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Cooling System Design and Thermal Analysis of 6.2MW Hybrid Direct-Drive Generator for Off-Shore Wind Turbine

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1. Introduction

The authors proposed a 6.2MW hybrid direct-drive generator for large scaled off-shore wind turbine, which is constructed with two stages of 2.5MW AFPM machines and 1.2MW RFPM machine. [1] The AFPM and RFPM machines proposed suffer from possible insulation failure and PM (permanent magnet) demagnetization [2] under sever thermal condition. The torque production capability of the hybrid direct-drive generator also depends on the temperature of the PM. [3] Accurate knowledge of the temperature distribution, therefore, allows prevention of insulation damage and PM demagnetization effects in design stage.

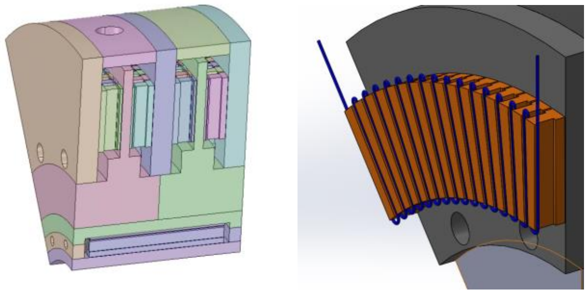
In the cooling system design, it is essential to predict the real operation of the machines to get good approximations of the heat transfer. The cooling systems, i.e. forced-air convection and liquid-cooled type system, have been developed in order to maintain the temperature of the PM below their working temperature, in which the heat transfer occurring in the air-gap between the stator and the PM mounted on the rotor was taken into account.

In the present study, the heat transfer occurring in the 6.2MW hybrid direct-drive generator using the developed cooling systems was investigated numerically, in which the real operation condition was taken into account. The temperatures on the surface of stator and PM were estimated by electro-magnetic and thermal-fluid interaction analysis. The thermal behaviors of the cooling systems consequently were evaluated and compared to each other.

2. Cooling system design

The cooling system for a 1/8 scale model by using the forced-air convection, as shown in Fig. 1(a), has several air flow paths, which consists of the outer axial air ducts and outlet holes for two stages of 2.5MW AFPM machines, inner axial air ducts for 1.2MW RFPM machine, and inlet holes. The atmospheric air is forced to blow by the blower fan.

Meanwhile, the liquid-cooled type system have been explored in a variety of applications in turbo-generators used to nuclear plant and hydropower plant, but with few applications to wind turbines so far. For example, a liquid-cooled direct-drive permanent magnet synchronous generator (LC DD-PMSG) was used, in which the heat transfer was occurred around the water channel passing through the middle of the stator. The water channel must be located in the middle of the stator due to minimize electrical losses. This can cause a lack of cooling performance [3], since the heat transfer occurs mainly on the surface of the stator. To improve thermal efficiency of the liquid-cooled type system, the position of the heat pipe closest to the surface of the stator must be taken into account, as shown in Fig. 1(b).



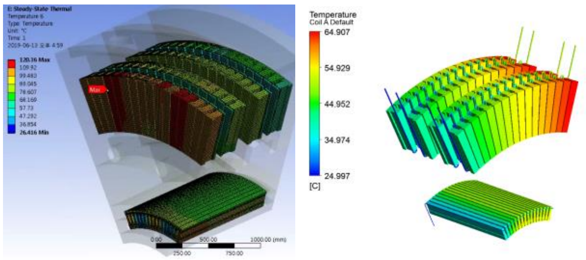
(a) forced-air type (b) liquid-cooled type
Fig. 1 Configuration of cooling systems

3. Thermal analysis

Power losses along the winding coils cause the heat generation, in which resistance of coils and iron, i.e. P_{cu} and P_{iron}, respectively, has a significant effect on the heat generation rate in the stator. The convective heat flux from the stator surface towards the air-gap was calculated using the equation of convection, which considers the flow rate of coolants. The convection energy is proportional to the temperature change ΔT, so that the rate of convective heat transfer ΔP_v can be estimated by Newton's law of cooling. Intake air flow rate by the forced-air convection type cooling system was set to a range, in which the reflux effect did not occur during the thermal analysis. The flow rate of the coolants from the stator surface towards the air-gap and in the heat pipe for the liquid-cooled type system was calculated using the Bernoulli's equation. Power generation of direct-drive generator depended on the performance of the PM, which can be influenced significantly by the radiated heat. The radiation heat from the stator towards the air-gap was estimated using the Stefan-Boltzmann law.

