 https://doi.org/10.1051/e3sconf/202126604012

Optimization of the energy system of the Taimyr coal basin through energy storage

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Abstract: This article examines the influence of energy storage on the possibility of increasing the efficiency of a power plant on the example of the model of the power system of the Taimyr coal basin. The main elements of the power system calculated in this paper included: household consumers (township of Dixon), industrial consumers (coal mining enterprises), sources of thermal and electric energy (coal-fired combined heat and power plant). Storage equipment was selected for the storage of thermal and electrical energy in the power system, such as energy storage systems based on lithium-ion batteries and hot water storage tanks. The changes in the operation modes of the combined heat and power plant during the introduction of battery systems in the power system were evaluated, and the efficiency of the combined heat and power plant was calculated for various modes of energy storage.

1 Introduction

The consumption of heat and electricity by industrial and household consumers of energy is uneven during the day. The uneven consumption of energy impacts the generation of energy: generation must adapt to the consumer, therefore electric and thermal power plants have variable operating modes during the day.

The efficiency of the CHPP (combined heat and power plant) equipment depends on the operating mode. The maximum efficiency is required only in a certain small range of operation. Due to the need to operate in a wide range of generating capacities, up to 90% of the time power stations can operate with an efficiency significantly lower than the maximum.

Currently, there are three ways to solve the problem of leveling daily load: 1. Management of energy consumption; 2. Management in generation systems; 3. Use of energy storage systems.The first direction is related to the concepts of the "Internet of energy" and "demand response". The disadvantage of this direction is the restriction for consumers in the use of energy, which can negatively affect technological processes and creates a number of problems for consumers [1, 8].The second direction is associated with the use of two or more generation sources, one of which is the main. It operates in the base part of the load with high efficiency. The other sources are highly maneuverable and used during peaks in demand, but usually, they have low efficiency [6, 11]. The third direction is associated with the use of energy storage systems in energy systems. It does not restrict consumers in the use of energy and allows the use of a highly efficient source of generation (CHPP, nuclear power plants etc.) without significant change of loading [1, 4, 12].

The storage of thermal and electric energy in the power system smoothes out the unevenness of the daily generation schedules, which allows the generation source to operate in a small range of capacities. This, with the optimal choice of main equipment, leads to an increase in the average efficiency of the power station and an increase in the efficiency of generation in general.

The use of high-power energy storage systems in energy systems is a modern and developing area of power generation.

In modern conditions of general continuous increasing of energy consumption and uneven daily schedules of it, there are specific requirements for the main equipment of thermal power plants. This equipment operates in mode of constant changes and stops in the load, with modes of daytime maximal loads and load reduction at night without reducing efficiency and reliability.

2 Purpose of the work

The purpose of this paper is to analyze the impact of energy storage in the energy system of the region on the efficiency and mode of operation of the power generation source.

3 Research methods and materials

3.1. Object of modeling

The study was conducted on a mathematical model of the power system, namely the power system of the Taimyr coal basin.A model for calculating the operating modes of the CHPP was developed in an Excel program. The initial data for calculating are the values of the heat and electric load. The model is a Rankine calculation of the cycle of a steam turbine of a combined CHPP with regenerative and heating selection, as well as the calculation of fuel consumption, taking into account the efficiency of the main equipment of the CHPP, depending on the load and electricity consumption for its own needs.

By 2024, Vostokugol Company plans to produce up to 30 million tons of anthracite per year on the Taimyr Peninsula. Due to the expansion of production, the infrastructure of the region will be expanded. The likely energy system of the region was calculated. The main elements of the power system include the town of Dixon (household consumers), mining coal enterprises (industrial consumers), coal-fired steam turbine CHPP with rated electric power of 82 MW, and a rated thermal power of 153 MW (177.4 Gcal/h).The values of thermal and electric load of consumers are determined by aggregated indicators. The value of the rated power of the CHPP is determined in accordance with the values of the rated load of consumers [13].

