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Solving simple problems of thermal power plants using simulation techniques

ABSTRACT

A steam/thermal power station uses heat energy generated from burning coal to produce electrical energy. Because of the huge amounts of fuel (coal), this kind of power station can be used to produce large amounts of electrical energy. Wide range of commercial heat and mass balance simulation, analysis and optimization software packages are available on the market. In this paper is presented the use of IPSEpro from SimTech Simulation Technology. The so called software IPSEpro is an exploiting engineering system for calculating heat and mass balances and simulating processes, as well. In the study are presented some simple problems of thermal power plants to calculate mass and energy balances using the simulation program. With this program it was for us possible to analyze the performance of a standard plant as well as the investigation of the influence of particular components on the whole system. Therefore, the constructive design of particular power plant components can be implemented or improved based on the results of the simulations being performed. Our paper is presenting some real simple problem solution using the above mentioned simulation procedure, and we have calculated process conditions through mass and energy balances. Also we have shown the graphical presentation of the most important parameters governing the process for different units of the entire plant.

Keywords: *IPSEpro, thermal power plants, simulation.*

1. INTRODUCTION

A thermal power station is a power station in which heat energy is converted to electric power. In many places in the world the turbine is steam-driven. The water is heated, turns into steam and spins a steam turbine which drives an electrical generator. Then, afterwards it passes through the turbine, the steam is condensed in a condenser and recycled to where it was heated; this is known as the Rankine cycle. The greatest variation in the design of thermal power stations is due to various sources of energy; dominates fossil fuel, although nuclear heat energy and solar heat energy are also used [1-9]. Some people, researchers prefer to use the term energy center because such facilities convert forms of heat energy into electricalenergy. The thermal power stations,in addition to producing electricity, are designed to produce heat energy for industrial purposes, or district heating, or for water desalination.

Almost all coal, petroleum, nuclear, geothermal, solar thermal electric, and waste incineration plants, as well as many natural gas power stations are thermal units. Frequently natural gas is combusted in gas turbines as well as boilers. The waste heat from a gas turbine, in the form of hot exhaust gas, can be used to raise steam, by passing this gas through a heat recovery steam generator (HRSG) the vapor is then used to drive a steam turbine in a combined cycle plant that improves overall efficiency. Power stations burning coal, fuel oil, or natural gas are often called fossil fuel power stations [10].

Commercial electric utility power stations are designed for continuous operation and usually constructed on a large scale. Virtually all electric power stations use three-phase electrical generators to produce alternating current (AC) electric power at a frequency of 50 Hz or 60 Hz [2]. Large companies or institutions may have their own

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power stations to supply heating or electricity to their facilities, especially if steam is created for other purposes anyway [10].

The direct cost of electric energy produced by a thermal power station is the result fuel cost, capital cost for the plant, operator labor, maintenance, and such factors as ash handling and disposal. Indirect, social or environmental costs such as the economic value of environmental impacts, or environmental and health effects of the complete fuel cycle and plant decommissioning, are not usually assigned to generation costs for thermal stations in utility practice, but may form part of an environmental impact assessment [10].

A steam/thermal power station uses heat energy generated from burning coal to produce electrical energy [5,8]. Wide range of commercial heat and mass balance simulation, analysis and optimization software packages are available on the market. In this paper is presented the use of IPSEpro from SimTech Simulation Technology established and licensed in Austria. IPSEpro is a software system for calculating heat balances and simulating processes [3]. In this material are presented calculations of mass balance and energy for some simple examples. Program modules are used to: calculate heat balances and predict design and off-design performance, verify and validate measurements during acceptance tests, monitor and optimize plant performance on-line and to plan modifications and upgrades of the existing plants. It comprises a set of software modules for creating process models for a wide range of applications and for utilizing these models throughout the lifecycle of process plants [3]. This program covers the entire lifecycle of a process plant from conceptual design to plant operation.

2. MATERIAL AND METHODS

Mathematical models are affective tools for analyzing systems or processes. They can be used to develop a new system or to evaluate the performance of an existing one [11]. Modeling usually describes a system using a set of variables and equations and sets up relationships among the variables related to process energy efficiency and can be utilized for both static and dynamic systems [11].

