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OPTIMUM DESIGN OF MULTIPLE WINDING INDUCTION MOTOR

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ABSTRACT

Out of total electrical motors 80% are three-phase squirrel-cage induction motors which are widely used in industrial and domestic applications because of the relatively low cost and high reliability. When oversized, most of these motors operate in low efficiency and poor power factor. Adjustable flux motors with multiple winding connections can be an energy efficient solution in variable and fixed load applications, improving the efficiency and power factor by means of properly adapting motor flux to the actual load. In this paper, a design optimization method is proposed. The optimal design of a multi-flux stator winding to improve motor efficiency and power factor in a wide load range is proposed using Genetic Algorithm. This algorithm is a population-based search algorithm characterized as conceptually simple, easy to implement and computationally efficient. A parameter-less loss approach is incorporated in the proposed algorithm to handle the constraints effectively. A comparison of optimum design with the conventional design for a 2.2-kW three phase squirreal-cage induction motor is presented. It is demonstrated that the optimal design produce better efficiency over the entire load range including energy saving which is most suitable for industrial applications

Keywords: *Adjustable Flux, Energy Efficient, Multiflux Stator Winding, Less Parameter Approch, Population Algorithm.*

NOMENCLATURE

R_s	Stator resistance(in ohms)
X_s	Stator leakage reactance(in ohms)
X_m	Magnetizing reactance(in ohms)
R_c	Core loss Resistance(in ohms)
R_r	Rotor resistance(in ohms)
X_r	Rotor leakage reactance(in ohms)
s	Slip
V_{ph}	Supply voltage(in volts)
P_{SCL}	Stator Copper Loss (in watts)
I_{ph}	Phase Current (in Amps)
P_{RCL}	Rotor Copper Loss (in watts)
ρ_r	Resistivity of material of bars and rings (constant -0.021 ohms/ m and mm^2)
S_2	No. of rotor slots
I_b	Rotor bar current (in Amps)
a_b	Rotor bar area (in m^2)
D_e	Mean end ring diameter (in mm)
L_r	Length of the core (in m)
P	Numbers of poles
P_{SIL}	Stator Iron Losses (in watts)
W_t	Weight of the stator teeth (in kilo gram)
W_c	Weight of the stator core (in kilo gram)
P_{tk}	Stator tooth portion losses (inW/kg)
P_{ck}	Stator core losses (in W/kg)
η	Efficiency
P_0	Power output (in kilo watts)
P_F	Friction losses (in watts)
θ_{ms}	Stator temperature rise
τ_c	Cooling coefficient
S_s	Stator cooling surface area
S_r	Rotor cooling surface area
k	Constant (range of 0.003 to 0.005)
u	Relative peripheral speed
f	Frequency(in Hz)
D	Diameter of stator in m
S_i	Inside cylindrical surface area
S_o	Outside cylindrical surface area
G_4 & G_5	Magnetizing constants
X_1	Stator winding conductors length (m)
X_2	Stack length/pole pitch ratio
X_3	Stator slot depth to width
X_4	Stator core depth(in mm)
X_5	Average air gap flux density (tesla)
X_6	Stator current density (A/mm^2)
X_7	Rotor current density (A/mm^2)
$P.F$	Power Factor

1. INTRODUCTION

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Three-phase squirrel-cage induction motors (SCIMs) are widely used in industry, because of their rugged construction and simple operation. Oversized three phase SCIM operate in poor efficiency and power factor. Therefore, in the three phase SCIM design the energy efficiency and power factor are key issues[1]. Oflate, the society has realized that energy saving is significant for higher economic development. In conventional induction motor design, stator consists of double layer with fixed connection. Flux in the core is constant from no load to full load which restricts the motor performance [2]. Multi- flux motor provides the solution to overcome the limitation of constant flux by splitting the stator coils and connecting them in various combinations based on the load demand [3] and [4]. In this study, the multiflux SCIM proposed with different possible [5] winding connection modes, which allow the magnetizing flux to be adjusted different levels [6] is being considered.

The objective is achieved by flux control, which is done by splitting the stator winding into two sets and arranging them in various winding configurations [7] and[8]. By adjusting the flux with different stator winding configurations, the losses are reduced and the power factor and efficiency are in turn enhanced.

The equivalent circuit induction motor using shown in Fig.1. It is basically a per-phase representation of a three-phase SCIM in the frequency domain, comprising of 6 lumped parameters, namely, stator resistance R_s, stator leakage reactance X_s, magnetizing reactance X_m, core loss resistance R_c, rotor leakage reactance X_r , and rotor resistance R_r, all referred to stator side [9] and [10]. The rotor resistance value varies with the slip s, being defined by R_r/s. The mechanical power developed in the rotor is given by $3I_r^2(1\text{-}s)/s$. This power minus the mechanical losses gives the motor shaft output power.

