Optimal Design of Induction Motor with Multi-Parameter by FEM Method

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Abstract

There are a lot of parameters to improve the efficiency of squirrel cage induction motors. Most of the studies deal with only one parameter at a time. However, Optimization of all parameters are needed to get the most efficient motor. This paper shows that three phase induction motor parameters including rotor slot type, stator slot type, steel sheet and rotor material optimized by using the module Rmxprt in Maxwell. The Results show that 157% increasing torque and 4.1% increasing efficiency are obtained.

1. Introduction

Three-phase squirrel cage IMs (induction motors) are widely used owing to their robust nature and their less maintenance necessity. Energy consumption of the IMs is an important part of the total energy consumed. Because of increasing energy demand, it is necessary to increase efficiency of IMs. Minimization of losses is required to do so. Losses in the induction motor are iron losses, stator resistance losses, rotor resistance losses, windage and friction losses and stray load losses. Iron losses are related to core laminations. Stator losses depend on stator windings. Rotor losses are linked in rotor bars and end rings. All of these losses can be reduced by optimized motor parameters.

There are various optimization techniques to design high efficient IM. Recently, studies show that IM parameters optimized by FEM (Finite Element Method) based programs. To design optimum IM, cast parameter is taken in consideration and three motor-cost function performed [1, 2]. That all of the parameters to be optimized are necessary to achieve the best efficiency. Modified method should be used instead of simple optimization methods to achieve high performance IM. Multi-objective optimization design using FEM methods with a weighted function is performed [3]. On the other hand, Genetic algorithm is used to optimize IM instead using NLP techniques [4]. Also, Particle swarm optimization is usable for multi-variable design problem [5].

For IM optimization, stator slot type, rotor slot type, bar shape, rotor dimensions are used [6]. Also, it includes rotor material and steel sheets. Most of studies are taken a parameter in hand. A new model which includes only one rotor slot type is optimized [7, 8]. Instead of this, by using computer programs e.g. FEM, Maxwell, efficient IM rotor shape parameters are obtained. Then rotor geometry effects on magnetic field end slot ripples are analyzed for SPIM (single phase induction motor) [9]. Rmxprt, a template-based, design tool offers calculating machine performance and performing hundreds of "what if" analysis in a matter of second. Optimization parameter and rules can be changed by user. Slot shapes of SPIM optimized by using Rmxprt [10]. Various stator slot shapes effecting energy consume parameters are compared with others by using existing motor models in Rmxprt [11]. In addition, optimal design of copper and aluminum rotor based on starting torque value and efficiency value realized with FEM. The result of study that copper rotor is more efficient, but it has lower starting torque [12]. Moreover, the outcomes of inconvenient design will cause inadequate torque and undesired noise of the IM with variable frequency drives. Torque and noise parameters noise are calculated and measured for hybrid electric vehicle drives [13]. Design optimization based on a level set with time-harmonic magnetic analysis is provided the optimal design parameters considering operating characteristics [14].

The other studies show that rotor and stator lamination thicknesses have effect on IM losses. These parameters are optimized with a function including efficiency, power factor and loss field. The result of comparing steel sheet having 0.35 mm and 0.5 mm thickness that thinner one is more efficient [15]. Also, some standards of steel lamination analysis show that the impact of the parameter is small.

The most important parameter rotor material analyzed in some studies. Die-cast copper rotor material has an advantage about %40 energy saving with 11 kW IM [16]. Additionally, some materials which is realistic and fictious are used for having less loss. In the study, materials having low resistivity e.g. Fe-Cu and Fe-Si alloys support more energy saving [17].

In this study, each parameter will be simulated with Rmxprt in Maxwell to achieve the best performance. The optimization cost using in this paper have only approach for finding the highest efficiency. Material price is not taken in consideration. Parameters to be optimized are slot types, steel sheets and rotor materials.

2. Optimization

Generally, optimization problem is solved by analytical or numeric solution technique. Nevertheless, numerical methods is used because it's multi-parameter problems. Optimization methods use initial design and constraints to solve a problem. In sciences, parametric solution with a finite number of steps or iterative methods that converge to a solution or Heuristic algorithm that can satisfy proximate solutions is used.

