Numerical Analysis and Optimal Design of Double Squirrel Cage Induction Motor for Electric Vehicle

Subong Jang[1], Kyung-Won Jeon[1], Yong-Jae Kim[2], Sang-Yong Jung[1]

[1]School of Electronic and Electrical Engineering, Sungkyunkwan Univeristy 300, Cheoncheon-Dong, Jangan-Gu, Suwon, Kyeonggi-Do, 440-746, Korea
[2]Dept.of Electrical Engineering College of Engineering, Chosun University, 375, Seosuk-dong, Dong-gu, Gwangju 501-759, Korea

syjung@ece.skku.ac.kr

***Abstract*— In this paper, the dynamic characteristics of induction motor (IM) for electric vehicle (EV) are numerically investigated by changing rotor slot shapes. The rotor with double squirrel cage is selected to optimize the slot shapes by Response Surface Method (RSM). Double squirrel cage has the high starting torque than other rotor type. The dynamic characteristics of the optimized model for IM are compared with those of the initial model by equivalent circuit analysis (ECA) and finite element analysis (FEA). The speed-torque curve of the optimized model shows good performance through whole-speed range.**

***Index Terms* - Induction Motor, Equivalent Circuit Analysis, Finite Element Method, Response Surface Method, Electric Vehicle.**

I. INTRODUCTION

Recently, China's export policy is changing to curb the permanent magnet main material NdFeB for export. Therefore the development of motor is needed about reducing NdFeB or none use. Especially, IM is one of attractive electronics and control technique is developing very fast recently. So, it's possible to control about the speed as DC motor and PM synchronous motor. On the other hand, IM is lower efficiency than the BLDC and PMSM, when IM reached high efficiency, is suggest such as lifetime, robustness, reliability, and many advantages. In fact, vehicles are possible drive in stop, low speed and backward movement and etc. Each speed requires acceleration and climbing. Generally, the electrical vehicles require power for each speed for several purposes of driving

In this paper, IM is considered as driving motor in the EV due to its robustness compare to others. The advantages of IM are that the structure of the motor is simple, easy to maintain and to EV. Besides these advantages, the induction motor receives high praise in cost and reliability. Therefore, double squirrel cage of induction motor to drive EV is designed using RSM for optimized design.

II. CHARACTERISTICS OF ELECTRIC VEHICLE

A. *Characteristics of Motor for Electric vehicle*

Induction motor for whole speed ranges drives usually have the characteristics shown in Fig.1.

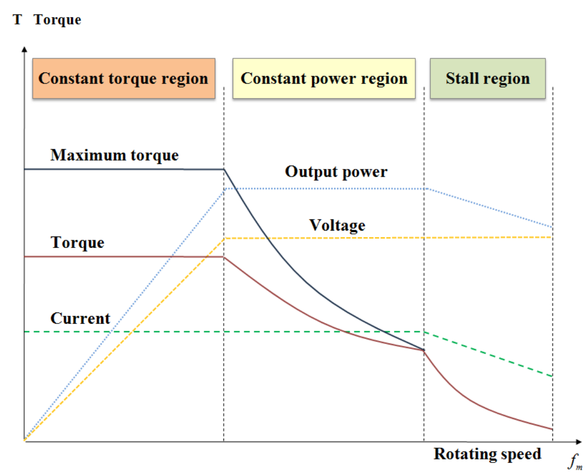


Fig. 1. Characteristic curve of induction motor

B. *Initial design of Induction Motor*

Design specifications are as follows; rated output is 40kW, number of pole is 4, rated voltage is 380V, rated frequency is 60Hz and rated speed is 1800rpm

TABLE I
Initial model of Induction motor dimensions

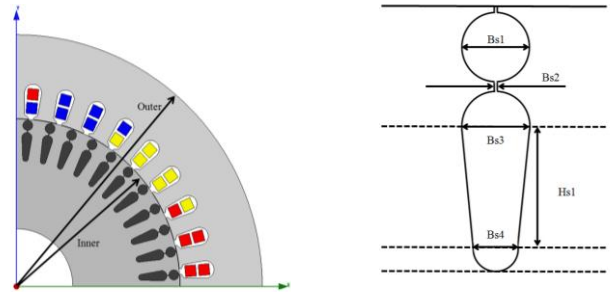
Stator Diameter		Air Gap [mm]	Length [mm]
Outer [mm]	Inner [mm]		
240	160	0.7	190

Dimensions of initial double squirrel cage slot are represented in Table II, 5 parameters for design valuables that are height and width.

TABLE II
Dimensions of initial slot

Hs1 [mm]	Bs1 [mm]	Bs2 [mm]	Bs3 [mm]	Bs4 [mm]
15	4	0.85	4	2

As seen in the Table II, we make that the initial model is designed when Hs1= 15, Bs1= 4, Bs2 = 0.85, Bs3=4 and Bs4 =2 [mm]. The initial model of induction motor is shown in Fig. 2.



