Design and Characteristic Analysis of Novel Hybrid Transverse Flux type Switched Reluctance Generator for Wind Turbine

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***Abstract*—This paper proposes a novel hybrid transverse flux switched reluctance generator (H-TFSRG) for wind turbine. To increase the output power of TFSRG, the volume of TFSRG must be increased because TFSRG is designed using D^2L method. Therefore a novel H-TFSRG is proposed to maintain the volume of the TFSRG and to increase the output power. Design parameters of the H-TFSRG are calculated using torque equation. Based on the design of the TFSRG, the volume of magnet is calculated to design the H-TFSRG. 3-D finite element analysis (FEA) is performed to verify the design results and to analyze the characteristics of the novel H-TFSRG. Shape optimization of the H-TFSRG is performed to maximize the output power per volume. The Kriging model based on the latin hypercube sampling and a genetic algorithm are utilized to optimize the design. The output power per volume of the optimized H-TFSRG is increased by 8.7% compared to the TFSRG.**

***Index Terms*—Hybrid, Transverse type, Switched Reluctance Machines**

I. INTRODUCTION

Gear boxes have been widely used to increase output power of wind turbines, but these are heavy, expensive and difficult to maintain. Accordingly there has been a growing demand for a direct drive generator system. And as an alternative, switched reluctance generator (SRG) have been actively studied because the SRG has excellent durability, heat-resistance, and is easy to control variable rotor speed compared to induction or DC machine [1].

However, the SRG has been rarely applied to wind turbine generators as highly efficient efficiency permanent magnet synchronous generator (PMSG) has been developed. Therefore transverse flux type switched reluctance generator (TFSRG) which has shorter flux path and higher flux density is requested, however related research has been scarce [2].

As the capacity of wind power increases rapid pace, research on reducing size and enhancing efficiency of wind turbine systems have been actively progressing. Thus it is very important to enhance the output power per volume, because the size of generator becomes bigger to increase the output power [3]. Some of the latest researches include using permanent magnet of high energy-density in generator such like neodymium, which increases efficiency and the output power [4].

This paper proposes a novel hybrid TFSRG (H-TFSRG) that uses permanent magnet to increase the output power per volume than TFSRG with a same rated speed and volume. The D^2L method is used to design H-TFSRG in consideration of the permanent magnet (PM), and the PM is placed within a stator to align flux of PM with the direction of the main flux. To analyze characteristics of the designed TFSRG and H-TFSRG, 3D-finite element analysis (FEA) is performed. The asymmetric bridge converter is used for the generation mode, and the switching angle for turn on/off is decided considering a decreasing section of the inductance.

II. DESIGN OF A H-TFSRG

The D^2L method is revised to design H-TFSRG as shown Fig. 1, which is commonly used for the design of switched reluctance machine [5]. To compare performances, it is designed as the same rated speed and volume with TFSRG. The design parameters can be decided using the torque equation (1).

$$T = kD_r^2 \cdot L_{stk} \tag{1}$$

where, k is output coefficient, D_r is outer diameter of rotor and, L_{stk} is stack length. The k is set to be 15 for industrial small generator. Also, D_r and L_{stk} are calculated by the equation, and D_s is calculated to apply D_r/D_s=0.71, which is decided empirically. Subsequently, after the operating point of PM is determined, the volume of the PM is calculated. Its height, width and depth are decided to ensure maximum energy product using FEA. The design shapes of TFSRG and H-TFSRG are shown in Fig. 2.

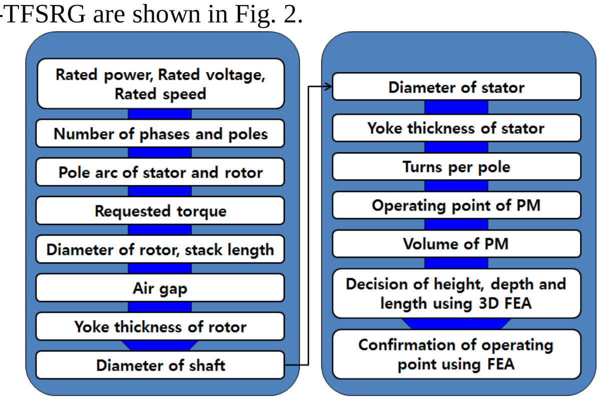

Fig. 1 Design process of H-TFSRG

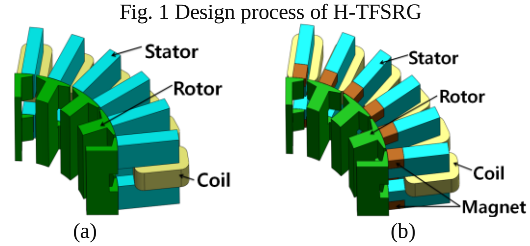

Fig. 2 Designed shape (a) TFSRG. (b) H-TFSRG.

