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Numerical analysis of end part temperature in the turbogenerator end region with magnetic shield structure under the different operation conditions

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ABSTRACT

Due to the serious overheating problem of end parts in the large turbogenerator end region, accurate calculation of end-part temperature has become a key design factor. In this paper, 3-D fluid and thermal coupling model in the end region of 1250 MW turbogenerator are given. The loss values gained from 3-D transient electromagnetic field calculation are applied to the solving end region as heat sources. Pressure value of fan outlet and fluid velocities of end region inlets from flow network calculation are applied to the solving end region as boundary conditions in the 3-D fluid and thermal coupling analysis model. The fluid flow and temperature distribution of end parts in the end region of large turbogenerator with magnetic shield structure are studied under the different operation conditions. The distribution of fluid velocity in the ventilation duct of stator end core is obtained. The temperature distribution laws of stator-end copper coils, screen plate, finger plate, press plate, and magnetic shield are researched under the different operation conditions. The location of the highest temperature point in the turbogenerator end region with magnetic shield structure is determined. The accuracy of numerical calculation is validated by experimental measured values.

1. Introduction

Large turbogenerator is energy conversion device in the power stations. In order to resolve concentrated leakage magnetic flux of stator end core and reduce the temperature of end parts, magnetic shield is installed between press plate and screen plate. Magnetic shield in the turbogenerator end region has lots of advantages. Magnetic shield is made by silicon steel sheet, which forms a magnetic path. The leakage magnetic flux is guided to this low reluctance path, which results in the uniform distribution of leakage magnetic flux along the axial direction. The end region in a large turbogenerator is extremely complex. This end region includes mainly the finger plate, press plate, magnetic shield, screen plate, complex three-dimensional stator-end winding. As the capacity of a large turbogenerator increases, electromagnetic and thermal loads of turbogenerator become higher. It leads to a sharp increase in the losses and temperature of end parts in the turbogenerator end region, which affects the safe and stable operation of turbogenerator. Furthermore, the heat of the end parts is taken away by the fluid flow. Therefore, a study of complex fluid flow, losses of end parts, and temperature of end parts in the turbogenerator end region with magnetic shield structure has an important practical significance.

Experts have studied extensively the physical field of electrical machine. For example, Traxler-Samek et al. researched cooling airflow, losses, and temperatures in large air-cooled synchronous machines [1]. Camilleri et al. predicted the temperature and flow distribution in a direct oil-cooled electrical machine [2]. Nategh et al. performed thermal modeling of directly cooled electric machines using lumped parameter and limited CFD analysis [3]. Jungreuthmayer et al. performed a detailed heat and fluid flow analysis of an internal permanent magnet synchronous machine by means of computational fluid dynamics [4]. Some other researchers studied extensively physical field of electrical machine [5–9], but very few focused on fluid flow and temperature of end parts in the turbogenerator end region with magnetic shield structure under the different operation conditions.

In addition, complex fluid flow and thermal fields in a fully air-cooled hydrogenerator are calculated and analyzed in Ref. [10]. Influence of the end ventilation structure change on the temperature distribution in the 330 MW turbogenerator end region with copper shield structure is studied in Ref. [11]. 3-D complex fluid flow and temperature distribution are researched in the 330 MW turbogenerator end region with copper shield structure in Ref. [12]. However, this paper focuses on end part temperature in the 1250 MW turbogenerator end

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region with magnetic shield structure under the different operation conditions. In this paper, using a 1250 MW turbogenerator with end magnetic shield structure as an example, 3-D fluid-thermal coupling analysis model of turbogenerator end region is established. Pressure value of fan outlet and fluid velocities obtained from the flow network calculations are applied to the turbogenerator end region as boundary conditions. The losses obtained from 3-D transient electromagnetic field calculations are applied to the end parts as heat sources in the fluid and thermal coupling analysis. After solving the fluid and thermal equations with fluid–solid conjugated heat transfer, the fluid flow and temperature distribution of end parts in the turbogenerator end region with magnetic shield structure are researched. The distribution of fluid velocity in the ventilation duct of stator end core is determined. The temperature distribution laws of stator-end copper coils, screen plate, finger plate, press plate, and magnetic shield are studied under the different operation conditions. The location of highest temperature point is determined in the turbogenerator end region with magnetic shield structure. New strategies and theoretical basis will be provided for the optimal design of the larger turbogenerator end region.

2. Fluid-thermal coupling analysis in the turbogenerator end region with magnetic shield structure

2.1. Establishment of fluid-thermal coupling analysis model

According to the actual structure and size of 1250 MW turbogenerator end region, 3-D fluid-thermal coupling analysis model of turbogenerator end region is established, as shown in Fig. 1.

