The use of drive turbine cooling systems based on renewable energy sources

K V Osintsev, M V Tregubova, Y A Perekopnaya, Iu S Prikhodko

South Ural State University, 76, Lenina ave., Chelyabinsk, 454080, Russia

E-mail: pte2017pte@mail.ru

Abstract. The mechanical energy of the turbine is converted into electric energy by means of a rotating magnetic field of the rotor in the stator. The voltage and current in the rotor windings create a thyristor excitation system. The generator on the shaft of the central turbine usually has problems with cooling the turbine. The progress of turbine construction mainly depends on the success in solving this problem today. The article describes the main scientific idea of improving the efficiency of electric generators, namely the possibility of using renewable energy sources. For the first time, data on the possibility of using cooling systems based on renewable energy are presented.

1. Introduction

During the operation of the synchronous generator, its windings and steel are heated. The permissible heating temperatures of the stator and rotor windings depend primarily on the insulating materials used and the temperature of the cooling medium. During the operation of the generators, the insulation of the windings is gradually aging. The reason for this is pollution, humidification, oxidation by oxygen of the air, exposure to an electric field and electrical loads. However, the main cause of aging insulation is its heating. The higher the heating temperature of the insulation, the faster it wears out, the less its service life. The service life of the insulation at a temperature of up to 120 °C is about 15 years, and when heated to 140 °C it reduces to almost 2 years. The same insulation at a heating temperature of 105 °C ages much more slowly and its service life increases to 30 years. Therefore, during operation in any mode of operation of the generator, it is not allowed to heat its windings above permissible temperatures. In order for the heating temperature not to exceed the allowable values, all generators are performed with artificial cooling. According to the method of heat removal from the heated stator and rotor windings, indirect and direct cooling is distinguished. With indirect cooling, the cooling gas is fed into the generator and driven through a non-magnetic gap and ventilation channels using fans built into the rotor ends. In this case, the cooling gas is not in contact with the conductors of the stator and rotor windings and the heat generated by them is transferred to the gas through a winding insulation. With direct cooling, the coolant contacts the conductors of the generator windings, bypassing the insulation and the steel. The authors [1,2] consider the cycle of microelectric power, including the organic Rankine cycle. In these studies, it was shown that an increase in the efficiency of a power plant is possible only with the use of low-boiling heat carriers. In [1,2] the authors consider similar problems, but here the solution to the problem of increasing efficiency is considered for capacities of approximately 1 MW. There are two air cooling systems, namely, flow and closed. The flow-through cooling system is rarely used and only in turbo-generators with a capacity of up to 2 MW, as well as in hydro-generators up to 4 MW. At
the same time, air from the engine room, which quickly contaminates the insulation of the stator and rotor windings, is driven through the generator, which ultimately reduces the life of the generator. With a closed cooling system, the same amount of air circulates in a closed circuit. In order to improve the cooling efficiency of turbine generators, the length of the active part of which is particularly large and the air gap is small, use a multi-jet radial ventilation system. To increase the contact surface of the heated parts with cooling air in the steel of the machine that is shown in figure 1, a system of ventilation ducts is used [3, 4]. After passing through the radial ventilation channels in the steel, the heated air goes into the exhaust chambers [5]. Multi-jet ventilation provides uniform cooling of the turbogenerator along its entire length [6, 7].

---

![Figure 1. The standard scheme of air feed to the electric generator: 1 - atmospheric air input; 2 - air filter; 3 - shutoff valve; 4 - centrifugal fan; 5 - electric drive; 6 - air recirculation line; 7 - electric generator; 8 - water-air heat exchanger](image)