III. FINITE ELEMENT ANALYSIS

In 3D-FEA, TFSRG and H-TFSRG are rotated at a rated speed of 500 rpm, and the output power is verified with loaded resistance on the converter from DC voltage. Same asymmetric bridge converter is utilized, and switching angles for the turn on/turn off are set with respect to inductance profile as shown in Fig. 3 (a) and (b) at a section with reduced inductance. Fig. 3 (c) shows the generating voltages, for which the value of H-TFSRG is 3.8 % higher than TFSRG. Fig. 3 (d) shows the output power of both generators. For H-TFSRG, the output power per volume is 6.2 % higher than TFSRG due to increased flux linkage.

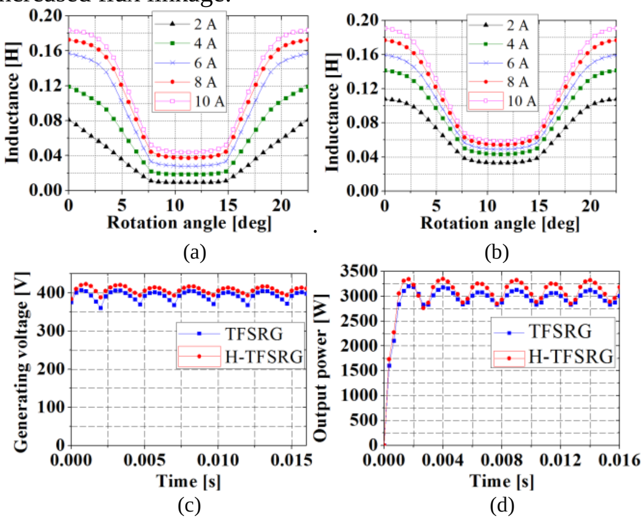

Fig. 3 Analysis results (a) Inductance profile of TFSRG. (b) Inductance profile of H-TFSRG. (c) Generating voltages. (d) Output powers.

IV. OPTIMAL DESIGN

To maximize the output power, the optimal design of H-TFSRG is performed as shown in Fig. 4. The LHS is applied for sampling, and the Kriging model is utilized to approximate the objective and constraints function. A genetic algorithm is used for the optimization algorithm. The optimal results obtained by the optimization algorithm are verified by 3D-FEA as shown in Table I. The objective function of the optimal design is to maximize the output power, and the constraint is to maintain the PM volume and cogging torque of initial model. To satisfy the objective function and the constraints, design variables are established. X1 and X2 represent the depth and height of PM as shown in Fig. 5. Compared to the initial model, the output power per volume of the optimized model is increased by 2.5 %. Therefore, in the optimal model, the output power per volume is improved by 8.7 % compared to the TFSRG.

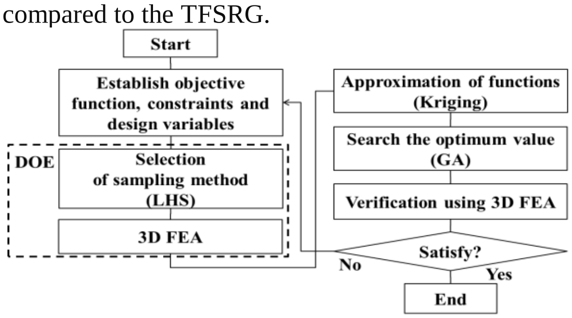

Fig. 4 Optimal design process

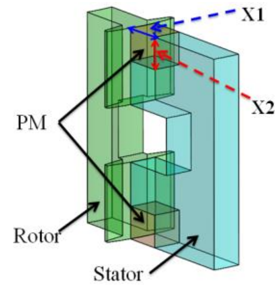

Fig. 5 Optimal design variables of H-TFSRG

TABLE I
OPTIMAL DESIGN RESULTS OF H-TFSRG

Items		Unit	TFSRG	H-TFSRG (initial model)	H-TFSRG (optimal model)
Total volume		cm^3	4646.4		
Volume of rotor		cm^3	901.1		
Volume of PM		cm^3	-	240	
Design variables	X1	mm	-	18.1	20.15
	X2	mm	-	18	16.11
Electrical input power		W	1009.8	1009.8	1009.8
Torque		Nm	53	53.8	54
Mechanical input power		W	2775.1	2816.9	2832.7
Electrical output power		W	3068.8	3260.1	3335.7
Generation efficiency		%	81.08	85.19	86.81
Output power per volume		W/cm^3	4.201	4.247	4.264

V. CONCLUSION

This paper proposes a novel H-TFSRG to increase the output power per volume compared to the conventional TFSRG. To compare performances, H-TFSRG is designed based on the revised D^2L method with a given rated speed and volume. 3D-FEA is performed to verify the design results and characteristics, and the asymmetric bridge converter is utilized. The switch of converter is turned on in a section with reduced inductance. The analysis results show that the output power per volume of H-TFSRG is 6.2 % higher than TFSRG due to increased flux linkage. The Kriging model and a genetic algorithm are used for optimal design of H-TFSRG, and as an optimal result, the output power per volume is increased by 8.7 % compared to TFSRG. These results show that the proposed H-TFSRG has the ability of improving the output power per volume.

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