The daily operation schedule of the CHPP can be seen in Figure 1, which shows: “Qthermal” - thermal load; “Nel” -electrical load; “N+Q” – the total load (the sum of thermal and electrical load); “efficiency” - the efficiency of CHPP. This schedule is based on typical daily schedules of thermal and electric energy consumption for household and industrial (coal mining enterprises) consumers.

The relation between the efficiency of the main equipment of the CHPP and current workload are shown in Figures 2, 3, 4, 5, where: “η” is efficiency, “d” is the ratio of the current steam output of the boiler to the rated steam output of the boiler (equal to the ratio of the current value of steam flow to the turbine to rated value of steam flow to the turbine and to the ratio of the current flow of feed water to the boiler to rated flow of feed water to the boiler); “D” is the current steam output of boiler (equal to the current steam flow to the

 https://doi.org/10.1051/e3sconf/202126604012

turbine and to the current flow of feed water to the boiler); “D0” is the rated steam output of boiler (equal to the rated steam flow to the turbine and to the rated flow of feed water to the boiler):“n” is the ratio of the current electrical output power to the rated electrical output power;“N”» is the current electrical output power; “Nrated” is the rated electrical output power.The initial data for plotting these graphs are: for a steam turbine - a typical energy characteristic of the turbine; for a boiler-a boiler mode map; for a generator - passport characteristics; for feed pumps – pressure-flow rate characteristics.

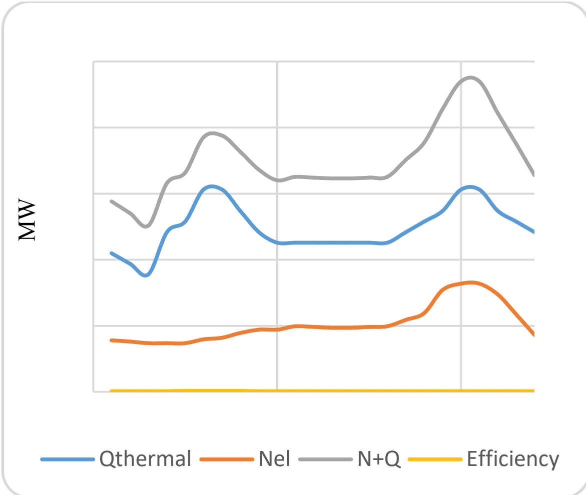

Fig. 1. The operation mode of the CHPP during the day.

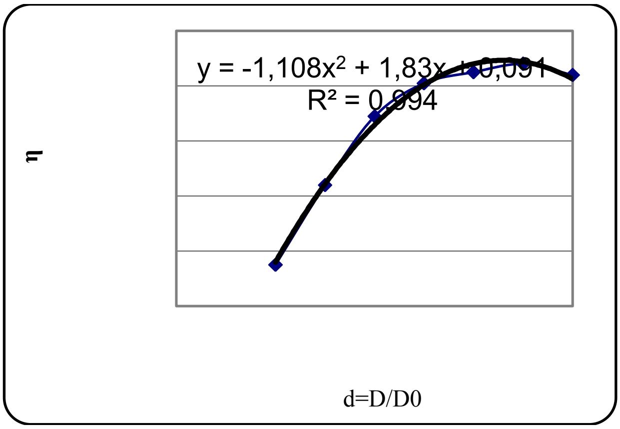

Fig. 2. The relation between internal efficiency of a steam turbine and flow of steamto the turbine.

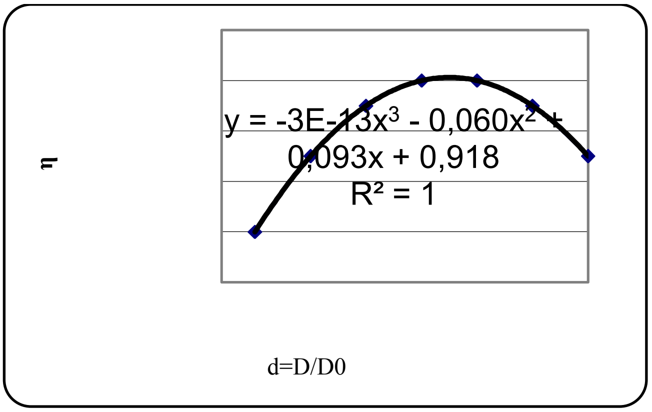

Fig. 3. The relation between boiler efficiency and steam output of the boiler.