Rmxprt produced by Maxwell Ansoft Corp has used for some general motors designing e.g. induction motor, synchronous motor, dc motor and universal motor. Motor parameters as slot types, materials, motor dimensions, and electrical parameters are changed easily and torque, current, losses, resistivity values can be calculated. The optimization tool in Rmxprt includes gradient, search-based and random search algorithm. In this paper, Quasi-Newton algorithm proposed by William C. Davidon is used for minimizing total loss.

However, some parameters are allowed for optimizing at the same time. Therefore, the goal finding highest performance has three steps in this paper (Fig.1). Firstly, slot type is optimized. Then, the selection of the best result after each optimization is applied on next step. In all optimization step, maximum iteration number is selected as 1000 because of calculation time constraint.

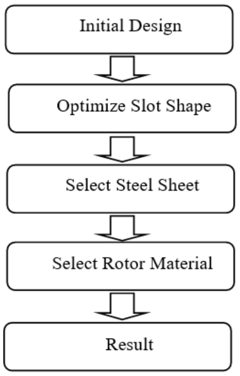

Fig. 1. Optimization steps

2.1 Motor Model

The 11kW motor having design parameter, shown in Table 1, is optimized in this study. Rotor slot type, stator slot type, steel sheet and rotor bar material are chosen as optimization variables. These parameters have a significant effect on motor characteristics e.g. efficiency, torque, current.

Table 1. Design Specifications of IM

General Data	Given Output Power	11 kW
	Rated Voltage	380 V
	Winding Connection	Delta
	Number of Poles	4
	Given Speed	1462 rpm
	Frequency	50 Hz
	Stray Loss	220 W
	Frictional Loss	127.755 W
	Windage Loss	28.4726 W
	Total Loss	1198.61 W
	Efficiency	90.1735%
Stator	Number of Stator Slots	36
	Outer Diameter of Stator	260 mm
	Inner Diameter of Stator	170 mm
	Type of Stator Slot	2
	Type of Steel	M19_24G
Rotor	Number of Rotor Slots	26
	Air Gap	0.5 mm
	Inner Diameter of Rotor	60 mm
	Type of Rotor Slot	2

According to the variables given in the Table 1, performance characteristics are as shown in Fig. 2, and Fig. 3. Considering IEC 60034-30-1 standards on efficiency classes for low voltage AC motors, without optimization the motor classifies as an IE2 (High efficiency) class motor. To describe the motor efficiency as IE4 (Super-Premium efficiency), its efficiency must be more than 93.3%.

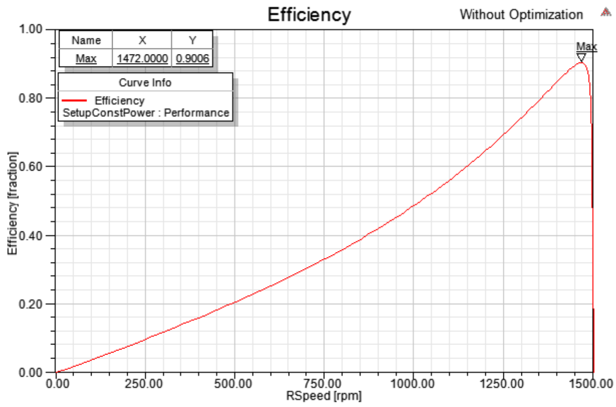

Fig. 2. Efficiency without Optimization

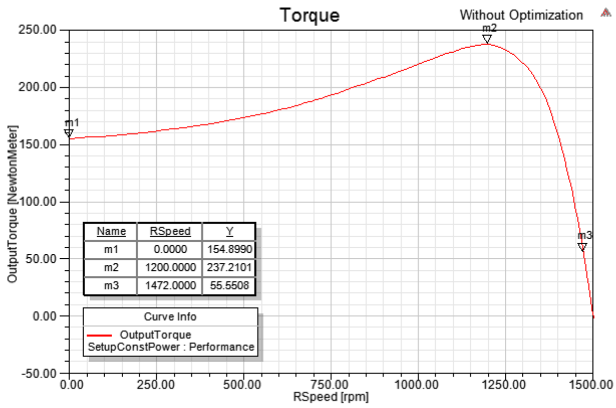

Fig. 3. Torque characteristic without optimization

2.2 Optimization of Slot Types

Traditionally, researcher start with existing values of slot parameters and continue to optimize until achieving their goal. By optimizing slot shape, efficiency can be increased partly.

