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Daily Analysis of Changes Taking Place in Heat Exchangers Used in Combined Heat and Power Plants

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ABSTRACT

The article discusses the principle of operation of a combined heat and power plant. Aspects of diversification are commented. The principle of operation of heat exchangers used in combined heat and power plants is discussed, as well as a daily analysis of changes taking place in the exchangers. The paper presents the method of analysis based on parametric models. In the discussed research, the ARX model was used with the use of MATLAB tools. The entered data allowed to obtain comparative ARX models presented in the charts. Paper starts from the exemplary data set description, through the other suitable data set, then the formulation of resulting simulation function, and it finalizes in the presentation of real data graph in the comparison to simulating function graph. Conclusions are described in the aspect of different levels of energy generation diversification. An increase in energy demand in the evening and night hours has been noticed. The obtained models are adequate with each other, which confirms that the data has been correctly entered into the application. Through this simulation better energy safety can be provided and positive social impact with ecological goals can be reached.

Keywords: heat and power plant, heat exchangers.

INTRODUCTION

Power engineering is an area that is constantly being developed, despite the fact that some heat plants, combined heat and power plants and power plants in the world have been operating for a long time [1, 2]. Over time, more and more of these enterprises are being modernized. Currently, the energy sector uses mainly three types of heat and energy management systems [3]. It is also worth adding that there are enterprises or buildings that are designed to generate energy for their own needs, which makes them self-sufficient [4, 5]. Heat plants focus solely on the production of heat, power plants on the production of energy, and combined heat and power plants on the production of heat and energy, sometimes called combined heat [6, 7]. Modern solutions are introduced to optimize the functioning of systems used in energy companies. Each element of the installation is important in the entire system. However, there are components that are of particular importance throughout the installation [8]. Heat exchangers are such an element [9–11]. Generally speaking, a heat exchanger is a device whose main function is to exchange heat between two or more fluids [12]. The design of heat exchangers can be diverse, and for its proper design, complete parameters of its operation should be obtained, which include: type of factors and their properties; inlet and outlet temperature; flow rate and volume; maximum and minimum pressure; resistances related to deposits [13–15]. Applications and examples of exchangers will be discussed in the following chapters.

It should be mentioned that this combined heat and power production is one direction of diversification. The other ones can be through different fuels combusted in the same plant in different boilers but well integrated then this diversification can go through various energy conversions in so called hybrid systems [16–18]. Such composed diversification of energy production provides higher level of energy safety but at the same time, requires different attempt to system control and simulation methods. That is why, the authors focus on consideration of parametric methods for simulations which are likely to provide results without the necessity to analyze details of all physical processes and phenomena occurring in one integrated plant – just in and out signals.

MATERIALS AND METHODS

Heat exchangers in general system characteristic

The basic division of heat exchangers is mainly divided into: contact and non-contact. Non-contact heat exchangers include regenators, recuperates and fluidization beds, and contact heat exchangers include those with immiscible liquids, liquid and vapor, liquid and gas [19]. There is also another division, which includes co-flow, cross-flow, counter-flow and complex heat exchangers. Water, heated in the boiler through heat exchangers, circulates in heating installations in buildings. This can be used in electricity and heat generation plants (CHP) [20]. Generally there are three heat transfer mechanisms, including conduction, convection, and radiation. Conduction is the movement of heat without mass movement, e.g. through the wall of the exchanger, while convection is the movement of heat with the simultaneous movement of the mass. An example would be convection from a liquid to an exchanger wall. Radiation is the movement of heat through thermal waves without any contact material and becomes substantial at high temperature difference between non adjacent surfaces. Various types of fuel are used in hot water systems and in space heating. Nowadays, ecological solutions are chosen in the first place, thanks to which the emission of toxic substances into the environment is reduced. CHP plants use those resources that are lost during the operation of the power plant. Power plants focus only on electricity generation, and the point is to combine the generation of heat and power for better fit into the environment, which is beneficial. The possibility to recover some energy for the benefit of another element of the installation is considered to be environmentally friendly and serves for sustainable development.

Methods

The simulation tool MATLAB Signal Analyzer and System Identyfication are used in this article. The tools used also allowed to obtain the relationship between power and temperature [21]. The toolbox estimate nonlinear system dynamics using Hammerstein-Wiener and Nonlinear ARX models [22]. In the Figure 1, 2, 3 shows ARX models generate in MATLAB 2020 from results of data.