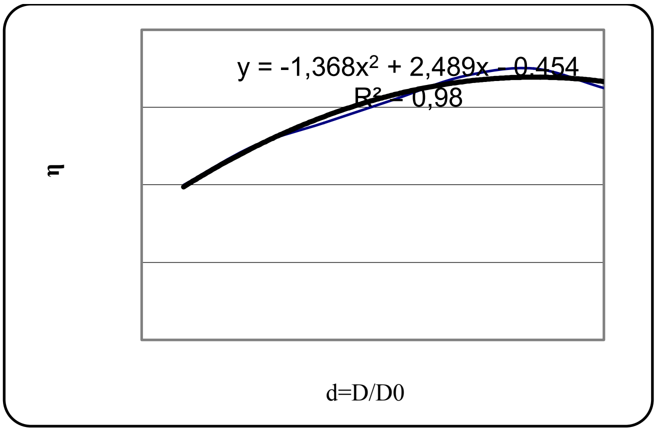

Fig. 4. The relation between efficiency of feed pumps and value of feed water.

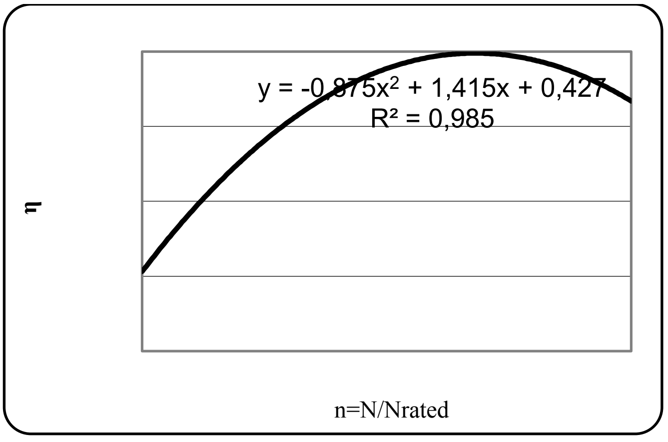

Fig. 5. The relation between efficiency of the electric generator from out power.

As we can see from figures 2-5, the maximum efficiency of the equipment is in a certain range, slightly below the maximum workload. If you deviate from this range, the efficiency of the equipment decreases; it leads to a decrease in the overall efficiency of the power station and an increase in fuel consumption per unit of energy output.

3.2. Energy storage

At this stage of the paper, the option with full leveling of the daily schedule of the thermal and electric load was considered.

The operation mode of the CHPP using the battery and in the standard mode is shown in Figure 6, which shows the values: "«Q(thermal1)" is thermal load graph without using a thermal storage system; "Q(thermal2)"is thermal load graph with full load leveling using a thermal storage system; "N (electric1)" is electrical load graph without using electricity storage system; "N (electric2)" is electrical load graph with full load leveling using the electricity storage system. These graphs are derived from the condition of maintaining the constancy value of energy consumption (the total consumed thermal and total consumed electrical energy during the day remain constant values).

The characteristics of the storage equipment that is necessary for full leveling of the load schedule were determined: a 1000 m^3hot water storage tank with the with a required energy capacity of 94 MWh and a charge/discharge speed equivalent to 35 MW; lithium-ion batteries with a total energy intensity of 128.2 MWh and a charge/discharge power of 30.6 MW. These values were determined from the requirement for full leveling of the load schedule during the day.Power (charge/discharge rate) is determined as the maximum difference between the daily schedules of the standard operating mode and the mode with storage of energy. The energy intensity of the storage systems was determined as the maximum value of the sum of the differences between the standard mode graph and the storage mode graph in the range between two points of intersection of these graphs .In this paper, hot water storage tanks were adopted for the use of thermal energy storage because these are the most common, well-researched, and reliable thermal accumulators. Lithium-ion batteries were adopted for the accumulation of electricity due to the growing number of electricity storage systems in power systems based on them; this direction is rapidly developing and promising in the field of energy supply [3, 5, 7].