(a) Dimension of rotor (b) Slot of rotor

Fig. 2. Initial model of induction motor

III. RESPONSE SURFACE METHOD (RSM)

Changing slot shape using RSM will improve the starting torque of induction motor. The objective function is selected torques at the each speed. Then, the chosen variable design parameter regions for each objective function are not overlapping between each slot. [1-4]

A. *Target for RSM*

Torques at each speed and efficiency are selected as objective functions. The design variables for each objective functions are not overlapped between each slot.

The optimized parameter to find object function and variable design parameters are represented on Table V [5].

TABLE V

Object function and variable design parameters region

Objective Function	Torque@0rpm	Maximum
	Efficiency	Maximum
Subject [mm]	$12 \le Hs1 \le 15$	
	$4 \le Bs1 \le 5$	
	$0.7 \le Bs2 \le 1$	
	$4 \le Bs3 \le 5$	
	$2 \le Bs4 \le 2.5$	

B. *Optimized Design Result*

As seen the Table V, Hs1, Bs1, Bs2, Bs3, and Bs4 are generated parameters within a given ranges. As a result, we make 54 models generated.

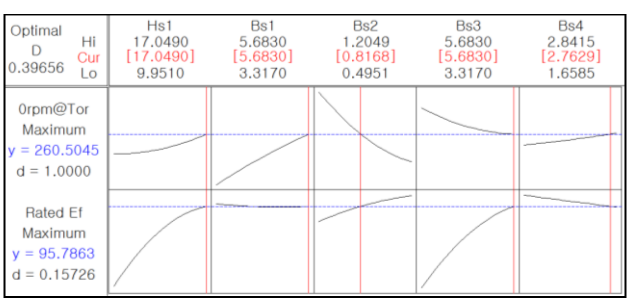


Fig. 5. Result of response surface method

As seen in Fig. 5, we found that the objective function is optimized when Bs1= 5.7, Hs1= 17, Bs2 = 0.8, Bs3=5.7 and Bs4 =2.8[mm]. The torque at 0rpm of induction motor model should be improved by shape optimization using RSM. Variable design parameters by RSM for each resource reservation are found the optimized point of the torque measurements in order to determine the design of the rotor slot shape.

IV. ANALYSIS RESULT

As seen in Table VII, The speed-torque curve of the optimized model is improved apparently. That is the torque of the optimized model at 0[rpm] is improved by 1.039[%] and the efficiency is improved by 1.012[%].

TABLE VI

Comparison of torque and efficiency

Torque [Nm]	@0rpm	Efficiency
Initial Model	223.1545	94.8117
Optimized Model	231.9922	95.9013
Ratio[%]	+1.039%	+1.012%

V. CONCLUSION

This paper deals with the induction motor characteristics of EV driving. Particularly, the shapes of rotor slots by Response Surface Method are optimized to meet high starting torque characteristics for EV. Each parameter (subject of RSM) is influenced to efficiency and torque. Also the torque and efficiency of the optimized model are higher than those of the initial model, such as torque of the optimized model at 0[rpm] is improved by 1.039[%] and the efficiency is improved by 1.012[%]. The rated characteristics of the induction motor analyzed by equivalent circuit analysis (ECA), and the dynamic characteristics of the induction motor are analysis by finite element analysis (FEA). Then, they are compared with the speed-torque curve of the optimized model shows good performance through whole-speed range.

VI. REFERENCES

[1] Dianhai Zhang , Chang Soon Park , and Chang Seop Koh, " A New Optimal Design Method of Rotor Slot of Three-Phase Squirrel Cage Induction Motor for NEMA Class D Speed-Torque Characteristic Using Multi-Objective Optimization Algorithm", *Magnetics. IEEE Trans.*, Vol. 48, No. 2, pp. 879 – 882, Feb. 2012.

[2] J. H. Lee, I. K. Lee, Y. H. Cho, T. W. Yun, "Characteristics Analysis and Optimum Design of Anisotropy Rotor Synchronous Reluctance Motor Using Coupled Finite Element Method and Response Surface Methodology", *Magnetics. IEEE Trans*., vol. 45, no.10, pp. 4696-4699, Oct. 2009.

[3] Byeong-Hwa Lee, Jung-Pyo Hong, and Jung-Ho Lee, " Optimum Design Criteria for Maximum Torque and Efficiency of a Line-Start Permanent-Magnet Motor Using Response Surface Methodology and Finite Element Method", *Magnetics. IEEE Trans.*, Vol. 48, No. 2, pp. 863 – 866, Feb. 2012.

[4] Byeong-Hwa Lee , Kyu-SeobKim , Jung-Pyo Hong , and Jung-Ho Lee, " Optimum Shape Design of Single-Sided Linear Induction Motors Using Response Surface Methodology and Finite-Element Method", *Magnetics. IEEE Trans.*, Vol. 47, No. 10, pp. 3657 – 3660, Oct. 2011.

[5] Wang, L., Lowther, D.A., "Reducing the Design Space of Standard Electromagnetic Devices Using Bayesian Response Surfaces", *Magnetics. IEEE Tran.*, vol. 46, no.8, pp. 2884-2887, Jul. 2010.