Analysis of a Segment Type Switched Reluctance Generator for Wind Power Generation

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***Abstract*— The authors proposed a novel segment type reluctance generator (RG) and presented the experimental performance. It had similar induced voltage to the usual three phase synchronous generator, but the efficiency was low. This paper presents a novel segment type switched reluctance generator (SRG) to improve the efficiency and describes its FEM analysis for wind power generation. The performance is compared with the segment type RG.**

Keywords-component; Switched reluctance generator, Wind power generation, Rare earth less machine

I. INTRODUCTION

Recently, permanent magnet synchronous generator has been developed for bulk wind power generation because of high efficiency [1].

The authors previously proposed a novel segment type reluctance generator (RG) to decrease the cost, and presented the experimental performances. It was composed of a stator with an exciting winding and 3-phases full-pitch armature windings and a rotor with segment cores embedded in an aluminum block. It produced similar induced voltage to the usual 3-phases synchronous generator. It had special merits of low cost, rare earth less, robust structure, but the power factor and efficiency was low.

This paper proposes a novel segment type switched reluctance generator (SRG) to improve the efficiency and describes its design analysis results for 2 MW and direct drive type generator. The performance is compared with the segment type RG[2].

II. SEGMENT TYPE RG AND SRG

A. Construction and characteristics

Fig.1 shows model of the segment type RG and SRG. The number of stator poles is 6 and the number of rotor cores is 4. The stator has full-pitch armature winding and has a series connected excitation winding for RG and three phases excitation windings for SRG. The rotor is composed of an aluminum block and segment cores for both generators.

In RG, a direct current is given to the excitation winding at all times. The electromotive force is induced on the armature windings in response to time variation of the flux.

In SRG, the three phases exciting currents are switched according to the rotational angles shown in Fig. 2. Fig.3 shows flux distribution at aligned position. When the rotor rotates in a counterclockwise direction from the initial position of Fig. 1 and the rotational angle becomes 30deg, inductance of the phase-A winding reaches the maximum value. The inductance decreases with the rotor rotating more. If the phase-A winding is excited by direct current pulse from 30 degree to 60 degree like Fig. 2, braking torque is generated and the electromotive force is induced on the armature winding.

Fig.4 shows the external load circuit. Induced voltage is rectified by the full wave rectifier circuit.

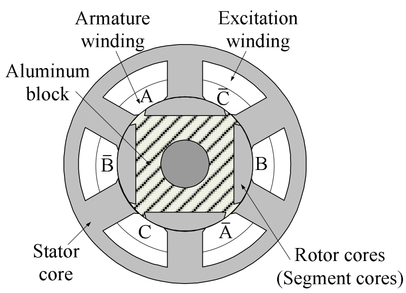

Figure 1. Construction of segment type RG and SRG

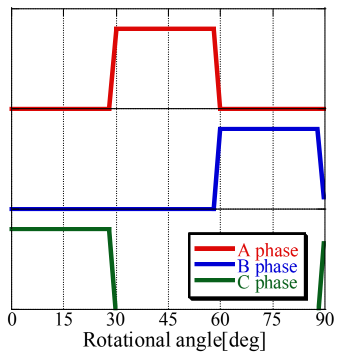

Figure 2. Input current

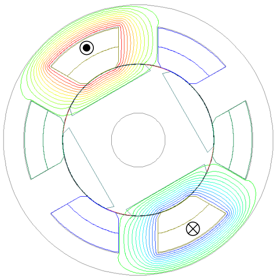

Figure 3. Magnetic flux on the aligned position (angle: 30deg)

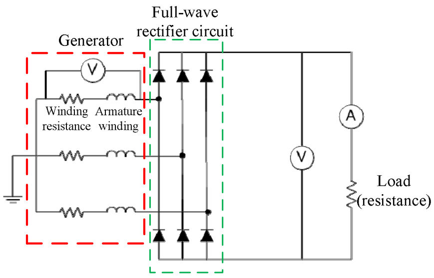

Figure 4. External circuit (load side)

B. *Design of segment type RG and SRG*

We design the segment type RG and SRG using the FEM. The outer diameter and stack height are same as the 2MW class and direct drive type permanent magnet synchronous generator [1].