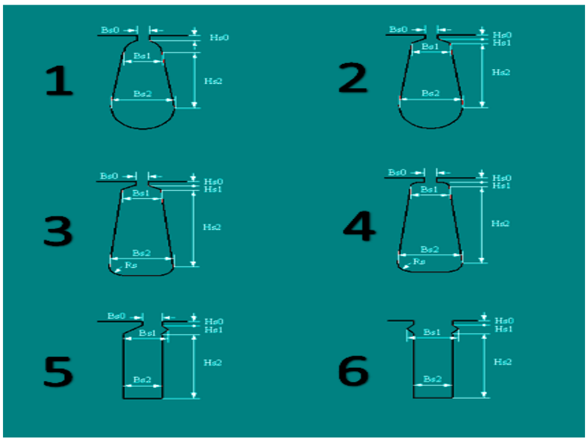

Fig. 4. Slot Types

Fig. 4 shows types of slot shape and their parameters. Both stator and rotor slot type are optimized simultaneously. Each type have five or more parameters. Up to ten parameters optimized for optimal slot design.

In reality, it is difficult to manufacture exactly because of manufacturing restriction.

As it is shown in Fig. 5, both slot type is optimized after 1000 iterative solution. Type 5 and Type 6 have a significant effect on efficiency. The initial efficiency values depend on initial parameter values.

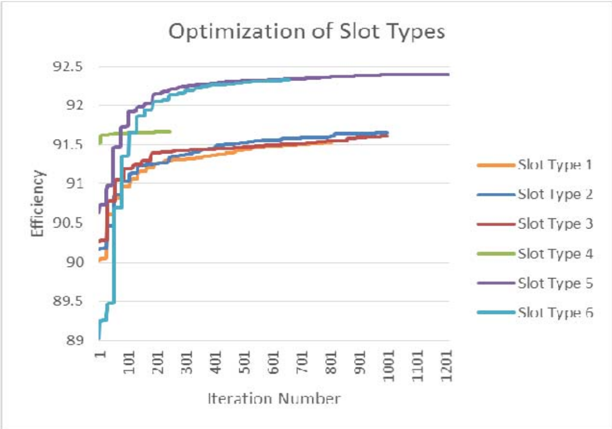

Fig. 5. Efficiency of slot types optimized parameters

2.3 Selection of Steel Sheet

Electrical steel sheets are classified according to European Standard EN 10106. Data in Table 2 relates to products manufactured by Cogent at Surahammars Bruks AB.

Table 2. Data Specifications Of Steel Sheets

Steel Sheet Type	Max loss (W/kg) at 50 Hz at 1.5 T	Thickness (mm)	Resistivity (μΩ)
M235-35A	2.25	0.35	59
M270-35A	2.47	0.35	52
M330-35A	2.94	0.35	42
M330-50A	3.03	0.5	42
M400-50A	3.57	0.5	42
M530-50A	4.46	0.5	31
M600-50A	5.17	0.5	30
M700-50A	5.68	0.5	25
M800-50A	6.6	0.5	23
M700-100A	6.24	1	44
M800-100A	7.2	1	39

It is clear that thinner sheet has much performance than thicker one. Approximately, the efficiency of IM increased by 1%.

2.4 Selection of Rotor Material

Considerable rising is obtained with changing rotor material in this paper. Results show that copper rotor material have significant improvement on efficiency. With copper rotor, total loss reduction is 15.51%. In addition, rising torque is 26.1%. Also, starting torque is increase too.