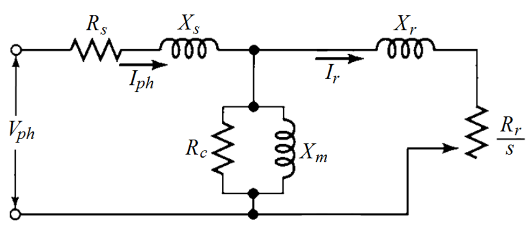

Fig. 1. Equivalent circuit of three phase SCIM.

In the past, the design of SCIM has been attempted for achieving better performance characteristics in terms of efficiency, power factor and operating temperature [11] and [12]. These were carried out on trial and error method which is solely based on professional experience and analytical studies. Digital computers have made possible to use better optimization techniques in the design of electrical machines [13].

For the design optimization of three phase SCIMs, the most frequently used objective functions are the motor efficiency and power factor. Several techniques such as Genetic Algorithm (GA), Neural Networks [14] and Fuzzy Logic have been used to solve the three phase SCIM design problems. However, these techniques do not always guarantee the global optimal solution. They normally provide suboptimal solution. The GA is a modern, evolutionary, population-based, search algorithm, characterized as conceptually simple, easy to implement and computationally efficient. Using GA technique, the maximum efficiency and power factor are computed for each stator winding connection mode, and the overall motor stator and rotor design is then optimized in order to obtain the maximum combined efficiency and power factor over the entire operating load range.

The application of the proposed design in such motors can lead to significant energy savings with efficiency and power factor improvement. This novel motor can be of great value in industry due to its flexibility, particularly, for variable load fixed-speed applications [15] - [17], in which significant energy savings can be obtained.

The main objective of the present paper is to get optimum design parameters with power factor and efficiency improvement in all connection modes. The optimal design parameters are obtained for each winding configuration.The design parameters obtained from the conventional design technique and the optimum data obtained from GA technique are compared. In order to validate the results of the presented work, different stator winding combinations have been attempted on a 2.2-kW three phase SCIM.

2. GENETIC ALGORITHM PROCESS

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GA technique is used to design the 2.2-kW, 4-pole, 50-Hz, multiflux SCIM. MATLAB 7.1 simulation [18] software package has been used. The main objective of the present work is to get optimum design parameters with power factor and efficiency improvement in all connection modes. In the most general sense, GA-based optimization [19] is a stochastic search method [20] that involves random generation of potential design solutions and then systematically evaluating and refining the solutions until optimal solution is met [21] and [22].

There are three fundamental operators involved in the search process in genetic algorithm, namely, selection, crossover, and mutation.

The selection is a process in which individual strings are selected according to their fitness. The selection probability can be defined by the selection probability P_j and the objective function $F(xi)$.

The crossover is the most powerful genetic operator. One of the commonly used methods for crossover is single-point crossover. As shown in the following examples, a crossover point is selected between the first and the last bits of the chromosome. Then binary code to the right of the crossover point of chromosome *1* goes to offspring *2* and chromosome *2* passes its code to offspring *1*. This operation takes place with a defined probability P_c that statistically represents the number of individuals involved in the crossover process.

The mutation is a common genetic manipulation operator and it involves the random alteration of genes during the process of copying a chromosome from one generation to the next. Raising the ratio of mutations, increases the algorithm's freedom to search outside the current region of parameter space. Mutation changes from a "1" to a "0" or vice versa. It may be illustrated as 110000010_110001010.

A Implementation Steps

The genetic algorithm implementation steps are shown in Fig. 2 and are as follow:

- Define parameter and objective function (Initializing);
- Generate first population at random;
- Evaluate population by objective function;
- Test convergence. If satisfied then stop else continue;
- Start reproduction process (Selection, Crossover and Mutation);
- New generation. To continue the optimization, return to GA point that produces optimal results in many practical problems is composed of the following three operators.

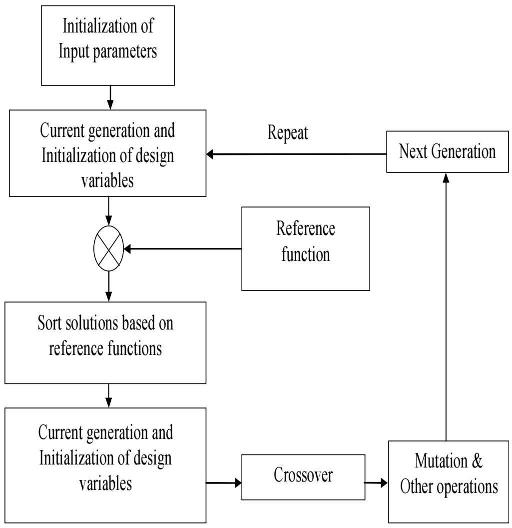

Fig. 2. The main steps in a GA.

Then the optimization process should be carried out based on fundamental operators (selection, crossover mutations) of genetic algorithm and the specification of The SCIM design, to maximize power factor and efficiency is achieved using GA approach. Then the parameter-less loss approach is incorporated in the proposed algorithm to handle the constraints effectively.

objective functions. This optimization process has been evaluated for each and every individual population (specific limits) of the design variables. The optimization process starts with necssary intial values and untill the process converges, the initial design values will be varied and at the end of the process, optimal design values will be computed by the process.

