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Analysis Of Scientific Research on Improving Energy Efficiency in Modern Thermal Power Plants

Pardaev Zokir Elmurodovich

Docent, department "Power Engineering", Karshi State Technical University, Karshi, Uzbekistan

ABSTRACT: The article presents an analysis of scientific research aimed at increasing energy efficiency in modern thermal power plants. The author studies the main problems encountered in the operation of steam turbine units installed in thermal power plants (TPPs). The use of solar energy technologies for the complete replacement of regenerative heaters and partial replacement of economizers and evaporator surfaces of steam generators is studied. Schemes are presented that represent the efficiency of solar-electric power plants for hybrid solar-organic fuel power plants developed by equipping existing steam cycle power plants with solar energy technology. Simulation modeling studies of a sample steam power unit with installed heaters and an economic analysis of the proposed solution are carried out using the Ebsilon Professional software.

KEYWORDS: steam turbine, thermal power plants, energy efficiency, integrating steam-power cycle power plants.

I. INTRODUCTION

Today, one of the main problems encountered in the operation of steam turbine devices installed in thermal power plants (TPPs) is their inability to provide the required performance parameters due to the wear of their components. Also, the failure to increase the net energy efficiency (EF) above 38-40% in modern steam turbine devices is a waste of fuel and energy resources, economic and environmental damage, and adds to the list of many operational problems. Numerous studies have been conducted to solve the listed problems, and we have conducted an analysis of the efficiency of steam turbine TPPs based on the results of the latest research.

The results of scientific experiments, and computational and modeling studies conducted by scientists of leading research institutions in our country and abroad were used in the analysis of data.

II. METHODS AND MATERIALS

E. Matjanov and Z. Akhrorkhujaeva studied the issue of integrating steam-power cycle power plants with solar energy [1]. The researchers studied the use of solar energy technologies for the complete replacement of regenerative heaters and the partial replacement of economizers and evaporator surfaces of steam generators.

A solar-electricity efficiency equation was proposed for hybrid solar-organic fuel power plants developed by equipping existing steam-power cycle power plants with solar energy technology.

The schemes of the 155 MW steam turbine of the Tashkent power plant were analyzed as an example of the introduction of solar energy technologies. Several values of the aperture surface of parabolic cylindrical concentrators were studied in the analytical data.

The modeling results show that the higher the solar heat input temperature to the cycle, the higher the solar-electric efficiency $\eta_{sol}^{e}:=$ 0.078 when replacing low-pressure water heater No. 1 and η_{sol}^{e}= 0.270 when replacing high-pressure heater (HPH) No. 6. The higher the solar heat input temperature to the cycle, the greater the reduction in the amount of organic fuel burned in the steam generator: each unit of solar heat input saves 0.22 units of fuel burned in the steam

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generator in low pressure heater (LPH) No. 1, 0.77 units in high pressure heater No. 6, and 1.12 units when partially replacing the economizer and evaporator surfaces of the existing steam generator [2].

Researchers have estimated that converting an organic fuel steam generator into a solar steam generator by applying solar energy technology to the economizer and evaporation surfaces will result in a high EF of η_{sol}^{e}= 0.344 (Figure 1).

