Improve the Efficiency and Power Factor of 2.2kW, Three Phase, Multi-Flux, Squirrel Cage IM through Optimal Design

S.S.Sivaraju, N.Devarajan

Abstract :This paper is proposed the novel method for design and optimization of three phase squirrel cage induction motor. The optimization is one of the key steps in the validation of the design process of the motor design and manufacturing systems and it is needed for eliminating inadvertent design mistakes and to achieve the maximum efficiency and power factor during variable load applications. This paper demonstrates the different optimization algorithms such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO) algorithm and Extreme Learning Machine (ELM) Algorithms are used. Then finally the multiple stator winding design and optimization process are carried by each algorithm and the obtained optimization results are compared by MATLAB Program.

Index Terms- Induction Motor, Genetic Algorithm (GA), Particle Swarm Optimization (PSO) algorithm, and Extreme Learning Machine.

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1 INTRODUCTION

Three phase squirrel-cage induction motors are widely used for various industrial and domestic applications such as pump drives, variable speed drives and etc., More than 80% of the electrical motors are three-phase squirrel-cage induction motors because of low production costs, more reliability and other features Induction motors are the main energy consuming devices in industries contributing to more than 80% of electromechanical energy conservation. Most physically large sized three-phase squirrel-cage induction motors operate with low efficiency [1, 10] large amount of power [11], which are the most important causes of poor power factor in industrial installations [6]. In the design, optimization of energy efficient induction motor is therefore the need of the day [7,8]. Two different optimization algorithms are considered to optimize the induction motor.

2. PROBLEM FORMULATION

The problem in the induction motor design is to select an appropriate combination of the design variables [5] which we minimized the losses and improved the efficiency, power factor of the three phase squirrel-cage induction motor during light loading periods. The design ultimate process is much complicated while using too many variables [3]. Therefore the number of design variables selection is important in the motor design [2] optimization. The design has some constraints, to guarantee the same motor performance indices. The design optimization problem can be formulated as a general nonlinear programming problem of the standard form:

Find X $(x_1,x_2\ldots\ldots x_n)$ such that J(X) is a maximum subject to and , where is the set of independent design variables with their lower and upper limits as xLi and xUi, for all 'n' variables. J(X) is the objective function to be optimized and is the constraint imposed on the design.

a.Definitions

If the J is the objective function to maximize the efficiency [4,9], it depends upon the design variables X= $(x_1,x_2\ldots\ldots x_n)$ and the corresponding optimization problem can be written as:

MAX J (X)
Subject to G(X)

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

b.Induction Motor Design Variables

A set X of seven independent variables which affect to constraints and objective functions are listed below

1. Ampere Conductors/m
2. Ratio of Stack Length to Pole Pitch
3. Stator Slot Depth to Width Ratio
4. Stator Core Depth (mm)
5. Average Air Gap Flux Densities (wb/m^2)
6. Stator Current Densities (A/mm^2)
7. Rotor Current Densities (A/mm^2) -

The remaining parameters can be expressed in terms of these variables or may be treated as fixed for a particular design.

c. Full Load Efficiency:

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

where
P_0 - Power in KW
W_{SCL} - Stator Copper Loss in W
W_{RCL} - Rotor Copper Loss in W
W_{SIL} - Stator Iron Losses in W
W_F - Friction Losses in W

d). Full Load Power Factor:

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$$PF = \frac{R_s + G_4}{\sqrt{\left\{(R_s + G_4)^2 + (X_5 + G_5)^2\right\}}}$$

where
R_S - Stator Resistance in Ohm
X_5 - Average Air Gap Flux Density (wb / m^2)
G_4, G_5 - Magnetizing Constants

3. DESIGN AND OPTIMIZATION ROBLEM

3.1. An 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 and then systematically evaluates and refines the solutions until a stopping criterion is met. There are three fundamental operators involved in the search process of a genetic algorithm: selection, crossover, and mutation. 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 then stop else continue.

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

Step 6: New generation. To continue the optimization, return to step 3. Genetic algorithm that produces good results in many practical problems is composed of the following three operators

Selection: Selection is a process in which individual strings are selected according to their fitness. The selection probability can be defined by

Where as
Pj is selection probability
F (xi) is objective function.

Crossover: This is the most powerful genetic operator. One of 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 chromosome1 goes to offspring2 and chromosome2 passes its code to offspring1. This operation takes place with a defined probability Pc that statistically represents the number of individuals involved in the crossover process.

Mutation: This 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 of the current region of parameter space. Mutation changes from a "1" to a "0" or vice versa. It may be illustrated as follows.