The ranges of operation of the main equipment of the CHPP in the standard mode without storage of energy (blue area) and the mode with storage of energy (red area) were determined, which are shown in Figure 7, 8, 9, 10. The designations are the same as in Figures 2-5.

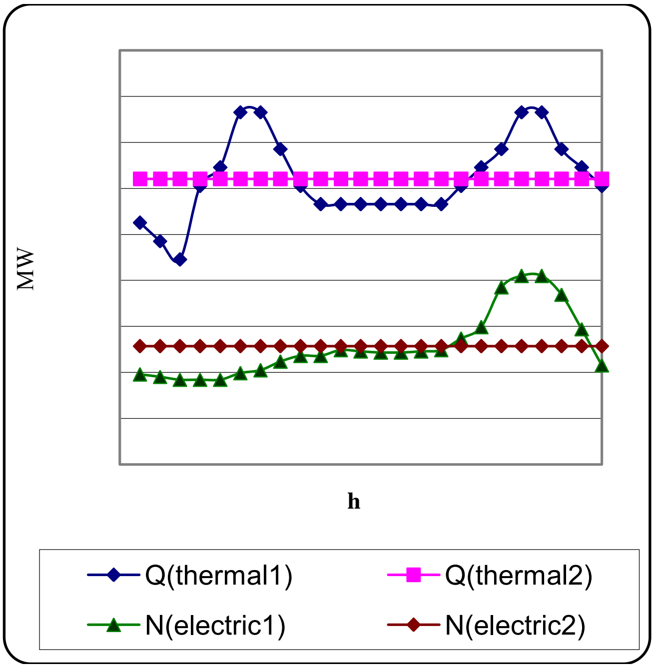

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Fig. 6. The operation mode of the CHPP during the day with and without using energy storage systems.

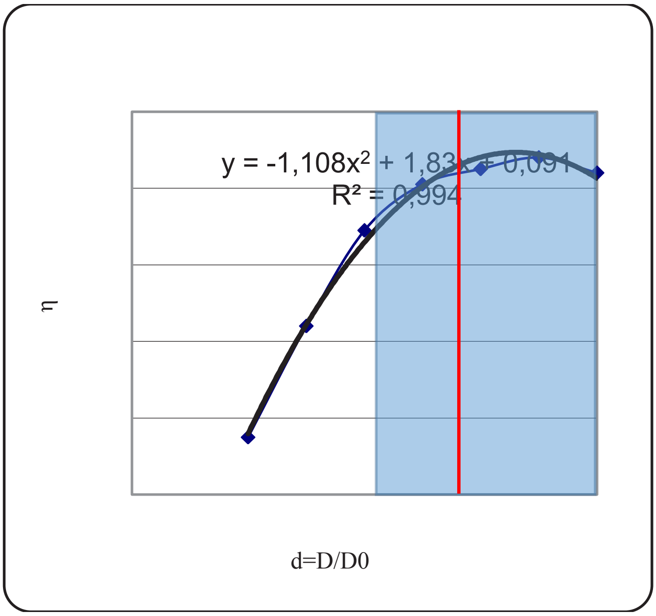

Fig. 7. The range of operation of the steam turbine with and without using the energy storage system.

