements, or model parameters. The six impedances are stator resistance R1, stator leakage reactance X01, magnetizing reactance Xm, core loss Resistance Rm, rotor leakage reactance X02, and rotor resistance R2. In the present chapter, the approaches and methods used to calculate the motor performances are based on the works.

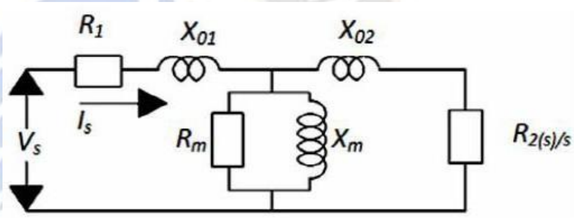

Figure 1.1 Equivalent circuit model of induction motor

To apply the GA approach to a 2.2 kW single winding induction motor, an objective function has to be defined for each motor design. This objective function may include all the geometrical dimensions of the motor. A large subset of constraints (geometrical constraints) has to be handled to ensure the physical
Feasibility of the motor.

4. DESIGN OF 7.5 KW INDUCTION MOTOR USING GENETIC ALGORITHM

The design of 7.5 kW single winding induction motor equivalents to the circuit model is shown inthe Figure 1.1. This is the same approach as that of the 2.2 kW motor except that the ratings are adjusted. The flow chart of the design optimization procedure is depicted in the Figure 1.2.

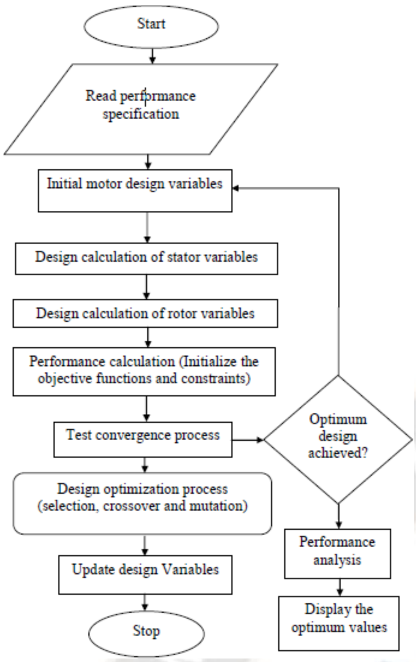

Figure 1.2 Flow chart for design optimization using Genetic Algorithm

Population	500	Crossover Rate	0.5
Generation	100	Mutation rate	0.015

Figure 1.3 Genetic Algorithm parameters

For testing the optimization method, the GA is applied by considering various performance parameters as shown in the Figure 1.3. Each block consists of a number of subroutines like, generation fitness scaling, current best individual, average distance between the variables, raw scores &score histogram, generation fitness of each individual, generation selection function and stopping criteria as discussed below.

1. Generation fitness scaling is the process of generation of GA parameters and it will select the fitness of the parameters and also find best and mean fitness value.
2. Current best individual is the analysis of current best variables to achieve better optimized values
3. The graph shows average distance between the variables from initial to final optimization.
4. The graph shows the scores of histogram from parameters of GA.
5. Generation Fitness of each individual is the process generate the variables and functionsduring optimization
6. The graph shows that fitness of the each individual during optimization
7. The graph shows that priority based selected function during initial to final optimization
8. Graph shows that total stimulation time and total generation during initial to finaloptimization.

Execution of the program starts with the performance specifications such as the initial motordesign variables, the number of generations, population size, crossover rate, and mutation rate. Population size, number of generations, crossover rate and mutation rate can be selecteddepending on the user. Each design parameter and penalty limits for penalty function can bevaried within its domain. The design parameters of the stator and rotor layout are then calculated.

5. COMPARATIVE RESULTS

Comparison of the performance of the GA based design motor with that of the conventionalmotor for 2.2 kW and 7.5 kW, reveals that the conventional motor design displays poor efficiency, low power factor and higher losses. This is because in the conventional motor design the variables are manually selected, but in the proposed GA based optimal design, the design variables are automatically varied to find the optimal solution. Hence, the optimally designed three phase SCIM attains higher efficiency, better power factor and lowlosses. Comparison of the conventional and optimal design values for 2.2 kW & 7.5 kW induction motor is shown in the Table 1.1 and Table 1.2 respectively. For conventional design, performance characteristics of 2.2 kW.