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3.2 Design and Optimization of Multiple Flux Stator Winding Using PSO

In this design, the PSO is used to find a set of design variables which ensure that the function F(X) has a minimum value and all the constraints are satisfied. The penalty-parameter-less approach is used to optimize the design. Hence the optimal design problem reduces to obtaining the design variables which correspond to the minimum value of an unconstrained function J(X). The procedure for optimal design of induction motor is as follows:1) Read specifications and performance indices of the motor; 2) Initialize PSO parameters such as Wmax, Wmin, C1, C2 and Itermax; 3) Generate initial population of N particles (design variables) with random positions and velocities; 4) Compute objective value and performance indices of the motor; 5) Calculate fitness: Evaluate the fitness value of current particle; 6) Update personal best: Compare the fitness value of each particle with its Pbests. If the current value is better than Pbest, then set Pbest value to the current value; 7) Update global best: Compare the fitness value of each particle with Gbest. If the current value is better than Gbest, set Gbest to the current particle's value; 8) Update velocities: Calculate velocities. 9) Update positions: Calculate positions. 10) Return to step (4) until the current iteration reaches the maximum iteration number; 11) Output the optimal design variables of the motor in the last iteration.

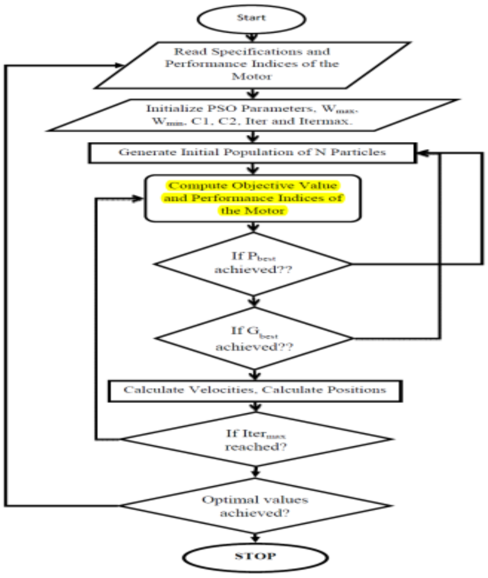

Fig.1 Flowchart for PSO Based Optimization Process

3.3.Optimization of Multiple Flux Stator Winding Using EMLA ections

In the ELM, the output weights are analytically computed by using the MP generalized inverse instead of iterative learning scheme. . As shown in Fig.2, the ELM consists of single-hidden layer feed forward networks (SLFNs). Fig. 3 shows the learning procedure and structure in ELMThe significant features of ELM can be summarized as follows:

1. The learning speed of ELM is extremely fast. It can train SLFNs much faster than classical learning methods.
2. The ELM tends to reach not only the smallest training error but also the smallest norm of weights. Thus, the ELM tends to have good performance for neural networks.
3. The ELM learning algorithm can be used to train SLFNs with non-differentiable activation functions.
4. The ELM tends to reach the solutions straightforward without such trivial issues.

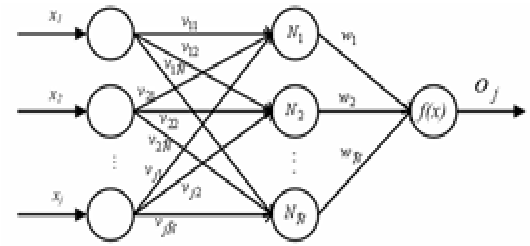

Fig.2-The structure of ELM

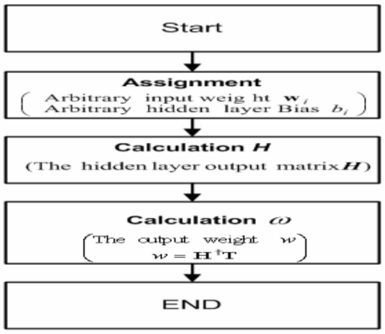

Fig. 3- The Learning Process of ELM

4. Simulation Results and Discussion

Conventional design of three phase induction motor parameter has been compared with optimally designed machine, which is proved that the optimization process is required for the induction motor design before manufacturing process to reduce the cost, and to achieve maximum efficiency, power factor at variable load applications, and also thus the tabulated results are better efficiency, power factor and less losses compare with the conventional design. From the tableted results observed among the three different types of algorithms the EMLA is produce the maximum efficiency and power factor, the Fig.4 shows that the efficiency as a function of percentage of load and Fig.5 power factor as a function of output power for the conventional double winding machines.

