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Probabilistic model of district heating operation process in changeable external conditions

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ABSTRACT

In this paper, district heating is described and its operation process is considered in varying operation conditions over time. Taking into account the ordered thermal power which affects the amount of heat supply to consumers, the system operation states are introduced. Heat supply to consumers is carried out by means of a heat-carrying agent having the necessary parameters: required quantity, temperature and pressure, in a specific location, under certain operational conditions and timeframe. To model the system operation process and describe the changes between the operation states the semi-Markov process is applied. The identification of the district heating operation process is performed on the basis of real operational data obtained from the District Heating Company in the city of Rzeszow. Using the data and considering the specific character of the system, the main characteristics describing the safety of heat supply to consumers were determined.

1. Introduction

District heating belongs to a class of complex systems due to the large number of components used in their construction and their complicated operating processes [1]. Apart from their complexity, heat supply systems are characterized by specific features that differentiate them from other technical systems. One of the fundamental differences is the variability of thermal loads over time as result of climate conditions. According to the Energetic Law [14], the aim of heat engineering is to provide an uninterrupted and reliable supply of heat for consumers using commonly available services. One of the measures of the provided services by the heating industry is the reliability of this supply [2]. There are many methods using mathematic and simulative tools that can be applied to the evaluation of the reliability and safety in management of various technical systems [4,13,15]. The theory of reliability in heating, ventilation and air conditioning was concentrated on in publications [7,10].

The complexity of the system and its operation processes in changeable external conditions causes difficulties in the system operation process analysis and further in the evaluation of the heat supply system reliability. Temperature changes during the year that affect the required heating power causes the heat supply system to work with a full or partial thermal load [11,16]. What is more, is that we can observe changes in time of the thermal power in a heat supply system under different operational conditions, which will be the subject of further work. In the heat supply system, similarly as in other technical systems, the environment and infrastructure have a significant influence on the system operation process [9,12].

To build a probabilistic model of a district heating operation process, the semi-Markov process is used [5,6]. The matrix of probabilities of the system operation process transitions between the operation states is determined on the basis of data collected from the heat supply system in Rzeszow, during the year 2012. From this data, the mean values of the system operation process conditional sojourn times and the mean values of the system operation process unconditional sojourn times in particular operation states are calculated. Finally, the limit values of the transient probabilities of the heat supply system operation process at particular operation states are determined.

2. Structure of the district heating

The issue of district heating (heat supply system-HSS) operation analysis requires taking into consideration their complexity in operation process and the extent of realization. In the heat supply system we can distinguish three subsystems: the subsystem of

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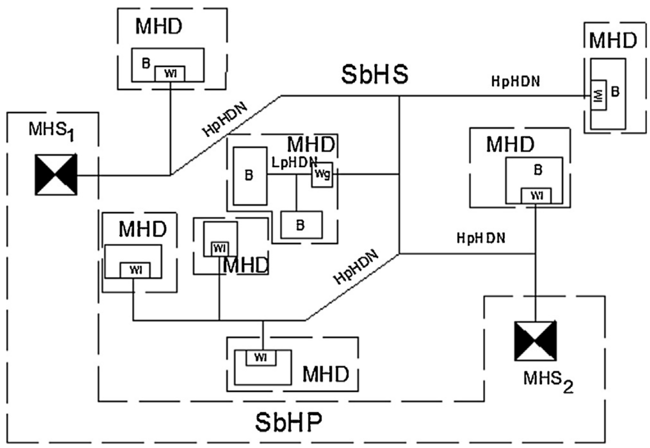

Fig. 1. The scheme HSS supplied by two heat sources. B – building; IDHS – individual district heating substation; CDHS – collective district heating substation; HpHDN – high-parameter heat distribution network; LpHDN – low-parameter heat distribution network; SbHP – subsystem of heat production; HSM_1, HSM_2 – heat supply modules (heat sources); SbHS – subsystem of heat supply; HDM – heat distribution module.

heat production (SbHP), the subsystem of heat supply (SbHS) and the subsystem of heat distribution (SbHD), which consequently consists of modules (M), objects and elements [1]. There are connections between particular HSS elements and their coherent influence on the operational reliability of the whole system. The structure of HSS decomposition into subsystems with two heat sources (HSM) is presented in Fig. 1.

In the separated heat production, in the general case, SbHP can consist of a few j-independent technological lines of heat production called heat production modules (HPM) (Fig. 2).

