Numerical Design Compatibility of Induction Motor with respect to Voltage and Current Source

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***Abstract*—In this paper, the optimal driving point is selected when identical torque is supplied in induction motor using current source. Moreover, induction motor using current source is compared with one using voltage source whether two models are interoperable and conformable. To verify, vector control is explained for selection of the optimal driving point. Also, the characteristic analysis for induction motor is performed by Finite Element Method (FEM). In addition, comparative analysis for the result, such as flux saturation, performance characteristic, and loss is conducted according to the optimal point in designing procedure. By the result of analysis above, the compatibility of analysis using current source is verified by comparing with the one using voltage source**.

***Index Terms*—Induction motor, Vector control, Voltage source, Current source, Finite Element Method (FEM)**

I. Introduction

Induction motor is long-time researched and has high reliability, fine structural robust and good industrial competitiveness. Especially in system requiring acceleration and transmission, the response on changing condition of speed and load is considerably fast and the driving characteristic in high speed region is qualitative. Therefore induction motor can be applied to various speed application such as servo-machines, spindle and actuation system for traction motor[1]-[2]. To realize this performance, the vector control of driving induction motor will be suitable method because it can make possible driving in wide speed range and field weakening driving by controlling rated voltage and current of inverter[3]. Thus in this paper, an optimal driving point is selected when analyzing current, considering voltage and current constraints on vector control of induction motor. Moreover, the analysis on characteristics is conducted by FEM and the result of it is compared with that of using general voltage source to verify conformance and interoperability[4].

II. Characteristic of Induction Motor

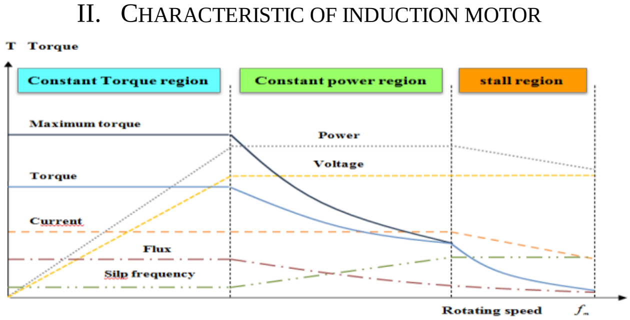


Fig. 1 Characteristic Curve of Induction Motor

Adjustable varying speed actuation of induction motor can be divided into three regions by adjusting voltage and frequency. In first region, constant torque region, torque has retained value under base speed and in second region, constant power region, power has retained value over base speed. Lastly, third region, characteristic region, has maintained maximum frequency over base speed. The characteristic curve of induction motor is in Fig. 1 as follows.

III. Optimal Point to Current Source Analysis

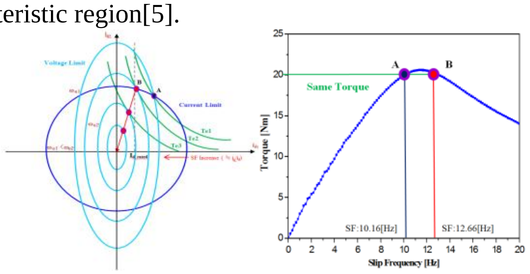
Voltage and current constraints of induction motor can be expressed in equation (1) and (2) by inverter capacity.

$$V_{ds}^{e*2} + V_{qs}^{e*2} \le V_{smax}^{2} \quad (1)$$

$$I_{ds}^{e*2} + I_{qs}^{e*2} \le I_{smax}^{2} \quad (2)$$

Torque of vector-controlled induction motor is shown as Fig. 2. The driving point producing maximum torque with minimum current is an intersection of ellipse by voltage constraint and current constraint, and that is point A in Fig. 2. However, d-axis current on that point is larger than rated d-axis current. It would result in the severe saturation of the magnetic circuit of the machine. In this case, d-axis current should be set as rated current. Therefore, the optimal driving point is set as point B in Fig. 2 and maximum available torque is decided only by q-axis current. Consequently, the maximum torque is always the same in constant torque region.

In constant power region, the ellipse by current constraint is decreased. So, the optimal driving point is moved by way of decreasing d-axis current and increasing q-axis current. The speed gets faster and when the ellipse by voltage constraint is located inside of ellipse by current constraint, both d-axis and q-axis current is decreased as shown in Fig. 2(a), which is in characteristic region[5].



(a) Vector Control of Induction Motor (b) Torque & Slip-Frequency
Fig. 2 Optimal Point of Current Source Analysis

As a result, in every region of induction motor, actuation the optimal point to produce maximum torque is in the way of increasing each frequency and it can be shown in the way of increasing slip frequency in Fig. 2(b). At the view of analysis of current source, the relationship between torque voltage and slip-frequency is shown on Fig. 3.

