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A GSA Based Torque and Loss Optimisation of an Induction Motor

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ABSTRACT: This paper presents an effective multi objective optimization method for minimizing losses and maximizing torque of an Induction Motor by Gravitational Search Algorithm (GSA) .The objective function related to torque is considered as first objective and objective function related to losses is taken as second objective for multi objective optimization. The parameters of induction motor considering above two objectives are calculated with developed GSA. Losses and torque of an optimally designed motor is compared with the existing motor having the same rating. Simulation results are discussed to validate the proposed concept. The simulation results exhibits a better characteristics and efficient induction motor for industrial application.

Keywords: Gravitational Search Algorithm (GSA), Gravitational constant, Induction Motor, Loss minimization, and Torque maximization.

I.INTRODUCTION

Within the past few years, many researchers have tended toward optimization-based approaches [1]–[4] for solving equations. The enhanced bee swarm optimization algorithm and self-adaptive modified firefly algorithm are implemented in [1] and [2], respectively, for solving the complex dynamic economic dispatch problem. One of the newest evolutionary algorithms is gravitational search algorithm (GSA), presented by Rashedi et al. in [5]. GSA is extensively used in different optimization problem due to fast convergence and suitability of handling mixed integer problems.

Three phase induction motor is used in industrial, commercial, domestic application for several decades. Particularly squirrel cage induction motor is mostly used for this purpose. Thus it is very essential to design efficient induction motor. To get maximum efficiency, losses should be minimized but at the same time torque must be optimum. Regarding the optimization of motor loss and torque the motor parameters i.e. resistances and inductances of the stator and rotor are taken for optimization [6].Initially the expression of torque of an induction motor is maximized with developed Gravitational Search Algorithm, then the expression of loss of an induction motor is minimized. Finally both the torque and loss expression is optimised considering multi-objective optimization of GSA.

Standard non-linear programming method can be used to solve these types of problem. But due to its expensive computational time it is rarely used [7-9]. With loss& torque expression it is possible to calculate the optimum value of resistance and inductance. Thus GSA [10] is applied to calculate the parameters for optimization of losses and torque.

II.INDUCTION MOTOR EQUIVALENT CIRCUIT

The equivalent circuit for a three-phase induction motor is shown in Fig.1. Where s represents slip, R_s is the stator resistance, R_r is the rotor resistance, L_s is stator inductance, L_r is rotor inductance. R_c is the core loss resistance which represent core loss of an induction motor & L_m is the mutual inductance.

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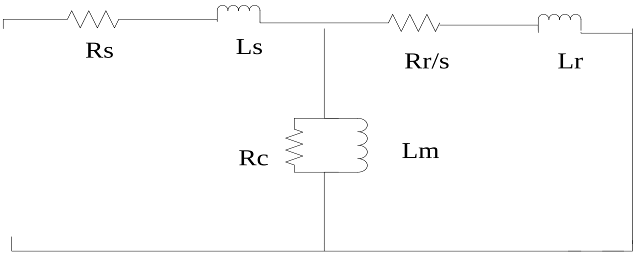

Fig. 1 Induction motor equivalent circuit

III.PROBLEM DEFINITION AND IMPLEMENTATION USING GSA

The expression of torque and losses are optimized using GSA to get optimum parameter value. Firstly the expression of torque is maximized to get rated torque at a particular voltage. The equation (1) represents the torque equation.

$$T = \frac{V^2}{n}\frac{R_r}{\left(R_s+\frac{R_r}{s}\right)^2+(X_s+X_r)^2} \qquad (1)$$

Where X_s=2πfL_s, X_r=2πfL_r, n is synchronous speed.
The objective function for torque maximization is given in equation (2)

$$\text{Minimize } \frac{1}{T} \qquad (2)$$

Secondly the expression of losses of an induction motor, shown in equation (3) is minimized for a particular voltage. In induction motor stator and rotor copper losses and core loss dominate the overall power losses. Stray, friction and windage losses exist, however they are small enough to be considered negligible. In this case, the total power losses of the motor can be expressed as

P_loss= stator copper loss + rotor copper loss + core losses

$$P_{loss}=|I_s|^2R_s+|I_r|^2R_r+|V_m|^2/R_c$$

$$=V^2\left[\left|\frac{Z_2+Z_m}{Z_T}\right|^2R_s+\left|\frac{Z_m}{Z_T}\right|^2R_r+\left|\frac{Z_2Z_m}{Z_t}\right|^2/R_c\right] \qquad (3)$$

Where,

$$Z_1=R_s+j2\pi fL_s,\ Z_2=\frac{R_r}{s}+j2\pi fL_r,\ Z_m=\frac{R_c j2\pi fL_m}{R_c+j2\pi fL_m},$$

$$Z_T=Z_1Z_2+Z_1Z_m+Z_2Z_m$$

Slip $s=\frac{N_s-N_r}{N_s}$.
Finally the expression of torque and losses i.e equation (2) and (3) are optimized using proposed algorithm.