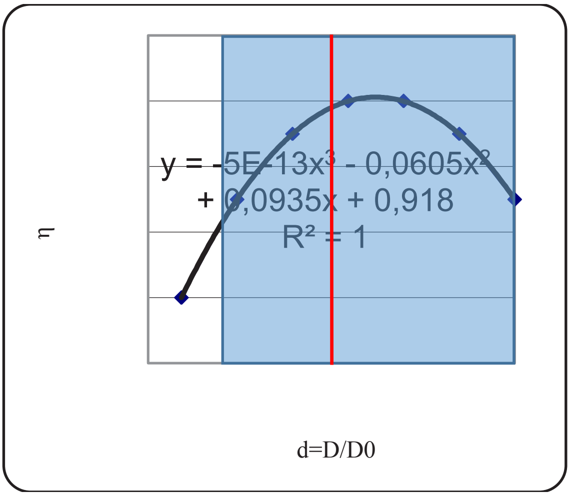

Fig. 8. The range of operation of boilers with and without using the energy storage system.

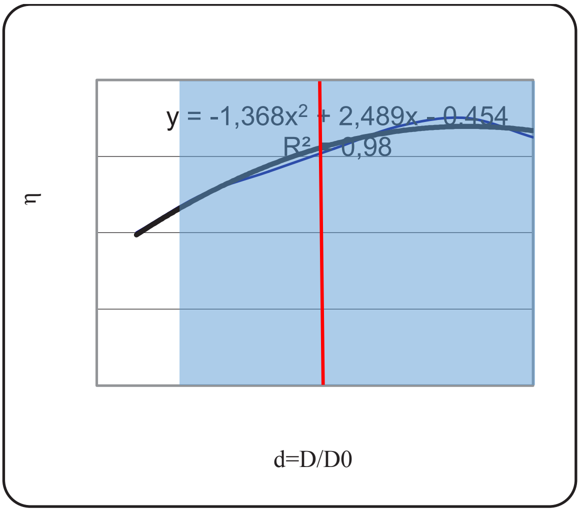

Fig. 9. The range of operation of feed pumps with and without using the energy storage system.

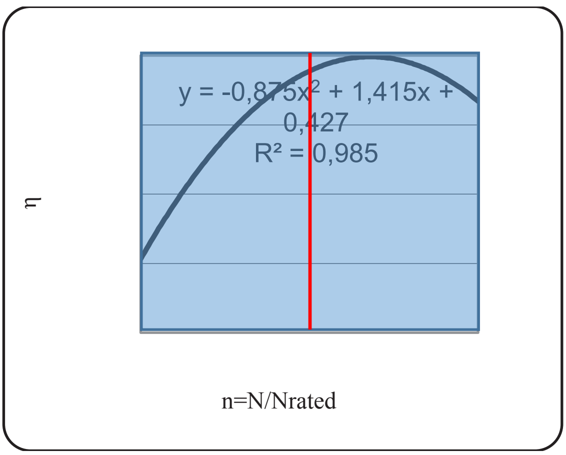

Fig. 10. The range of generator operation with and without using the energy storage system.

As we can see, the range of operation of the CHPP equipment is reduced, the operating time of the main CHPP equipment with high-efficiency increases. The performance indicators of the CHPP under these conditions, namely the change in the average efficiency and fuel consumption, are presented in Tables 1-4 below in the results of the paper.

3.3. Optimized selection of CHPP equipment

Since the range of operation of the CHPP equipment is reduced, a new method of selecting the CHPP equipment is likely. It is possible to select equipment that will operate in modes with the highest possible efficiency in a specific small power range.

Due to the fact that the accumulation of electric energy is much more expensive, modes with full leveling of thermal loads, and full and partial leveling of the electric loads were considered.

Schedule of electrical loads in the modes with different electric energy storage (reduction of deviation from the value in the full leveling graph at a different percentage): N(el.0) is the standard mode, N(el.80%) is the reduction of deviation by 80%, N(el.60%) is the reduction of deviation by 60%, N(el.40%) is the decrease in deviation of 40%,as presented in Figure 11. The ranges of operation of the main equipment of the CHPP in these modes of energy storage are shown in Figures 12, 13, 14, and 15, other designations are the same as in Figures 2-5.