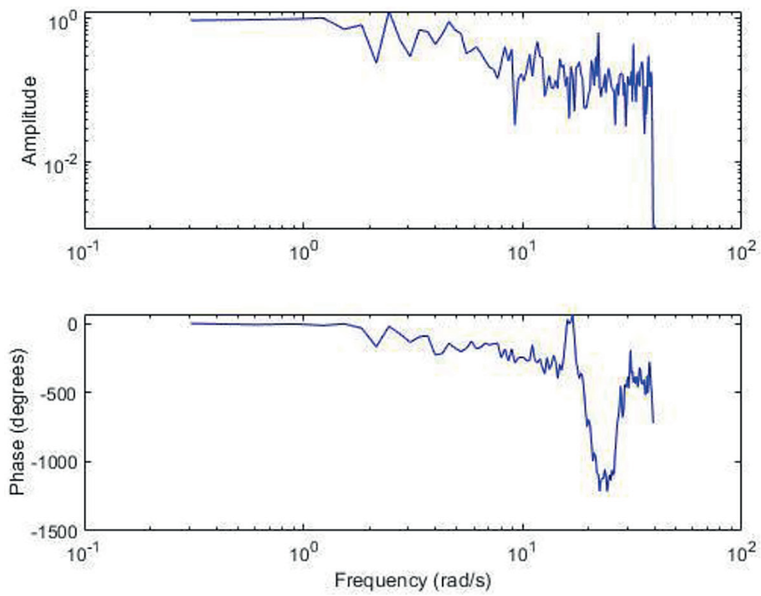

Fig. 1. ARX Models of amplitude

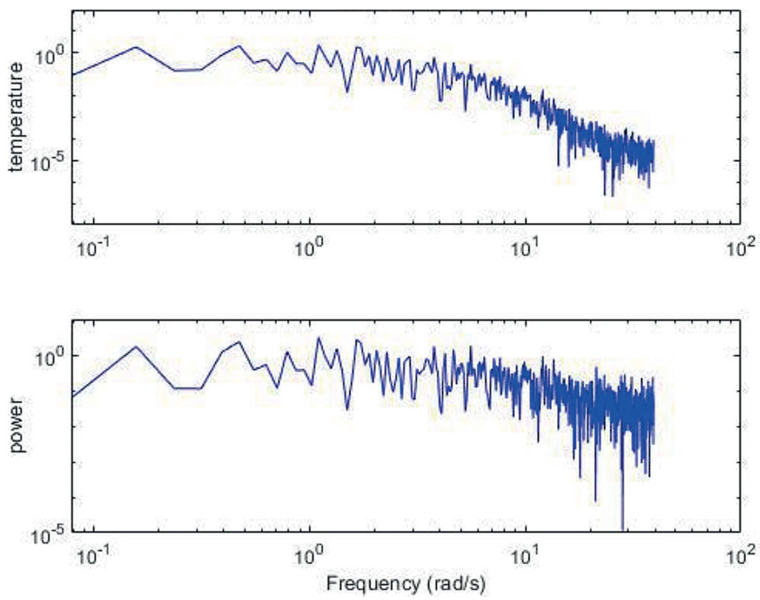

Fig. 2. ARX Models of temperature – periodogram

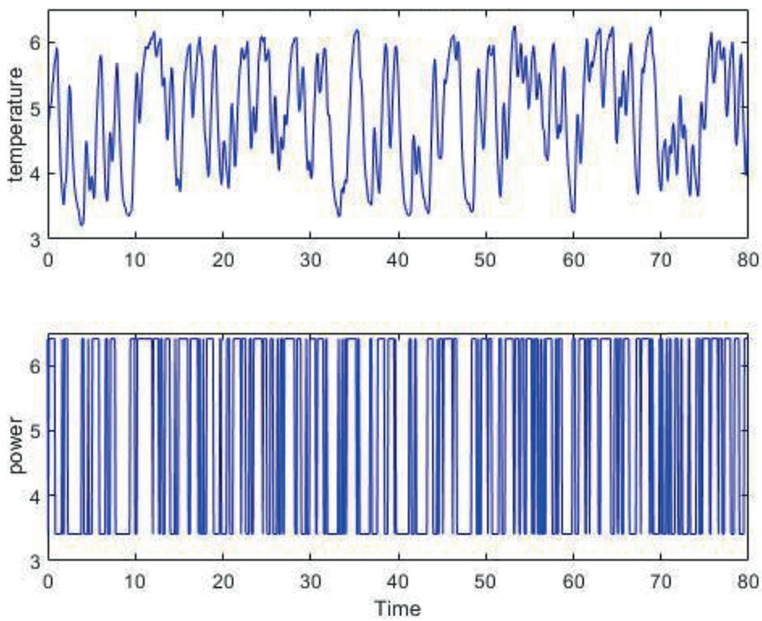

Fig. 3. ARX Models of temperature – input and output signals

Model ARX

Simulated response comparison shows satisfying coincidence which is right because the data comes from controlled plant. Then, the research consideration is rather focused on the question whether similar system can be simulated with satisfying accuracy for anticipated performance in upcoming periods and how long these periods can be.