TABLE 1
COMPARISON OF CONVENTIONAL AND OPTIMAL DESIGN VALUES

Variables/ indices	Conventional Design	Optimal design GA	PSO	EMLA
Full-Load Efficiency (%)	84.176	93.234	93.427	93.743
Full-Load Power Factor	0.8432	0.893	0.943	0.962
Maximum Stator Temperature Rise in Degree Celsius	72.437	59.213	58.867	57.320
Maximum Rotor Temperature Rise	72.437	59.028	58.657	57.341
Maximum to Full-Load Torque ratio	2.598	2.623	2.658	2.712
Starting to Full-Load Torque Ratio	1.509	1.521	1.523	1.526
Starting to Full-Load Current Ratio	3.725	3.82	3.85	3.88
Length of Stator m	0.334	0.329	0.326	0.325
Diameter of Stator in m	0.252	0.234	0.232	0.233
Outer Diameter of Stator in m	0.319	0.297	0.295	0.296
Ratio of L/ τ	1.453	1.4766	1.4872	1.4952
Stator Iron Loss in Watts	144.57	132.89	130.57	130.32
Rotor Copper Loss in Watts	88.54	80.65	78.76	78.56
Stator Copper Loss in Watts	189.23	150.46	149.74	149.85
Ampere Conductors	15000	15000	15000	15000
Stack Length to Pole Pitch Ratio	1.2768	1.2658	1.2649	1.2634
Stator Depth to Width Ratio	3.8963	3.8565	3.8491	3.8472
Stator Core Depth mm	3.9258	3.9182	3.9176	3.9152
Average Air gap Flux Density (wb / mm2)	0.4125	0.4025	0.3992	0.4078
Stator Winding Current Density in Amps	4.25	4.221	4.235	4.258
Rotor Winding Current Density in Amps	7.75	7.814	7.827	7.856

4.1.Normal Design Efficiency Vs Percentage of Load

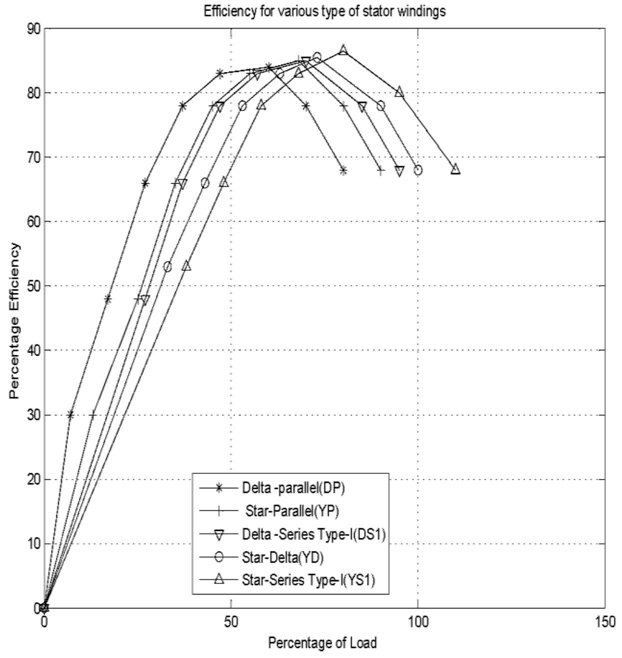

Figure 4a. Efficiency Vs Percentage of Load for DP,YP,DS1,YD and YS1 types of Stator Winding Connections

4.2.Normal Design Power Factor Vs Output Power

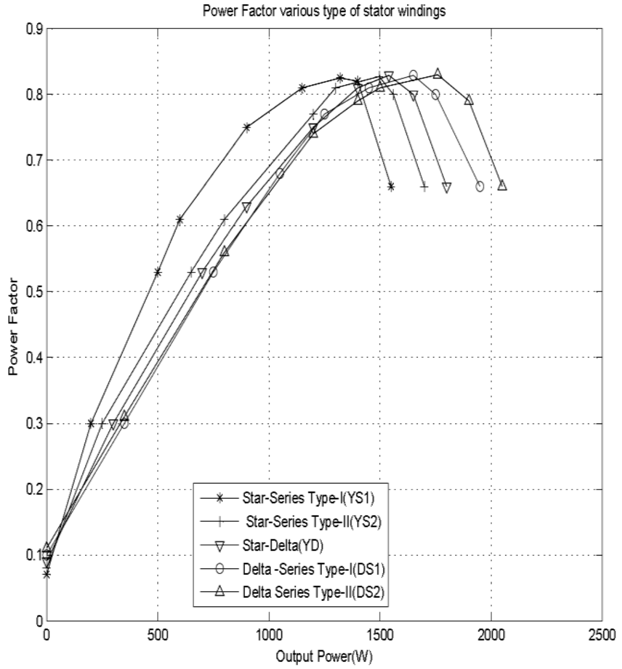

Figure 5.a. Power factor Vs Output Power for YS1, YS2, YD, DS1, and DS2 types of Stator Winding Connections