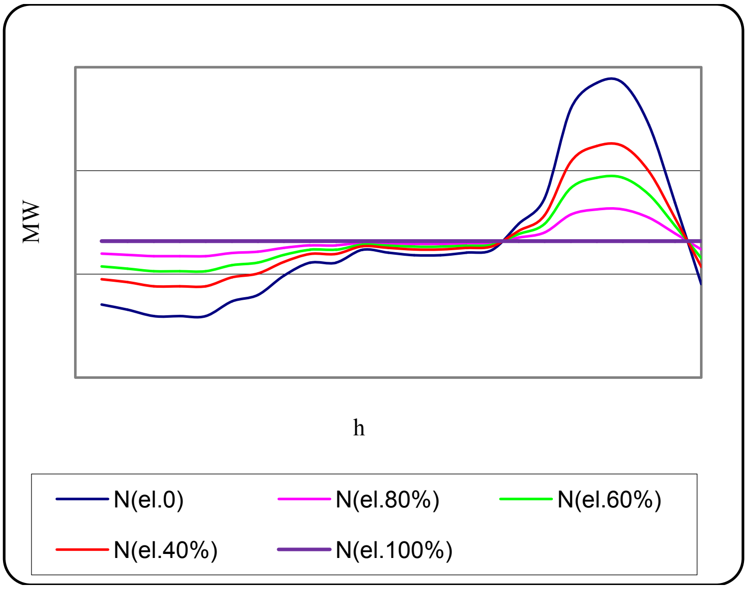

Fig. 11. Graphs of the electrical power of CHPPin different modes of accumulation.

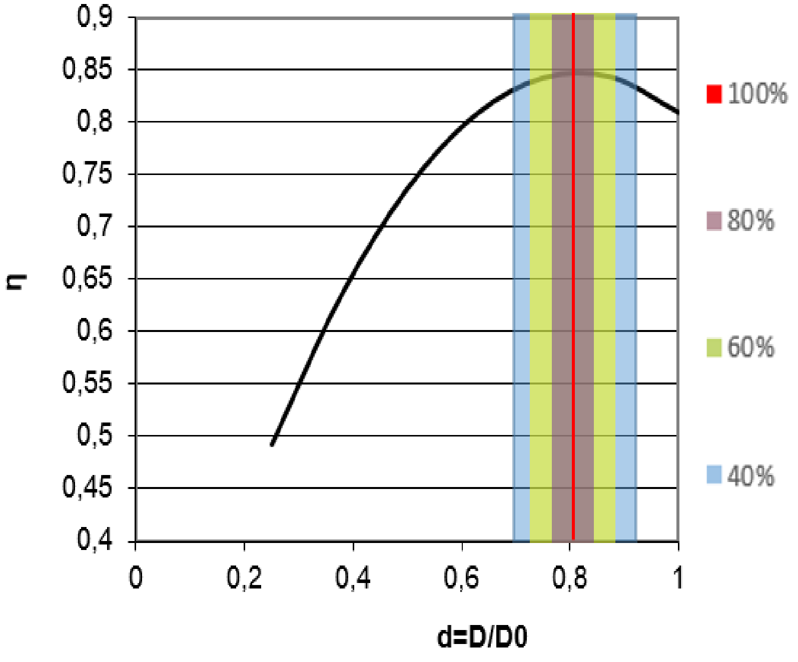

Fig. 12. Ranges of turbine operation in modes with different accumulation.

