Improvement to electricity generation systems by using a refrigeration machine and solar concentrator for air cooling

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Abstract. A process scheme of using the absorption refrigeration machine in electricity generation systems in case of application of air cooling system of the steam turbine electric generators has been developed. The proposed scheme increases thermal power plant efficiency by 0.1-0.2% according to preliminary estimates, primarily by reducing power consumption on pumps and fans drive, as well as by reducing temperature of cooling heat carrier in the period with high ambient temperatures. A feature of the proposed technology is the combination of the most efficient air-cooling scheme and the absorption plant cycle in a single power technology complex. In this refrigeration machine, the working fluid is a binary mixture, one of the components of which is called a refrigerant, and the other one is an absorbent, where the liquid absorbent can absorb the refrigerant vapor. For the first time it is proposed to use an absorption refrigerating machine as the cooling system element of steam turbine electric generators. Currently, there are advanced air-cooling systems using multi-jet cooling for turbo-generators with a capacity of 3 to 180 MW. Finally, it can be used to increase the unit capacity of power units on the thermal power plants that use air-cooled power generators.

1. Introduction

Non-block thermal power plants with cross connections are widely used in the Eastern Europe countries, the CIS, and in Russia. Most often, they are used to connect various types of equipment to produce superheated steam [1, 2]. There are direct ways to increase the thermal power plants efficiency and indirect ones [3, 4].

The direct measures include increasing the initial superheated steam parameters, decreasing exhaust steam pressure, using secondary steam superheating, and increasing heat fuel combustion [5, 6]. Indirect measures include actions to influence heat carrier parameters, which are involved in the process scheme of the thermal power plant, for example, technical and feed water, oil, air. Air is used in various processes: as an integral part of the reagent mixture supplied to the boiler, in aspiration systems when solid fuel burns, as a heated agent in a cooling processes [7, 8].

2. Scientific novelty. The principle of operation

The authors [1] consider the cycle of electric power station, including the absorption refrigeration machine. In these studies, it was shown that increasing the efficiency of a power plant can be achieved by changing the flow parameters at a thermal power plant. In [3], the authors consider similar problems, but in that case, the solution to the problem of increasing efficiency is considered for capacities of approximately 1-2 MW.

Two cooling methods of electric generators are used at modern thermal power plants. The first method is cooling by hydrogen and the second is cooling by air. Indirect cooling of stator windings with hydrogen and direct rotor winding cooling are used in generators. Air system is more reliable from the point of view of safety, but it is also less effective than cooling by hydrogen. The main air cooling elements are a water-air heat exchanger, axial fans on the rotor, an air-feed system for the electric generator, Fig. 1.
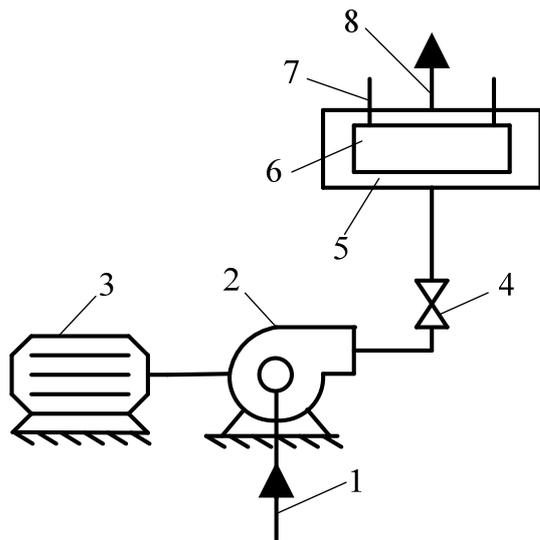

Figure 1. The process scheme of electric generator air cooling: 1 – atmospheric air input; 2 – centrifugal fan; 3 – electric drive; 4 – shutoff valve; 5 – electric generator; 6 – water-air heat exchanger; 7 – water; 8 – atmospheric air output
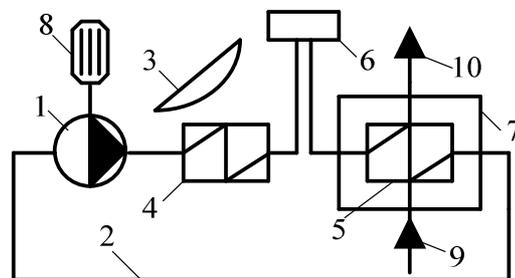
Figure 2. The new process scheme of electric generator air cooling and water heating: 1 – pump; 2 – water line; 3 – solar concentrator; 4 – absorption machine; 5 – water-air heat exchanger; 6 – heat water consumption; 7 – electric generator; 8 – electric drive; 9 – atmospheric air input; 10 – atmospheric air output