The presented simple set shows the idea of this analysis but to form reliable conclusion many data sets have been analyzed by the authors. The other example results are presented in additional graphs in Figure 4.

The auto-regression model ARX (AutoRegressive with eXogenous input) type MISO (Multiple Input, Single Output) and has the form of Equation 1.

$$A(q)y(t) = \sum_{i=1}^{nr} B_i\,(q)u_i(t - nk_i) + e(t) \quad (1)$$

where: $y(t)$ – discrete input signal series;
$u(t)$ – discrete output signal series;
nk – output – input delay, i.e. discrete step number, after which the discrete response $y(t + nk)$ is given for the discrete impulse $u(t)$;

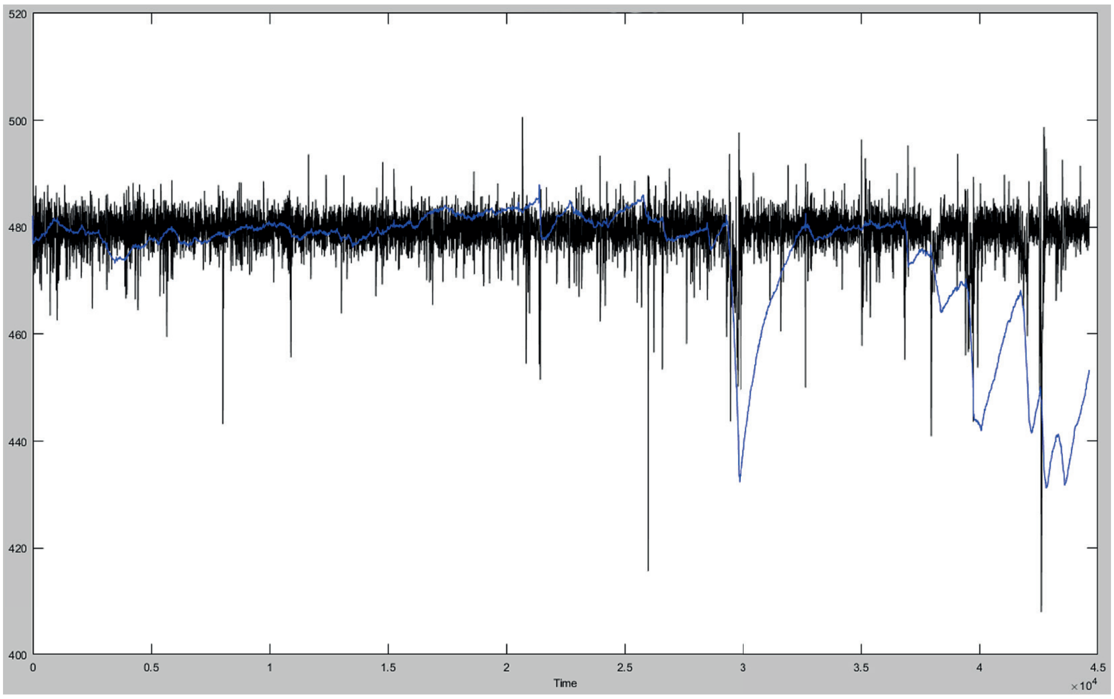

Fig. 4. Measured and simulated model output [23]

nr – input signal number;
$e(t)$ – white noise series;
$A(q) = 1 + a_1q^{-1} + ... + a_iq^{-i}$; $B(q) = b_0 + b_1q^{-1} + ... + b_jq^{-j}$ – polynomials of a_i, b_j parameters;
i, j –number of polynomial coefficients.

