DESIGN AND PERFORMANCE EVALUATION OF THREE PHASE INDUCTION MOTOR USING OPTIMIZATION TECHNIQUES AND GENETIC ALGORITHMS

Krishnamoorthy A. [1], Dharmalingam K. [2]

[1] Research Scholar, Sathyabama University, Chennai, India

[2] Dean, Academic Activities, RMD Engineering College, Kavarapettai, Chennai, India

Email: [1]ayyasamikrishnamoorthy@yahoo.com, [2]rmddharma@yahoo.com

Abstract

Optimization is usually done for any one of the functions associated with a system. In design problems usually a single objective function (say, Cost, Efficiency, Volume of Material used, Starting Current etc.) will be identified, which shall include the constraints imposed on the system also. Optimization can also be carried out with multiple objectives (say, Cost & Efficiency, Volume of Material & Stress handling capacity etc.), in which case, the problem becomes multi – objective programming problem and it can be solved by constructing an overall objective function as a linear combination of multiple objective functions. A research work is under progress on “Design and Performance Evaluation of Three Phase Induction Motor using Optimization Techniques and Genetic Algorithms”, which aims at developing a software, which upon providing minimum basic input data about the machine (such as overall dimensions, specification constraints etc) to be designed, designs the various parameters ably supported with suitable optimization techniques, to obtain an optimized end result. Induction motor design optimization is a problem in non-linear programming solved by the method of Sequential Unconstrained Minimization Technique (SUMT). Design Optimization is to be carried out using Hooke and Jeeves method of optimization and also using Genetic Algorithms.

Key words: : Hooke and Jeeves method, Genetic Algorithms, SUMT, Harmonic Analysis

I. INTRODUCTION

In recent years digital computers are being widely used in all stages of Electrical Machine Design namely analysis, synthesis and optimization. The high-speed digital computers enable the implementation of optimization procedure for electrical machines to satisfy certain specification constraints. Optimization is the act of obtaining the best result under the given circumstances. The quantity to be optimized may be one of the many varieties of different possibilities, e.g., a particular item of performance, cost of device or quality or reliability. A research work is under progress on “Design and Performance Evaluation of Three Phase Induction Motor using Optimization Techniques and Genetic Algorithms”, which aims at developing a software, which upon providing minimum basic input data about the machine (such as overall dimensions, specification constraints etc) to be designed, designs the various parameters ably supported with optimization technique, to obtain an optimized end result. Induction motor design optimization is a problem in non-linear programming solved by the method of Sequential Unconstrained Minimization Technique (SUMT).

Design Optimization is to be carried out using Hooke and Jeeves method of optimization and also using Genetic Algorithms. In this research work, it is proposed to carry out Cost optimization in the design of three phase induction motor (i.e., Single objective optimization). Additionally Efficiency optimization along with cost optimization will also be carried out (Multi – Objective Optimization), which can be solved by constructing an overall objective function as a linear combination of multiple objective functions(4, 6). If $f_1(X)$ and $f_2(X)$ denote two objective functions, then the Overall objective function for Optimization is represented as

$$f(X) = \alpha_1 f_1(X) + \alpha_2 f_2(X) \qquad (1)$$

where α_1 and α_2 are constants whose values indicate the relative importance of one objective function with respect to the other. The various aspects associated with the design of three phase induction motor (including the constraints) is being studied.

The various aspects associated with the proposed research are summarized below:

- Study of Electrical Machine Design, including special machines' designs.
- Collection of data relevant to machine design (such as overall dimensions, rating, specification constraints etc) from the electrical machine manufacturers.
- Design to be carried out using conventional optimization technique, Hooke and Jeeves Method.
- Design to be carried out using Genetic Algorithms.
- Design to be carried out combining the merits of conventional Optimization techniques and Genetic Algorithms.
- Software development to satisfy all the design criteria and specification constraints focusing the end results.

- Comparative study of the optimized parameters obtained.

The proposed research, upon successful completion, shall provide the electrical machines manufacturers wide options in the design parameters and enable them to use the best one of their choice.

As a part of the research, an attempt has been made to optimize the design of phase controlled (stator voltage controlled) induction motor. A method for the analysis of the performance is also presented. In this method, the Fourier sinusoidal components of the non-sinusoidal stator voltage are applied to the steady state harmonic equivalent circuit of the induction motor. Using the principle of superposition, the currents and torques from each of the equivalent circuits can be summed to give the total response of the machine. These operational parameters are introduced as constraints while optimizing the total material cost of the induction motor. Eleven geometric parameters having predominant influence on the cost and performance of the motor are chosen as independent variables. Optimization has been carried out using the direct search method, Hooke and Jeeves method.