A closed cooling system provides for the circulation of the same air volume in a closed circuit from the cold air chamber using fans on the generator shaft. At first, air is forced into the machine. Then air cools the stator and rotor surfaces, moves the hot air chamber, passes through the air cooler and re-enters the generator. Air passes through oil filters to compensate for loss due to leaks. Improving the air cooling system and the use of multi-jet cooling made it possible to create turbines with a capacity of 3 to 180 MW. In these turbines, thermo-reactive insulation in the stator and rotor windings is used. The air is forced into the generator cavity to create an increased pressure, which prevents the external dust penetration. Traditionally, generator sets of this type are fixed on the plates used in construction for foundations. The number of bearings in the generator set engineering system varies depending on the model.

Most generator sets models of this type are equipped with horizontal and vertical gas coolers installed on shock-absorbing suspensions. In places, where the maximum temperatures can be reached, the resistance thermometers installation is foreseen. Many key structural elements of generator sets used in CHP are made of solid steel forgings. Testing for limiting operating temperatures is carried out by the resistance method. The ventilation ducts in this engineering system divide the stator core. Ventilation ducts packages are made of special electrical steel. The heat released in the turbine is removed by four air coolers installed inside the turbine stator housing along the machine axis. The air cooler is the tubular heat exchanger.

Water circulates through the tubes and cools the air space inside the generator stator. The cooling water is the technical water of the turbine unit circulating system. Cooling water is supplied to the air coolers by gas cooler pumps. The cooling water flow rate is changed by the control valve [9, 10]. The air cooler consists of the few components. There are a frame, tube plates, cooling tubes with fins, chambers and a cover. Tube plates are rigidly connected by two frames, which are interconnected with special struts.

The air coolers are enclosed into shells, which on the water supply side have openings with flanges for connecting the external water supply line and the cooling water drain. Removable water chambers lids allow cleaning the inner cavity of the shells, cooling tubes and monitoring their condition without disturbing the stator body tightness [11, 12].

The shell outer flange on the output side has an elastic connection to the stator. The shell outer flange on the turbine side is rigidly connected to the stator housing by single push frame. In air coolers, an anti-corrosion coating is applied to the shell's surfaces and covers in contact with the cooling water [13, 14].

3. Analogues
Cooling by air can be performed on opened and closed systems. The air ventilation is allowed only for generators with a capacity of 750 and 1500kW. More powerful generators are used in a closed cooling system. The air passes filters for separation suspended particles before it enters the generator. In case of closed cooling system, the heated air is directed under the pressure of the fans mounted on the rotor shaft into the air cooler chamber.

Air coolers are heat exchangers of the recuperative type [15]. The tubes of the air coolers flow water from the pressure pipes of the condenser. In an emergency case there is a backup supply of water to the air coolers from the technical water supply. The cooling water passes through a water filter before entering the coolers. It is needed to protect the tubes of air coolers from contamination.

The operating instructions indicate the temperature of the cooling gas, which must be maintained when the generator is operating. Mercury thermometers are installed on each faceplate and on the stator housing in the zone of the highest temperature to measure the temperature of the cooling gas. Resistance thermometers are installed in front of each fan and in the outgoing air stream.

4. Scientific novelty
Nowadays, there are standard process schemes of cooling with air. Steam turbines are using process schemes that increase the thermal power plant efficiency. The proposed technology feature is the combination of the most efficient air-cooling process scheme and the absorption unit in a single energy technology complex. For the first time it is proposed to use an absorption refrigerating machine as the cooling system element of steam turbine electric generators. Finally, it can be used to increase the unit capacity power units of thermal power plants that use air-cooled power generators, Fig. 2.

5. Practical significance of technology
The adjustment of the temperature of the vapours withdrawn from the reflux condenser is one of the main operations in the operation of absorption chillers. Excessive super cooling of vapour after a reflux condenser causes partial condensation of ammonia vapours, which significantly reduces the performance of the machine. In this case, the rectifier and the reflux condenser will idle in a closed loop.