B. Flow Chart for Optimization Procedure

The flow chart of the design and optimization procedure is depicted in Fig.3. Every block consists of specific objectives to achieve optimal solutions. Execution of the program starts with initial motor design variables, the number of generations, population size (upper and lower limits), crossover rate and mutation rate. Each and every design

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parameter of SCIM stator and rotor layout are calculated.

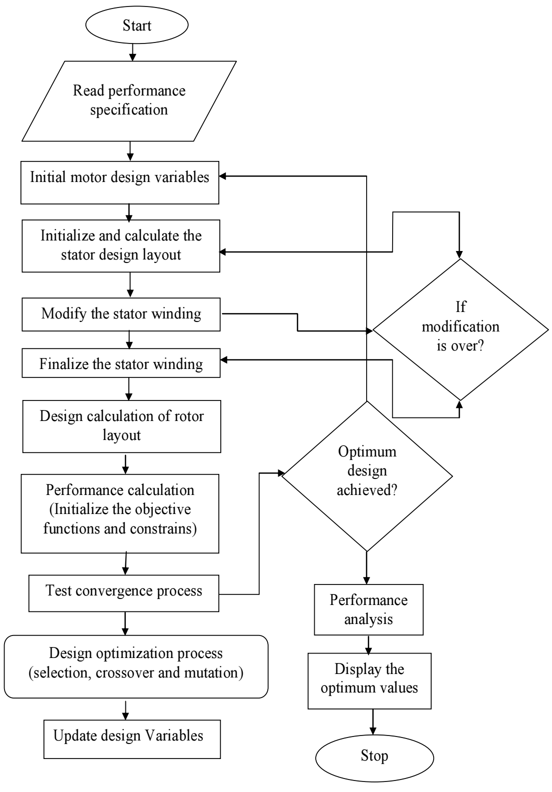

Fig. 3. Flow chart for design and GA-based optimization process.

C. GA Optimization Process

The GA optimization process is aimed to obtain a flatter combined efficiency as a function of motor load considering that the six stator winding connection modes properly managed as a function of the input line current. In the end, the average motor efficiency and power factor along the load range (correspoding integration of the efficiency or power factor over from 0 to 100% load) are both significantly improved in relation to the non-optimized base case.

For testing the optimization method, the GA is applied by considering various performance parameters as shown in the Fig.4. Each block consists of a number of subroutines. Execution of the program starts with the performance specifications such as the initial motor design variables, the number of generations, population size, crossover rate, and mutation rate. Population size, number of generations, crossover rate and mutation rate can be selected depending on the user. Each design parameter and penalty limits for penalty function can be varied within its domain.

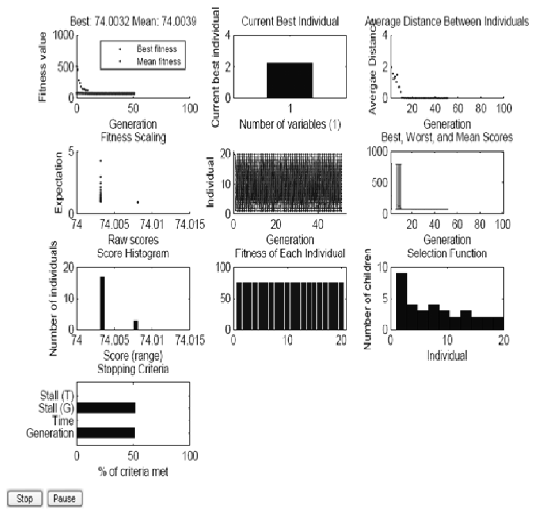

Fig. 4. Genetic Algorithm optimization process

The design parameters of the stator and rotor layout are then calculated. The design is evaluated for every individual in the population. The algorithm terminates after testing the specified convergence and achieving the optimum design. At this point, the designer is offered the option to view the performance analysis for the proposed design. If the optimization is satisfied, the design optimization process must then be stopped, otherwise the GA optimization process should be continued.

D. Objective Function

The designer can improve the value of the objective function reviewing constraint specifications. Here, an optimal design of an induction motor is designed which acts as a non-linear multi-objective optimization problem [23] - [26] and described by GA for its solution.

When a multi objective problem is treated, each objective conflicts with one another and unlike a single objective optimization, the solution to this problem is not a single one, but a family of solutions known as the Pareto-optimal set. To find the best solution for the entire problems one should take it into account the attributes of a handheld problem.