Through IPSEpro software can be visible the performance indicators of the process and the modules of this program were used to: a) calculate heat balances and predict design and off-design performance, b) verify and validate measurements during acceptance tests, c) monitor and optimize plant performance on-line, d) plan modifications and e) upgrades of existing plants.

Its component-level of flexibility and component-by-component approach allows us to model virtually any type of system. In the study are presented some simple examples calculated with specialized software [4]. IPSEpro from SimTech Simulation Technology in Austria [3] has been used for these examples.

3. RESULTS AND DISCUSSION

In this paper are presented some execution examples for power generation simulated by IPSEpro computer software such as: simple steam cycle, steam cycle with a de-aerator, and heat recovery steam generator with a single pressure level. To calculate respective mass and energy balances, we were consulted with guidelines and demonstration examples of the program, but using our data [4].

Application 1. We have considered a simple steam cycle, whose flow-sheet is presented in the figure 1.

As it can be seen, the steam cycle is modeled for the purpose of the calculations and later simulations for carrying out this application. The steam cycle is a closed loop. Formulation and the solution of the model equations, especially for the mass balances for each of the units was calculated. In a closed cycle, one of the mass balance equations was redundant, since it was automatically satisfied. Figure 1 consists of a boiler, a condenser, a generator and a turbine. The boiler model calculates energy required from the boiler based on the boiler feed water, the required drum pressure and the superheated steam conditions [12]. For this application the following conditions and numerical data are presented below:

Stream 002;	p= 45.0 bar; t =450.0 °C
Turbine 001;	eta_s 0.9

The high temperature steam from the boiler super heaters enters the high-pressure side of the turbine. In this turbine stage, part of the steam energy in converted to mechanical shaft. The turbine model transforms steam energy into electrical power. In a flow sheet, requires to be connected with one single steam input and one single stream output. The inlet conditions of the steam, shown in the figure 2, such as temperature, pressure and mass flow need to be defined [6,7]. The condenser transfers energy from one stream to another.