Each of these technological lines consists of an object of fuel supply, an object of heat production through the burning of fuel in the boiler and an object of pumping heating medium and transferring the heat to SbHS. Heat produced from fuels in SbHP, which consist of heat production modules (HPM) is delivered to SbHS, which is high-parameter heat distribution network. The subsystem of heat supply SbHS constitutes the main heat distribution networks, distributive ones, service ones, whose task is to transfer heat from the source to the district heating substation and internal installations constituting SbHD. SbHD consists of many independent heat distribution modules (HDM), in which the heat exchange takes place and the heat is distributed in installation to consumers.

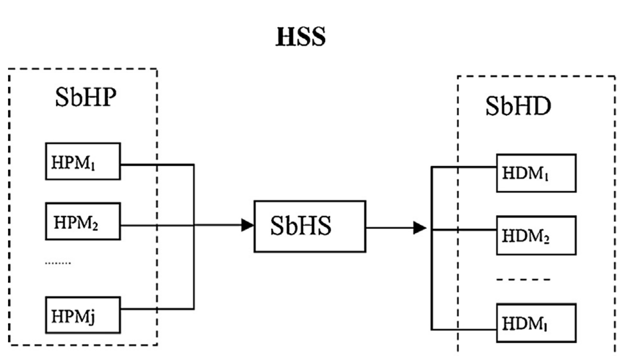

Fig. 2. HSS decomposition into subsystems (Sb) and modules (M) in the case of a few j-heat sources (HPM) and SbHD decomposition into many l-modules of heat distribution (HDM).

3. Variability of external conditions

Real external air temperatures are variable in time. Temperature variation during the year can be expressed by the thermal load factor, defined below:

$$\varphi = \frac{(\theta_{io} - \theta_e)}{(\theta_{io} - \theta_{eo})}, \quad (1)$$

where θ_{io} is the computational internal temperature, θ_e is the real external temperature, θ_{eo} is the computational external temperature.

The computational internal or external temperature result from polish legislation including requirements. Localization of the system and corresponding with it climatic conditions have been considered in terms of the external temperature. Building types and usage of premises relate to the internal temperature. The values of real external temperature come from data basis of the meteorological station in Rzeszow in the year 2012.

The graph of the thermal load factor (Fig. 3) presents the required thermal power assigned to different external air temperatures. The analysis has been charted for the meteorological station in the city of Rzeszow from data collected every day during the year 2012.

Thermal power occurring over time during the year 2012, determined by external conditions is presented in Fig. 4.

The thermal power presented in Fig. 4 has been calculated using real parameters occurring over time in the year 2012. These parameters, such as: mass flows, temperatures in flow and return conduits have been obtained from Heating Enterprise on the basis the normal system operation. The obtained values of thermal power, concerned with defined system operational states, allow to determine parameters of the system operations process.

4. Operational process of district heating

The operational process of district heating is complicated. A heat supply system can work with either a full or partial thermal load. The thermal load is characterized by a large variability throughout the year, so the operational processes of heat supply systems are characterized by the occurrence of many operational states. Different thermal power supplies characterize particular states.

According to the exploitation process of the system, six operational states have been distinguished:

- the operational state z_1 – the heat supply system operates at maximum capacity $\Phi_{z1} > 0.85 \cdot \Phi_n$, when Φ_n[MW] – termed ordered thermal power,
- the operational state z_2 – the heat supply system performs the supply of heat, but is not working at maximum capacity due to weather conditions; $0.70 \cdot \Phi_n < \Phi_{z2} \leq 0.85 \cdot \Phi_n$,
- the operational state z_3 – the central heating system slightly supplies heat due to weather conditions; $0.55 \cdot \Phi_n < \Phi_{z3} \leq 0.70 \cdot \Phi_n$,
- the operational state z_4 – the central heating system works with the following thermal power: $0.40 \cdot \Phi_n < \Phi_{z4} \leq 0.55 \cdot \Phi_n$,
- the operational state z_5 – the central heating system works with the following thermal power: $0.25 \cdot \Phi_n < \Phi_{z5} \leq 0.40 \cdot \Phi_n$,
- the operational state z_6 – the central heating system works with the following thermal power: $\Phi_{z6} \leq 0.25 \cdot \Phi_n$.

The ordered thermal power in a given heat supply system Φ_n is taken as its capacity. Production capacity is denoted by Φ_p. Variable Φ_{z1} denotes the real thermal power equivalent to aggregated heat power of heat sources in operational state z_1. Similarly, are defined the real thermal power Φ_{z2}, Φ_{z3}, Φ_{z4}, Φ_{z5}, Φ_{z6} at operational states z_2, z_3, z_4, z_5, z_6. Values of the real thermal power Φ_{zi}, $i = 1, 2, \ldots, 6$, come from real data (were collected during year 2012 in heat