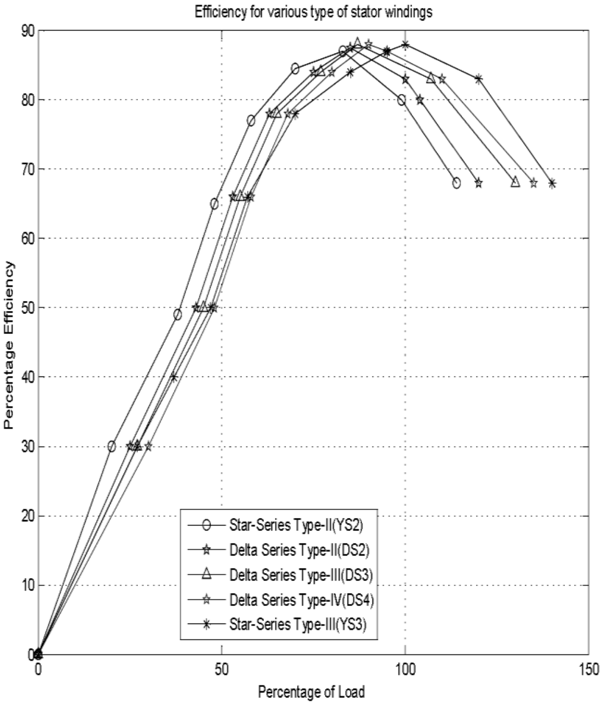

Figure 4.b. Efficiency Vs Percentage of Load for YS2,DS2,DS3,DS4 and YS3 types of Stator Winding Connections

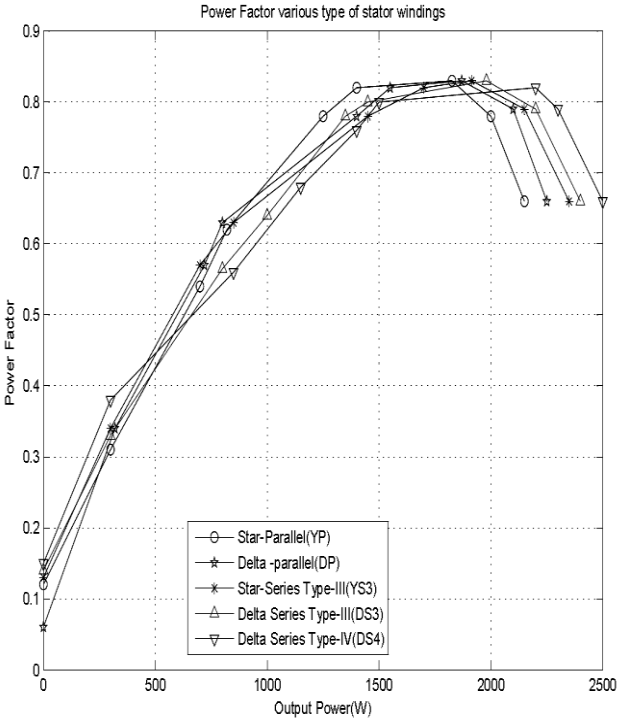

Figure 5.b. Power factor Vs Output power for YP, DP, YS3, DS3 and DS4 types of Stator Winding Connections.

4.3. Optimal Design by GA Efficiency Vs Percentage of Load

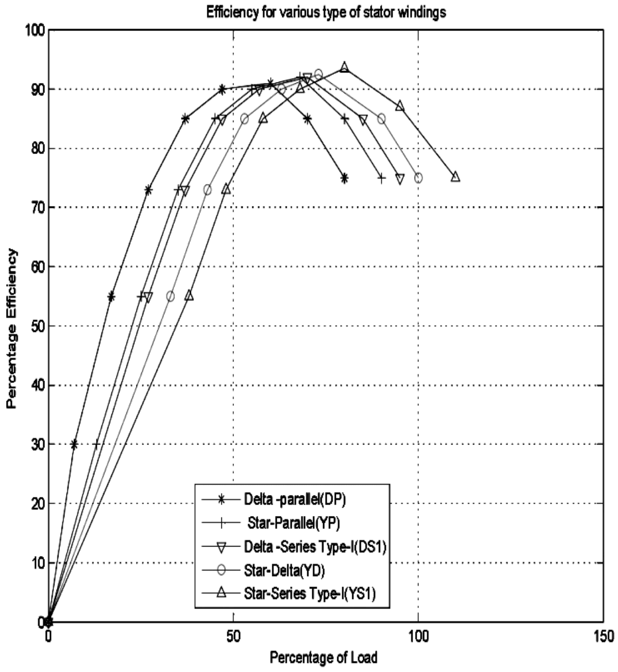

Figure 6.a. Efficiency Vs Percentage of Load for DP,YP,DS1,YD and YS1 types of Stator Winding Connections