The mathematical tool properties of MATLAB enable to obtain the resulting formula in the form of a polynomial [23].

$$A(z) = 1 - 2.365z - 1 + 2.337z - \\ - 2 - 1.333z - 3 - 0.1009z - 4 \tag{2}$$

$$B(z) = 0.2573z - 1 - 0.6793z - \\ - 2 + 0.5246z - 3 - 0.1009z - 4 \tag{3}$$

The temperature model obtained in the result of the research procedure has the form of the following image in Figure 5.

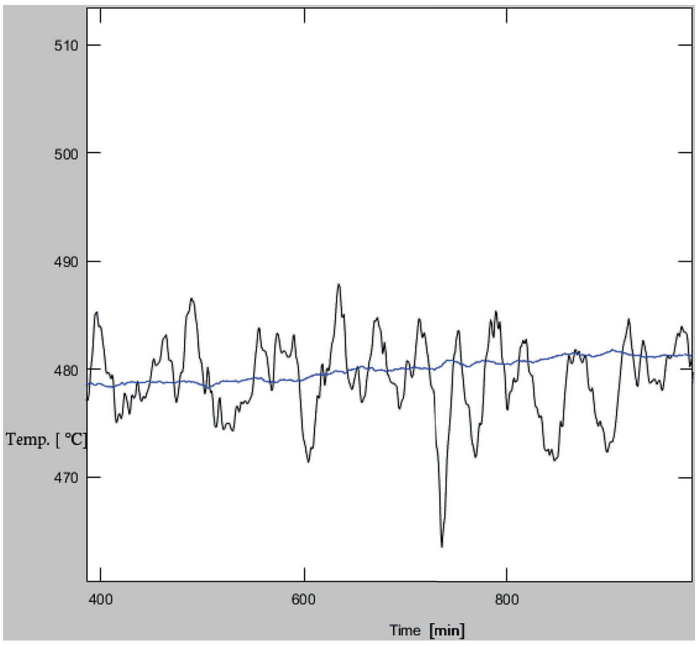

Fig. 5. Measured and simulated model output

RESULTS

The basic stage in daily analysis of heat distribution in CHP plants is daytime storage of measurements data (provided as mean hour, at established intervals or instantly) possibly as in the example presented in Table 1 and 2. This must be collected separately for inlet water, steam and condensate because the flows take place in different thermodynamic parameters.

Table 1. Data set of preliminary heat exchanger nr 1

Time	Heat Exchanger						
	Preliminary nr 1						
	Water				Steam	Condensate	
	Pressure		Temperature		Temperature	Temperature	Level
	Input	Output	Input	Output			
h	[MPa]	[MPa]	°C	°C	°C	°C	M
1	0.97	0.95	47.9	70.4	100	59.1	2.46
7	0.97	0.95	48.1	70.1	99	59.1	2.38
3	0.97	0.95	47.8	71.9	99	60.3	2.43
4	0.97	0.95	48.5	72.9	99	61.7	2.55
5	0.97	0.95	48.6	73.1	99	62	2.48
6	0.97	0.94	48.7	73.1	99	62	2.43
7	0.98	0.95	48.7	73.3	99	62.4	2.57
8	0.99	0.95	48.9	72.8	99	62	2.6
9	0.99	0.95	48.9	73.7	99	62.9	2.54
10	0.98	0.95	48.8	73.6	99	62.9	2.47
11	0.99	0.95	48.5	72.9	99	61.9	2.54
12	0.99	0.95	48.8	73.4	99	62.6	2.56
13	0.98	0.95	48.5	73.8	99	63	2.46
14	1.04	1	48.5	72.6	99	61.8	2.57
15	1.04	1	48.4	72.8	99	61.9	2.61
16	1.04	1.01	48.4	73.5	99	63	2.46
17	1.04	1.01	48.6	73.4	99	62.9	2.45
18	1.04	1	48.7	72.8	99	62.1	2.3
19	1.04	1.01	48.8	72.6	99	62	2.47
20	1.05	1.01	48.6	73.7	99	62.7	2.66
21	1.05	1.01	48.7	75.5	99	62.9	2.68
22	1.04	1.01	48.7	75.8	99	65.1	2.59
23	1.02	0.99	48.9	76	99	65.2	2.49
24	1.02	0.99	49.1	75.2	99	64.5	2.35
Average	1.01	0.97	48.59	73.29	99.04	62.33	2.50