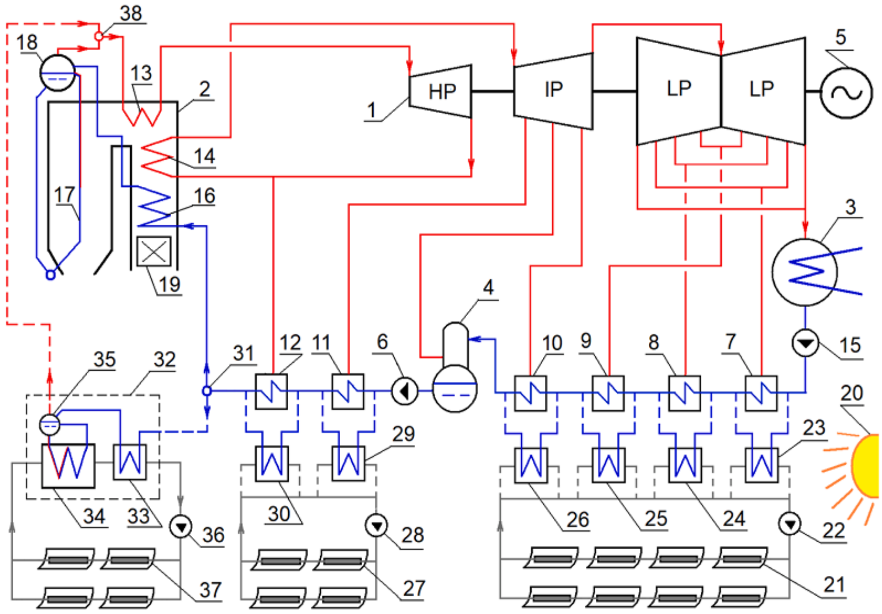

Fig. 1. General scheme of solar energy supply for the K-150-130 steam turbine plant.

1 – K-150-130 steam turbine; 2 – steam generator Ep-500/140GM; 3 – steam turbine condenser; 4 - deaerator; 5 – electric generator; 6 – supply water pump; 7 – LPH No. 1; 8 – LPH No. 2; 9 – LPH No. 3; 10 – LPH No. 4; 11 - HPH No. 5; 12 – HPH No. 6; 13 - superheater; 14 – intermediate heater; 15 - condensate pump; 16 – economizer; 17 – evaporator surfaces; 18 - drum; 19 - regenerative air heater. 20 - solar; 21, 27, 37 - parabolocylindrical concentrator; 22,28, 36 - circulation pump; 23÷26, 29, 30 – solar heat exchangers; 31 – separator valve; 32 - solar steam generator; 33 - economizer of the solar steam generator; 34– evaporator surfaces of the solar steam generator; 35 - the drum of the solar steam generator; 38 - mixing valve.

D. Popov’s scientific research on the use of solar energy in traditional organic fuel-fired combined cycle thermal power plants deserves more attention [2]. The researcher studied three options for using solar energy: A) Existing cycle. B) Replacement of the LPH with solar heaters. C) Replacement of all LPH with solar heaters. D) Replacement of all LPH and boiler economizers (partially) with solar heaters. In options B-D, the use of solar collectors with a total aperture area of 81,807 m^2 (option B), 64,280 m^2 (option C), and 129,656 m^2 (option D) is considered, and the electrical efficiency reaches 17.25% (option B), 34.03% (option C) and 39.23% (option D).

It was concluded that option B is the most optimal for existing thermal power plants. The power plant will be brought to almost “zero” modification, including a large share of solar energy generation, fossil fuel savings, and achieving high efficiency of the power plant. Option D is considered suitable for future power plants, where the share of solar energy generation can reach up to 25% of the power plant capacity, and the instantaneous efficiency at the design point will be more than 39%.

According to analytical data, D. Popov [2] proposed to take into account the above-mentioned specific features of the regenerative water heating system, namely, to reduce the steam consumption to the steam turbine when some regenerative heaters are out of operation by using solar energy. As a result, the steam consumption in the final stages of the turbine can be maintained at the design value, but the steam turbine power is reduced. The absence of exhaust steam in the regenerative water heaters leads to fuel savings.

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In the study by C. Polski et al., a concept for improving the adaptability of steam turbine thermal power plants using feedwater heaters was developed [3]. According to the results of the study, it is possible to reduce the power transmitted to the power grid and ensure the operation of the plant at low load using feedwater heating, when the boiler and its control system can operate under reduced load conditions. Using the Ebsilon Professional 15 software, it was demonstrated that the minimum load for grid generation could be reduced from 92 MW to 78 MW based on the developed model of a 200 MW model power plant. Although the efficiency of electricity generation decreased, the cost analysis showed that the proposed changes were reasonable due to the integration of the 200 MW power unit with the grid (Figure 2).