IV.GRAVITATIONAL SEARCH ALGORITHM

The Gravitational search algorithm (GSA) is a newly developed stochastic search algorithm based on the law of gravity and mass interactions. In this approach, the search agents are a collection of masses which interact with each other based on the Newtonian gravity and the laws of motion. In the Newton Gravitational Law, each particle attracts other particles with a force known as the Gravitational force [10]. The Fig.2 shows the acceleration vector and force vector of the Newton Gravitational Law, which is used in GSA. In GSA, agents are considered as objects and their performance are measured by their masses. All of the objects attract each other by the gravity force, while this force

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causes a global movement of all objects towards the objects with heavier masses. The heavy masses correspond to good solutions of the problem. In other words, each mass presents a solution, and the algorithm is navigated by properly adjusting the gravitational and inertia masses. By lapse of time, the masses will be attracted by the heaviest

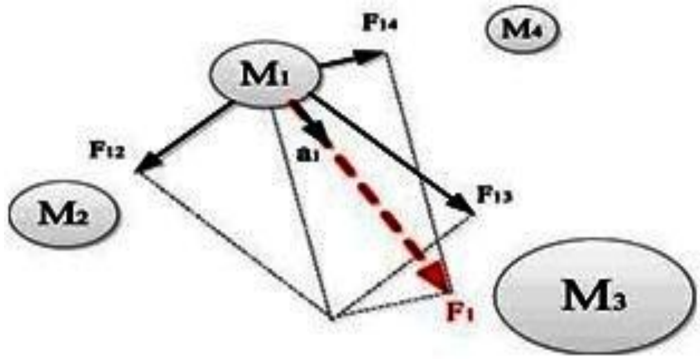

Fig. 2 Acceleration vector and force vector

mass which it presents an optimum solution in the search space. The Gravitational search algorithm implementation steps are shown as follows.

Step 1: Initialize the positions of the N number of agents randomly within the search interval. X= $(x_i^1,\dots\; x_i^d\; \dots\;)$ for i=1,2....N .Where, x_i^d presents the position of the agent i in the dimension ‘d’.

TABLE 1
VARIABLES AND THEIR LIMIT VALUE

Parameters	Description	Upper limit	Lower limit
x(1)	Stator resistance	15	5
x(2)	Rotor resistance	7.5	3.5
x(3)	Stator inductance	0.0139	0.0446
x(4)	Rotor inductance	0.0139	0.0446

In our problem Table.1 shows the upper and lower limits of the parameters within the search space.

Step 2. Perform the fitness evaluation for all agents in each iteration using equation (2) & (3) and also compute the best and worst fitness at each iteration defined as below.

$$\text{best}\ (t) = \min_{j\in\{1\dots\dots N\}} \text{fit}_j(t)$$

$$\text{worst}\ (t) = \max_{j\in\{1\dots\dots N\}} \text{fit}_j(t)$$

Where $fit_j(t)$ represents the fitness value of the agent j at iteration t.

Step 3.Mass of each agent is calculated as follows

$$M_i(t) = \frac{m_i(t)}{\sum_{j=1}^{N} m_j(t)} \qquad (3)$$

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Where $m_i(t)=\frac{fit_j(t)-worst\ (t)}{best\ (t)-worst(t)}$

Step 4. Calculate the Gravitational constant G(t) as a function of time t according to the formula

$$G(t) = G(0)*exp(-ß * \frac{t}{t\_max}). \quad (4)$$

where G(0) is the initial value which is set to 100, β is a constant and its value is set to 20, t is the current iterations, t_max is the maximum number of iteration. These parameters control the performance of GSA.

Step 5. Calculate the force acting on the i[th] agent
from a set of heavier masses should be considered based on the law of gravity according to

$$F_i^d(t) = \sum_{j \in kbest\ ,j \neq i} rand(j) G(t) \frac{M_j(t) \times M_i(t)}{R(i,j,t)+\varepsilon} (x_j^d(t) - x_i^d(t)). \quad (5)$$

kbest is the set of first k agents with the best fitness value and biggest mass and decreases linearly with time. *r* and *i* is the number in the interval[0,1]. M_i & M_j are the masses of agents i and j .ε is a small value and $R_{i,j}$(t) is the Euclidean distance between two agents i and j.