II. OPTIMIZATION TECHNIQUES

Optimization is the act of obtaining the best result under given circumstances (11). It can also be defined as the process of finding conditions that give the maximum or minimum value of a function. The design optimization problem can be solved using Sequential Unconstrained Minimization Technique (SUMT) (12). In SUMT, the constrained optimization problem is converted into a series of unconstrained problems in the following manner: The augmented function at the beginning of k^{th} iteration is

$$P^k(X) = F(X) + R^k \Sigma 1/(g_i(X)), \quad R^k > 0 \qquad (2)$$

F (X) is the cost function. The sigma term, called the penalty term, is to ensure that during the minimization process no constraint is violated. The process is started with an initial feasible design X^0, i.e., a design satisfying all the constraints and some value of R^1. The P^1 function is minimized with X^0 as starting point without any constraints to get to a point X^1. Now the new augmented function P^2 is formed with $R^2 < R^1$ and is again minimized with X^1 as the starting point. It is proved in SUMT that the sequence of minima created with decreasing values of R^k converges to the required solution of the constrained minimization problem. Essentially the problem is then to get the minimum of P.

Some of the optimization techniques widely used are (12): Steepest Descent method, Davidson-Fletcher Powell method, Powell's method of conjugate directions, Hooke and Jeeves method, Modified Hooke and Jeeves method, Random Search methods etc. Among the above-mentioned methods, Hooke and Jeeves method and Powell's method are best suited for the problem under consideration as they enable convergence quickly to the optimized values for the specified accuracy limits (11).

III. AN OVERVIEW OF GENETIC ALGORITHMS

Genetic Algorithms (mimic the principles of Natural Genetics and Natural selection to constitute search and optimization procedure(2). 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 evaluates and refines the solutions until a stopping criterion is met (9,13). There are three fundamental operators involved in the search process of a genetic algorithm: selection, crossover, and mutation. The detailed flowchart of genetic algorithm is shown in Fig. 1. 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.

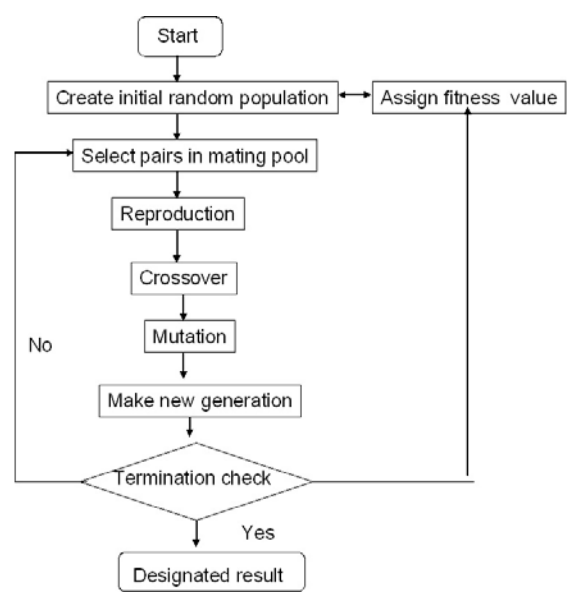

Fig. 1. Flowchart of Genetic Algorithm

In the recent works connected with GAas in the design optimization of Electrical Machinery, it has been observed that the GAs locate the global optimum region faster than the conventional direct search optimization techniques (1, 3, 8, 13, 14, 16).

IV. OPTIMIZATION OF INDUCTION MOTOR

As a part of the research work mentioned, optimized design of Induction motor has been carried out. Induction motor design optimization is a problem in Non-Linear Programming solved by the method of Sequential Unconstrained Minimization Technique (SUMT) (10). In this project, an attempt has been made to optimize the design of phase controlled induction motor. It has been found that direct search methods are best suited for the types of function occurring in rotating machine design problems and hence Hooke and Jeeves method of optimization is adopted in the design. A general non-linear programming problem (12) can be stated mathematically as follows:

Find $X = (X_1, X_2, \ldots\ldots X_n)$ such that F (X) is a minimum and $g_i(X) \geqslant 0$ for i = 1, 2, ...n (3)