Table 2. Data set of primary heat exchanger nr 1

Time	Heat exchanger						
	Primary nr 1						
	Water				Steam	Condensate	
	Pressure		Temperature		Temperature	Temperature	Level
	Input	Output	Input	Output			
h	[MPa]	[MPa]	°C	°C	°C	°C	m
1	0.88	0.86	70.2	88.8	108	99.6	1.39
2	0.88	0.86	70.2	88.9	106	99.2	1.38
3	0.88	0.86	72.1	89.8	109	100.2	1.23
4	0.88	0.86	72.8	90	109	100.3	1.19
5	0.88	0.86	72.6	89.9	114	100.3	1.12

Table 2. Cont. Data set of primary heat exchanger nr 1

6	0.88	0.86	73.2	90.1	120	100.3	1.04
7	0.89	0.86	73	89.7	136	100.4	1.07
8	0.89	0.86	72.5	89.5	137	100.3	1.51
9	0.89	0.86	73.5	89.9	152	98.4	1.48
10	0.89	0.86	73.4	89.9	144	99.4	1.35
11	0.89	0.86	72.9	85.5	154	99.9	1.73
12	0.89	0.86	73.1	89.6	165	35.3	1.72
13	0.89	0.86	73.5	89.9	166	94.7	1.57
14	0.94	0.91	72.5	89.2	159	97.2	1.79
15	0.94	0.92	72.6	84.3	165	94.2	1.77
16	0.94	0.91	73.3	89.7	177	97	1.58
17	0.94	0.91	72.9	89.7	162	93.5	1.57
18	0.94	0.91	72.6	89.7	120	96.8	1.62
19	0.95	0.91	72.3	89.2	166	95.2	1.72
20	0.95	0.92	73.8	89.8	222	94.2	1.71
21	0.95	0.95	75.1	90.6	238	99.7	1.41
22	0.94	0.92	75.7	91.1	233	100.5	1.37
23	0.93	0.91	75.7	91.3	193	100.6	1.19
24	0.92	0.92	74.7	91	133	102.5	1.23
Average	0.91	0.89	73.09	89.46	153.67	95.82	1.45

Table 3. Outflows in the system

Time	Temp. of water behind heat exchanger	Condensate flow from the exchangers
h	°C	t/h
1	80.7	110
7	80.8	110
3	83	114
4	83.2	115
5	82.9	116
6	83.6	116
7	83.3	117
8	82.5	120
9	83.3	125
10	83.2	123
11	82.9	114
12	82.6	123
13	83.2	123
14	82.2	117
15	82.5	125
16	83.1	122
17	82.9	122
18	82.8	115
19	82	115
20	83.4	120
21	84.6	128
22	85.2	128
23	85.2	122
24	84.4	118
Average	83.06	119.08

The analyses performed by parametric methods can be carried out together in one model. This model can show relation between several inputs and one output without the necessity of detailed analysis of physical phenomena occurring in the considered system. If the results providing satisfying coincidence (+/-5%) between original data and simulated results are obtained then it is justified to test next level model with several inputs and at least two outputs. Outflows in the system shows Table 3.

The analysis contains elements of signal processing and is presented by means of MATLAB 2020 signal processing software module.

The graphs in Figure 6 shows difference between input and output pressure in the preliminary heat exchanger nr 2. Figure 7 show necessary elements of signal analysis such as amplitude and frequency in two graphs compared as output functions from ARX.

In Figure 6, it can be seen that the input parameters have a higher pressure than the output. Which is in line with the proper functioning of the exchanger. A large pressure difference can be observed at 6 o'clock in the morning. The pressure remains constant between 8:00 and 13:00, which may also be associated with lower demand.