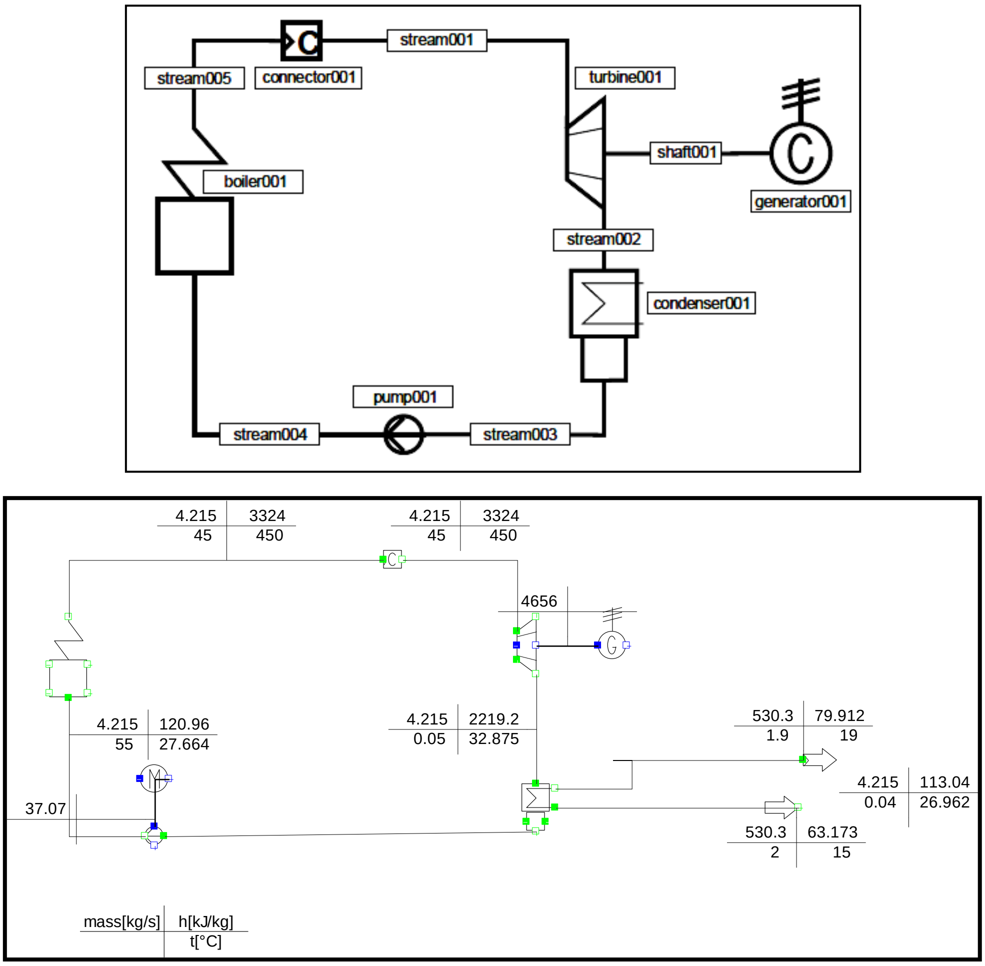

Figure 1. Flow sheet of a simple steam cycle [4]

Slika 1. Protočni tok jednostavnog ciklusa pare

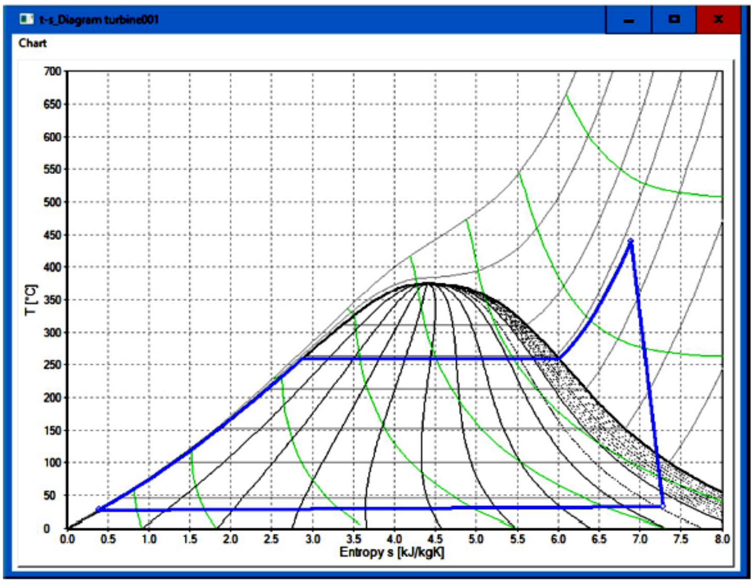

Figure 2. T-s diagram for the simple steam cycle

Slika 2. T-s dijagram za jednostavan ciklus pare

From the simulation results were obtained the T-s diagram for the simple steam cycle. This graphical presentation is very important for the specialists in the chosen field. Also from the simulations results are determined the generator power (1kW), pressure at stream 3 (0.05 bar) and the electrical power input for motor (1 kW). Table 1 shows the simulation results.

Application 2. A second attempt was done in a case of modeling and simulation for a steam cycle with de-aerator. For this application we have shown a simple sketch intending to know how to create a part-load model for the extended process scheme as shown in the figure 3.

The standard turbine model in the Advanced Plant Library (part of the architecture of the computer program) does not contain bleed streams.

Table1. Simulation results for a simple steam cycle

Tabela 1. Rezultati simulacije za jednostavan ciklus pare

Object	Unit	Description	Value
source001	bar	pressure	2.00
source001	°C	temperature	15.00
sink001	°C	outlet temperature	19.00
motor001 motor001	--- ---	electrical efficiency mechanical efficiency	0.98 0.98
generator001	---	electrical efficiency	0.98
generator001	---	mechanical efficiency	0.98
pump001	----	pump efficiency	0.70
pump001	----	mechanical efficiency	0.90
condenser001	°C	subcooling temperature	2.00
condenser001	bar	pressure drop, hot side	0.01
condenser001	bar	pressure drop cold side	0.10
turbine001	----	isentropic efficiency	0.90
turbine001	----	mechanical efficiency	1.00
boiler001	kW	heat input	15000.00
boiler001	---	boiler efficiency	0.90
boiler001	bar	pressure drop boiler	10.00
stream003	bar	pressure	0.05
stream002	bar	pressure	45.00
stream002	°C	temperature	450.00