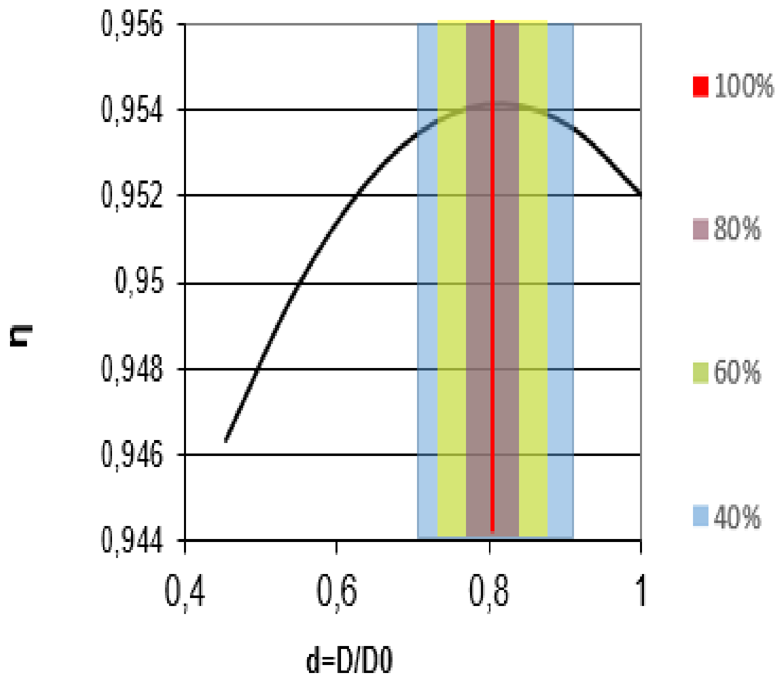

Fig. 13. Ranges of operation of boilers in modes with different accumulation.

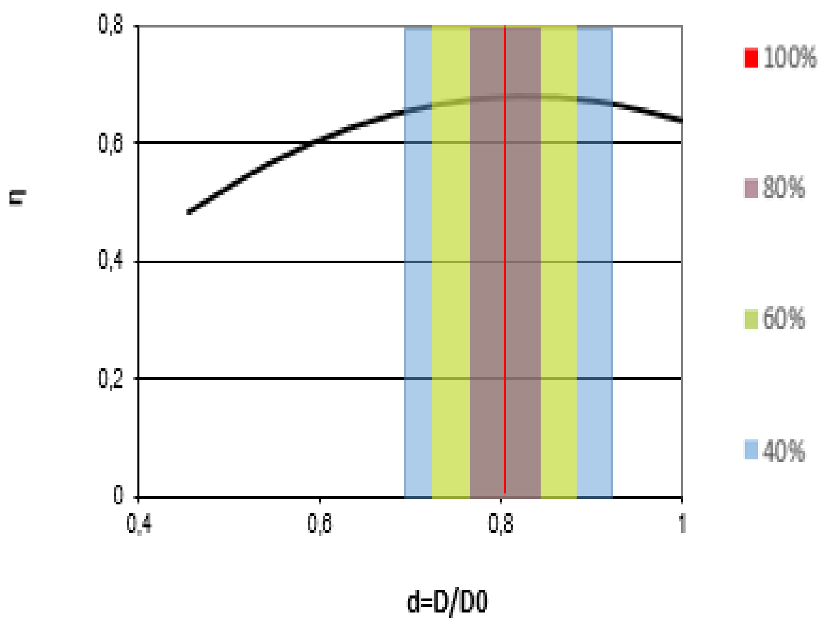

Fig. 14. Ranges of operation of feed pumps in modes with different accumulation.

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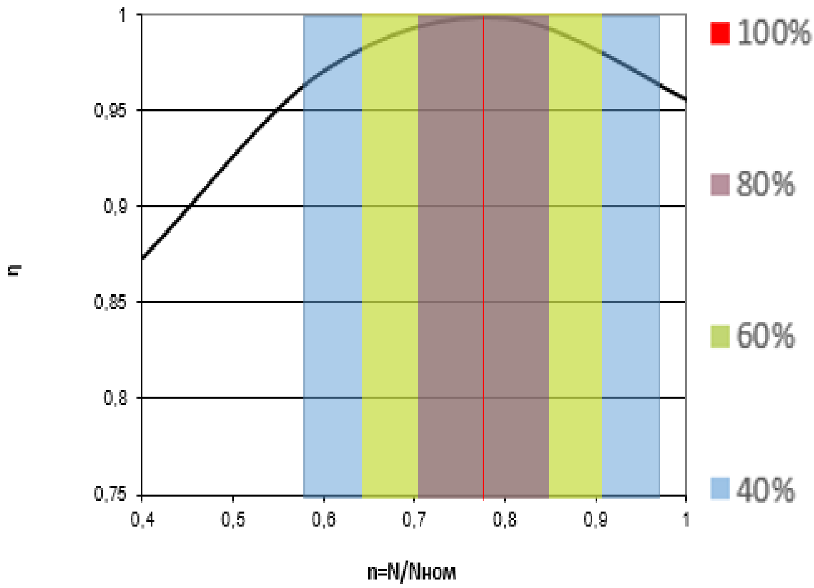