Step 6. According to Newton rules in classic mechanics, the acceleration of i[th] agent at iteration t in direction d by the following equation. can be computed as follows:

$$a_i^d(t)=F_i^d(t)/M_i(t). = \sum_{j \in kbest\ ,j \neq i} rand(j) G(t) \frac{M_j(t) \times M_i(t)}{R(i,j,t)+\varepsilon} (x_j^d(t) - x_i^d(t)). \quad (6)$$

Acceleration vector and force vector are shown in Fig. 2.

Step 7. Compute velocity and the position of the agents at the next iteration (t+1) using the following equation

$$V_i^d(t+1) = rand*V_i^d(t) + a_i^d(t); \quad (7)$$

$$x_i^d(t+1) = x_j^d(t) + V_i^d(t+1); \quad (8)$$

Where x_i^d represents the position, V_i^d represents velocity & a_i^d represents acceleratin of ith agent and in dth dimension. *r* and *i* is a uniform random variable in the interval [0,1]. This random number is applied to give a randomized characteristic to the search.
Repeat **Step 2** to **Step 7** until the iteration reaches the maximum iteration number or allowable tolerance limit. Finally return the best fitness value.

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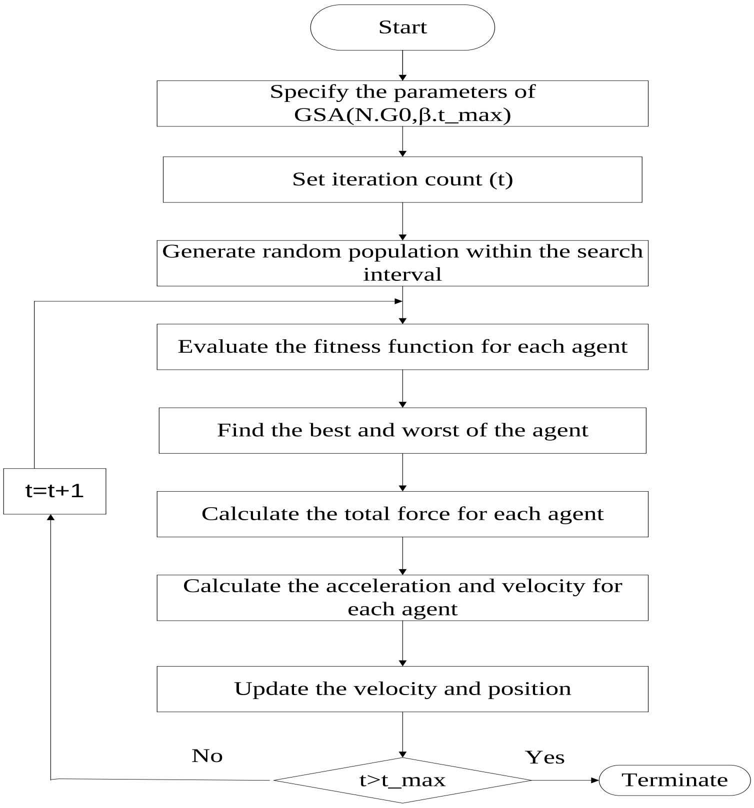

Fig. 3 Flowchart for calculating optimum parameters value of an induction motor

The flowchart for torque and losses optimisation of three-phase induction motor is shown in Fig. 3.

IV.SIMULATION RESULTS AND DISCUSSION

A 4 pole, 1.5 hp, 380 volt, 50 Hz slip ring induction motor is taken for simulation using MATLAB 7.8. From the conventional test (blocked rotor & no-load tests) the parameters values of induction motor are given below
Core loss component (R_c) = 3.3114kΩ
Magnetizing reactance(L_m) = 0.5098H,
Stator resistance(R_s) = 6.4333Ω,
Rotor resistance(R_r) = 4.1178Ω,
Stator & rotor inductance(L_s&L_r) = 0.0289H[1]
The parameters value for maximum torque of specified induction motor using GSA with varying supply voltage is shown in TABLE 2.

