10 MW급 gearless 타입 초전도 풍력발전기의 개념 설계

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Conceptual design of 10 MW class gearless type superconducting synchronous generator for wind turbine

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Abstract - This paper describes a conceptual design of 10 MW class gearless type superconducting synchronous generator for wind turbine. The main benefits of gearless type generator are decrease of the process of maintenance and loss caused by drive-train. The designed generator improves efficiency of high-capacity wind turbine by applying superconducting coil making high magnetic field. Conventional wind turbines were investigated for up-scaling of generator and the generator had been designed with estimated design parameters using a finite elements method analysis tool.

1. Introduction

There are many indications that the dependency on fossil fuels must be diminished to solve electrical and environmental problems such as lack of resources of fossil fuels and emission of CO_2. Wind power is considered as one of the major renewable energy resources to decrease the energy dependency of fossil fuels [1].

Because of economical and electrical efficiency of wind turbine, researchers have been trying to make a higher-capacity wind power generation system. The biggest capacity of developed wind turbine in the world is 7.5 MW from Enercon. As a capacity of wind turbine becomes bigger, weight of blade and nacelle is also getting increased and this heavy drive-train takes a lot of share of expense for installation of wind power generation system to support huge wind turbine. The high current density achievable in superconducting (SC) coil also makes it possible to create very compact and power dense electrical rotating machines [2].

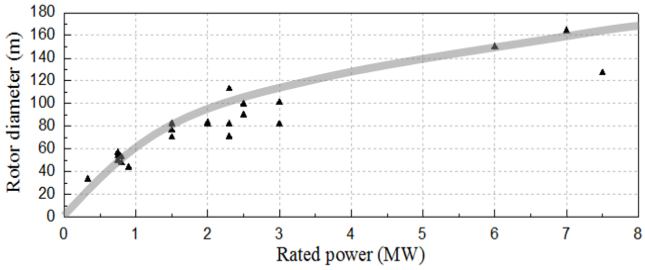
In this paper, a 10 MW class gearless type superconducting synchronous generator (SCSG) was designed for wind turbine. A considerable difference of SCSG and conventional generator for wind turbine is that SCSG has SC coil as a field-winding in generator. Conventional wind turbines were investigated to estimate proper conceptual design parameters of 10 MW class gearless type SCSG [3]. MagNet was employed as a finite elements method (FEM) analysis tool to design SCSG and its characteristics.

The conceptual design results with MagNet present the mechanical structure of the SCSG and confirm that the SCSG is capable of high-capacity wind turbine due to the generation of high magnetic field which makes the generator smaller and lighter.

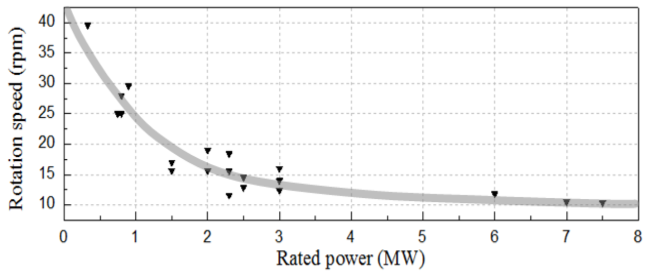
2. Conceptual design of 10 MW class gearless type SCSG

2.1 Design parameters

For the conceptual design of a 10 MW class gearless type SCSG, the design parameters of SCSG had been predicted from parameters of conventional wind turbines. Fig. 1 shows a tendency of rotor size and rotation speed of gearless type wind turbine depending on a rated power. The searched conventional wind turbines are made by Enercon, Unison, Vensys, JSW, Siemens, Vestas, and Nordex. When a rated power of wind turbine increases, the rotor diameter also grows to get more power from wind and the rotation speed decreases by increase of rotor weight. Table 1 contains the properties of a scaled version of a 10 MW gearless type SCSG. Four gearless type wind turbines with different rated power from Enercon were considered for up-scaling of 10 MW SCSG [3]. The rated wind velocity was obtained with 13 m/s and the rated rotation speed and maximum power coefficient were estimated with 10 m/s and 0.49



(a) Rotor diameter depending on rated power



(b) Rotation speed depending on a rated power

<Fig. 1> Rotor diameter & rotation speed of conventional gearless type wind turbine depending on a rated power

<Table 1> Scaling of wind turbine properties for 10 MW gearless type SCSG

Company		Enercon				Up-scaled 10 MW SCSG
Turbine name		E-48	E-82	E-101	E-126	
Rated power	P_R (MW)	0.8	2	3	7.5	10
Rated wind velocity	v_R (m/s)	14	13	13	14	13
Tip-speed ratio	v_{TIP} (m/s)	8.000	8.200	8.028	7.560	9.257
Rotor diameter	D_{blade} (m)	48	82	101	127	145
Rated rotation speed	ω_R (rpm)	28	15.6	12.4	10.36	10
Maximum power coefficient	C_{Pmax}	0.5	0.5	0.478	0.483	0.49

respectively. The rotor diameter and tip-speed ratio for 10 MW SCSG were calculated by equation (1), (2)