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The problem in the induction motor design is to select an appropriate combination of the design variables which can minimize the losses and improve efficiency and power factor [27] of SCIMs during low loading conditions, without reducing the full-load performance. The design process is much complicated while using too many variables. Therefore the number of design variables selection is important in the motor design optimization. The design optimization problem can be formulated as a general nonlinear programming problem of the standard form Find$X(X_1, X_2, \ldots, X_n)$, such that $J(X)$ is a maximum subject to $g_j(X) \geq 0, j = 1, 2, \ldots m$ and $xL_i \leq xL_i \leq xU_{ii} = 1, 2, \ldots n$, where is the set of independent design variables with their lower and upper limits as xL_i and xU_i, for all n variables. $J(X)$ is the objective function to be optimized and $g_i(X)$ is the constraint imposed on the design.

If J is the objective function to maximize the efficiency, it depends on the design variables X = (X_1, X_2, X_3… Xn), the corresponding optimization problem can be written as:

$$\begin{cases} \text{MAX } J(X) \\ \text{Subject to } G(X) \geq 0 \end{cases}$$

A set X of seven independent variables which affect constraints and objective function is listed below:

- Stator winding conductors length (m), X_1
- Ratio of stack length to pole pitch, X_2
- Stator slot depth to width ratio, X_3
- Stator core depth (mm), X_4
- Average air gap flux densities (T), X_5
- Stator current densities (A/mm^2), X_6
- Rotor current densities (A/mm^2), X_7

The remaining parameters can be expressed in terms of these variables or may be treated as fixed for a particular design. The saturation effect is neglected in the analysis.

The following factors are considered as SCIM design constraints: (a) Stator Copper Loss; (b) Rotor Copper Loss; (c) Stator Iron Losses; (d) Friction losses; (e) Stator Temperature Rise; (f) Full Load Efficiency.

E. Design Variables

The design and optimization of three phase SCIM requires a particular attention in the choice of the objective function that usually concerns economic or performance features. In this proposed design, our main objective to improve the efficiency during light loads. The expression of objective function, in terms of the design variables are summarized in the form of different constraints as follows.

The *Stator Copper Loss*, P_{SCL}, are given by:

$$P_{SCL} = 3 \cdot I_{ph}^2 \cdot R_s \,, \quad (1)$$

where I_{ph} is the phase current (A) and R_s is the equivalent per-phase stator resistance (Ω).

The Rotor Copper Loss , P_{RCL}, are given by:

$$P_{RCL} = \frac{\rho_r S_2 I_b^2}{a_b}(L_r + \frac{2D_e}{P}) \,, \quad (2)$$

where ρ_r is a constant (0.021), S_2 is the number of rotor slots, I_b is the rotor bar current (A), D_e is the mean end-ring diameter (mm), L_r is the length of the core (m), and p is the number of poles.

The Stator Iron Loss, P_{SIL}, are given by:

$$P_{SIL} = W_t \cdot P_{tk} + W_c \cdot P_{ck} \quad (3)$$

where W_t is the weight of the stator teeth, W_c is the weight of the stator core, P_{tk} is the losses in stator tooth portion (W/kg), and P_{ck} is the losses in stator core (W/kg).

The Full Load Efficiency, η, is given in percentage by:

$$\eta = \frac{1000\ P_O}{1000\,P_O + P_{SCL} + P_{RCL} + P_{SIL} + P_F} \times 100 \,, \quad (4)$$

where P_o is the output power (kW) and P_F are the friction losses (W). The stray load losses are neglected in the analysis.

For continuously rated machines, the final stator temperature rise θ_{ms} is a determining factor and with the assumption that cooling by convection, conduction and radiation is

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proportional to the temperature rise. In self-cooling (external fan coupled with the motor shaft), assuming a constant speed, the average inner temperature rise is directly proportional to the heat developed due to the inner losses and indirectly proportional to the cooling surface area, according to (5 and 6):

$$\theta_{ms} = \frac{\tau_c \, (P_{SCL} + P_{SIL})}{S_S}, \tag{5}$$

Where τ_c is cooling coefficient, S_s is stator cooling surface area, P_{SCL} is stator copper loss , P_{SIL} is stator copper loss and S_s is stator cooling surface area.

$$\theta_{mr} = \frac{\tau_c P_{RCL}}{S_r}, \tag{6}$$

Where τ_c is cooling coefficient, P_{SCL} is stator copper loss , P_{RCL} is rotor copper loss and S_r is rotor cooling surface area.
The cooling coefficient τ_c is given by:

$$\tau_c = \frac{k}{1+0.1u} \tag{7}$$

Where k is a constant (range of 0.003 to 0.005)

and u is relative peripheral speed as given by

$$u = \frac{2\pi fD}{P} \tag{8}$$

and the calculate stator cooling surface area is:

$$S_S = S_i(1 + 0.1u) + S_o, \tag{9}$$

where S_i and S_o are the inside and outside cylindrical surface area of the motor respectively.

The full-load power factor can be defined as:

$$PF = \frac{R_s + G_4}{\sqrt{\{(R_s + G_4)^2 + (X_5 + G_5)^2\}}}, \tag{10}$$

where X_5 is the average air gap flux density (Wb/m^2) and G_4 and G_5 are magnetizing constants.