Fig. 5 shows the resultant RG and SRG. The rated speed is 24rpm, number of stator poles is 48, number of rotor cores is 32, stator diameter is 307cm, rotor diameter is 270cm, stack height is 130cm, and air gap length is 5mm. Fig. 6 shows the periodic symmetry model of the RG and SRG. The length of the rotor cores is 21cm, the width is 5.6cm.

C. *Output characteristics*

Fig.7 shows the output characteristics of the RG and SRG. The maximum output of the RG is 1.1MW and the SRG is 2.3MW. The output of the RG is small because the RG has motor torque which prevents generation as well as braking torque. The output of the SRG is increased by 105% compared with the RG.

D. *Characteristics of the eddy current loss*

Fig. 8 shows the characteristics of the eddy current loss. When the load current is small, the eddy current loss of the SRG is nearly as same as that of the RG. However, when the load current is large, the loss of the RG is larger than that of the SRG. It will be caused by the difference of the flux between the RG and the SRG. The effect of the flux leakage is enormous because the excitation current always flow through all excitation windings.

E. *Efficiency characteristics*

We calculate efficiency using Equation (1). We consider following losses; eddy current loss on the aluminum rotor block, iron loss, copper loss, mechanical loss, stray load loss.

$$\eta = \frac{P}{P + P_e + P_i + P_c + P_s + P_m} \times 100\ [\%] \tag{1}$$

P: Output P_e: Eddy current loss P_i: Iron loss P_c: Copper loss P_s: Stray load loss P_m: Mechanical loss

Table I shows calculated loss and efficiency. The copper loss of the SRG is smaller than the RG. Stray load loss P_s is estimated to 30 % of the copper loss P_c.

The iron loss of both generators is small but the eddy current loss developed in the aluminum block is very high. The iron loss of the RG is 46.89kW and that of the SRG is 16.69kW. It is decreased by 64% compared with the RG. It will be caused by the difference of the magnetic path.

The eddy current loss is calculated by FEM. The eddy current loss of the RG is 884kW and that of the SRG is 470kW. It is decreased by 47 % compared with the RG. It will be caused by that the linkage flux to an aluminum block is decreased.

The efficiency of the SRG is 73.7% and that of the RG is 41.9%.

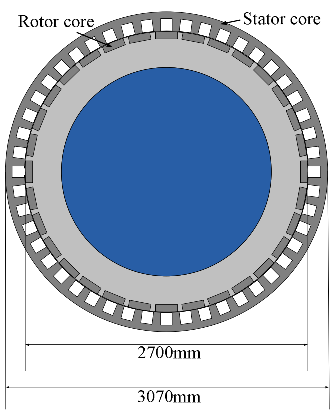

Figure 5. SRG full model (stator: 48 poles)

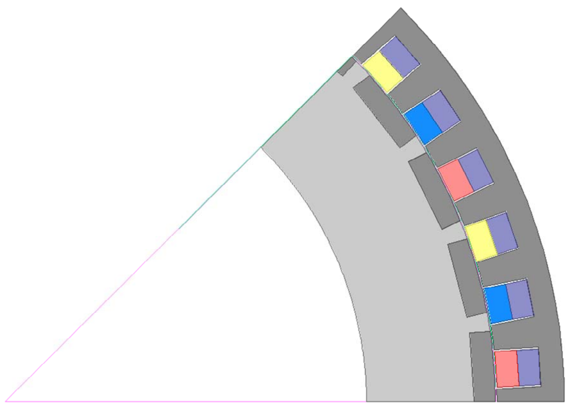

Figure 6. Periodic symmetry model (1/8)