Fig. 1(a) shows the end structures of 1250 MW turbogenerator. The turbogenerator end region is composed of solid region and fluid region. Solid region includes stator-end copper coils, stator end winding, water pipe within stator end winding, slot wedge, stator end core, finger plate, press plate, screen plate, wind board, and magnetic shield, ect. Fluid region includes hydrogen and cooling water. Fig. 1(b) shows water-pipe inlets and fan outlet. Fig. 1(c) gives the other inlets and outlets of solving region. Fig. 1(d) shows prototype of this turbogenerator. According to the property of the material, the thermal conductivities of screen plate, finger plate, and press plate are 43 W/($m{\cdot}K$).

According to network theory, the flow network within the turbogenerator could be established, which is based on the law of energy conservation, the law of mass conservation, and the Bernoulli equation. The flow network equations are calculated with the successive iterative method [13]. Pressure value of fan outlet and fluid velocities obtained from the flow network calculations are applied to the turbogenerator end region as boundary conditions.

The boundary conditions are given as follows. The inlet velocity of water pipes is 0.822 m/s. The inlet velocity of ventilation duct within stator end core is 52.19 m/s. The inlet velocity of wind board is 0.635 m/s. The inlet velocity of axial ventilation holes is 45.9 m/s. The inlet velocity of air-gap is 45.27 m/s. Rectangle inlet velocity is 13.34 m/s. Pressure value of fan outlet is 950.6 Pa. Pressure value of fan outlet and the inlet velocities (provided by the manufacturer) are gained from flow network calculation. The rated rotating speed of 1250 MW turbogenerator rotor is 1500 r/min. Under the rated-load operation, the inlet temperature of water pipes is 51.2 °C. The other inlet temperatures are 54 °C. Under the no-load operation, the inlet temperature of water pipes is 51.6 °C. The other inlet temperatures are 46.1 °C. These initial temperatures are provided by the manufacturer.

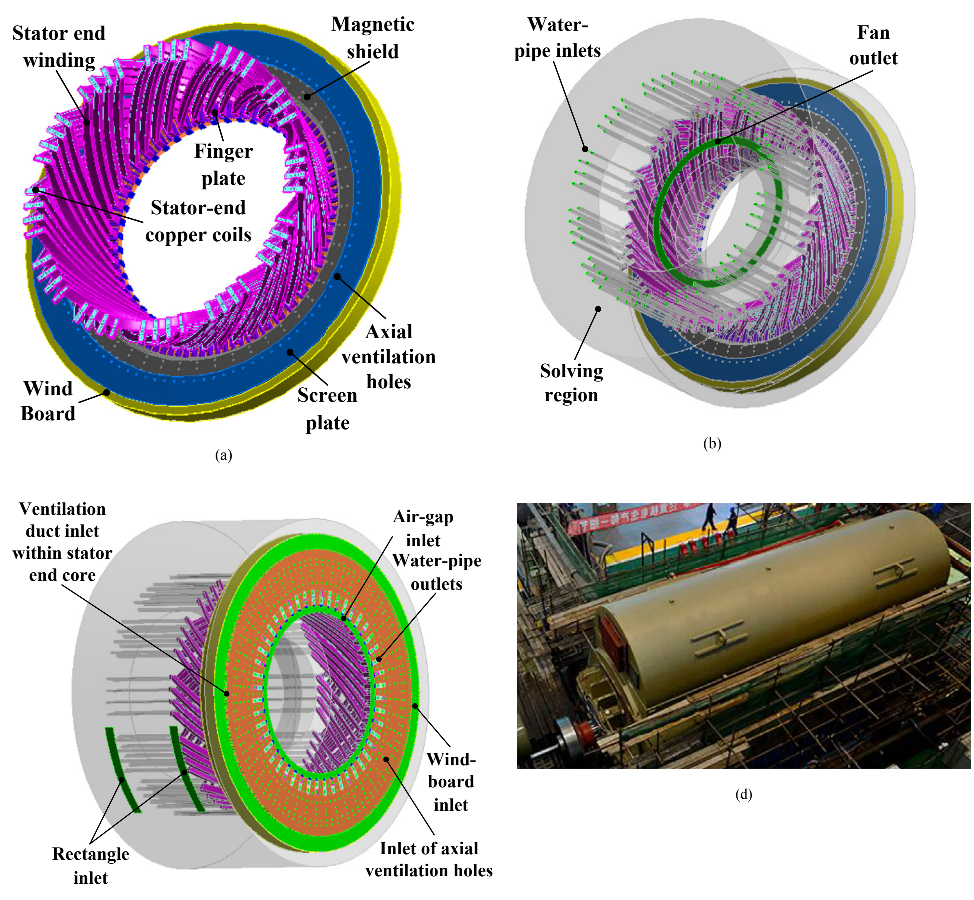

Fig. 1. 3-D fluid-thermal coupling analysis model of turbogenerator end region. (a) End structures of 1250 MW turbogenerator. (b) Water-pipe inlets and fan outlet. (c) The other inlets and outlets of solving region. (d) Prototype of this turbogenerator.