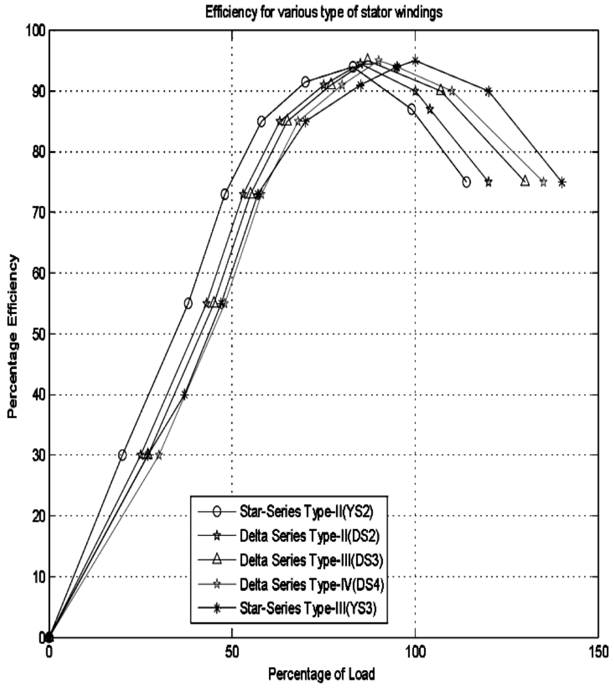

Figure 6.b. Efficiency Vs Percentage of Load for YS2,DS2,DS3,DS4 and YS3 types of Stator Winding Connections

4.4. Optimal Design by GA Power Factor Vs Output Power

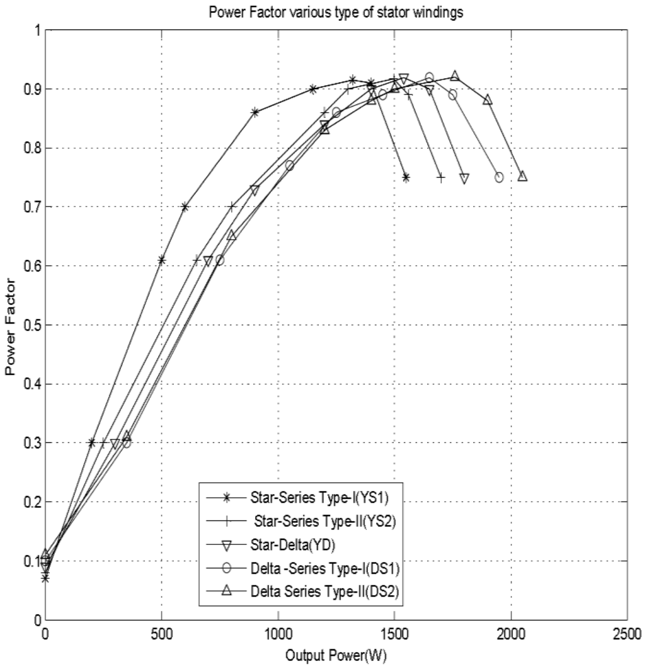

Figure.7.a. Power factor Vs Output power for YS1, YS2, YD, DS1, and DS2 types of Stator Winding Connections

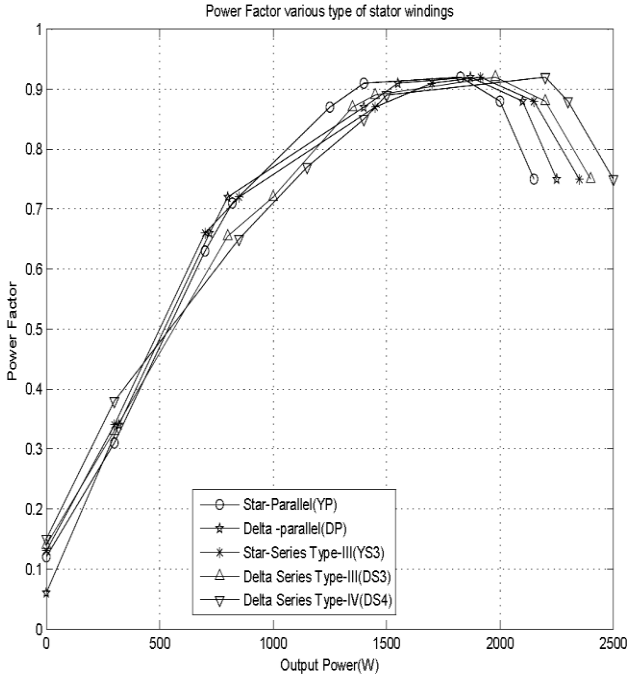

Figure 7.b. Power factor Vs Output power for YP,DP,YS3,DS3 and DS4 types of Stator Winding Connections

