Numerical Analysis and Design of Large Scale Interior Permanent Magnet Synchronous Generator under Mechanical Stress

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Abstract — This paper deals with characteristics of Interior Permanent Magnet Synchronous Generator (IPMSG) which has been developed for offshore wind turbine with variable operation condition. The representative performance of Wind turbine is THD (Total Harmonic Distortion) of back EMF (Electromotive Force) and torque ripple, which is related to efficiency, vibration and noise [1]. Also, a large capacity IPMSG has a disadvantage of high centrifugal force, because of large external diameter of rotor. Hence, it is important to analyze the electromagnetic field coupled mechanical stress. In this paper, we performed a 3D FEA for an accurate analysis related to performance of the IPMSG applied skew and slitting in order to reduce a THD [2-3]. In particular, this paper presents the design of 5.6MW IPMSG taking account of mechanical stress analysis.

I. INTRODUCTION

The driving system of wind turbine is classified by the presence of Gear Box. If it is not, the driving system is Direct-driven wind turbine. Recently, the wind turbine systems with low speed operation have adopted a lot of direct-driven system in order to solve the maintenance problem. The wind turbine must have the characteristics of high power density and efficiency in low speed operation. Surface-mounted Permanent Magnet Synchronous Generator(SPMSG) with high power and torque density have structural problems like the mechanical damage of Permanent Magnets. In contrast, IPMSG has the distinguished rotor structure with PMs buried interiorly, and the PMs is mechanically protected by the rotor [4]. Even though it is IPMSG, the design must be performed while taking caution not to damage the core, bridge, center-post, which holds the PMs, and the PMs itself. In order to obtain high power density, reducing the thickness of bridge and center-post is better. But it is important to maintain thickness of it more than regular interval in order to prevent the damage of PMs and rotor. Hence, the stress analysis is needed necessarily for design of IPMSG.

This paper presents the design of 5.6MW IPMSG taking account of the stress analysis. In particular, the design that guarantees the safety coefficient is proposed through various shape of IPMSG [5].

II. MECHANICAL STRESS ANALYSIS OF IPMSG

For reference, the conventional centrifugal force equation of IPMSG can be formulated as follows [6].

$$F = \sum_{n=1}^{N} (\rho \times A_n \times l_n \times \omega^2) \tag{1}$$

where, N is the total element number, p is the material density, A_n means the element area of n-th, l is the stack length, R_n is the distance from the origin, w is the angle speed.

The rotor shape of IPMSG is restricted by centrifugal force, with the various ingredients as angular velocity of rotor, distance between each material and the center of circle, material density, and etc [7]. In general, the maximum stress on the rotor is mostly generated at the bridge or center-post, which is between the PMs and surface of rotor. Also, the value of stress is changed by shape of the rotor and shaft. In this paper, the stress analysis is performed according to design variables such as bridge (x_1), center-post (x_2), spoke (x_3) and inner diameter (x_4) of rotor, as shown in Fig. 1.

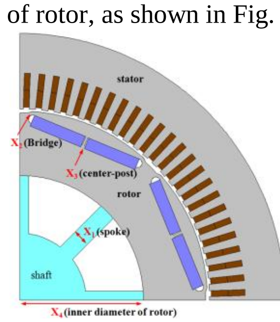


Fig. 1 The design variable of IPMSG taking account of mechanical analysis

Fig. 2 and Fig. 3 are shown as results of mechanical stress and displacement analysis.

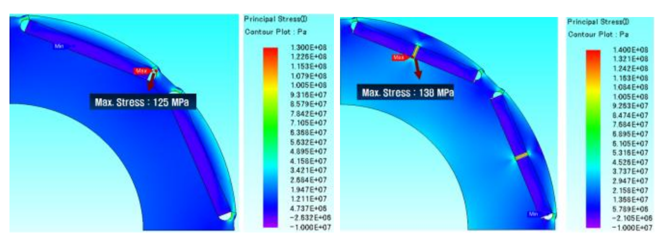


Fig. 2. Comparison results of mechanical stress analysis

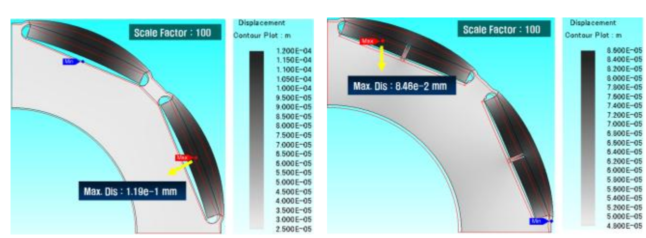


Fig. 3. Comparison results of mechanical displacement analysis

III. CHARACTER OF INTERIOR PERMANENT MAGNET SYNCHRONOUS GENERATOR (IPMSG)

IPMSG changes into electronic output through mechanical input and the energy is stored through the inverter. The ripple and harmonics of output voltage are the cause of increasing the loss. Hence, the method to remove they is important in the design of IPMSG. When shape design, slitting and skewing are applied for IPMSG, it can be greatly reduced.