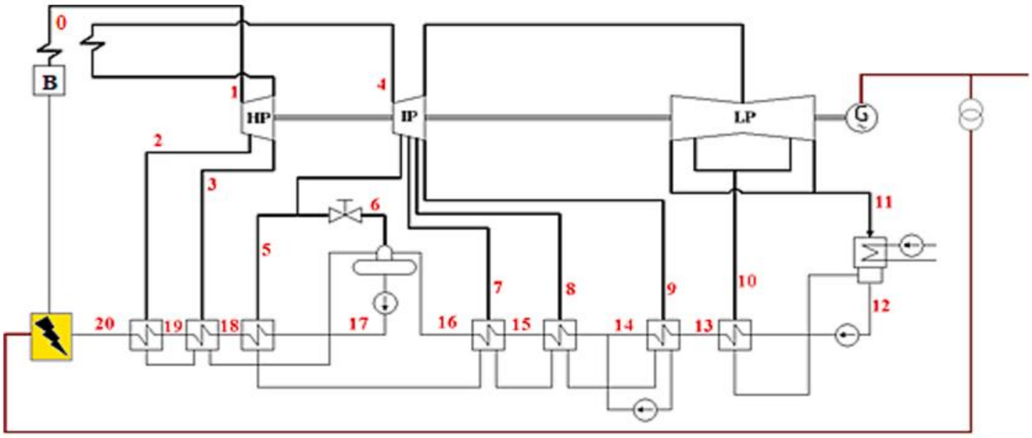

Figure 2. General view of a simplified technological system for a type 200+ steam power unit with electric feedwater heating. B – boiler, HP, IP, LP – high, medium and low pressure steam turbines, G – synchronous generator.

III. RESULTS

The permissible range of load changes (cyclic range of load), characterized as the ability to reduce power from maximum to minimum load while maintaining the ability to increase power output to the nominal level, is called the "adaptability of a steam turbine thermal power plant". This issue is especially important for power generation systems in the transition phase [4].

In scientific research, many methods, concepts, ideas, or attempts have been put forward to increase the adaptability of steam turbine thermal power plants. The presented concepts for improving adaptability are aimed at changing the operating environment, usually by throttling, at selected points of the technological system; improving the control schemes of thermodynamic parameters, or collecting thermal energy and its subsequent use [1-4].

Such a concept is proposed for the first time. This solution increases the power of the auxiliary equipment at loads close to the minimum level with the power required to operate the electric heater. Therefore, from the point of view of the power system operator, the power supplied to the network by the device may be lower than its minimum load. It is also important that the proposed method does not require extensive changes to the technological systems of the power plant, or large and expensive thermal energy storage systems. For information, such analyses have not been conducted before.
Today - the use of an electric water heater in the cycle of a steam turbine power plant should allow:
• reducing the minimum cost of electricity supplied to the power grid;
• increasing the temperature of the boiler water when operating at a power below the nominal load;
• ensuring electricity production by burning coal (without heavy oil) with power supplied to the power system below the minimum load of the power plant;
• reducing the operating costs of units equipped with fuel oil burners.
To prove the above assumptions, simulation modeling studies of a model steam power plant with installed heaters were conducted using Ebsilon Professional software, and an economic analysis of the proposed solution was conducted.

In their research paper "Power and Heat Integration in Regenerative Storage: Improving Thermal Storage Capacity and Efficiency", Sergej Belik et al. concluded that an electrically heated regenerative storage is an energy-efficient and cost-effective solution for converting excess electrical energy and storing it as high-temperature heat. A preliminary model

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was developed to characterize the thermodynamic state of the hybrid storage system with a small number of dimensionless parameters. These characteristic parameters are used to obtain key performance indicators for the thermodynamic evaluation of power-heat integration in regenerative storage. The results of the modeling studies demonstrate the energy-efficient placement of the electric heating elements inside the storage tank and provide a significantly improved thermal storage capacity and heat accumulation efficiency of the design. The benefits of power-to-heat conversion are particularly evident in increased economic efficiency and operational flexibility [5].