The stator temperature optimization is an important design aspect and becoming a more important component of the electric motor design process due to the push for reduced weights and costs and increased efficiency. To obtain an accurate analytical thermal model, all the important heat transfer paths must be included in the network and suitable algorithms should be used to calculate thermal resistances for such paths.

This usually requires the experience of a heat transfer specialist, to construct an accurate thermal network. However, motor optimal design mathematical model have developed genetic algorithm, which automatically constructs an electric motor thermal network from the users inputs for motor geometry and their selection of materials and cooling coefficient.

F. Assigned Parameters for Optimal Design

Table I shows the assigned parameter value for motor design and the Table II shows the lower and upper limits of variables and constraints for the optimal design to improve the power factor and efficiency of 2.2 kW three phase squirrel-cage induction motor.

Table I
Assigned value of parameters used in motor design data

Parameters	Assigned data
Winding factor	0.96
Stator slot opening in mm	3.00
Rotor slot opening in mm	2.00
Stator slot wedge height in mm	3.00
Rotor slot wedge height in mm	2.00
Stator slot fullness factor	0.35
Rotor slot fullness factor	1.00
Radial air gap length in mm	0.50
Cooling coefficient	0.03

Table II
Lower and upper bounds of variables and constraints

Constraints	Lower	Upper
Ampere conductors per meter	15000	25000
Ratio of stack length to pole pitch	0.90	2.00
Stator slot depth to width ratio	3.00	5.50
Stator core depth in mm	2.00	5.00
Average air gap flux densities in wb/m^2	0.40	0.80
Stator winding current densities in A/mm^2	4.00	15.00
Rotor winding current densities in A/mm^2	4.00	15.00
Maximum stator tooth flux density in	0.50	2.00

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wb/m^2		
Stator temperature rise, °C	20.00	70.00
Full load efficiency in percentage	80.00	100.00
No load current, pu	0.02	0.500
Starting torque, pu	1.50	10.00
Maximum torque, pu	2.20	10.00
Slip, pu	0.01	0.05
Full load power factor	0.80	1.00
Rotor temperature rise, °C	10.00	70.00

These upper and lower limits are fixed by GA. Genetic Algorithm will then find the optimal values at maximum efficiency and power factor. To perform the test convergence process, if the optimal designed values are not achieved, the motor initial design variables must be updated and the new population range fixed within the specified limits of the individual variables.The optimization process is continued and it will find the optimal design values. Until the optimal design values for efficiency and power factor are reached, this algorithm process will continue.

G. Multiflux Winding Diagram

All the three phase induction motor have six accessible terminal leads, being possible two different connections delta(D) and star(Y). The multiflux three phase SCIM being considered in the presented study, has two sets of turns in each phase which can be connected either in series or parallel with the input voltage supply. The voltages between the terminals of each set same phase and phase angle, because they share the same flux path in the stator core. Thus, it is possible to achieve different levels of magnetizing flux, which can be properly selected as a function of the actual load.

The different possibilities of stator winding connections are presented in the Figs. 5-14. Namely, Delta Parallel(DP), Star-Parallel (YP), Delta-series type- I (DS1), Star Delta (YD), Star-series type-I (YS1), Star-series type-II (YS2), Delta-series type-II(DS2), Delta-series type - II (DS2) Connection Delta-series type II (DS2) Connection Star-series type II (YS2). Particularly, the YD hybrid connection mode is quite innovative. The reference connection [3] is assumed to be the delta connection with the two sets of turns connected in parallel (DP). The six connections are different flux levels out of ten connections, remaining are nearest same flux levels.

Assuming a supply voltage with constant frequency and without distortion, and neglecting the stator winding leakage inductance and resistance, the average fundamental magnetizing flux per pole and phase of an induction motor under no-load operation is approximately directly proportional to voltage between the terminals of each set of turns. However, if the stator winding magnetizing flux is properly regulated, both efficiency and power factor of the motors can be improved significantly in the low-load operating periods[3].

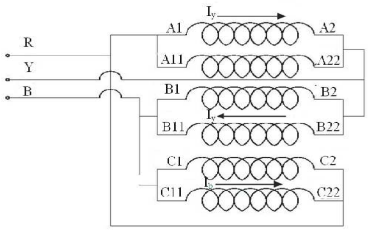

Fig. 5. Delta Parallel (DP) Connection.

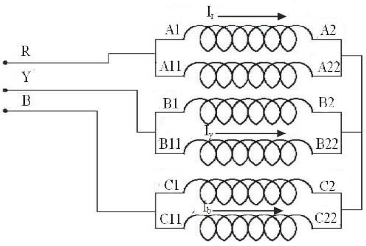

Fig. 6. Star-Parallel (YP) Connection.

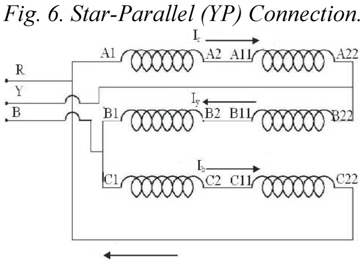

Fig. 7. Delta-series type I (DS1) Connection.