$$R = \sqrt{\frac{2(1+\epsilon)P_R}{\rho C_{pmax} \pi v_R^3}} \quad (1)$$

$$\lambda(v_R) = \frac{R\omega_R}{v_R} \quad (2)$$

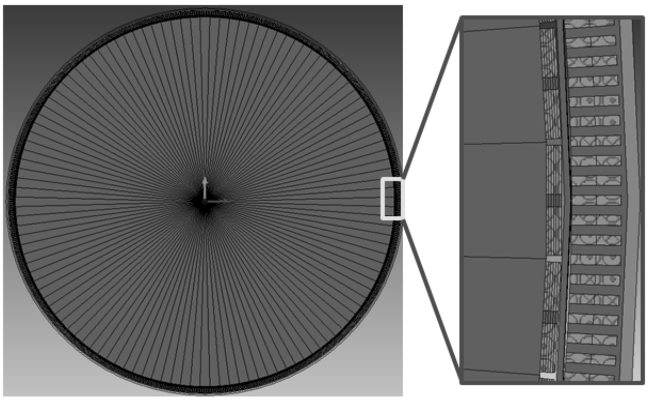
where ε=0.08 is a loss factor of the drive train and ρ=1.225 kg/m3 is the mass density of the air [4].

2.2 Conceptual design of SCSG

The conceptual design of 10 MW SCSG was progressed using MagNet with the estimated and calculated design parameters in previous section. A rotor of generator is composed of 120 poles to generate 10 Hz output voltage with 10 rpm rotating speed. A 3 double-pancake SC coils are placed and 11.108 km SC wire is used to make high magnetic field with single pole. The cryostat is expected to provide an environment where the SC coil can be operated at T=30K. A stator of generator is composed of 720 slots to provide 2 coils per phase and pole. The stator coil is wound with 5 turns to generate 13.8 kV line to line output voltage. The designed SCSG has an total diameter of 7.6 m and a length of 1 m, as shown in Table 2. Fig. 2 displays the configuration of the designed 10 MW gearless type SCSG.

<Table 2> Design properties of the 10 MW gearless type SCSG

Generator	Property	Value
Rotor	The number of pole	120
	Diameter	7.334 m
	Effective length	1 m
	Rotation speed	10 rpm
	Length bobbin of SC coil	20 mm
	Turns of SC coil	800
	The number of SC layer	6
	Length of SC wire per pole	11.108 km
	Field current	100 A
Air gap	Thickness	1 mm
Cryostat	Thickness	10 mm
Stator	The number of slot	720
	Turns of copper coil	5
	The number of wire per coil	78
	Diameter	7.554 m
	Output voltage	13.800 kV_{rms}
	Output frequency	10 Hz



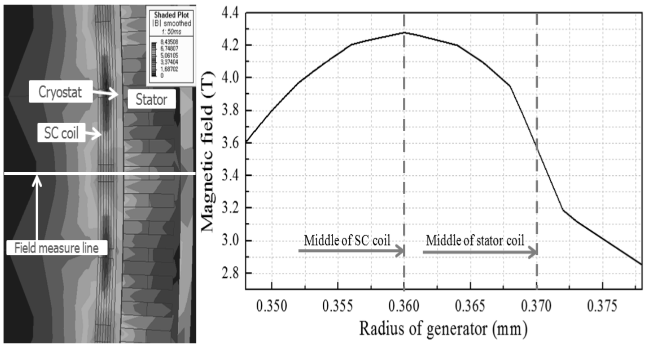
<Fig. 2> Configuration of the 10 MW gearless type SCSG with design parameters in MagNet

3. Simulation and the results

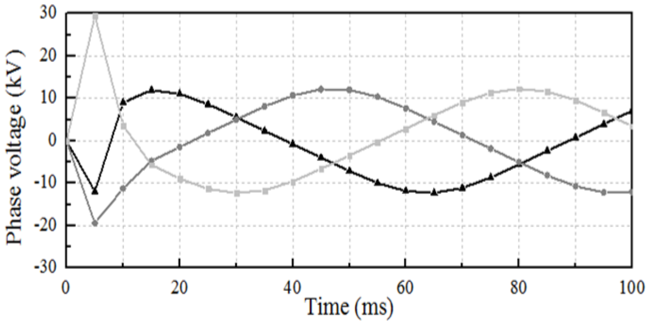
The designed 10 MW gearless type SCSG was simulated using MagNet to get data of magnetic field distribution and output voltage. Fig. 3 presents the magnetic field distribution of 10 MW SCSG. It is seen that the maximum magnetic field at the conductors is 4.3 T and that the magnetic field strength at the stator is 3.6 T. The 10 MW SCSG model represents that SC coils are producing a high magnetic field, whereby the amount of copper in the stator becomes small. The generated output voltage is illustrated in Fig. 4. The magnitude of generated output voltage is 13.8 kV and it is the same with result of equation (3)

$$E = 4.44 N \Phi_m f \tag{3}$$

where N is the number of turns of stator coil, Φ_m is magnetic flux from SC coil, and f is frequency of voltage. The frequency of generated voltage is 10 Hz.



<Fig. 3> Magnetic field distribution of the 10 MW gearless type SCSG in MagNet



<Fig. 4> Output voltage curves of the 10 MW gearless type SCSG in MagNet

4. Conclusion

In this paper, a 10 MW class gearless type SCSG is designed to improve the efficiency of high-capacity wind turbine. The simulation results verify that the designed 10 MW SCSG with 11.108 km SC wire generates high magnetic field and the same output voltage with design parameters. Conventional wind turbines were investigated for up-scaling and the generator was designed with FEM analysis tool. An optimization design skill will be needed to increase its efficiency and the model component of PSCAD/EMTDC will be developed to analyze its operational characteristics in the near future.

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