The heat sources calculation was carried on via Maxwell [4] considering the power losses caused by resistance of coils and iron. The resistive coils and iron-losses for AFPM and RFPM machines were 83 and 7.5kW, and 39.8kW and 3.6kW, respectively. From the thermal-fluid interaction analysis using ANSYS [5], hot spots all appeared on the stator winding, and the temperatures of PM for AFPM and RFPM machines correspondingly were up to 348°C and 425°C, respectively, which was obvious to cause the insulation damage and PM demagnetization.

To prevent possible insulation breakdown and PM demagnetization, the forced-air convection and liquid-cooled type systems described in previous section were indispensable for stable operation of the machine. In the case of forced-air convection type system, 25°C air with a flow rate of 1.4kg/s was blown from inlet holes into the machines and formed a flow field exiting at the outlet holes provided outside the housing. Meanwhile, the liquid-cooled type system consists of 8 cooling modules, where in each module 16 stators are wound by 1 heat pipe. The flow rate of the cooling water applied to each cooling module was 0.2kg/s.



(a) forced-air type (b) liquid-cooled type

Fig. 2 Temperature distribution of hybrid direct-drive generator with cooling systems

The results of thermal-fluid interaction analysis for the designed cooling systems applied to the hybrid direct-drive generator are shown in Fig. 2. The temperature occurred on the stators and PMs drops significantly. In the case of the forced-air type system as shown in Fig. 2(a), the hot spot of the AFPM machine appears on the stator winding at the outlet holes, and the maximum temperatures on the stators and PMs are up to 120°C and 72°C, respectively. The distribution of temperature for the RFPM machine is almost similar as the AFPM machine. The liquid-cooled type system shows better cooling performance results as shown in Fig. 2(b). Both AFPM and RFPM machines show similar temperature reduction effects. The hot spot appears on the stator wound by the heat pipe which the coolant is discharged. The maximum temperatures on the stators and PMs were maintained at 72°C and 66°C, respectively.

From the thermal analysis for the designed cooling systems, it is confirmed that insulation class B according to IEC 726 [6] is satisfied. Due to higher heat transfer coefficient of liquid coolant, the overall cooling performance of the liquid-cooled type system shows better than that of the forced-air type system, and this is able to ensure to prevent the PM demagnetization.

4. Conclusions

In the present study, the heat transfer occurring in the 6.2MW hybrid direct-drive generator using the developed cooling systems was investigated numerically, in which the real operation condition was taken into account. The results of thermal-fluid interaction analysis for the designed cooling systems show that the temperature occurred on the stators and PMs drops significantly. The forced-air convection and liquid-cooled type system provided the maximum temperatures on the stators of 120°C and 72°C, respectively, so that the insulation class B according to IEC 726 was satisfied. The temperatures on the PMs for each cooling system were maintained at 72°C and 66°C, respectively, which ensure to prevent the PM demagnetization.

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References

[1] H. J. Park, Y. G. Kim and S. H. Han, Conceptual Design of Hybrid Multi-stage Direct-drive Generator for Large-scale Wind Turbine, *Tran. of the Korean Society of Mechanical Engineers*, A 42(12) (2018) 1133-1139.

[2] M. Polikarpova, P. Royttam, J. Alexandrova, S. Semken, J. Nerg, and J. Pyrhonen, Thermal Design and Analysis of a Direct-Water Cooled Direct Drive Permanent Magnet Synchronous Generator for High-Power Wind Turbine Application, *XXth International Conference on Electrical Machines,* (2012) 1488-1495.

[3] X. Sun and M. Cheng, Thermal Analysis and Cooling System Design of Dual Mechanical Port Machine for Wind Power Application, *IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS*, 60 (5) (2013) 1724-1733.

[4] Maxwell, ANSYS Inc., https://www.ansys.com/products/electronics/ansys-maxwell/, (accessed on 14 June, 2019).

[5] ANSYS CFX, ANSYS Inc., https://www.ansys.com/products/fluids/ansys-cfx/, (accessed on 14 June, 2019).

[6] IEC 726, Dry Type Power Transformers, International Electrotechnical Commission (1982).