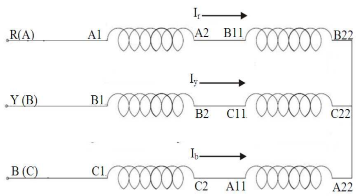

Fig. 8. Star Delta (YD) Connection.

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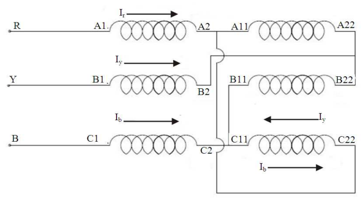

Fig. 9. Star-series type I (YS1) Connection.

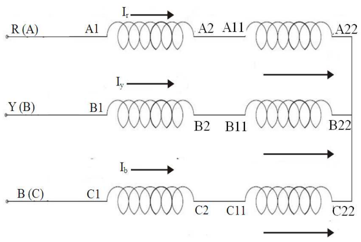

Fig. 10. Star-series type II (YS2) Connection.

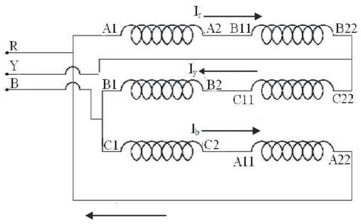

Fig.11. Delta-series type II (DS2) Connection.

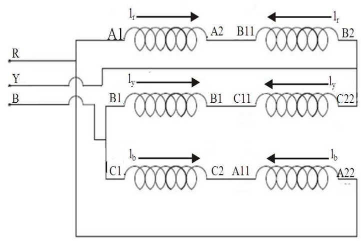

Fig. 13. Delta-series type III (DS3) Connection.

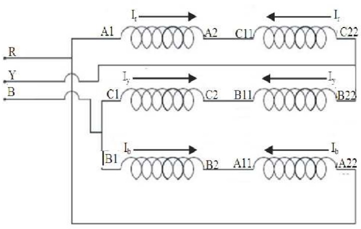

Fig. 14. Delta-series type IV (DS4) Connection.

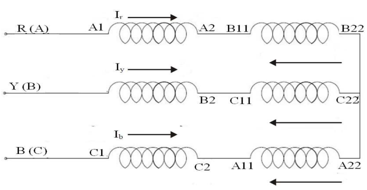

Fig. 15. Star-series type III (YS3) Connection.

3. SIMULATION RESULTS FROM GA-BASED OPTIMIZATION

In Fig. 15 , the simulated efficiency and power factor as a function of load for the different stator connections for the conventional design (base case) is shown. These curves were obtained experimentally and used to obtain the reference/initial values of the motor parameters. In Fig. 16, the simulated efficiency and power factor as a function of load for the GA-based optimized design is presented. The Table III shows the comparison of optimum values for maximum power factor and efficiency of different possible connections for of 2.2 kW three phase SCIM.

Based on the comparative analysis obtained for GA technique with different load conditions for each winding configuration. It is observed that GA provides optimal design of induction motor showing improved performance at various loads and also meets the design objectives. The results of simulation demonstrate that the proposed method

Table III
Comparison of the optimum data for 2.2 kWthreephase SCIM with different possible connections

Stator Mode Connection	% of Load	Maximum Efficiency		Maximum Power Factor	
		Conventional Design	Optimal Design	Conventional Design	Optimal Design
DP	60	87	91	0.86	0.89
YP	68	88	92	0.86	0.85
DS1	70	88	92	0.86	0.88
YD	75	88	92.2	0.86	0.86
YS1	80	88	92.7	0.87	0.89
YS2	83	89	93	0.87	0.90

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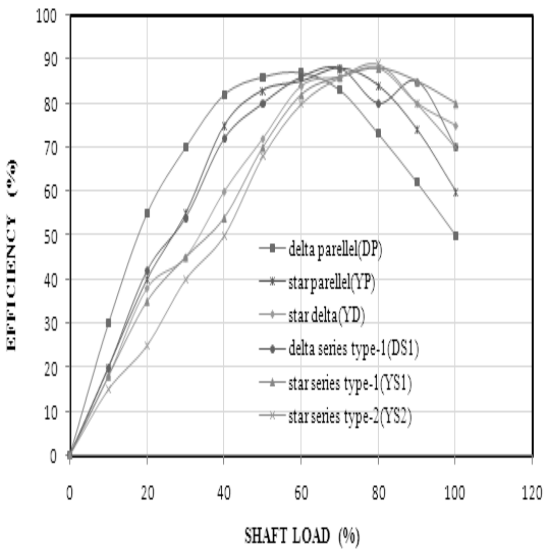

Fig. 15. Efficiency as a function of load for DP, YP, YD, DS1,YS1and YS2 conventional design connections .