X is a set of independent variable concerning the electrical and magnetic circuits of the machine. Out of the 50-odd variables concerning the electrical and magnetic circuits of the machine, only some have a predominating influence on the cost and performance of the motor (7). In the problem under consideration, eleven such predominant parameters listed in the Table 1 are considered as independent variables while the other parameters are either referred in terms of the 11 parameters listed in Table 1 or treated as fixed for a particular problem. All lengths are expressed in centimeters and air gap flux density in Tesla (5). The function to be minimized is formed by considering the cost of electrical conducting and magnetic materials. A penalty function is introduced in the design to incorporate the Constraints on specifications so that while optimizing the design, no constraint is violated (7). The various constraints imposed in the design are given in Table 2. The design procedure is based on the direct search method proposed by Hooke and Jeeves and the procedure requires no derivatives. The procedure assumes a unimodal function. Therefore, if more than one minimum exists or the shape of the surface is unknown, several sets of starting values are recommended. The motor designed has the following specifications: Motor rating 1 HP; Input Voltage 400 V, 50Hz., 3-Phase; No. of Poles –4; 1500 rpm; The function to be minimized is F, formed by considering the cost of electrical conducting and magnetic materials. (For this, the cost of Iron (Steel), Copper and Aluminium were taken as Rs. 80, Rs. 200, and Rs. 65 per Kilogram respectively.) F is the summation of costs of Stampings, Stator Copper and Rotor Cage Aluminium (5).

Table 1. Parameters for independent variables

Sl. No.	Description of the independent variable	Independent variable
1.)	Stator Bore Diameter	X_1
2.)	Stator Stack Length	X_2
3.)	Depth of Stator slot	X_3
4.)	Width of Stator slot	X_4
5.)	Depth of Stator core	X_5
6.)	Depth of Rotor slot	X_6
7.)	Width of Rotor slot	X_7
8.)	Air gap flux density	X_8
9.)	End ring depth	X_9
10.)	End ring width	X_{10}
11.)	Air gap length	X_{11}

Table 2. Identified constraints in the design

Sl. No	Description of the Constraint	Magnitude
1.)	Starting Current	? 9.09 A
2.)	Starting Torque	? 11.90 N m
3.)	Pull-out Torque	? 12.05 N m
4.)	Full Load Slip	? 0.17
5.)	Full Load Temperature Rise	? 75 º C
6.)	Full Load Power Factor	? 0.8

V. METHOD OF HARMONIC ANALYSIS

Phase control schemes offer a very economical method to vary the speed of induction motors in some special applications. The use of back-to-back connected thyristors in lines, as shown in Fig. 2, offer a simple method of speed control. The transient and steady state analysis of the induction motor under such conditions has given rise to new problems of analysis. The problems arise mainly because of the fact that the thyristors introduce current constraints and the period during which they conduct is initially unknown in general. A method using steady state harmonic equivalent circuits is also reported]. In this case, only ODD harmonics need be considered because of waveform symmetry. Triplen Harmonics will not be present since it is assumed that the motor has an isolated neutral. Good accuracy is obtained with just 17 harmonics. Also a method for the analysis of the performance of the stator voltage controlled induction motor is presented. In this method, the Fourier sinusoidal stator voltage is applied to the steady state harmonic equivalent circuit of the induction motor, which is shown in Fig. 3. Using the principle of Superposition, the current and torque from each of the equivalent circuit can be summed to give the total response of the machine. These operational parameters are introduced as constraints while optimizing the total material cost of the induction motor. There are five major steps in this analysis:

1.) Calculation of Phase angle

2.) Calculation of the supply voltage for various harmonics during ON period.

3.) Calculation of induced voltages for various harmonics during OFF period.

4.) Calculation of Phase voltages for various harmonics.

5.) Calculation of harmonic components of torque and current and finding the total response.