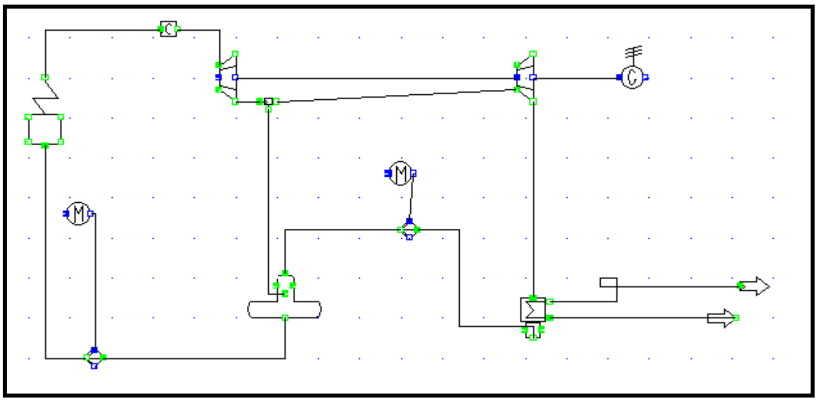

Figure 3. Steam cycle with de-aerator

Slika 3. Parni ciklus sa dearatorima

To model a turbine with a bleed stream it's necessary to use two turbine models and place a splitter between them. In a different situation, circumstance from the first application in the flow-sheet there is, also a necessity for a de-aerator and two turbines. The fundamental function of a de-aerator in power generation was the removal of oxygen and dissolved gases from boiler feed water. In the de-aerator, steam comes in direct contact with liquid water and therefore heat transfer occurs [13]. The process model developed in the program performs mass and energy balances considering all the input and output streams, heat and work into and out of each component. For this application the following conditions and numerical data are presented below:
Boiler: heat input= 20 MW
Turbine 001: isentropic efficiency=0.9
Stream 003 (stream after de-aerator): p=1.05 bar
Stream 010 (the outlet stream of second turbine): p=0.05 bar
Stream 002 (the outlet stream of connector): T=440^{0}C, p=40 bar

From the simulation results were obtained the characteristic for boiler, all characteristic of condenser, de-aerator, turbine (the isentropic enthalpy difference) and generator (electric power output).

For the figure 3 the simulation results are shown in Table 2.

Through the program we are able to determine all the mass flow, enthalpy, entropy, pressure and temperature of streams and also all the other characteristics of the condenser, generator etc. In this way it is possible to analyze the performance of a plant changing the input data. We can use different data and get the simulation results. Based on these results we are able to investigate the impact of particular components on the whole system.

Table 2. The simulation results for steam cycle

Tabela 2. Rezultati simulacije za ciklus pare

Object	Unit	Description	Value	Object	Unit	Description	Value
turbine001a	kJ/kg	isentropic enthalpy difference	422.87	turbine001	kJ/kg	isentropic enthalpy difference	794.00
motor001b	MW	electrical power input	0.00	boiler001	bar	--- profile calculation: mean evaporation pressure	45.00
deaerator001	-	steam quality at feed_hot	0.96	boiler001	bar	--- profile calculation: intermediate presssure	45.00
deaerator001	°C		100.98	boiler001	°C	--- profile calculation: intermediate temperature (sat liq resp. inlet)	257.43
deaerator001	kJ/kg		2593.3	boiler001	kJ/kgK	--- profile calculation: intermediate entropy (sat liq resp. inlet)	2.86
deaerator001	kJ/kgK		7.12	boiler001	kJ/kgK	--- profile calculation: auxilary variable (entropy)	3.80
source001	kg/s	mass flow	514.98	condenser001	kW/K	heat transfer coefficient x heat transfer area	667.24
sink001	kg/s	mass flow	514.98	condenser001	MW	transferred heat	8.62
sink001	bar	outlet pressure	1.90	shaft005	MW	transferred mechanical energy	3.35
motor001	MW	electrical power input	0.04	stream012	kg/s	mass flow	4.11
generator001	MW	electrical power output	4.72	stream008	kg/s	mass flow	0.59
stream001	kg/s	mass flow	4.69	stream011	kg/s	mass flow	4.11
stream005	kg/s	mass flow	4.69	stream010	kg/s	mass flow	4.11
stream009	kg/s	mass flow	4.11	shaft001	MW	transferred mechanical energy	0.00
stream004	kg/s	mass flow	4.69	shaft004	MW	transferred mechanical energy	4.92
stream007	kg/s	mass flow	514.98	stream007	kg/s	mass flow	514.98
stream003	kg/s	mass flow	4.69	stream002	kg/s	mass flow	4.69
stream006	kg/s	mass flow	514.98	Cooling water	kg/kg	mass fraction of WATER	1.00
shaft003	MW	transferred mechanical energy	0.04	Water_steam	kg/kg	mass fraction of WATER	1.00