Table 1.1 Comparison of the conventional and optimal design data for 2.2 kW induction motor

Description	Conventional Design	Optimal Design
Diameter of stator (in m)	0.075	0.07
Length of stator (in m)	0.10	0.09
Ration L/	1.89	1.99
Outer diameter of stator (in m)	0.11	0.12
Stack length (in m)	1.69	1.99
Stator depth to width ratio	3.00	3.01
Stator core depth (in mm)	2.00	2.01
Average air gap flux density (in wb/m^2)	0.72	0.79
Stator winding current density (in A/mm^2)	4.00	4.01

Rotor winding current density (in A/mm^2)	4.00	4.03
Stator Iron Losses (SIL) (in Watts)	68.34	45.57
Rotor Copper Loss (RCL) (in Watts)	98.84	70.56
Stator Copper Loss (SCL) (in Watts)	179.32	141.88
Average Efficiency	83.8	90
Average Power Factor	0.82	0.90

Table 1.2 Comparison of the conventional and optimal design data for 7.5 kW induction motor

Description	Conventional Design	Optimal Design
Diameter of stator (in m)	0.098	0.09
Length of stator (in m)	0.145	0.135
Ration L/	1.89	1.99
Outer diameter of stator (in m)	1.1	1.2
Stack length (in m)	1.69	1.99
Stator depth to width ratio	3.00	3.01
Stator core depth (in mm)	2.00	2.01
Average air gap flux density (in wb/m^2)	0.72	0.79
Stator winding current density (in A/mm^2)	4.50	5.01
Rotor winding current density (in A/mm^2)	4.50	5.03
Stator Iron Losses (SIL) (in Watts)	108.33	85.57
Rotor Copper Loss (RCL) (in Watts)	198.84	170.56
Stator Copper Loss (SCL) (in Watts)	279.32	241.88
Average Efficiency	85.5	89.00
Average Power Factor	0.81	0.92

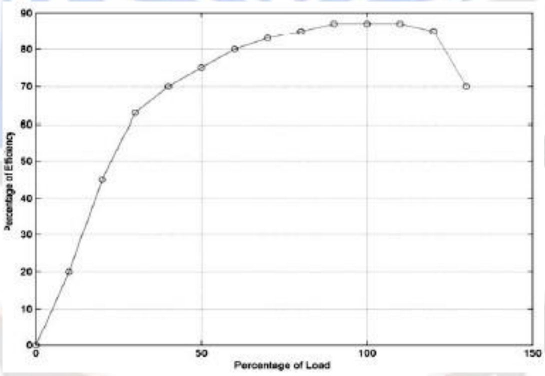

Figure 1.4 Efficiency characteristics of the 2.2 kW single winding conventional design inductionmotor

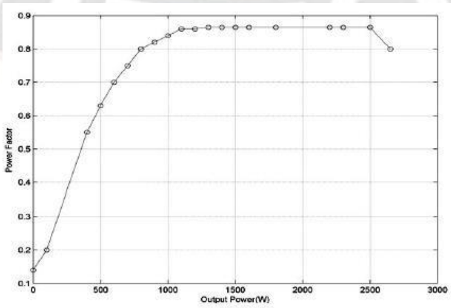

Figure 1.5 Power factor characteristics of the 2.2 kW single winding conventional designinduction motor

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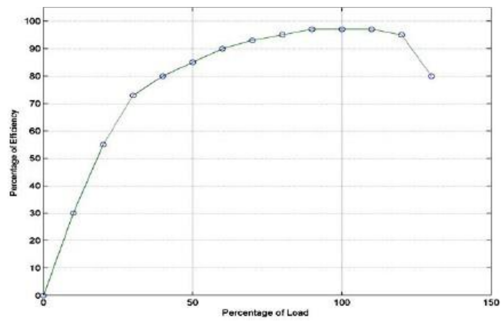

Figure 1.6 Efficiency characteristics of the 2.2 kW single winding optimal design inductionmotor

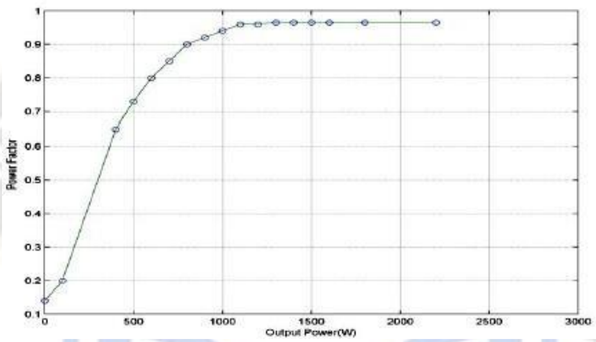

Figure 1.7 Power factor characteristics of the 2.2 kW single winding optimal design inductionmotor.