Electrically heated regenerative storage has recently gained attention due to its ability to convert excess electrical energy into heat and store it, providing savings at various temperatures in storage power plants, electrothermal energy storage systems, and Brayton cycle-based heat pump storage systems [10]. This heat is then used in the supply cycle to generate electricity on demand. As shown in Figure 1, such a storage system combines a power unit with an electric heater (EH) with a solid-state thermal energy storage (STES) device.

High-temperature HEs are currently used in industry in various types and power levels. The most common type on the megawatt scale is the tubular EH [6]. This type offers a large heat transfer area and is primarily used in mechanical engineering and the chemical industry for drying and air conditioning with a gaseous medium. The gaseous medium, usually air, flows directly over tubular heating elements and provides high-temperature process heat at a maximum gas temperature of 600 to 700 °C. This power-saving technology provides high-temperature heat at a low cost and is proposed for charging EH blocks in various storage facilities [3]. Storage block: A solid-state heat storage (SSHS) unit is a counter-flow regenerative heat storage (RHS) unit that has been tested in high-temperature facilities for the steelmaking and glass industries [3]. The concept is based on a thermally insulated tank through which a hot gas flows and transfers the heat directly to a porous solid medium. After this charging period, the gas source changes from hot to cold, so that the stored heat energy is recovered by the cold gas. The HIT, such as air, is used in combination with high-temperature materials, such as perforated bricks, stones, slag, and ceramics. The maximum operating temperature for such inexpensive materials is from 800 to 1200 °C [3].

Numerous theoretical studies have been devoted to the modeling and thermodynamic analysis of regenerative heat exchangers. In addition to the extensive work carried out by Hausen and Schumann, Schmidt and Wilmott have presented several modeling approaches based on the first law of thermodynamics and a comprehensive set of design methods derived from them [10]. Both founders serve as a basis for various theoretical [10] and experimental works [10] in further research of the SSHS blog.

The analysis of the presented literature shows that the research on the EH-SSHS systems is focused on the detailed modeling of the SSHS blocks. The electric heater, on the contrary, is modeled in a simplified way based on stationary models, therefore, the validation of the component dimensions and heat transfer values together with the SSHS block is not carried out. Therefore, this method aims to introduce and apply a numerical model that describes the thermodynamic state of the two components in a single hybrid storage system [1-10].

For this purpose, a compact and dimensionless model is proposed that describes the thermodynamic state of the EH-SSHS system with a small number of characteristic parameters. The first step is to simplify the one-dimensional model presented by Schumann and transform it into a formula with dimensionless parameters. These characteristic parameters are used in the second step to obtain technical key performance indicators (KPI) for evaluating the PtH integration. Then, in terms of energy density and related thermodynamic efficiency, various characteristic parameters are modeled to determine the optimal location for the electric heater [3,26]. Another modeling study shows the impact of PtH integration on the thermal storage volume and provides recommendations for energy-efficient design solutions with maximum storage utilization. The final study determines the improvement of storage performance based on power-related KPIs.

The goal of the numerical analysis is to develop a simple but non-trivial model that allows calculating the thermodynamic states of the EC and SSHS blocks under cyclic conditions.
This modeling approach considers heat transport only in the axial direction. Due to the low effective thermal conductivity of the solid and liquid phases, heat transfer in this direction is neglected. In addition, heat generation is not considered in this model.

In addition to these assumptions, the following simplifications are made:

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- the accumulation time of the liquid phase is ignored due to its finite heat capacity.
- the thermophysical properties of the solid and the liquid are independent of temperature.
- the effect of the thermal resistance within the solid is ignored since the heat transfer resistance is represented by a small Bio number (Bi <0.10).

