ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 2, February 2015

Flower Pollination Based Design for Enhancing Starting Torque of Induction Motor

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ABSTRACT: This paper presents a flower pollination based optimization (FPO) methodology for designing induction motor (IM) with improved starting torque. The FPO, inspired from the pollination process of plants, explores the problem space for finding the global best solution of the given optimization problem. The methodology optimizes only seven primary design variables with a view to improve the starting torque of the IM. The proposed design philosophy is applied on a sample induction motor and the optimal design parameters are presented in this paper.

KEYWORDS: induction motor design; starting torque; flower pollination based optimization

NOMENCLATURE

$C(x)$	a set of inequality constraints
IM	induction motor
I_{ph}	phase current, A
I_r	equivalent rotor current, A
I_{sc}	short circuit current per phase, A
npd	number of primary design variables
pdv_i	i-th primary design variables
PM	proposed method
SFL	slip at full load, per unit
T_{st}	starting torque, per unit
V_{ph}	phase voltage, V
w	weight constant of the penalty terms
Z	impedance per phase
η	a set of limit violated constraints
$\Phi(x)$	objective function to be optimized

I. INTRODUCTION

Though Induction motors (IM) have been popularly used almost in all drive systems due to their robustness and lower price. In commonly used squirrel-cage IMs, the resistance is fixed and smaller than its reactance during start, the frequency of rotor currents equals the source frequency, and the starting current lags by a large angle and currents. These behaviours make the starting torque current of around 1.5 times the full-load torque although the starting current is roughly 5-7 times the full-load current. But, the squirrel cage IMs cannot be employed many applications such as hoists, lifts, and electric locomotives requiring large starting torque, thereby necessitating the manufacturers to design the IMs with large starting torque. The design of IM for improving the starting torque is so complex as it involves nonlinear design equations and mixes both the art and engineering [1].

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Several classical approaches such as nonlinear programming [2], Lagrangian relaxation method [3], direct and indirect search methods [4], Hooks and Jeeves method [5], finite element method [6] and sequential unconstrained minimization technique [7] were suggested by the researchers for designing IMs. Most of these approaches require derivatives and pose convergence problems. To overcome the drawbacks of these approaches, nature inspired algorithms such as genetic algorithm [8,9], evolutionary algorithm [10], and particle swarm optimization[11] were employed in solving the IM design problems. These algorithms attempted to offer best and robust results for the design problem.

Recently, a Flower Pollination based Optimization (FPO), inspired from the pollination process of plants, has been suggested for solving optimization problems [12]. In this approach, problem solutions are denoted by pollens of flowers and the pollination is associated with sharing of pollens between local flowers and also from the global best flower. This paper attempts to apply FPO in solving the IM design problem with an objective of enhancing the starting torque.

II. PROBLEM FORMULATION

The IM design problem comprising a large number of design variables can be formulated as an optimization problem. But most of the design variables have no direct influence on the starting torque of the IM. A limited number of variables that have significant impact on the starting torque are treated as primary design variables and the rest are considered as secondary design variables. In the design problem, flux density in the core, rotor current density, stator current density, air gap length, ampere conductor, average value of air gap flux density, core length to pole pitch are taken as primary design variables. The design problem can be tailored as

$$\text{Maximize} \quad \Phi(x) = T_{st} = \left(\frac{I_{sc}}{I_r}\right)^2 * SFL \tag{1}$$

Subject to

$$C(x) \le 0 \Leftrightarrow \left\{ \begin{array}{l} \text{power factor} \ge 0.75 \\ \text{maximum flux density of stator teeth} \le 2 \\ \text{per unit no load current} \le 0.5 \\ \text{slip at full load} \le 0.05 \\ \text{maximum flux density of rotor teeth} \le 2.0 \\ \text{stator temperature rise} \le 70 \\ \text{starting to full load torque ratio} \ge 1.5 \end{array} \right\} \tag{2}$$

$$x_i^{\min} \le x_i \le x_i^{\max} \qquad i = 1,2,\cdots ndv \tag{3}$$

Where

$$I_r = 0.85 * I_{ph} \tag{4}$$

$$I_{sc} = \frac{V_{ph}}{Z} \tag{5}$$

III. PROPOSED METHOD

The proposed method employs the FPO in solving the IM design problem with an objective of enhancing the starting torque. It requires representation of design variables in the form of flowers and construction of a fitness function. Each flower [12] in the IM design problem is modelled to represent the primary design variables, outlined in the previous section, as

$$f_i = \left[pdv_1, pdv_2, \cdots, pdv_{ndv}\right] \tag{6}$$

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The fitness function is formed as

$$\text{Maximize} \qquad F = \frac{\left(\frac{I_{sc}}{I_r}\right)^2 * SFL}{1 + w\sum_{i \in \eta} [C_i(x)]^2} \tag{7}$$

Initially a population of flowers is randomly generated and the fitness of each flower is calculated using Eq. (5). The global or local pollination is stochastically performed to all the flowers in the population, thereby generating a new set of flowers. The process of generating a new set of flowers is represented as an iteration, which is continued by considering the population obtained in the previous iteration as the initial population for next iteration. The flower having the best fitness function value is stored along with its objective function at each iteration. The FPO iterative process of generating new population can be terminated after a fixed number of iterations.

IV. SIMULATION RESULTS

Table 1 Comparison of Results

	Primary Design Variables		PM	GADM
Primary Design Variables x	pdv_1	flux density in the core	1.54321	1.48782
	pdv_2	rotor current density	0.46719	0.50262
	pdv_3	stator current density	5924.29	5978.26
	pdv_4	air gap length	0.3105	0.28605
	pdv_5	ampere conductor	2.9718	2.81751
	pdv_6	average value of air gap flux density	6.9725	7.25236
	pdv_7	core length to pole pitch	1.23970	1.24152
Constraints $C(x)$	$C_1 \geq 0.75$		0.887	0.893
	$C_2 \leq 2$		1.320	1.599
	$C_3 \leq 0.5$		0.489	0.484
	$C_4 \leq 0.05$		0.018	0.019
	$C_5 \leq 2$		0.983	1.143
	$C_6 \leq 70$		25.445	28.754
	$C_7 \geq 1.5$		32.318	31.105
Objective function $\Phi(x)$	Starting Torque (Per unit)		**16.173**	**16.142**

The proposed FPO based design method (PM) is used to obtain the optimal design of 30 kW, 400 V, 6 pole, 50 Hz IM. The superior performance of the PM is illustrated by comparing the results with that of GA based design method (GADM) [13] in Table 1. The table contains the optimal design representing the values of the primary design variables and its starting torque. It is seen from the table that the PM offers a starting torque of 16.173 per unit, which is higher than that of GADM. The table also contains the values of the constraints of Eq. (2) along with their limits. It also seen that the PM brings all the constraints of Eq. (2) within the respective limits, as the limit violated constraints are included as penalty terms in the fitness function of Eq. (7). It is obvious that the PM offers better design in terms of larger starting torque.

V. CONCLUSION AND FUTURE WORK

The FPO, inspired from the pollination process of plants, searches for optimal solution for multimodal optimization problems. An elegant methodology using FPO was developed for solving IM design problem, which is a complex non-linear optimization problem involving large number of decision variables. The PM was applied on a IM design problem and exhibited that the PM provides the optimal values for primary design variables that enhances the starting torque of the IM. The design problem can be modified to include the other objectives such as reducing the manufacturing cost of the IM in future and solved using FPO.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the authorities of Annamalai University for the facilities offered to carry out this work

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