4.5. Optimal Design by PSO Efficiency Vs Percentage of Load

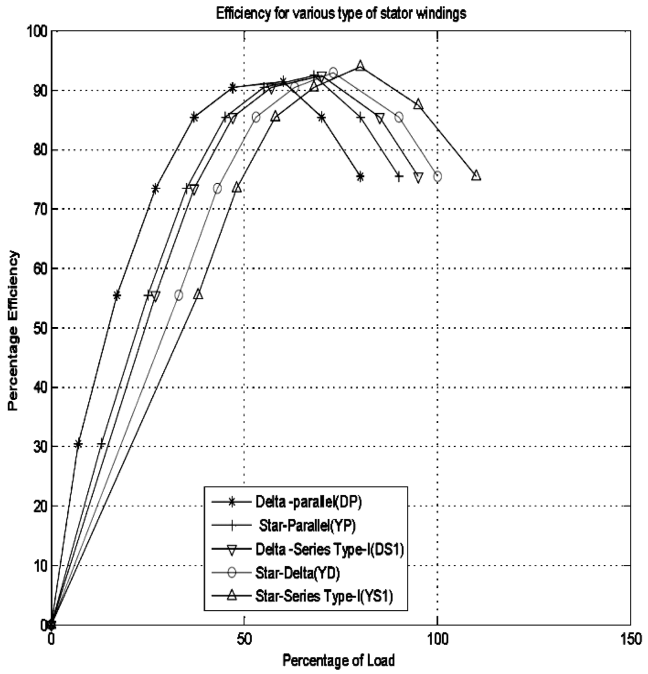

Figure 8.a. Efficiency Vs Percentage of Load for DP,YP,DS1,YD and YS1 types of Stator Winding Connections

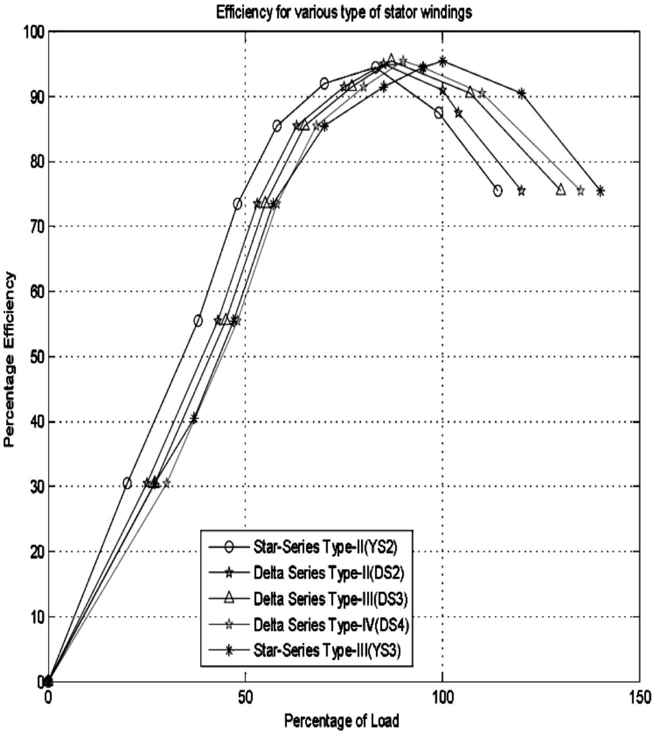

Figure 8.b. Efficiency Vs Percentage of Load for YS2,DS2,DS3,DS4 and YS3 types of Stator Winding Connections

4.6. Optimal Design by PSO Power Factor Vs Output Power

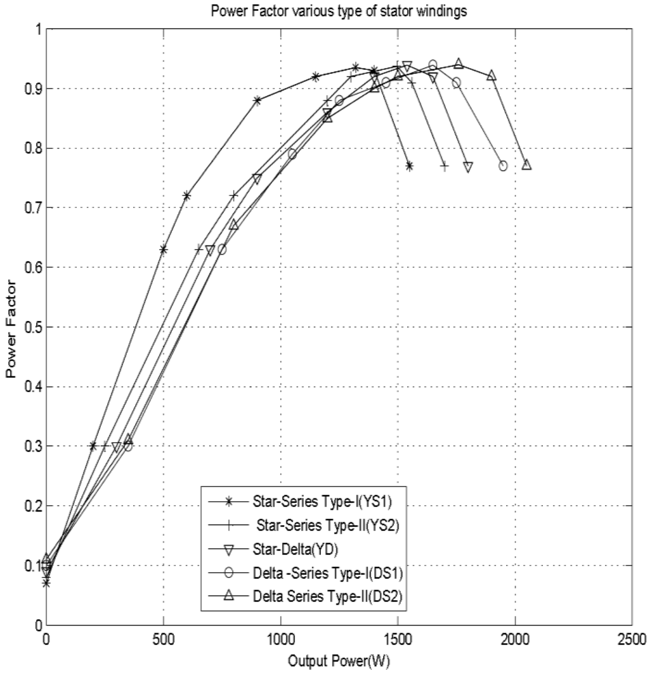

Figure 9.a. Power factor Vs Output power for YS1, YS2, YD, DS1, and DS2 types of Stator Winding Connections

