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System Analysis and Decision-Making During Synthesis of High-Performance Hybrid Boilers

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Abstract. The decision-making analysis for synthesis of high-performance hybrid boiler plants is based on current philosophy of system analysis and synthesis of combined heat and power plants. Energetic and exergetic utilization is used as performance criteria.

A generalized description of the system analysis approach for complex heat and power plants is referred to in [1]. However, as each new heat and power plant differs in structure and modes of operation, implementation of this approach requires basic methodological provisions of the system analysis, synthesis and optimization to be applied to the approach itself. A high-performance hybrid boiler plant would be an option in this case.

The boiler plant is a combination of conventional and alternative power sources. The conventional source generates heat energy for external consumers in the form of supplying hot water for heating, ventilation and tap hot water supply. The auxiliary system of the boiler plant required for heating up raw water, deaerator tank and demineralized water is facilitated by an alternative source – the solar trap [2] and the heat from an outside flue gas heat regenerator [3].

The boiler plant is also being discussed to operate as a mini-CHPP with gas reciprocating engines to generate the power for auxiliary systems of the boiler plant and to supply the power to third parties. Partially, the power is generated by an alternative source – solar cell batteries [2].

Therefore, the boiler plant is a combined source of heat and power energy generated by both the conventional and alternative sources, i.e. solar traps and solar cell batteries.

Based on the available philosophy of the system analysis, synthesis and optimization of heat and power complexes, the optimum structure and parameters of the hybrid boiler plant should be picked as follows [1].

1. External system parameters related to load connections and releases to atmosphere will be set.

2. The hybrid boiler plant will be structurally described to identify chains of dependent components (circuits) available or may be integrated after upgrading.

Structural modelling will define the number of equations n_{E} required for calculation of one or another component using simultaneous equations [4]

$$\left.\begin{aligned} n_{\mathrm{I}} &= n_{\mathrm{P}}^{'} + n_{\mathrm{AC}} - n_{\mathrm{uncert.}} \\ n_{\mathrm{E}} &= n_{\mathrm{P}} - n_{\mathrm{I}} \end{aligned}\right\}, \qquad (1)$$

where n'_{P} is the total parameters of incoming connections; n_{AC} is the number of conditions applied to the parameters of incoming connections; $n_{\mathrm{uncert.}}$ is the number of uncertainties for the parameters of outgoing connections; n_{I} is the number of independent parameters; n_{P} is the total number of parameters.

3. Further, a mathematical model will be constructed using balance equations and inequalities of imposed parametric limitations. The decisions on how to make islanding the plant, identify the components of circuits, chains of components to be calculated in sequence are followed, i.e. the results of structural analysis are in use.

The modelling will find a best parameter combination for the facility under process of synthesis based on a single or multiple criteria. In this case, it is the energetic and exergetic performance.

The problem can be defined as follows: To find the largest value of the function [5]

$$F\left(\tilde{O},\overline{X}\right)_{\sigma} \quad \text{when} \quad \left(\tilde{O},\overline{X}\right)\in R, \tag{2}$$

where R is the acceptable region defined by

$$\begin{aligned} &\left(f_p\right)_{\min} \le f_p\left(X,\overline{X}\right) \le \left(f_p\right)_{\max}, \qquad p=\overline{1,a} \\ &\overline{X}_{\min} \le \overline{X} \le \overline{X}_{\max}, \qquad \overline{X} \in \boldsymbol{\sigma}_s; \\ &X \in L_t \end{aligned} \tag{3}$$

The functions $F\left(\overline{X}\right)$ and $f_p\left(\overline{X}\right)$ are assumed to be differentiable if the values X are fixed.

Here X is the total discretely variable parameters of the boiler plant; $\overline{X}$ is the total independent parameters that continuously vary (seasonal parameters, weather conditions etc.); $\boldsymbol{\sigma}$ is the total external factors characteristics; $f=\left\{f_1, f_2, \ldots, f_a\right\}$ is the sum of operational characteristics of the boiler plant under the process of synthesis that are used for setting the limiting conditions; $\boldsymbol{\sigma}_S$ is the spatial dimension; L_t is the finite aggregate of discrete elements of dimension t; “min” and “max” means a minimum and a maximum value, respectively.

Energy efficiency has been considered as an energy-related effectiveness criterion [1]:

$$\eta_E = \frac{\sum \Delta Q_i^{\text{useful}}}{\sum \Delta Q_i^{\text{applied}}}, \tag{4}$$

The formula (4) uses the following features: $\Delta Q_i^{\text{applied}}$ is the heat value for the energy consumed by the plant with i-flow, kW; $\Delta Q_i^{\text{useful}}$ is the heat value for the useful effect of i-flow energy perception, kW.

Exergy efficiency has been considered as a thermodynamic effectiveness criterion:

$$\eta e = \frac{\sum \Delta E_i^{\text{useful}}}{\sum \Delta E_i^{\text{applied}}}, \tag{5}$$

The formula (5) uses the following features: $\Delta E_i^{\text{applied}}$ is the heat value for the exergy consumed by

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the plant with *i*-flow, kW; $\Delta E_i^{\text{useful}}$ is the heat value for the useful effect of *i*-flow exergy perception, kW.

4. An optimum solution is going to be found for the entire range of parameters by the gradient methods to have a combination of parameters that allow for maximum performance of both the energy and exergy efficiency.

The provisions of the system analysis have been implemented in a real facility – the boiler plant at Gazprom-dobycha Nadym, LLC taking weather conditions of Nadym into consideration [3]. The effect of upgrading the boiler plant is estimated at 1,320 tons of oil equivalent per annum that corresponds to efficiency rise approximately by 10%.

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