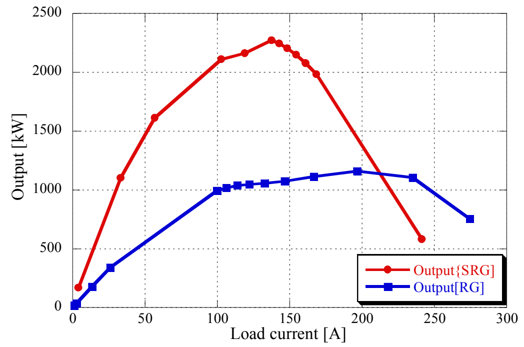

Figure 7. Output characteristics

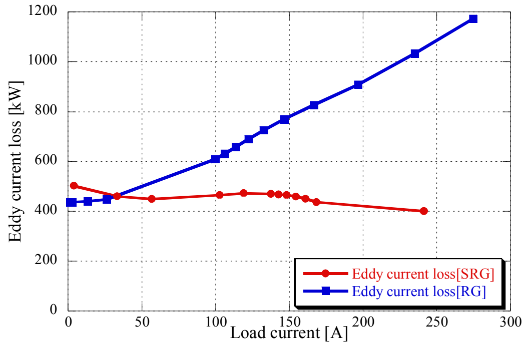

Figure 8. Characteristics of the eddy current loss

TABLE I. LOSS AND EFFICIENCY (MAXIMUM OUTPUT)

model	RG	SRG
Maximum output [kW]	1110	2274
Copper loss(excitation)[kW]	301.2	123.6
Copper loss(armature) [kW]	166.3	125.6
Stray load loss [kW]	140.3	74.77
Mechanical loss [kW]	0.489	0.489
Iron loss [kW]	46.89	16.69
Eddy current loss [kW]	884	470
Efficiency [%]	41.89	73.71

III. DESIGN FOR REDUCTION OF THE EDDY CURRENT LOSS

In this section, we designed the SRG for reduction of the eddy current loss. Specifically, we examined the height of the aluminum block because the eddy current loss developed in the aluminum block is very high.

Fig.9 shows the definition of the aluminum height. The aluminum block is divided into four. We lowered the height of the aluminum block every height and analyzed each model about output and eddy current loss characteristics.

A. Output characteristics

Fig.10 shows the output characteristics after modification of the aluminum height. As the aluminum height is lowered, the output becomes larger. The reason is the difference of maximum inductance and minimum inductance becomes more extreme. The leakage flux is decreased by reduction of the aluminum.

The maximum output of the 0/4 model is about 3MW. It is increased by 30% compared with the 4/4 model. As a result, we can expect an enlargement of output by reduction of the aluminum.