TABLE 2

V	R_s	R_r	L_s	L_r	Torque
60	8.0967	3.9258	0.0318	0.0258	0.024931
100	7.9567	3.9524	0.019	0.0373	0.06925
140	5.9067	4.2478	0.0137	0.0151	0.13573
180	6.7065	4.1392	0.0202	0.0299	0.22437
220	8.1262	3.8587	0.0317	0.0336	0.33518

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Fig.4 shows the variation of stator and rotor resistance with varying supply voltage for maximum torque of specified three-phase induction motor. Similarly Fig.5 shows the variation of stator and rotor inductance with varying supply voltage for maximum torque of specified three-phase induction motor.

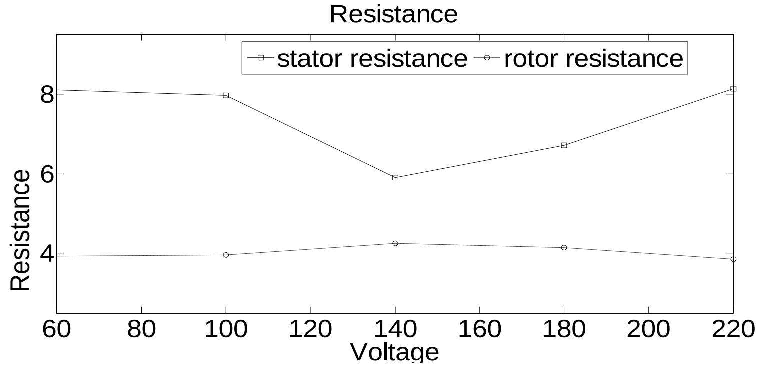

Fig. 4 Identified motor parameters(Resistance)

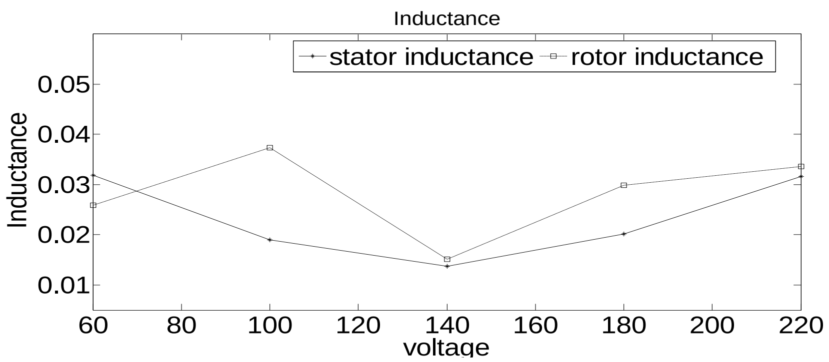

Fig. 5 Identified motor parameters(Inductance)

TABLE 3 shows parameters value for minimum losses of specified induction motor using GSA with varying supply voltage.

TABLE 3

V	R_s	R_r	L_s	L_r	Loss
60	5.30	7.4	0.044	0.026	1.0435
100	5.089	7.372	0.0445	0.0256	2.8967
140	5.032	7.411	0.0443	0.0332	5.6575
180	5.166	7.407	0.0443	0.0276	9.4057
220	5.147	7.234	0.0439	0.0266	14.0123

Fig.6 shows the variation of stator and rotor resistance with varying supply voltage for minimum losses of specified three-phase induction motor and Fig.7 shows the variation of stator and rotor inductance with varying supply voltage for minimum losses.

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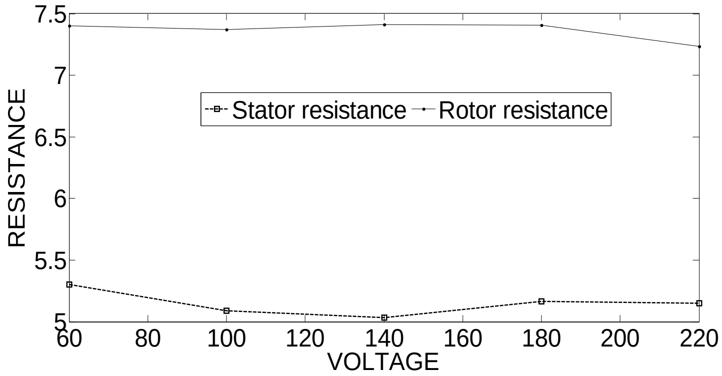