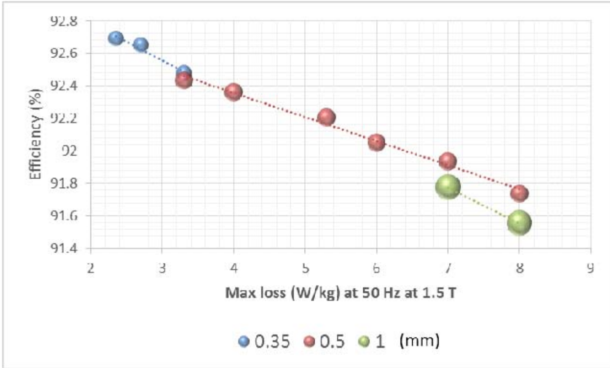

Fig. 6. Efficiency of steel sheets

3. Results

After the final optimization step, motor characterictics is changed as shown Fig. 7, Fig. 8 and Fig. 9. While the starting torque is approximately 150 Nm without optimization, after the optimization it is 398 Nm. Also, effiency is higher than the first one. On the other hand, current is increased owing to copper lower resistivity.

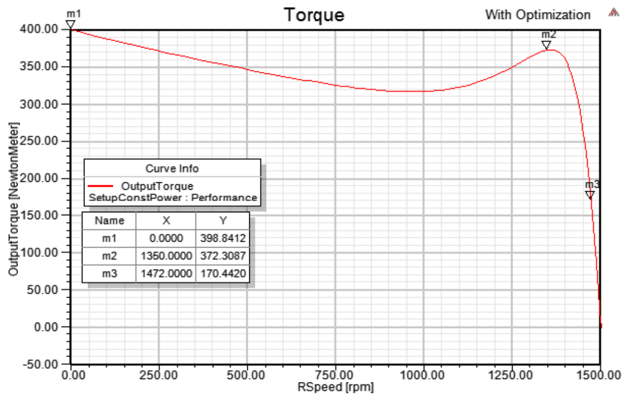

Fig. 7. Torque characteristic of optimized motor parameters

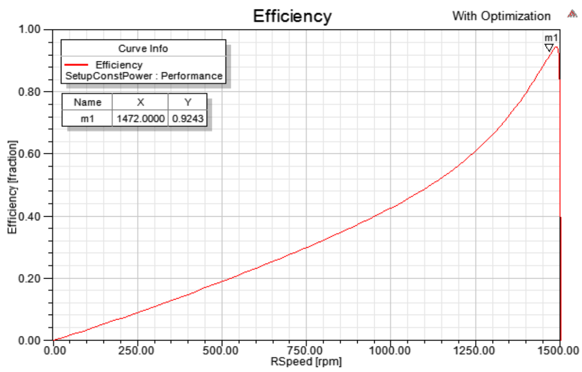

Fig. 8. Efficiency of optimized motor parameters

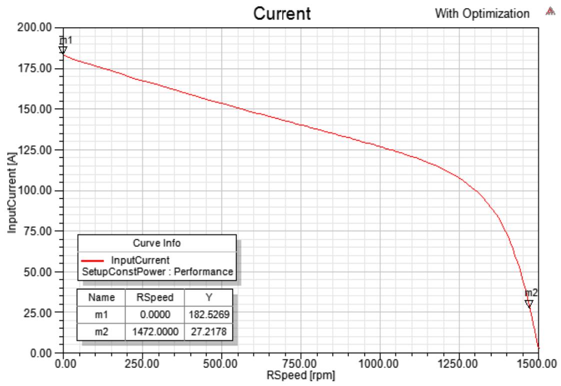

Fig. 9. Current of optimized motor parameters

The motor optimized parameters is 0.56 times more efficient than the initial one as shown in Table 3. With each optimization step total loss minimized.

Table 3. Optimization Results

	Efficiency Parameter [%]	Total Loss Parameter [W]	Locked Rotor Torque Parameter [N.m]
Without Optimization	90.1735	1198.61	154.913
Slot	92.3315	913.612	354.467
Sheet	93.257	795.247	316.308
Rotor	94.2451	671.842	398.961

4. Conclusions

Design of IM have many parameters related to each other. Therefore, the optimization problem have many local minimum values. To find out best parameters, all parameters calculated at the same time. In this paper, the best value depend on optimization steps and parameters initial values. By changing these, many new parameters for efficient motor design can be found. But, motor with 94.2451% efficiency is obtained by using the method studied.

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