ROTOR SLOT OPTIMIZATION OF AN INDUCTION MOTOR

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Abstract: Proposed paper is dealing with optimization of an induction machine rotor slot by using artificial intelligence. Electrical machine under investigation is commonly manufactured induction motor with simple deep rotor bars. Goal is to achieve the highest possible value of efficiency and power factor. This paper is dealing with description of rotor parametric model and set-up of the optimization algorithm. Results of optimization are proposed as well.

Keywords: induction motor, rotor slot, optimization, SOMA, Ansys Maxwell, RMxprt

1 INTRODUCTION

In today's world, ecology and energy saving is one of the biggest topics. This trend continues in the field of electrical machines design as well. Much of electrical energy is consumed by electrical machines. Thanks to that, electrical machines represent huge potential for energy savings. Induction machines are one of the most used electrical machines nowadays. Optimization by using artificial intelligence is therefore very promising way how to increase induction machine's efficiency e.g. [1] and [2]. The one optimized is commonly manufactured induction machine with deep rotor bars.

2 OPTIMIZATION

Optimization is performed by Self-Organizing Migrating Algorithm (SOMA). It has been firstly published and described by Zelinka in [2]. This algorithm is fast and durable, comparable to genetic algorithms or other differential evolution algorithms and can be used to any optimization problem, written in any programming language. In this case, software MATLAB has been used. Optimization script was written in its own programming language. This programing language is based on Fortran, which is suitable for numerical and scientific computations. In most cases the MATLAB's script is perfectly compatible with GNU Octave, which is freely redistributable software. This script is written to cooperate with Ansys Maxwell tool RMxprt. RMxprt offers fast analytic computation of electrical machine that is accurate enough for proposed application.
Right definition of cost function is essential for optimization algorithm. Appropriate settings have major impact in terms of optimization results. In this work the cost function is used as follows:

$$f_{cost} = W_1\left(\frac{\eta-\eta_w}{\eta_w}\right)^2 + W_2\left(\frac{cos\varphi - cos\varphi_w}{cos\varphi_w}\right)^2 + W_3\cdot smoothness \qquad (1)$$

where η is calculated efficiency, η_w is wanted efficiency, cosφ is power factor, cosφ_w is wanted power factor. Coefficients determining priorities of optimization elements are marked as W. Optimization goals are set to be $\eta_w = 1$ and $cos\varphi_w = 1$, because there's no set value and the values wanted are high as possible. Weight coefficients are chosen as $W_1 = 2.5$, $W_2 = 2$ and $W_3 = 1$.
As seen, all elements in the formula (1) are squared. This means that computation is able to get to the wanted value from both sides - negative (minus) and/or positive (plus). Third element of this formula

is called smoothness. As the name itself implies, it is a function, that controlls the shape of slot's geometry in term of smooth transition between layers. This function compares neighbour layers by their width value. If these values are different, smoothness' value is risen by 1 then. Mathematic description of function is as follows:

$$\begin{aligned} &\textbf{for} \quad i=1 \quad \textbf{to} \quad i=n-1 \\ &\textbf{if} \quad b_i-(b_{i-1})\geq 0 \quad \textbf{and} \quad b_{i+1}-(b_i)\geq 0 \quad \textbf{or} \quad b_i-(b_{i-1})\leq 0 \quad \textbf{and} \quad b_{i+1}-(b_i)\leq 0 \\ &\textbf{then} \quad smoothness = smoothness+0 \\ &\textbf{else} \quad smoothness = smoothness+1 \end{aligned} \tag{2}$$

The more layers are in the parametrical model, the higher value may smoothness reach. Because efficiency and power factor are unable to reach value of 1, smoothness' values might cause bad optimization results.