At the same time, insufficient cooling of the vapour after the reflux condenser leads to a significant increase in water vapour in the vaporous ammonia, which impairs the operation of the evaporator. In this case, it is necessary to maintain a lower pressure in the evaporator in order to achieve the same temperature to the absorption chiller.

During absorption, a large amount of heat is released, which is transferred by the passing water. A solution that is formed in the absorber because of the absorption of ammonia vapours is pumped over with a pump. Between the steam generator and the absorber, the process scheme includes a heat exchanger in which a solution at 40-50°C is heated.

6. Conclusion

In this research, the process scheme for a unit for air cooling was considered. For comparison, let us take a boiler operating on organic fuel and variants of absorption heat pumps. The absorption heat pump used for cooling of electric generator on thermal power plant with a conversion factor of less than 2.6-3.0 compared with a single steam generator does not save energy. The value 2.6 is used for solid fuel boilers. The value 3.0 is used for gas or liquid fuel.

Taking into account the higher specific capital investments compared to absorption heat pump in combination with electric power generation, the use of the absorption heat pump can be economically justified. The acceptable payback period for additional capital investments is a ratio of 4.0-5.0.

7. Acknowledgments

References

[1]   Ma W, Liu T, Min R and Li M 2018 Effects of physical and chemical properties of working fluids on thermodynamic performances of medium-low temperature organic Rankine cycles (ORCs) *Energy Conversion and Management* **171** 742-749

[2]   Zhu Y, Li W, Sun G and Li H 2018 Thermo-economic analysis based on objective functions of an organic Rankine cycle for waste heat recovery from marine diesel engine *Energy* **158** 343-356

[3]   Bo Z, Sang Z, Lu X and Weng Y 2018 Effects of different working fluids on the performance of a radial turbine in an organic Rankine cycle power system *Journal of Mechanical Science and Technology* **32(9)** 4503-4515

[4]   Bukowska M, Nowak K, Proszak-Miąsik D and Rabczak S 2017 Concept of Heat Recovery from Exhaust Gases *IOP Conference Series: Materials Science and Engineering* **245** 052057 23-25

[5]   Urazmetov S, Kraev V, Verevkin A, Kiryushin O and Skatov K 2013 Method for determining the viscosity of nonlinear viscous liquids and the device for its implementation *Federal Intellectual Property Service Official Bulletin* **16** 21-24

[6]   Baniasad A, Oukati S and Ameri M 2015 Energy management and economics of a trigeneration system Considering the effect of solar PV, solar collector and fuel price *Energy for Sustainable Development* **26** 43-55

[7]   Cocco D and Cau G 2015 Energy and economic analysis of concentrating solar power plants based on parabolic trough and linear Fresnel collectors *Journal of Power and Energy* **229(6)** 677-688

[8]   Pugsley A, Zacharopoulos A, Mondol J and Smyth M 2016 Global applicability of solar desalination *Renewable Energy* **88** 200-219

[9]   Osintsev K V, Prikhodko I S and Zavyalova M I 2018 Methods for improving energy efficiency of air handling unit using factor analysis of data *IOP Conference Series: Earth and Environmental Science* **194** 052019 7-12

[10] Aidarova S, Bekturganova N, Kerimkulova M and Sharipova A 2014 The influence of surfactants to the stability of coal water suspension *Periodica Polytechnica Chemical Engineering* **58** 21-26

[11] Osintsev K, Zhirgalova T and Khasanova A 2017 Operation principles of gas turbine generator *Industrial Engineering, Applications and Manufacturing* **121** 17285369 1-4

[12] Thulukkanam K 2013 *Heat Exchanger Desing Handbook*, 2nd ed (CRC Press) p 1245

[13] Danilov O L, Garyaev A B, Yakovlev I V et al 2011 *Energy Saving in Heat Power Engineering and Heat Technologies,* ed A V Klimenko (Moscow: MPEI Publishing house) p 424

[14] *Thermal calculation of boilers (Standard method)* 1998 (Saint-Petersburg: NPO CKTI) p 256

[15] Sadhu S 2011 *Handbook of Mechanical Engineering* (S. Chand & Company Ltd) p 2080