As shown in Figure 4, the modifications introduced into this model involve splitting the solid phase into two, one for the inventory of the EIH, and the other for the generation of the EIH heating area and its resulting heat. This heat is produced according to Joule’s principle and is considered as initial data in the heat balance equation of the solid phase (1b). The heat loss to the environment in the liquid phase is taken into account for both components. Based on these considerations, the temporal and spatially variable temperature field during the operation of the heat cycle is calculated for both phases of the SSHS (equation symbol “a”) and EQ blocks (equation “b”).
The solid phase of the SSHS block:

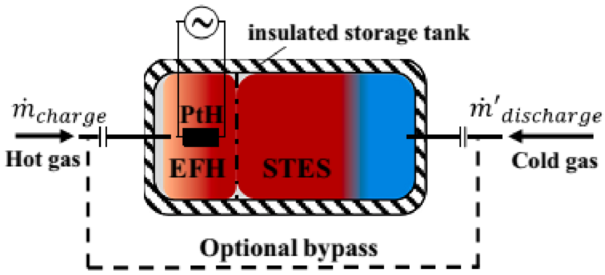

Figure 3. Schematic view of an electric heater and a solid medium thermal energy storage system with a circulating cycle.

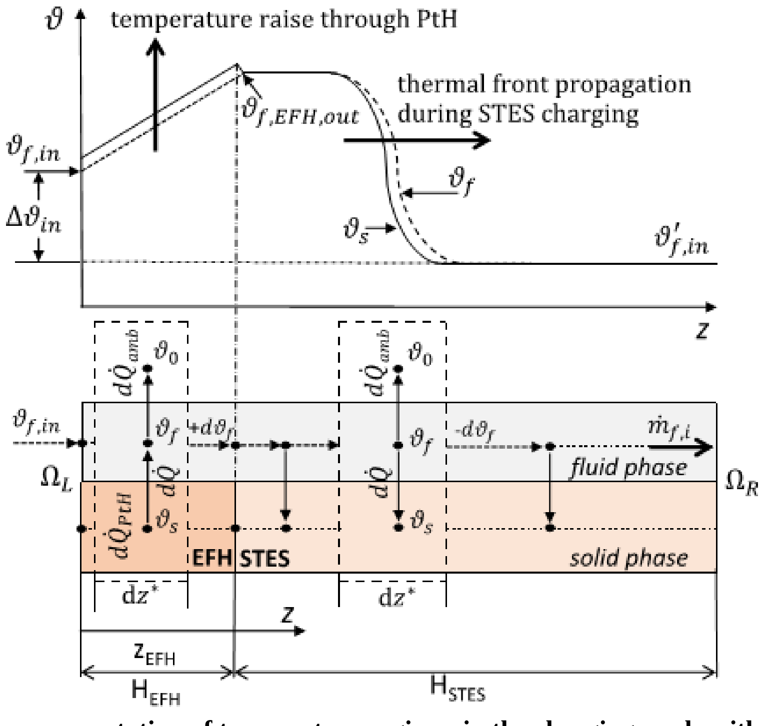

Figure 4. Schematic representation of temperature regimes in the charging mode with the corresponding discretization scheme of the two-phase sphere.

IV. CONCLUSIONS

During the research, Φ-Λ-St modeling was carried out, focusing on the conversion of power to heat. This, firstly, helps to determine the location and expansion of the EI inside the reservoir, and secondly, to obtain the results of the implemented KPI based on the wide variation of Φ, Λ, and Stanton numbers, and increases the storage efficiency in the PtH process.

The analysis of the presented literature shows that the research of the EH-SSHS systems is focused on the detailed modeling of the SSHS blocks. The electric heater, on the contrary, is modeled in a simplified way based on stationary models, therefore, the verification of the component dimensions and heat transfer values together with the SSHS block is not carried out. Therefore, the purpose of this method is to introduce and apply a numerical model that describes the thermodynamic state of two components in a single hybrid storage system

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