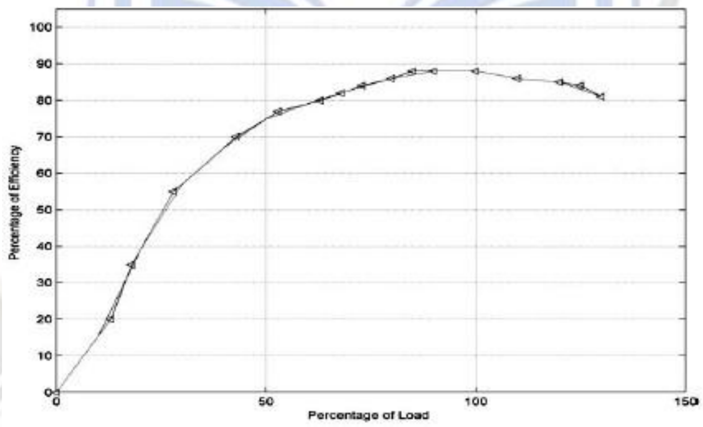

Figure 1.8 Efficiency characteristics of the 7.5 kW single winding conventional design inductionmotor

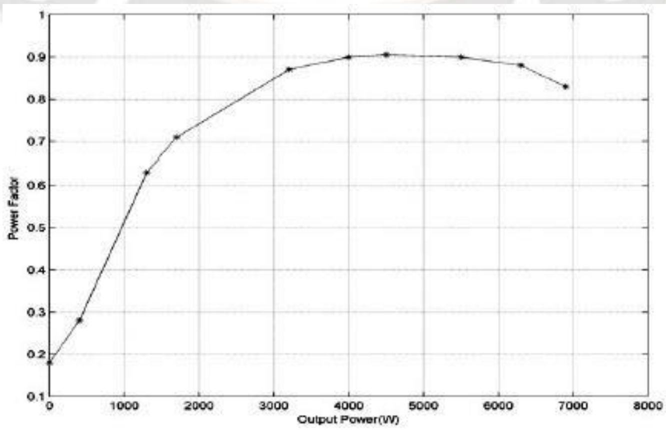

Figure 1.9 Power factor characteristics of the 7.5 kW single winding conventional designinduction motor

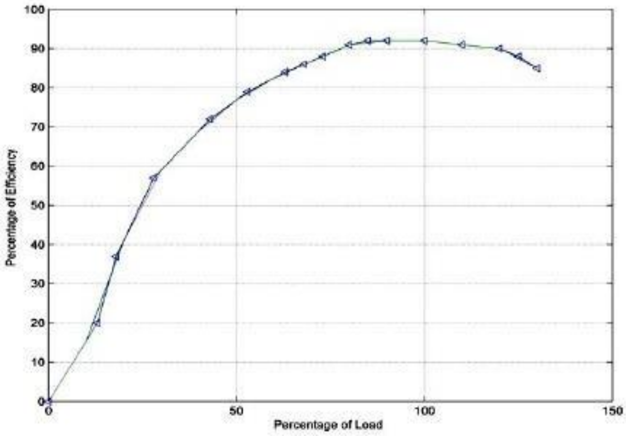

Figure 1.10 Efficiency characteristics of the 7.5 kW single winding optimal design inductionmotor

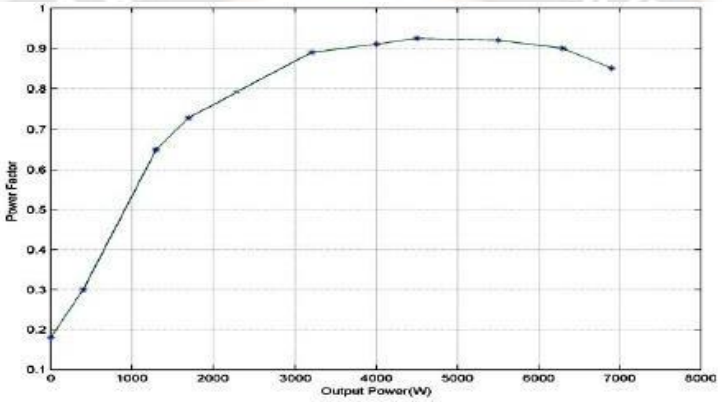

Figure 1.1 Power factor characteristics of the 7.5 kW single winding optimal design inductionmotor.

6. CONCLUSION

In the present chapter, optimally designed single winding three phase SCIM using Genetic Algorithm has been compared with the conventional motor for the same ratings. An optimization technique based on GA has been applied to the design of both 2.2 kW and 7.5 kW three phase SCIM. Comparison of the optimum design with the conventional design indicatesan improvement in the performance.

Using GA, the efficiency which is 83.8 % in the conventional design improves to 89.3%. Similarly, the power factor improves to 0.91 from 0.82 for 2.2 kW conventional design SCIM.For 7.5 kW SCIM, the efficiency improves from 85.5% in the conventional design to 89%. Similarly, the power factor improves to 0.92 which is 0.81 for the conventional design. The optimal design parameters are presented for 2.2 kW and 7.5 kW induction motor. It is observed that the power factor and efficiency of the optimally designed induction motor are comparatively improved.

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