2. **Variants and scientific analogues**

Turbine generators with indirect hydrogen cooling have the same ventilation scheme as in air cooling. The difference is that the volume of cooling hydrogen is limited to the generator housing, and therefore the coolers are built directly into the housing [8, 9]. Hydrogen cooling is more efficient than air cooling, since hydrogen, as a cooling gas compared to air, has a number of significant advantages. It has a 1.51 times higher heat transfer coefficient and 7 times higher thermal conductivity [10, 11]. The latter circumstance determines the low thermal resistance of the hydrogen layers in the insulation and gap gaps. Significantly lower hydrogen density in comparison with air allows reducing ventilation losses 8-10 times, as a result of which the efficiency of the generator increases by 0.8-1%. The absence of oxidation of insulation in a hydrogen environment as compared to the air environment increases the reliability of the generator and increases the service life of the winding insulation. The advantages of hydrogen include the fact that it does not support combustion, therefore, it is possible to refuse a fire extinguishing device in hydrogen-cooled generators. The hydrogen filling the generator in a mixture with air forms an explosive mixture. It is most difficult to make reliable oil seals on the generator shaft that prevent gas leakage. The higher the hydrogen overpressure, the more efficient the cooling of the generator, therefore, with the same dimensions of the generator, it is possible to increase its rated power. However, with an overpressure of more than 0.4-0.6 MPa, the increase in generator power does not justify the cost of overcoming technical difficulties arising from this. Therefore, the pressure of hydrogen in modern generators of more than 0.6 MPa is not applied. Generators with indirect hydrogen cooling can, if necessary, work with air cooling, but their power is reduced accordingly [11, 12].

3. **Statement of the problem. Scientific novelty**

There is an urgent problem of cooling generators. Currently, there are several ways. However, the effectiveness of these methods is low. This article proposes a solution to this problem. Nowadays, there
are standard air cooling schemes for steam turbine generator sets that increase the thermal power plant efficiency. The proposed technology feature is the combination of the most efficient air-cooling scheme and the absorption unit cycle in a single energy technology complex that is shown in figure 2. For the first time it is proposed to use an absorption refrigerating machine as the cooling system element of steam turbine electric generators. Finally, this can be used to increase the unit capacity power units of thermal power plants that use air-cooled power generators.

Figure 2. Technological scheme of using absorption refrigerating machine: 1 – pump, 2 – experimental area, 3 – refrigerating machine, 4 – electric drive, 5 – heat exchanger, 6 – water circuit

4. The scheme of cooling the electric drive
Let us consider the work principle of the first scheme element, it is the heat pump. There are two very important requirements for this substance pair: their normal boiling temperatures \( t_s \), the difference between which should be as great as possible; components must be dissolved in each other indefinitely. In addition, the low-boiling refrigerant agent of the ARM is presented with the entire requirements set what is typical of the working fluid of the vapor compression refrigerating machine. The most common binary solutions of the ARM are a mixture of water and ammonia and a mixture of water and lithium bromide. Moreover, ammonia in the first solution and water in the second are refrigerating agents. The simplest ARM scheme works as follows. Let us consider, for example, water-ammonia ARM. Low-potential heat is supplied to the generator filled with a water-ammonia solution, as a result of which the low-boiling component will be boiled out of the solution \([13, 14]\). Further, ammonia vapor moves to the condenser, liquefies with the phase transition heat removal, is throttled and boils in the evaporator, producing an artificial cold. The formed ammonia vapors are transferred from the evaporator to the absorber, where they are absorbed and dissolved in a weak water-ammonia solution coming from the generator through a throttle valve. The absorption process intensity and ammonia vapor dissolution in water depends on the solution temperature, as the temperature increases, the solubility drops sharply. To maintain the high absorptive ammonia vapor capacity, flowing cold water is pumped through the absorber, with which the absorption heat is removed \([15, 16]\).

5. Practical significance
A principled scheme of using the absorption refrigeration machine for the air cooling system of the steam turbine electric generators has been developed. The proposed scheme increases thermal power plant efficiency according to preliminary estimates by 0.1-0.2%, primarily due to the reducing power consumption on pumps and fans drive, as well as by reducing temperature of cooling heat carrier at the summer period on the thermal power plant. Similar effects can be calculated by the proposed schemes. In addition, the introduction of such systems is beneficial in terms of reducing the impact of CHP on the environment.

6. Conclusion
Thus, the following scientific and practical results are identified and disclosed in the article. The technology has been developed that combines the most efficient air-cooling scheme for electric generators of steam turbines on thermal power plants and an absorption refrigeration machine in a single energy technology complex. In comparison with standard cooling schemes, the proposed option is more efficient as well as ecologically clean from the point of view in using renewable energy sources. Further development of the technology involves the use of environmentally friendly fuels \([17, 18]\). In addition, the use of such fuel increases the efficiency of the thermal power plant.
7. Acknowledgments
The work was made in South Ural State University and supported by Act 211 of the Government of the Russian Federation, contract № 02.A03.21.0011.

