

# Teaching-Learning Based Design for Reducing the Active Material Cost of Induction Motor

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**ABSTRACT:** This paper presents a teaching-learning based optimization (TLO) methodology for designing induction motor (IM) with lowest manufacturing cost. The TLO, inspired from the behavior of the students in improving their performance through gaining the knowledge from the teacher and interacting with other students, 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 lower the active material cost 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; active material cost; teaching-learning based optimization

## NOMENCLATURE

$C(x)$	a set of inequality constraints
IM	induction motor
$npd$	number of primary design variables
$pdv_i$	i-th primary design variables
PM	proposed method
$w$	weight constant of the penalty terms
$\eta$	a set of limit violated constraints
$\Phi(x)$	objective function to be optimized
$R_{iron}$	rate of Iron
$R_{copper}$	rate of Copper
$W_{iron}^{stator}$	stator iron weight
$W_{iron}^{rotor}$	rotor iron weight
$W_{copper}^{stator}$	stator copper weight
$W_{copper}^{rotor}$	rotor conductor weight

## I. INTRODUCTION

Though Induction motors (IM) have been popularly used almost in all drive systems due to their robustness and lower price. The ever increasing raw material cost has become a major factor in designing the IM. The design of IM with lowest manufacturing cost through using lowest active materials is very important in order to survive in the competitive market. The cost of active materials, which comprise the cost of stator-rotor stampings and winding materials, is typically considered as the objective function and minimized through appropriate combination of the design parameters. The design of IM for lowering the active material cost (AMC) 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, teaching learning based optimization (TLO), inspired from teaching-learning process in class rooms, was suggested for solving optimization problems by Rao et al. [12]. It mimics the behaviour of the students in improving their performance through gaining the knowledge from the teacher and interacting with other students. This paper attempts to apply TLO in solving the IM design problem with an objective of reducing the active material cost.

## 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 AMC of the IM. A limited number of variables that have significant impact on the AMC 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 AMC of the motor, determined by computing the motor iron and copper masses and their corresponding market cost, is considered as the objective function. The overall design problem can be tailored as

$$\text{Minimise } \Phi(x) = \left( W_{iron}^{rotor} + W_{iron}^{stator} \right) \times R_{iron} + \left( W_{copper}^{rotor} + W_{copper}^{stator} \right) \times R_{copper} \quad (1)$$

Subject to

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

$$x_i^{\min} \leq x_i \leq x_i^{\max} \quad i = 1, 2, \dots, ndv \quad (3)$$

## III. PROPOSED METHOD

The proposed method employs the TLO in solving the IM design problem with an objective of lowering the AMC. It requires representation of design variables in the form of students and construction of a performance function. Each student [12] in the IM design problem is modelled to represent the primary design variables, outlined in the previous section, as

$$f_i = [pdv_1, pdv_2, \dots, pdv_{ndv}] \quad (4)$$

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The performance function is formed as

$$\text{Maximize } F = \frac{1}{1 + \Phi(x) + w \sum_{i \in \eta} [C_i(x)]^2} \quad (5)$$

Initially a class room of students is randomly generated and the performance of each student is calculated using Eq. (5). The best among the student population is considered as teacher. The teaching and learning phases are performed with a view of altering the students grade points. The process of altering the grade points of the students is represented as an iteration, which is continued by considering the students obtained in the previous iteration as the initial student population for next iteration. The student having the best fitness function value is stored along with its objective function at each iteration. The TLO iterative process of generating new population can be terminated after a fixed number of iterations. The pseudo code for TLO is available in [12].

## IV. SIMULATION RESULTS

Table 1 Comparison of Results

	Primary Design Variables	PM	HSODM
Primary Design Variables $x$	$pdv_1$ flux density in the core	1.96202	1.91057
	$pdv_2$ rotor current density	0.67385	0.65350
	$pdv_3$ stator current density	26403.36	28065.85
	$pdv_4$ air gap length	0.25978	0.25221
	$pdv_5$ ampere conductor	3.59911	3.58084
	$pdv_6$ average value of air gap flux density	7.98949	7.85194
	$pdv_7$ core length to pole pitch	1.60948	1.61837
Constraints $C(x)$	$C_1 \geq 0.75$	0.805	0.802
	$C_2 \leq 2$	1.854	1.854
	$C_3 \leq 0.5$	0.490	0.500
	$C_4 \leq 0.05$	0.029	0.029
	$C_5 \leq 2$	1.656	1.656
	$C_6 \leq 70$	69.110	69.192
	$C_7 \geq 1.5$	4.055	4.089
Objective function $\Phi(x)$	AMC (Rs)	<b>17326.182</b>	<b>17475.276</b>

The proposed TLO based design method (PM) is used to obtain the optimal design of 30 kW, 400 V, 6 pole, 50 Hz IM. While calculating the cost of the motor, the cost of iron for stampings is considered as Rs.50 per kg and the cost of copper that is used as the winding material for both stator and rotor is considered as Rs. 35 per kg. The cost is calculated from the view point of manufacturers. The superior performance of the PM is illustrated by comparing the

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results with that of HSO based design method (HSODM) [13] in Table 1. The table contains the optimal design representing the values of the primary design variables and its AMC. It is seen from the table that the PM offers an AMC of Rs. 17326.182, which is lower than that of HSODM. 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. (5). It is obvious that the PM offers better design in terms of lowest AMC.

## V. CONCLUSION AND FUTURE WORK

The TLO, inspired from the teaching-learning process of students in class room, searches for optimal solution for multimodal optimization problems. An elegant methodology using TLO 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 reduce the AMC of the IM. The design problem can be modified to include the other objectives such as enhancing the efficiency and starting torque of the IM in future and solved using TLO.

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