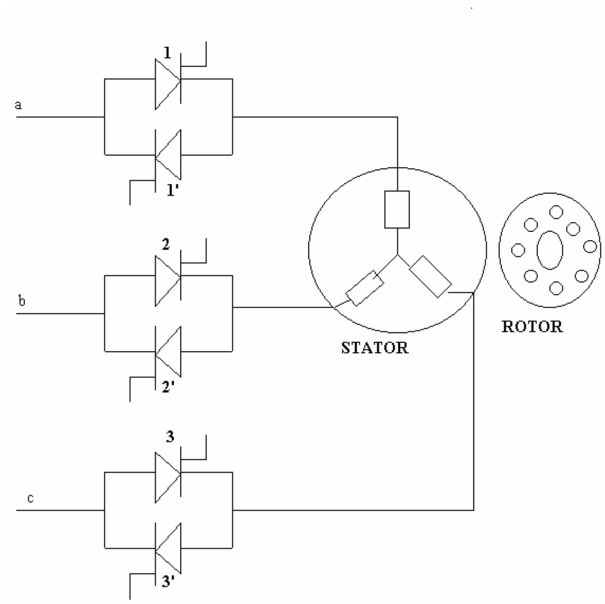

Fig. 2. Fort Phase Control

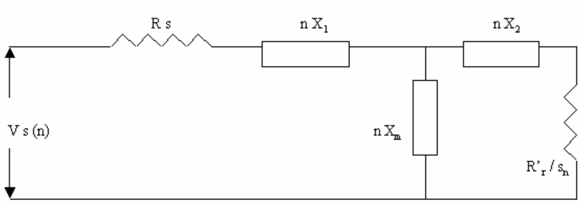

Fig. 3. Steady State nth Harmonic Circuit

VI. RESULTS

The programs written for the stator voltage controlled induction motor problem under consideration have been tested & the results have been tabulated. For the sake of clarity, only few iterations and the final value are shown in the results presented in the tabular forms. Variations of main dimensions with each iteration are shown in Table 3. Variations of constraints with each iteration are shown in Table 4 and Variations of cost with each iteration are shown in Table 5. For the motor under study the speed variation contemplated is from 1340 rpm to 1295 rpm under full load conditions using thyristors. The conduction angles assumed are from 180º to 150 º in steps of 5 º. The performance of the motor for these conduction angles is presented in Table 6.

Table 3. Variations of Main Dimensions with each iteration

It. No.	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}
0	8.4	7.25	0.3893	1.543068	2.0752	0.14777	1.1754	0.5	0.77	0.702	0.03384
1	8.4	7.25	0.3893	1.543068	2.0752	0.14777	1.2754	0.51	0.87	0.702	0.03284
2	8.4	7.25	0.3693	1.543068	2.0552	0.14777	1.2954	0.512	0.89	0.702	0.03264
3	8.4	7.25	0.3653	1.543068	2.0512	0.14777	1.2994	0.5124	0.886	0.698	0.0326
Final Value	8.4	7.25	0.3653	1.543068	2.0512	0.14777	1.2994	0.5124	0.886	0.698	0.0326

Table 4 Variations in constraints with each iteration

It. No.	Starting Current, A	Starting Torque N m	Pull-Out Torque, N m	Full Load Slip, per unit	Full Load Power Factor, per unit	Full Load Temperature rise, °C
1	8.615075	25.46026	27.40202	0.109249	0.993058	71.51138
2	8.678681	25.19471	26.81576	0.106397	0.993286	73.74187
3	8.669104	25.12957	26.7301	0.106398	0.993294	74.09694
Final Value	8.64788	24.9925	26.55198	0.106429	0.993308	74.83279

Table 5. Variations of cost with each iteration

It. No.	Steel Cost, Rs.	Copper Cost, Rs.	Aluminium Cost, Rs.	Total Cost, Rs.
1	425.3	1146	10.8	1582
2.)	423	1087	10.98	1521
3.)	422.3	1078	10.98	1512
Final Value	420.9	1060	10.99	1492

Table 6. Variations in the performance of motor for various conduction angles

Conduction Angle	Starting Current		Torque		Full Load Slip		Full Load Rotor Current	
	A	Per unit	N m	Per unit	-	Per unit	A	Per unit
180°	8.601147	1	12.542	1	0.106429	1	1.2754	1
175°	8.527243	0.9914	12.328	0.983	0.108878	1.023	1.284	1.0067
170°	8.430346	0.9801	12.032	0.959	0.112215	1.0544	1.3427	1.0528
165°	8.311092	0.9663	11.662	0.93	0.116654	1.0961	1.4279	1.1196
160°	8.16791	0.9496	11.217	0.894	0.122419	1.1502	1.5229	1.1941
155°	7.997831	0.9299	10.702	0.853	0.129828	1.2199	1.6122	1.2641
150°	7.797303	0.9065	10.143	0.809	0.139226	1.3082	1.6758	1.3139

VII. CONCLUSION

From the results it is concluded that the presence of harmonic voltages and hence currents not only increases the full load current and consequently the heating of the machine but the starting torque and pull out torque are also deteriorated. . Also it is observed that the motor power rating has to be increased when the effect of harmonics are included. From the study of effects of harmonics using Fourier analysis technique, it is found that the motor power rating has to be increased by a factor 1.63 when the effects of harmonics are included.

