Methodological provisions to the formation of district-distributed heating systems

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Abstract. The main methodological principles for the transformation of district heating systems into ones of a district-distributed type, optimally combining distributed (decentralized) and district (centralized) areas, are proposed, based on a comprehensive solution of problems of assessing the economic efficiency and reliability of heating to consumers. Wherein, the distributed sector is formed based on a prosumer that has its own generation, covering part of its own heat load and providing an additional functional and time redundancy for the system. As a result, conclusions and directions for further research are formulated.

1 Introduction

Optimal functioning and development of district heating system (DHS) involves solving a number of methodological problems. The fundamental research monograph [1] provided a rather extensive methodological base for solving them as applied to the currently DHSs. At the same time, the expansion of distributed generation leads to the fact that DHS is being transformed into the *district-distributed heating system* (DDHS) in order to optimally combine both types of generation with the integration of various energy technologies (including renewable energy sources) to achieve maximum efficiency and reliability of heating to consumers. This stage of the energy transition in heating corresponds to the 4th generation of district heating [2–5]. The distributed heating part in DDHS is formed mainly at the level of *prosumers* (professional consumers or producers & consumers) [6–9]. Implementation of prosumers with their on-site heating sources (HS) determines the new properties of the operation of studied systems, which requires the elaboration of methodological support to solve the problems of their operation, control, and development. One of these problems is to determine the optimal ratio of district heating and distributed heating parts. At the same time, feasible technical and economic solutions for the optimal distribution of loads between sources must meet the requirements of reliability of delivering heat to consumers. This paper proposes general methodological issues and principles for solving problems of analysis and ensuring the efficiency and reliability of DDHS with prosumers. The methodology being developed involves application the main provisions of the energy systems research [10], technical and economic criteria for the efficiency of heating systems, the theory of reliability and stochastic processes, etc.

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2 Brief description of methods

A number of methods are proposed to solve the formulated methodological problems (analysis and ensuring the efficiency and reliability of DDHS) based on the previous methodological developments of the authors for ensuring the efficiency and reliability of heating using criterion of the *effective heating radius* (EHR) and a *comprehensive-hierarchical approach* to the reliability analysis of heating systems. These approaches have been adapted to solve the corresponding problems for DDHS with prosumers. When solving both general problems (efficiency and reliability), a nodal approach is used, which allows obtaining the most detailed results, corresponded to real-life conditions.

Efficiency. The main idea of the proposed method for the efficiency assessment of the heating to consumers is that for each HS of the studied system it is necessary to calculate the EHR range for each direction of the heating network (HN) connected to it. This approach is nodal, i.e. it implies the calculation of operating costs for each node connected to pipelines of HN. The technique of EHR determination is the following main steps: 1) formation an information base for district heating, incl. the studied system diagram, consumer loads, parameters of HSs and HN, etc.; 2) calculation of the connected heat load for each district HS; 3) determination of the distance of the transmission pipelines for each HS according to the obtained loads; 4) flow distribution analysis in the system by the methods of the theory of hydraulic circuits [11]; 5) calculation of specific costs of generation and distribution of thermal energy for each node of the transmission pipeline from sources; 6) determination of the EHR range for each transmission pipeline, i.e. a subset of its nodes, for which the cost of heat production does not exceed the designated criterion value (usually, corresponding to some regulatory documents). All mathematical models used in the described method were detailed considered in [12, 13]. So, for the nodes within the EHR range, the transition is made to the reliability analysis.

Reliability. The heating to consumers must meet not only the requirements of economic efficiency, but also the reliability requirements. To verify that these requirements are met, we carry out a reliability analysis based on the *nodal reliability indices* (RI) [14, 15]. We propose a comprehensive approach to the reliability analysis consisting in determining the overall impact of all objects (or components) of the system on the reliability of heating to consumers. The reliability analysis is divided into two main part: 1) probabilistic and 2) physical modeling of system operation. The set of states of the studied system is formed as a combination of states of its subsystems (HS and HN) accounting. Determination of probabilities of system states is performed given the specified reliability parameters of components (failure and restoration rates) based on the markov random processes [14, 16]. Assessment of emergency states of the system is provided based on the thermal and hydraulic modeling using methods of the theory of hydraulic circuits [11]. The final result is the nodal RI calculated using the previously obtained results of probabilistic and physical modeling of the emergency states. The main RI are the availability factor and the failure-free operation probability [14]. The methodology of comprehensive reliability analysis for DHS and its practical applications are considered in [15, 17–19].

3 General algorithm for DDHS formation

The considered methods formed the basis of the algorithm for transforming existing DHS into DDHS with the implementation of prosumers to cover the load that goes beyond the efficiency of district heating. The decision to form (localize) the distributed heating sector is made under a combination of two conditions: 1) a part of the DHS scheme is located outside the EHR range; 2) there is no possibility of structural and parametric solutions to expand the EHR range within the existing district part of the system.