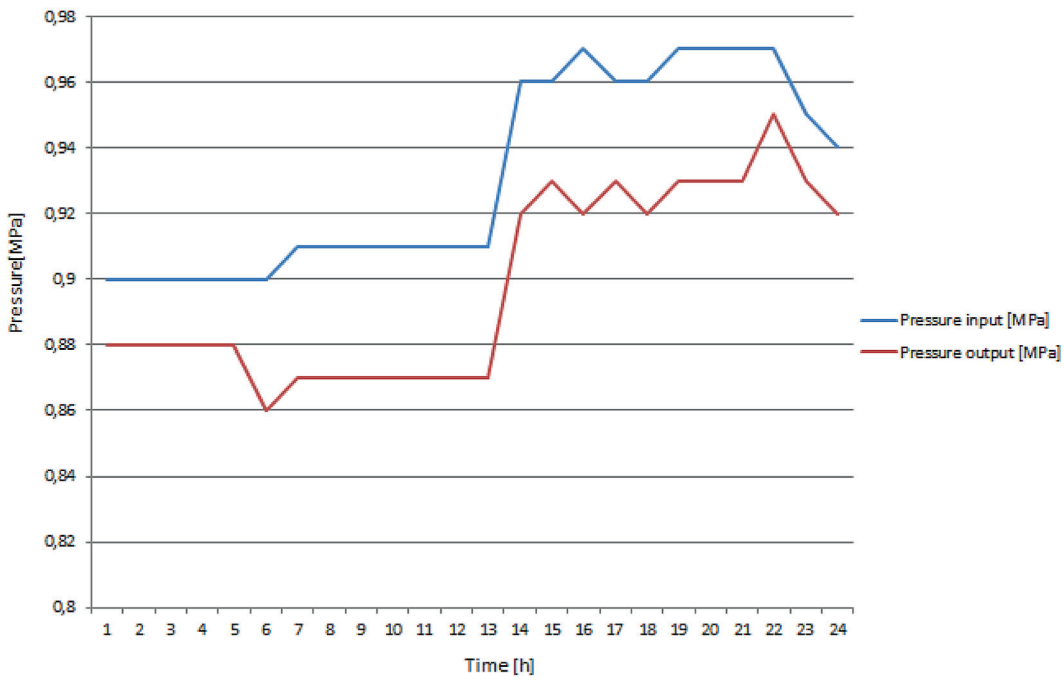

Fig. 6. Difference between input and output pressure in the preliminary heat exchanger nr 2

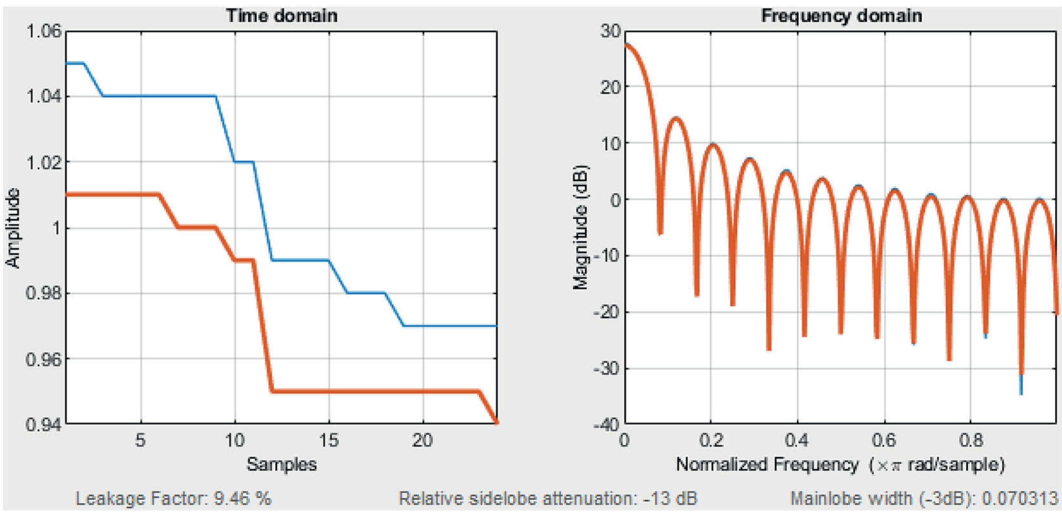

Fig. 7. Model ARX from MATLAB 2020

In Figure 7, the time and frequency domain model is consistent with the data. Moreover, it can be seen that in the time domain the amplitude decreases proportionally as does the data in the frequency model.

CONCLUSIONS

Repeatability of some parameters was observed in the tested heat exchangers. The average input pressure did not exceed 1MPa in primary heat exchanger. The highest water temperature was recorded at 10 pm and was 75.8 °C at the water outlet. The temperature in preliminary heat exchanger for the steam was constant at 99 °C. In primary nr 1 heat exchanger, the highest temperature was recorded for the pair at 9 p.m. It exceeded 230 °C. The greatest jumps in heat exchanger parameters were observed in the morning and evening hours. This may be related to the needs of the surrounding neighborhoods. The good coincidence of simulation results and real data measurements let the authors guess that this is the right way to attempt simulation of highly diversified plants such as for example the hybrid composed of coal steam boilers, gas or biogas boilers, biofuel (corn) boilers and heat pumps with supporting photovoltaic systems. Through this simulation better energy safety can be provided and positive social impact with ecological goals can be reached. From the other point of view this method requires multi stage attempt for simulation and few year data set of continuous online measurements with reliable storage but it is worth collecting.

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