Effects of harmonic currents on the iron losses have not been included in this study. It is likely that increased iron losses may further push up the cost and heating of the rotor and hence further de-rating of the motor may have to be carried out.

REFERENCES

[1]. Abdelhadi, B., Benoudjit, A. and Nait,N., 2004, "Identification of Induction machine parameters using a new adaptive genetic algorithm. Electric Power Components and Systems", EMP 32(8), pp. 763-784.

[2]. Bianchi, N, and Bolognani, S. 1998, "Design Optimization of Electric Motors by Genetic Algorithm", IEE Proc.-Electr. Power Appl. col. 145, no. 5, pp. 475-483.

[3]. Çunkaş, M. and Akkaya R 2004, "Design optimization of three-phase induction motors by using genetic algorithms", Int. Aegean Conf. on Electrical Machines and Power Electronics, Istanbul, Turkey, pp. 408-413.

[4]. Kim, M.K, Lee C.G. and Jung H.K. 1998, "Multiobjective Optimal Design of Three-phase Induction Motor Using Improved Evolution Strategy", IEEE Trans. On Magnetic, vol. 34, no. 5, pp 2980-2983.

[5]. Krishnamoorthy, A. 1993, "Design Optimization of Phase Controlled Induction Motor", Dissertation, M.E. (Applied Electronics), Coimbatore Institute of Technology, Coimbatore-14.

[6]. Liuzzi, G., Lucidi, S., Parasiliti, F. and Villani, M. 2003, "Multiobjective Optimization Techniques for the Design of induction motors", IEEE Trans. on Magnetics, vol. 39, no. 3, pp. 1261-1264.

[7]. Marimuthu, P. and Krishnamurthy, M.R. 1982 "Optimization of Pole-Changing Single Winding Induction Motor Design", Int. Conf. on Electrical Machines, Budapest, GP3/7, pp. 826-829.

[8]. Mehmet, C. and Ramazan, A. 2006, "A View of Genetic Algorithms Approaches to Electrical Machines Optimization", Proceedings of 5th Int. Symposium on Intelligent Manufacturing Systems, pp. 258-268.

[9]. Mehmet, C. and Ramazan, A. 2006, "Design optimization of induction motor by genetic Algorithm and comparison with existing motor", Proceedings of Mathematical and Computational Applications, vol. 11, no. 3, pp. 193-203.

[10]. Ramarathnam, R. and Desai, BG 1997 "Optimization of Polyphase Induction Motor Design: A non-linear programming approach", IEEE transactions on Power Apparatus and Systems, vol.PAS-90, pp. 570-578.

[11]. Ramarathnam, R., Desai, B.G. and Subba Rao, V.1972, "A Comparative study of minimization techniques for optimization of Induction motor Design", IEEE Trans. on Power Apparatus and Systems, pp. 1148-1453

[12]. Rao, S.S. 2001, "Optimization Theory and Applications", Wiley Eastern Ltd.,

[13]. Sareni, B., Krahenbuhl, L. and Nicolas A. 2000, "Efficient Genetic Algorithms for solving hard constrained optimization problems", IEEE Trans. on Magnetics, vol.36, no. 4, pp.1027-1030.

[14]. Üler, GF, Mohammed, OA., and Koh CS 1995, "Design Optimization of Electric Machines using Genetic Algorithm", IEEE Trans. on Magnetic, vol. 31, no. 3.

[15]. Wieczorek, J.P, Göl Ö, and Michalewicz Z 1998 "An Evolutionary Algorithm for the Optimal Design of Induction Motors", IEEE Transactions on Magnetics, vol. 34, no. 6, pp.3882-3887.

[16]. Wurtz, F, Richomme M, Bigeon J, and Sabonnadiere J.C 1997 "A Few Results for Using Genetic Algorithms in the Design of Electrical Machines", IEEE Trans. On Magnetics. vol. 33, no. 2, pp. 1892-1895.