Fig. 6 Identified motor parameters (Resistance) for minimum losses

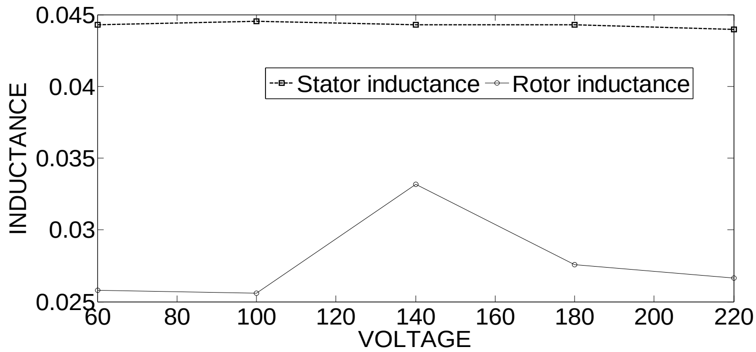

Fig. 7 Identified motor parameters (Inductance) for minimum losses

TABLE 4 shows parameters value for optimum losses and torque of specified induction motor using GSA with varying supply voltage. The torque of a conventional three-phase induction motor is compared with optimal design three-phase induction motor torque and result is shown in Fig.8. Similarly Fig. 9 shows comparative result of losses of a conventional induction motor with optimal design motor. It is no doubt that optimal design motor sows better results than that of a conventional motor. Variation of loss and torque of an optimum design induction motor with supply voltage is shown in Fig. 10.

TABLE 4

V	R_s	R_r	L_s	L_r	Torque(pu)	Loss
60	6.26	3.51	0.014	0.014	0.029	2.50
100	5.16	3.51	0.028	0.015	0.083	6.04
140	5.13	3.62	0.043	0.024	0.151	10.6
180	5.21	4.13	0.044	0.024	0.23	15.4
220	5.14	4.24	0.037	0.024	0.334	23.1

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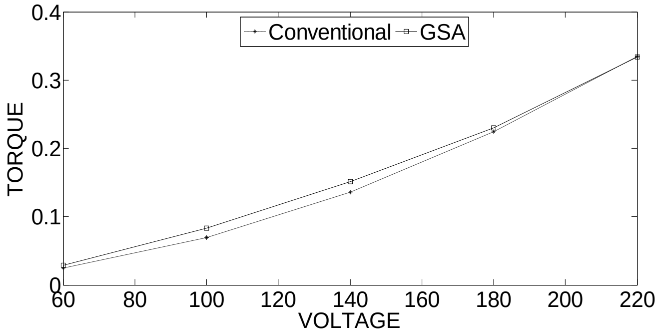

Fig.8 Variation of torque with supply from conventional test value and GSA value

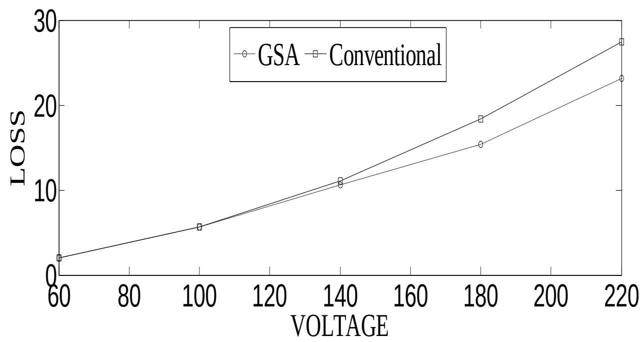

Fig.9 Variation of losses with supply from conventional test value and GSA value

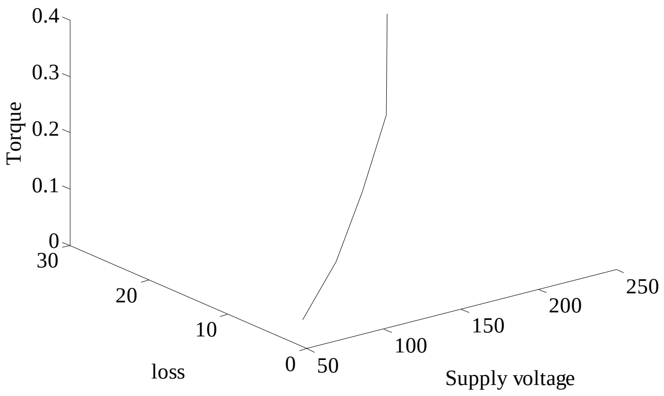

Fig.10 Variation of losses and torque with supply from GSA value

V.CONCLUSION

The torque and losses of an induction motor is optimized using gravitational search algorithm (GSA). The stator resistance, rotor resistance, stator leakage reactance and rotor leakage reactance are calculated using developed GSA. Then torque and loss are calculated using optimum parameters value with varying supply voltage. Torque and loss for optimum values are compared with conventional parameters values. The simulation results shows that torque and loss for optimum values are better than that of conventional values.

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