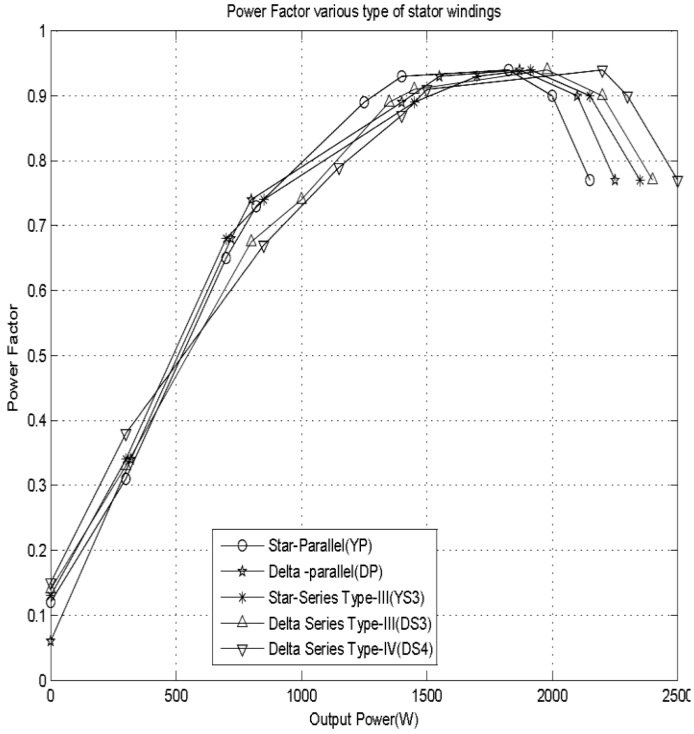

Figure 9.b. Power factor Vs Output power for YP,DP,YS3,DS3 and DS4 types of Stator Winding Connections.

4.7. Optimal Design by EMLA Efficiency Vs Percentage of Load

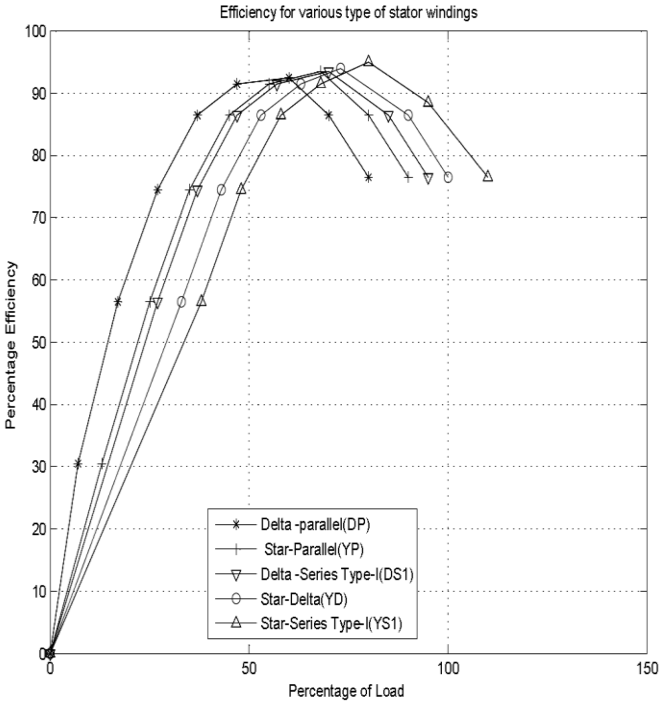

Figure 10.a. Efficiency Vs Percentage of Load for DP,YP,DS1,YD and YS1 types of Stator Winding Connections

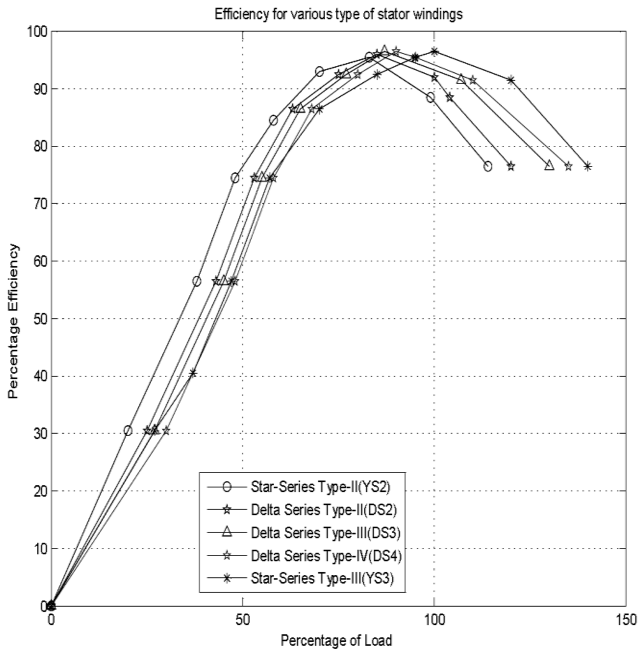

Figure 10.b. Efficiency Vs Percentage of Load for YS2, DS2, DS3, DS4 and YS3 types of Stator Winding Connections