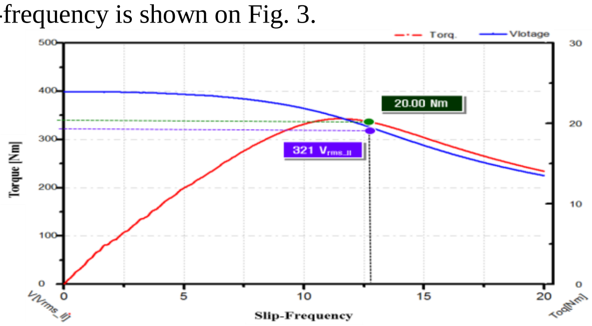


Fig. 3 Torque-Voltage vs Slip-Frequency of Current Source Analysis

IV. Analysis of Voltage Source

Most of Induction motor has been designed with the voltage source based on the equivalent circuit modeling and corresponding FEM. The result of voltage source analysis for induction motor is shown Fig. 4. Therefore, numerical analogy of the voltage source is identified for the compatibility to the one of the current source. In particular, the torque and voltage characteristics versus Slip-Frequency, shown in Fig. 3, will be the most critical one for analysis and design of Induction motor.

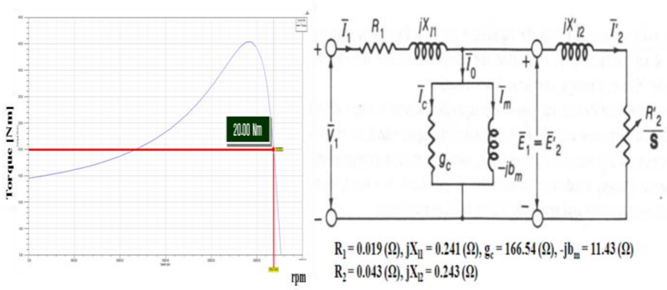
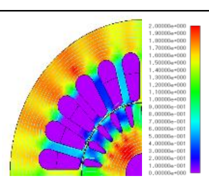
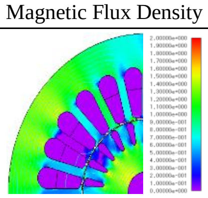
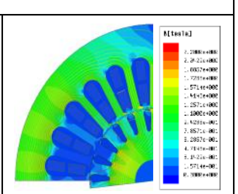
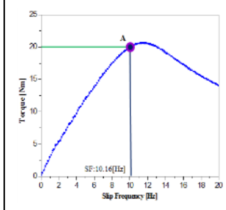
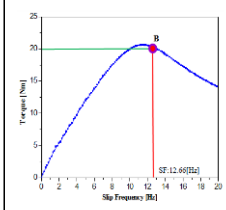
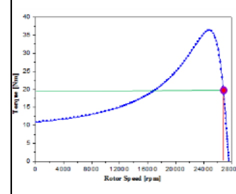


Fig. 4 Voltage Source Analysis of Induction Motor

V. Result

The results of current and voltage source analysis of induction motor are shown in legends of flux density distribution, torque-slip frequency, and loss in Table I. Especially in case of using current source, the optimal driving point B abovementioned is verified by comparing two different driving point.

TABLE II.
Results of using Voltage and Current Source Analysis

Current Source		Voltage Source
Point A	Point B	
Magnetic Flux Density		
		
Torque-Slip Frequency		Torque-Speed
		
26997rpm @ S-F 10.16	26824rpm @ S-F 12.66	26824rpm @ S-F 13.19
Current		
116.7 A_{rms}		113.8 A_{rms}
Voltage		
359 V_{rms}	321 V_{rms}	323V_{rms}
Slip-Frequency [Slip/Frequency]		
10.16 [Hz] [0.0223 / 457.2 Hz]	12.66 [Hz] [0.0276 / 459.7 Hz]	13.19 [Hz] [0.0286 / 451.2 Hz]
Torque		
21.3 Nm	21.1 Nm	20.0 Nm
Conductive loss		
1709 W	1783 W	1953 W
Iron loss		
1211 W	986 W	532 W
Total loss		
2920 W	2769 W	2485 W
Efficiency		
95.34 %	95.53 %	95.82 %

VI. Conclusion

In this paper, the characteristics of torque, voltage, and frequency are verified considering voltage and current constraints in designing by electromagnetic numerical analysis using FEM. Especially the frequency-analytic case of using current source, frequency and slip which are critical element to decide speed and torque of induction motor, are compared in two different driving point producing same torque. In addition, analysis using current source is compatible with general analysis using voltage source according to the result of characteristic analysis.

References

[1] Ion Boldea, Syed A. Nasar "The Induction Machines Design Handbook, Second Edition" 2nd Edition, CRC Press, 2009.

[2] Tiecheng Wang, Ping Zheng, Qianfan Zhang and Shukang Cheng, "Design characteristics of the induction motor used for hybrid electric vehicle," *IEEE Trans on, Magn*, vol. 41, pp. 505-508, 2005.

[3] Sang-Hoon Kim and Seung-Ki Sul, "Maximum torque control of an induction machine in the field weakening region *IEEE Trans on, Industry Applications*, vol. 31, pp. 787-794, 1995.

[4] Y. Ohdachi, Y. Kawase and M. Hirako, "Dynamic analysis of vector controlled induction motor using finite element method," *IEEE Trans on, Magn*, vol. 31, pp. 1904-1907, 1995.

[5] Seung-Ki Sul "Control of Electric Machine Drive Systems" WILEY-IEEE Press, 2011 pp. 262-267.