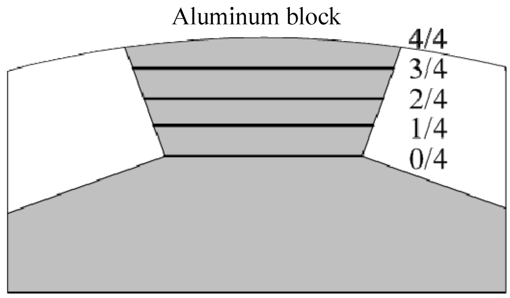

Figure 9. Definition of the aluminum height

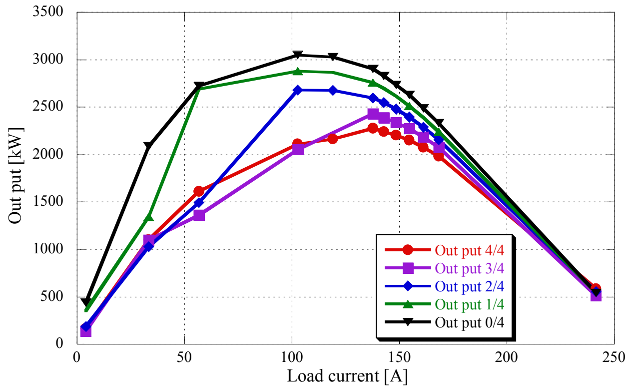

Figure 10. Output characteristics

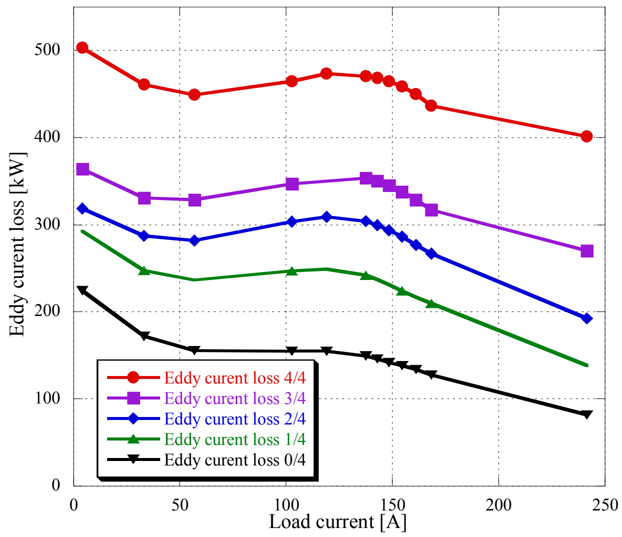

Figure 11. Characteristics of the eddy current loss

B. *Characteristics of the eddy current loss*

Fig.11 shows characteristics of the eddy current loss. As the aluminum height is lowered, the eddy current loss decreased on the whole. It will be caused by reduction of the leakage flux through the aluminum block. The eddy current loss of the 0/4 model is decreased by about 50% compared with the 4/4 model.

C. *Efficiency characteristics*

Fig.12 shows the efficiency characteristics. The maximum efficiency is 78.8% in 0/4 model.

IV. Conclusion

In this paper, we designed and analyzed the 2 MW class segment type reluctance generator and the switched reluctance generator. The maximum output of the RG was 1.1MW and the SRG was 2.3MW. The efficiency of the RG was 41.9% and the SRG was 73.7%. Also, the eddy current loss which developed on an aluminum block is decreased and the output is enlarged by reduction of the aluminum.

Next time, we will show the experimental performances of the 2 kW segment type RG and SRG in Fig.12.

V. Acknowledgment

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VI. References

[1] T. Kuroiwa, K. Karikomi, Y. Hayashi, M. Shibata, and Y. Ueda: "New Products and Technologies of Mitsubishi Wind Turbines", Mitsubishi Heavy Industry Technical Report, Vol. 41, No. 3, pp. 170-173 (2004-5)

[2] K. Yamada, S. Fukumoto, T. Higuchi: "The Fundamental Characteristics and principle of Novel Switched Reluctance Generator", Journal of conference of Industrial applications Society, Vol.3, No.3-40, pp.271-272 (2010.8)

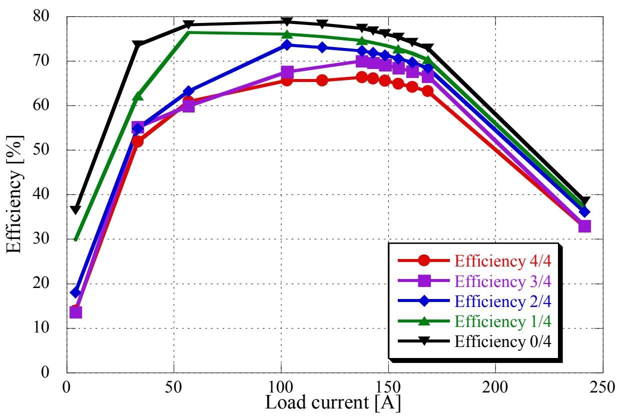

Figure 12. Efficiency characteristics

Figure 12. The 2kW segment type SRG