Fig. 15. Ranges of generators operation in modes with different accumulation.

As we can see from the above figures, with an optimized selection of main equipment of a CHPP and energy storage, the operating ranges of the main equipment of the CHPP are in the areas of maximum efficiency or close to it.

4 Results

The main results of the paper are presented in Tables 1-4.

Table 1. Generation efficiency indicators with storage of energy.

Indicators	Standard mode without storage	Mode with energy storage (100%) without optimization	Modes with energy storage and optimization of equipment selection			
			40%	60%	80%	100%
Total generation, GWh per day	4.211	4.229	4.224	4.226	4.227	4.229
The average efficiency of CHPP, %	62.8	63.11	63.45	65.02	66.44	69.95

Table 2. Storage of electrical energy

Indicators	Mode with energy storage (100%) without optimization	Modes with energy storage and optimization of equipment selection			
		40%	60%	80%	100%
Energy intensity, MWh	128.2	51.3	76.9	102.6	128.2
Power, MW	35	12.2	18.4	24.5	30.6
Value of energy storage, MWh per day	257.6	103.0	154.6	206.8	257.6

Losses in batteries, MWh/day	7.73	3.09	4.64	6.29	7.73

Table 3. Storage of thermal energy

Indicators	All modes of storage
Energy intensity, MWh	94
Power, MW	35
Value of energy storage, MWh per day	340
Losses in batteries. MWh per day	10.2

Table 4. Fuel economy. Thousands of tons of oil equivalent per year

Mode with energy storage (100%) without optimization	Modes with energy storage and optimization of equipment selection			
	40%	60%	80%	100%
0.09	1.44	6.37	10.64	20.48

5 Discussion

As we can see, when accumulating energy in this power system, the average efficiency of the CHP can be increased up to 7.15 %. In this example, the average CPH efficiency was increased from 62.8 % to 69.95 % with full leveling of the generation schedule and optimization of the selection of CHPP equipment. Also, in this power system, due to increased generation efficiency, fuel savings of up to 20.48 thousands of tons of oil equivalent per year can be achieved with an initial consumption of 210.43 thousands of tons of oil equivalent per year.

In addition to increasing the average efficiency of the CHPP, it is also possible to reduce the rated power of CHPP.

6 Conclusion

The influence of thermal and electric energy storage in the power system on the efficiency of the energy source, aCHPP, on the example of the model of the energy system of the Taimyr coal basin was considered in this paper.

The use of energy accumulators made it possible to reduce the peak and minimum average hourly energy output, as well as to increase the operating time of the CHPP with higher efficiency, and increase the average efficiency of the station.

Changing the range of operating allowed to more optimally select the main power plant equipment, which has higher efficiency in a given range of operation, which also led to an increase in overall efficiency.

Despite additional losses in the batteries and, as a result, increased energy output, fuel consumption decreased due to a significant increase in the efficiency of generation.

In the considered power system, due to energy accumulation and optimization of the selection of the main equipment of the CHPP, depending on the volume of accumulated energy, it is possible to save up to 20 480 tons of oil equivalent per year and increase the average efficiency of the CHPP by up to 7.15%.In addition to increasing the average efficiency of the CHPP, it is also possible to reduce its rated power.

In the future work, it is planned to consider in more detail the various options for storage equipment and the justification for the use of a specific type of accumulators, including consideration of heat accumulators based on the phase transition, which has a high density of stored energy [1, 9, 10].

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