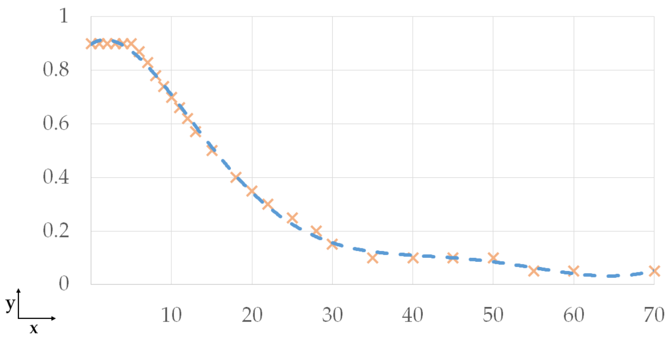

Figure 1: Custom function curve (x = smoothness, x = converted value)

That's why its value needs to be converted via a function, which values are in 0 to 1 range. To get a smooth shape of slot, smoothness' value needs to be small. First in mind is the exponential slope function e^{-x}, which has positive maximum in 0. Negative range is neglected, because smoothness can not achieve values lower than 0. Another solution is to define a custom function with chosen points and then create a curve by interpolation of these points. This gives the user a power to indirectly influence the result shape of slot or any optimized geometry. In this case the result function can be seen on fig.1 and its mathematical expresion is:

$$-2\cdot 10^{-10}\cdot h^6+5\cdot 10^{-8}\cdot h^5-6\cdot 10^{-6}\cdot h^4+3\cdot 10^{-4}\cdot h^3-0.0061\cdot h^2+0.0189\cdot h+0.8979 \tag{3}$$

3 RESULTS

The optimization has been performed for following three variants:

A: Smoothness without any change. Its value is not controlled.

B: Smoothness as exponential function e^{-x}.

C: Smoothness as custom function, see equation 3.

The results were as follows.

parameter	marking	value				
		original machine (measuring)	original machine (simulation)	A	B	C
efficiency	η [-]	0.889	0.917	0.9175	0.916	0.919
power factor	cosφ [-]	0.83	0.77	0.86	0.87	0.85

Table 1: Optimization results (values)

Comparison of optimized shapes with original one is shown in Figure 2. As expected, because of the nature of exponential function is the slot geometry in case B very smooth. Steepness of the function in variant C is lower, so the smoothness is not pushed so hard to value of 0 and the geometry is much more varying.

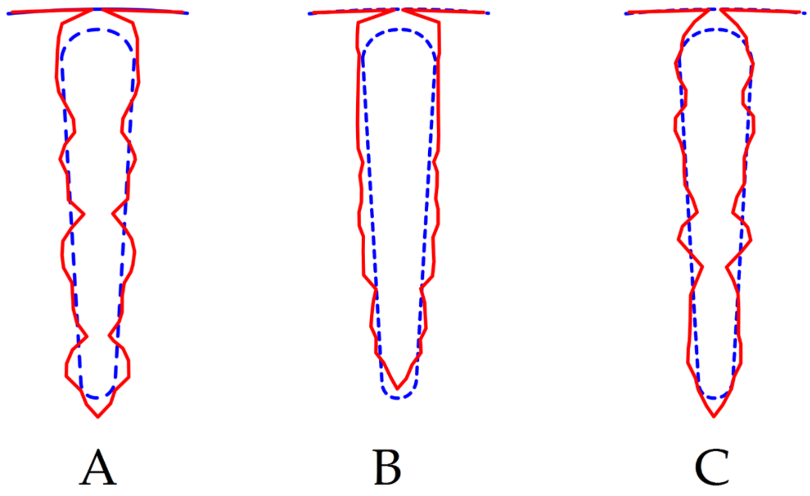

Figure 2: Optimization results (geometry)

By comparing observed values before and after optimization, it can be concluded that optimization lead to improvement of desired parameters. Highest efficiency shows case C, but best value of power factor has been reached in case B. It has the most smooth shape of slot as well, what makes it easier to manufacture. The one not mentioned, case A shows the second highest efficiency and power factor but the geometry is chaotic and it would be very hard to manufacture. Another important aspect of these geometries is mechanical strength.

4 CONCLUSION

Optimization is one of many aspects of improving efficiency and power factor and thus the ecology of an electrical machine itself. As shown, SOMA with little modifications and improvements is more than capable of beating this challenge not just in the field of optimizing rotor slot shape, but in improving any geometry in electrical machine. Only thing needed is a parametric model, which is easy to make in a software like Maxwell. That makes this kind of optimization available to any electric-machine-designing business. It can be concluded that parameters of electrical machine can be improved by using optimization aglorithms. Optimized electrical machine under investigation is going to be manufactured and measured. Presented paper can be easily used as a guidline for optimization of any induction machine rotor slot geometry.

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