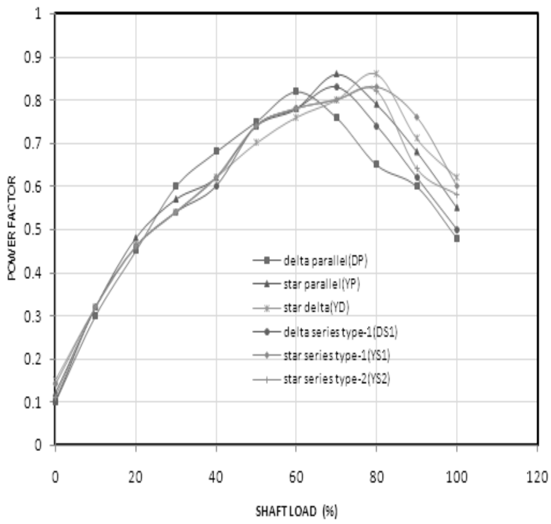

Fig. 16. Power factor as a function of load for DP, YP, YD, DS1,YS1and YS2 conventional design connections

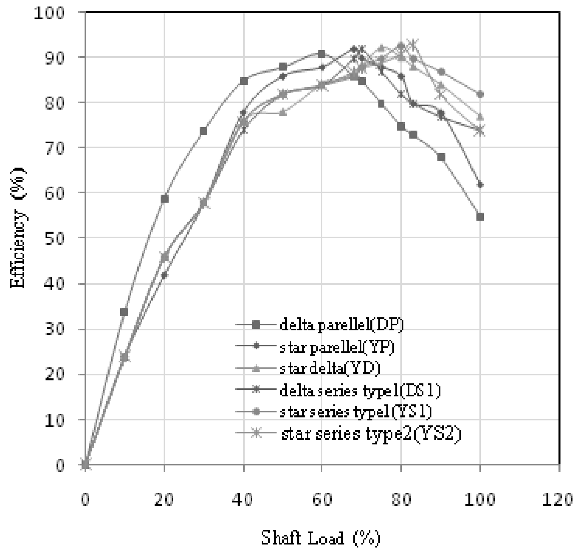

Fig. 17. Efficiency as a function of load for DP, YP, YD DS1, YS1 and YS2 optimum design connections.

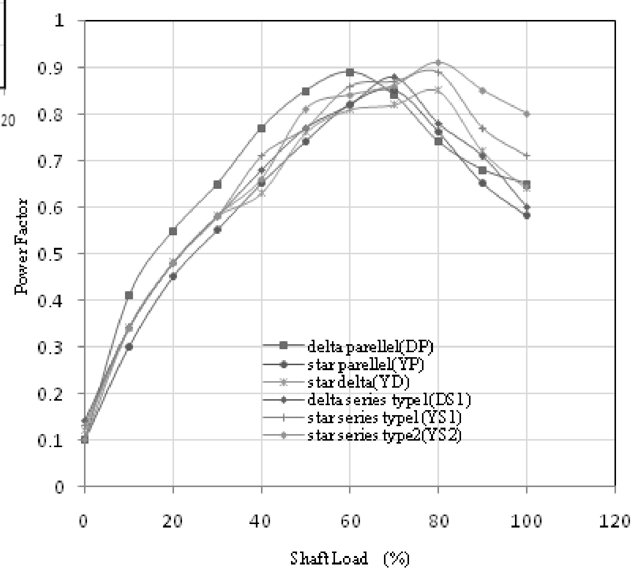

Fig. 18. Power factor as a function of load for DP, YP, YD DS1, YS1 and YS2 optimum design connections.

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can lead to a significant improvement in the efficiency and power factor of multi-flux SCIM, contributing to an increase in energy savings. Fig. 17 shows the efficiency characteristics and Fig.18 shows the power factor characteristics for multiflux stator winding with different connection modes of 2.2 kW three phase SCIM optimal design motor.

Table IV
Comparison of the conventional and optimal design data for 2.2-kW three phase SCIM.

Description	Conventional Design	Optimal Design
Length of stator in m	0.100	0.095
Diameter of stator in m	0.105	0.120
Ratio of L/ τ	0.5	0.40
Outer diameter of stator in m	0.210	0.165
Ampere conductor per meter	15000	23000
Stack length to pole pitch ratio	1.27	1.26
Stator depth to width ratio	3.89	3.85
Stator core depth in mm	3.92	3.91
Average air gap flux density in wb /m^2	0.45	0.5
Stator winding current density in A/mm^2	4.25	4.22
Rotor winding current density in A/mm^2	5.7	5.8
Stator Iron Loss (SIL) in watts	140	120
Stator Copper Loss (SCL) in watts	195	174
Rotor Copper Loss (RCL) in watts	110	94
Average efficiency	85	90
Average power factor	0.86	0.91

In Table IV, a comparison of the results for conventional and optimal designs is presented. It can be concluded that the otpimized three phase SCIM design results in significantly improved efficiency curves for all the connection modes. The parameter-less loss approach incorporated in the proposed algorithm to handle the constraints, prove to be effective.