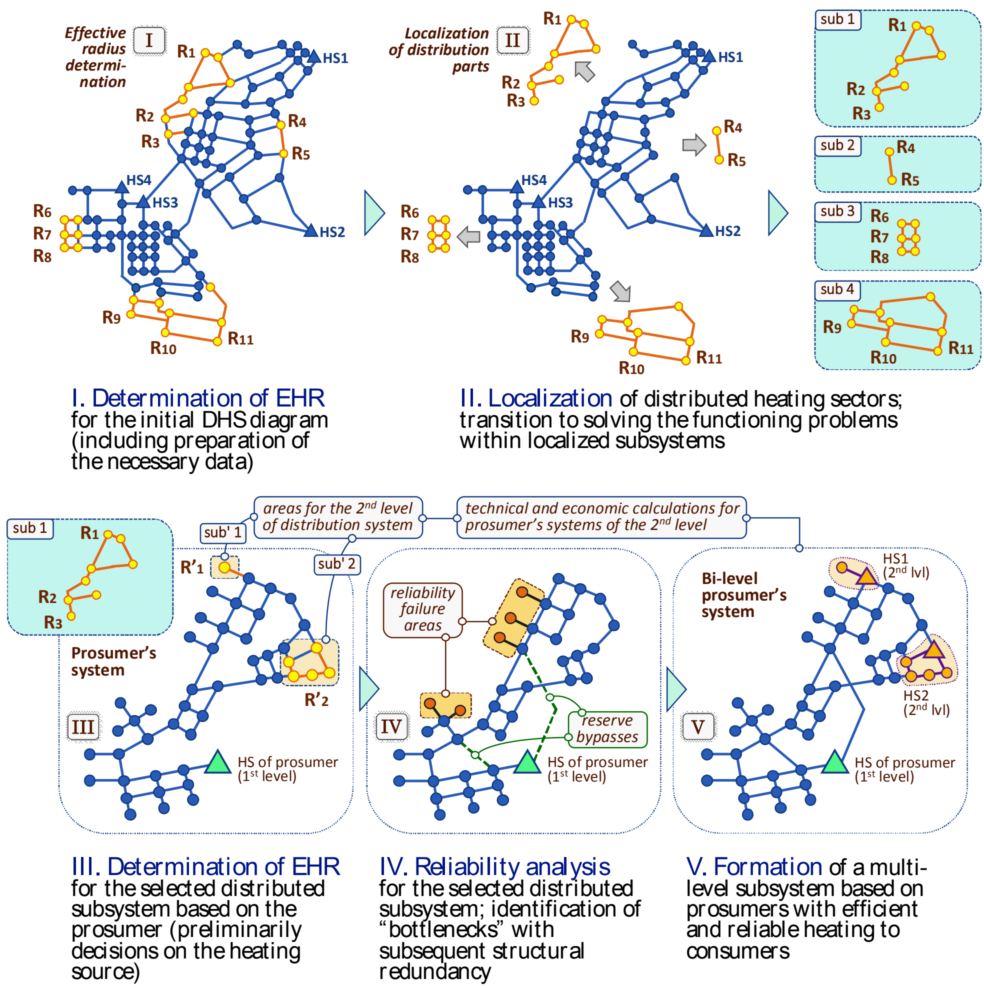

Fig. 1. Main stages of formation of DDHS by the defining criteria of economic efficiency and reliability of heating to consumers (effective heating radius and nodal reliability indices)

The main stages of the formation the DDHS with prosumers are shown in Fig. 1. At stage I, ranges of the district heating efficiency of the initial system diagram are determined based on the EHR criterion. Further, at stage II, the localization of distributed sectors is carried out with the transition to solving similar problems for each localized prosumer subsystems. Stage III corresponds to the determination of EHR ranges within the selected distributed prosumer sector (technical and economic issues are preliminarily decided on the choice of local HS). If there are consumers outside obtained ranges, they are supposed to be connected to the source of the second level of distributed heating: in this way, a two-level (in the general case, a multi-level) hierarchical structure is formed with prosumers at corresponding level. At stage IV, the problem of reliability analysis is solved for the selected distributed sector of prosumer with the identification of "unreliable" nodes and subsequent development of measures for structural redundancy. At stage V, the final multilevel distributed subsystem is formed based on prosumers with efficient and reliable heat supply to consumers. For the district part of the studied system, the reliability analysis is also provided, and if the reliability requirements are not met the transition to the stage of its optimization (synthesis) is carried out, accounting the redundancy of prosumers.

4 Conclusions

In this paper, we have combined methodological developments on solving the problems of ensuring efficiency and reliability of district heating systems to form main principles and approaches for solving the corresponding problems as applied to hybrid district-distributed heating systems with prosumers. The proposed methods and models formed the basis of the algorithm for transforming existing district heating systems into district-distributed heating systems with implementation of prosumers to provide heat loads that fall outside the range of efficient operation of a district heating part. The applied methods the proposed algorithm are not considered as a completed stage of research. Further development of the proposed methodology involves the solution of many methodological and applied problems. At this next stage, the focus will be on the development of methods for the optimal (with respect to the economic criterion) loading of district and distributed sources in accordance with the heat load curve for the calculated period (for example, the heating season).

As a result, it is planned to obtain a set of reasonable decisions on the development of studied district heating sustems, accounting the transition to a district-distributed structure of heat supply.

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