References
[1] Fan J, Liu Q and Song F 2018A new corresponding-states model for estimating the vaporization heat of working fluids used in Organic Rankine Cycle Fluid Phase Equilibria 469 40–47
[2] Shi L, Shu G, Tian H and Deng S 2018 A review of modified Organic Rankine cycles (ORCs) for internal combustion engine waste heat recovery (ICE-WHR) Renewable and Sustainable Energy Reviews 92 95–110
[3] Modlinski N, Szczenk K, Nabaglo D, Madejski P and Modlinski Z 2019Mathematical procedure for predicting tube metal temperature in the second stage reheater of the operating flexibly steam boiler Applied Thermal Engineering 146 854–865
[4] Yu F, Yongfeng Y, Honghai W, Donghua Z and Bo L 2018Modelling and simulating for marine exhaust gas boiler Advances in Intelligent Systems and Computing 856 40–48
[5] Sobota T 2018 Improving steam boiler operation by on-line monitoring of the strength and thermal performance Heat Transfer Engineering 39(13-14) 1260–1271
[6] Shaposhnikov V and Biryukov B 2018 On the efficiency of heat and electric power plants based on combined-cycle plants with overexpansion of the working fluid in the gas turbine and injection of steam into the gas path Chemical and Petroleum Engineering 54(1-2) 94–99
[7] Ghosh D, Ray S, Mandal J, Mandal N and Shukla K 2018 A failure analysis of PRDS pipe in a thermal power plant boiler Journal of the Institution of Engineers 99(2) 233–238
[8] Chattopadhyay S and Ghosh S 2018 Combined energetic and exergetic assessment of a biomass-based integrated power and refrigeration plant Journal of the Brazilian Society of Mechanical Sciences and Engineering 40(3) 133–134
[9] Zhao X, Fu L, Wang X, Sun T and Zhang S 2018 Analysis of the recovery system of flue gas from combined heat and power plant with distributed peak-shaving heat pumps Harbin Gongye Daxue Xuebao/Journal of Harbin Institute of Technology 50(2) 152–159
[10] Largeron C, Krinner G, Ciais P and Brutel-Vuilmet C 2018 Implementing northern peatlands in a global land surface model: Description and evaluation in the ORCHIDEE high-latitude version model (ORC-HL-PEAT) Geoscientific Model Development 11(8) 3279–3297
[11] Liu L, Zhu T, Gao N and Gan Z 2018 A Review of Modeling Approaches and Tools for the off-design Simulation of Organic Rankine Cycle Journal of Thermal Science 27(4) 305–320
[12] Khasanova A, Zhiringola T and Osinetsev K 2017 Method for processing coal-enrichment waste with solid and volatile fuel inclusions IOP Earth and Environmental Science 87 03–07
[13] Rastvorov D, Oisnsete K and Toropov E 2017 Influence of burner form and pellet type on domestic pellet boiler performance IOP Earth and Environmental Science 87 010–013
[14] Cerutti M, Riccio G, Andreini A, Facchini B and Picchi 2019 A Experimental and numerical investigations of novel natural gas low NOx burners for heavy duty gas turbine Journal of Engineering for Gas Turbines and Power 141(2) 06–09
[15] Han D, Hao L and Yang J 2019 Experimental investigations on vibration characteristics for bearing-rotor system of micro gas turbine Mechanisms and Machine Science 63 343–356
[16] Cocco D and Cau G 2015 Energy and economic analysis of concentrating solar power plants based on parabolic trough and linear Fresnel collectors Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy 229(6) 677–688
[17] Bogomolov A, Valiulin T, Vershinina K, Shevyrev S and Shlegel N 2019 Igniting soaring droplets of promising fuel slurrys Energies 12(2) 208
[18] Vershinina K, Glushkov D and Strizhak P 2017 Characteristics of the ignition of the drops of organic coal-water fuels based on waste oils and industrial oils Solid Fuel Chemistry 51(3) 188–194