Application 3: In this example it's created a model of a heat recovery steam generator with a single pressure level. The model is created by arranging a series of heat exchangers appropriately. This approach provides much higher flexibility than the one with a single model [4]. This model is shown in figure 4.

The model requires two compositions: one for exhaust gas and one for the water/steam. The scheme consists of three heat exchangers, one drum and a pump.

For this application the following conditions and numerical data are presented below:

Source 001: mass flow: 15 kg/s, T=550^{0}C.

Stream 009 (the stream at the outlet of second heat_counter); mass flow= 20 kg/s.

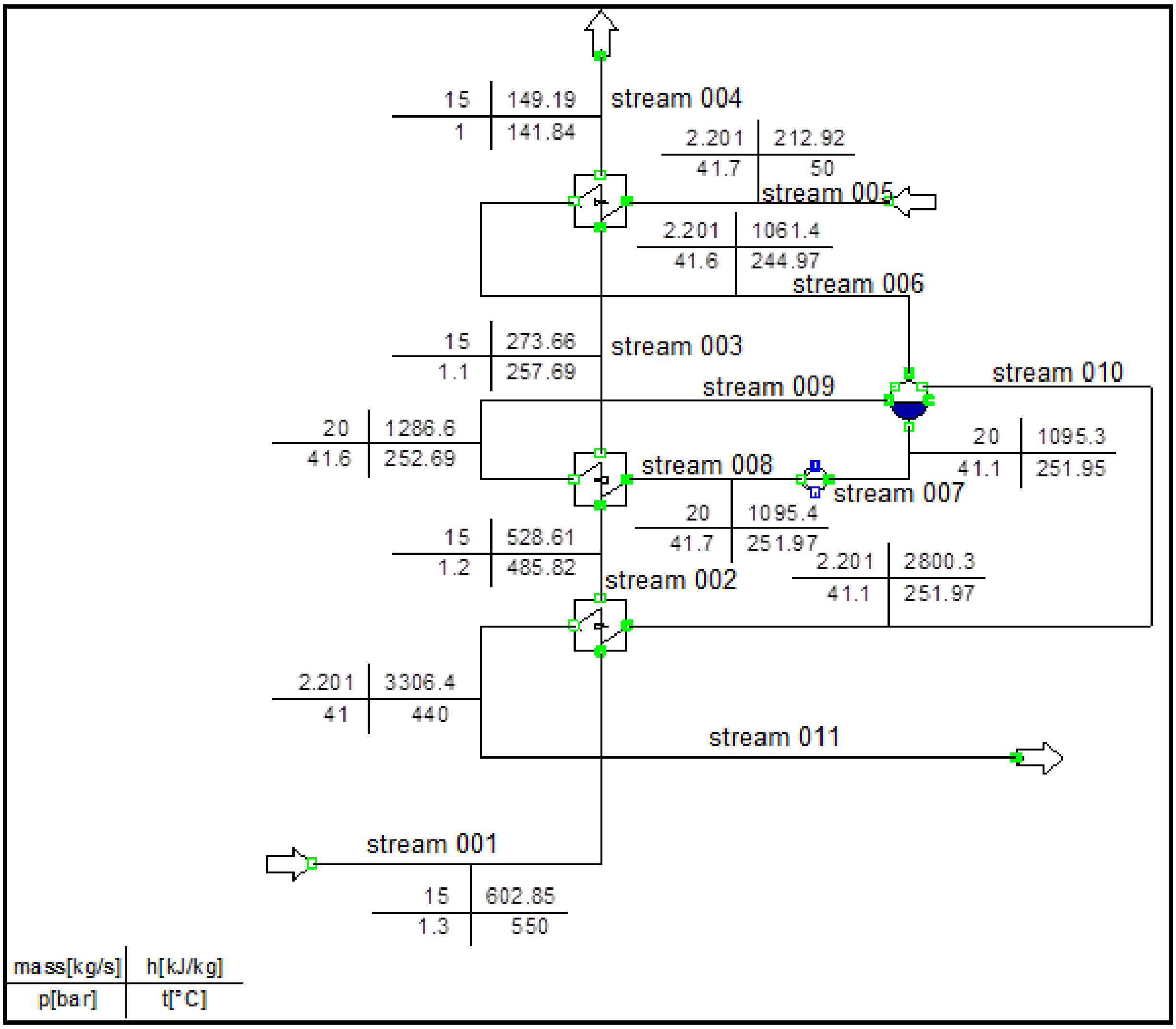

Figure 4. Heat recovery steam generator

Slika 4. Generator pare toplote

From the simulation results were obtained the characteristic (temperature, pressure, enthalpy, entropy and mass flow) for each stream, temperature difference at the inlet of the low temperature side, temperature at the outlet of the low temperature side, heat transfer coefficient x transfer area for each of the hetx-counter and the characteristic of drum.

Some of the simulation results are presented in table 3.

Table 3. Some simulation results for heat recovery steam generator

Tabela 3. Neki rezultati simulacije za generator pare

Mass flow (kg/s)	Value	Object	Description	Value
Stream 001	15	drum	Approach point temperature	7 ^{0}C
			Circulation ratio	144.66
Stream 011	2.2	Htex-counter1	dt_in	256.1^{0}C
Stream 002	15		dt_out	139 ^{0}C
Stream 008	240		Heat transfer coefficient x transfer area	4.3912 kw/K
Stream 009	20		Transferred heat	841.47kW

Streams 8 and 9 have a greater mass flow than the streams 1, 11 and stream 2. Streams 8 and 9 are pump and drum streams. From the simulations results is calculated the transferred heat (841.47 kW) and the heat transfer coefficient.

4. CONCLUSIONS