4.8. Optimal Design by EMLA Power Factor Vs Output Power

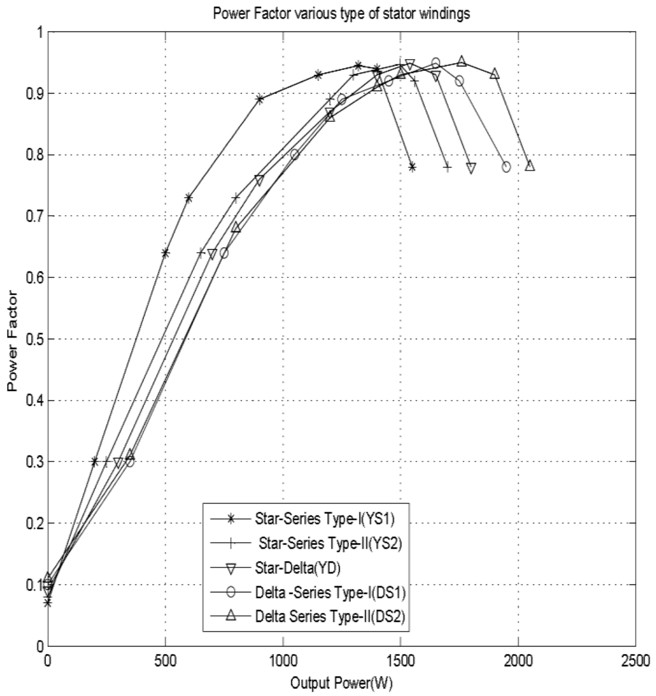

Figure 11.a. Power factor Vs Output power for YP1, YS2, YD, DS1, and DS2 types of Stator Winding Connections

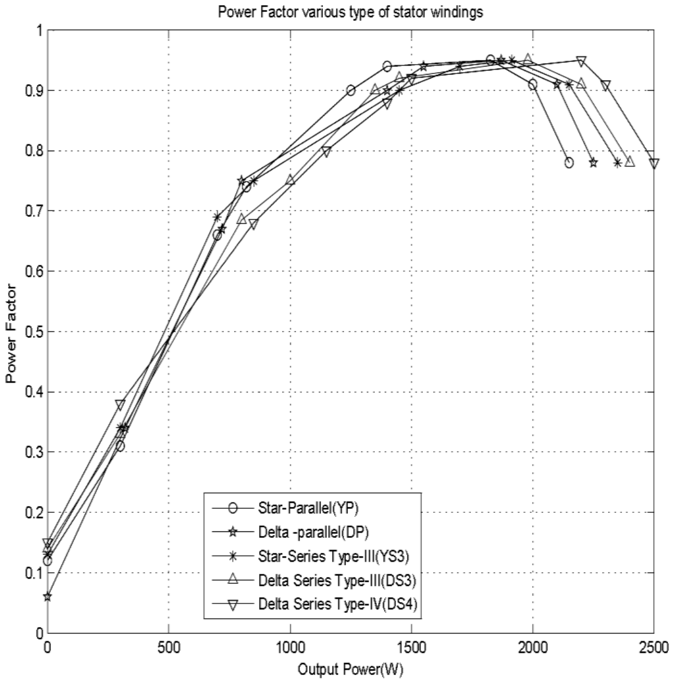

Figure 11.b. Power factor Vs Output power for YP,DP,YS3,DS3 and DS4 types of Stator Winding Connections.

Fig.6, 8, and 10 shows that efficiency as a function of percentage of load for optimal design of GA, PSO and ELM respectively, Fig. 7,9 and 11 shows that power factor as a function of output power for optimal deign of GA,PSO and ELM respectively. From the graphical analysis EMLA based optimal design to produce maximum efficiency and power factor. The Table.1 obtained from different optimization process which carried out by three phase induction motor.From these analyses the EMLA based optimal design is provide better efficiency, power factor and less losses compare with conventional design and other optimization algorithms.

6.CONCLUSION

A multiple stator winding incorporating a three-phase stator winding with two sets of turns is proposed, and also the connection modes are analyzed. The multiple stator winding can be used as a spare motor up to ten different nominal power levels and, in fact, it can operate as a high-efficiency motor for lower power levels. If necessary, at rated frequency for the nominal power, it can be used as a multi-voltage motor and can be fed with different line-to-line voltage levels without efficiency and power factor. The described concept can be used in motors with wide load variations and with long low load operating periods, in which the magnetizing flux regulation can lead to significant energy savings and power factor, efficiency improvements, as it has been optimally designed by GA, PSO and ELMA approach. An optimization technique based on GAs has been applied to the design of 3 HP (2.2 kW) three-phase induction motor. A package program that analyzes and optimizes induction motors in multi flux levels of stator windings and performance of the design has been developed. Comparison of the final optimum designs is made with the existing design. Finally, it is found that optimal designs produce larger efficiency, power factor and less losses of three phase squirrel cage induction motor.

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