In this paper, the purposely built IPMSG aimed for wind turbine propulsion has been designed with applying slitting and skewing. The capacity of IPMSG is 5.6 MW at the rated speed (1096rpm). The other specifications, such as the number of poles (=8) and slots (=96), the outer diameter (1200mm), have been fixed. Table. I and Fig. 4 show the 3D structure and specification of IPMSG. Fig 5. shows the flux density distribution of the designed IPMSG

Table I. Specification of designed IPMSG

Motor Type	IPMSG
Poles / slots	8 / 96
Rated Torque	50.29 Nm
Rated Speed	1096 rpm
Stator diameter	1200 mm
Stack	885 mm
Core material	50PN470

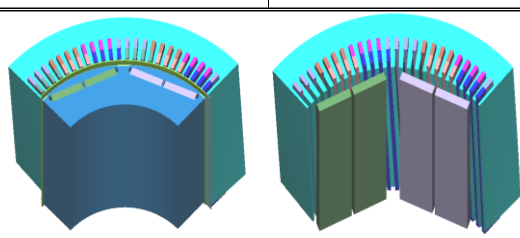


Fig. 4. The structure of IPMSG

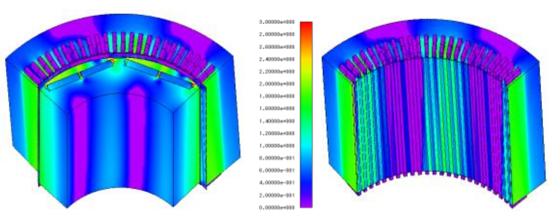
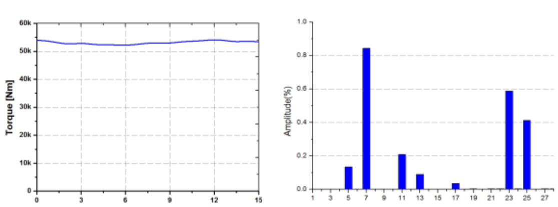


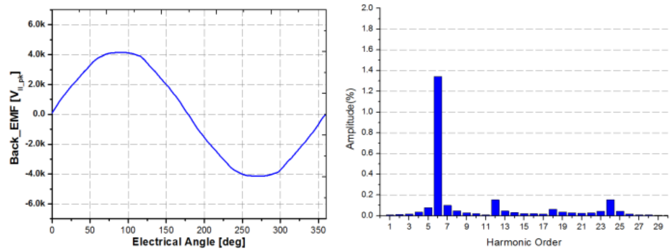
Fig 5. The flux density distribution of designed IPMSG at the rated condition (5.6MW, 1096rpm)

Fig. 6 shows the calculated torque ripple and THD. The average torque is 50.29Nm of designed IPMSG. Torque ripple (3.86%) causing the noise and vibration should be reduced appropriately electric wind generator. Fig. 7 shows the back EMF (4165Vll_pk @1096rpm) and THD (1.62%). Fig. 8 is shown Performance of IPMSG.



(a) Torque ripple (b) THD of Torque ripple

Fig 6. The Torque ripple and THD at the rated condition



(a) Torque ripple (b) THD of back EMF

Fig 7. The Torque ripple and back EMF at the rated condition

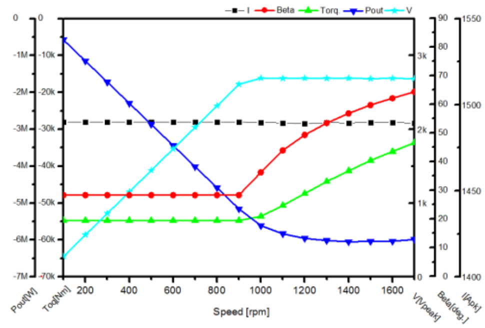


Fig 8. Performance of IPMSG

IV. CONCLUSION

This paper presented the design of IPMSG applying to wind turbine systems. The slitting and skewing is applied in order to remove harmonic and voltage-ripple. Also, the design of IPMSG taking account of stress analysis is performed to prevent damage of the rotor and PMs by centrifugal force. In particular, the design methodology of IPMSG is presented in order to obtain high safety coefficient.

V. REFERENCES

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