Using this IPSEpro program through different applications, it was possible to analyze the performance of a standard plant as well as the investigation of the influence of particular components on the whole system. Therefore, the constructive design of particular power plant components can be implemented or improved based on the results of the simulations being performed. Our paper is presenting some real simple problem solution using the above mentioned simulation procedure, calculating process conditions through mass and energy balances. Also we have shown the graphical presentation of the most important parameters governing the process for different units of the entire plant. This program allows us to simulate the behavior of single elements of processes, of parts of a process and of models of entire plants, also provides efficient data management and uses robust algorithms that result in extremely short calculation time.

We hope in the future to solve more complex problems based on the current applications.

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IZVOD

REŠAVANJE JEDNOSTAVNIH PROBLEMA TERMOELEKTRANE KORIŠĆENJEM SIMULACIONE TEHNIKE

Para/termoelektrana koristi toplotnu energiju proizvedenu iz sagorevanja uglja za proizvodnju električne energije. Zbog obilja goriva (uglja), ova vrsta elektrane se može koristiti za proizvodnju velikih količina električne energije. Širok spektar komercijalnih simulacija balansa toplote i mase, analiza i optimizacija softverskih paketa su dostupni na tržištu. U ovom radu prikazana je upotreba IPSEpro-a iz SimTech Simulation tehnologije. Takozvani softver IPSEpro je eksploatacioni inženjerski sistem za izračunavanje toplotnih i masenih balansa i simulacija procesa. U radu su prikazani pojedini jednostavni problemi termoelektrana za proračun masenih i energetskih bilansa pomoću simulacionog programa. Ovim programom bilo je moguće analizirati performanse standardnog postrojenja kao i ispitivanje uticaja pojedinih komponenti na celi sistem. Stoga se konstruktivni dizajn pojedinih komponenti elektrane može implementirati ili poboljšati na osnovu rezultata izvršenih simulacija. Ovaj rad predstavlja jedno stvarno jednostavno rešenje problema koristeći gore pomenutu simulacionu proceduru i izračunati su procesni uslovi kroz bilanse mase i energije. Takođe, grafički su prikazi najvažniji parametari koji regulišu proces za različite jedinice celog postrojenja.

Ključne reči: *IPSEpro, termoelektrane, simulacija.*

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