4. Experimental Results

The present paper is aimed at improving the efficiency and power factor by reducing magnetizing flux at light loads through the connection mode change. The core losses are reduced by providing various stator winding combinations by which air gap flux has been controlled. Two 2.2.kW, 415 volts, 4 pole, 36 slots, three phase multi-flux squirrel cage induction motors have been fabricated and tested for two designed parameters. In the first design, conventional design procedure is adopted whereas an optimal design procedure like GA is adopted for second design.

In order to validate the optimized design second machine models have been fabricated with designed values that are obtained from GA optimization technique. The two machine models have been tested for their performances. The mean value of efficiency and power factor are also calculated from experimental.

Table- V
Comparison of the conventional, simulated design using GA and Machine Model with GA design data for 2.2-kW multi-flux SCIM.

Description	Conventional Design	Simulated GA Design	Model with GA Design Data
Length of stator (m)	0.100	0.095	0.095
Diameter of stator (m)	0.105	0.120	0.120
Outer diameter of stator (m)	0.210	0.165	0.165
Average air gap flux density (Wb/m^2)	0.45	0.5	0.5
Stator Iron Loss (W)	140	120	130
Stator Copper Loss (W)	195	174	185
Rotor Copper Loss (W)	110	94	100
Average Efficiency (%)	83.3	92.15	89.5
Average Power Factor	0.84	0.87	0.86

The Table IV shows the comparison of design and performance of conventional machine model and optimized design model. The following observations are made:

- Designed parameters using GA have been adopted in the design;
- The simulated efficiency obtained from the GA based design is 90% whereas in the designed model it is 88.5%;

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- The simulated power factor obtained from the GA based design is 0.91 whereas in the designed model is 0.89;
- The simulated stator Iron loss in the GA based design is 120 W whereas in the designed model it is 130 W.
- The simulated stator copper loss in the GA based design is 174 W whereas in the designed model is 185 W;
- The simulated rotor copper loss in the GA based design is 94 W whereas in the designed model is 100 W.

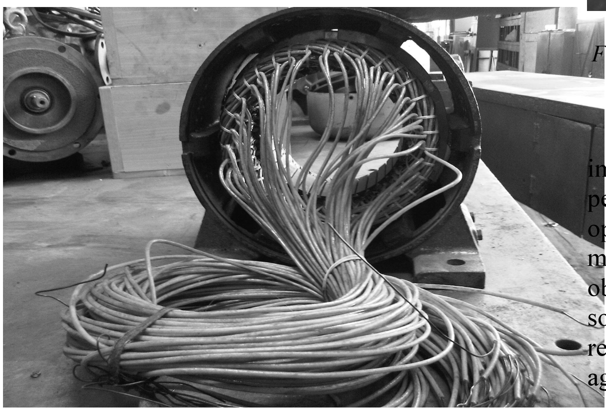

Fig. 19. 2.2- kW Multi-flux Stator winding for different connections

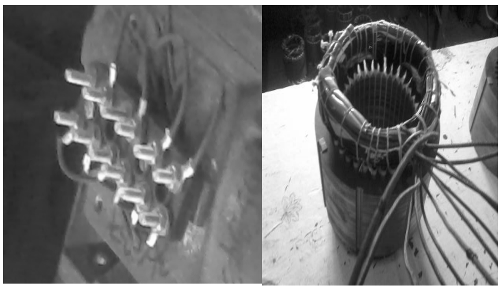

Fig. 20. 2.2- kW Stator winding with 12- terminals

The test results of the machine model based on GA almost agree with the simulated results. 2.2- kW multi-flux stator winding for different connections shown in the Fig.19. The stator core with winding 12- terminals for 2.2 kW multi-flux stator winding SCIM shown in the Fig. 20. The experimental studies have been carried out on a 2.2 kW multi-flux stator winding SCIM with suitable load as shown in the Fig. 21.

Fig. 21. Experimental setup for 2.2- kW multi-flux stator double layer winding SCIM

The soft computing GA technique is implemented for optimizing the design and performance of the induction motor. GA based optimized design values are used to fabricate a machine model. From the experimental it is observed that GA based design provides better solution than the conventional design. The test results of the machine model based on GA almost agree with the simulated results.

5. CONCLUSION

A GA-based design approach has been successfully applied to a 2.2-kW, 4-pole, multiflux three phase SCIM, in order to improve the efficiency and power factor cheraterstics from each possible connection mode. A software package that analyzes and optimizes the steady-sate performance of multi-flux SCIMs has been developed. The presented simulated results demonstrate that the proposed method can lead to signiifcant improvements in the efficiency and power factor of multiflux SCIM, contributing to increase their benefits in terms of energy savings. The improvement in performance is achieved by reducing the core losses by controlling the flux level. The result of simulation and comparative analysis for GA technique is presented in this paper. The test results of the machine model based on GA matches with the simulated results.

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