A Model for Control of Steady State of Intelligent Integrated Energy System

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***Abstract* — Modern cities and industrial centers boast a developed energy infrastructure, including fuel, electric, heating, and cooling systems. The integration of many separate systems into a single technological entity can provide new functional capabilities, the application of more advanced technologies for operation, and the establishment of intelligent integrated energy systems (IIES). Such systems have a multidimensional structure of functional features and properties of development. They combine a large number of components; intelligence; efficiency; reliability; controllability; flexible use of energy conversion, transportation, and storage technologies; and active demand. The IIES control represents an urgent and a rather challenging task. The paper is concerned with a model for control of a steady state of an intelligent integrated energy system. An algorithm intended for the calculation of joint operating conditions of electric and heating systems when integrated is presented. The results of the research into the joint operation of electric and heating systems are demonstrated on the example of a typical urban area with residential housing that has district electric and heating systems. The obtained results highlight the problems related to separate consideration of expansion and operation of the energy systems, as well as equipment wear and the need to improve the technological and technical level of these systems and use them as a basis for an intelligent integrated energy system.**

***Index Terms* — Intelligent integrated energy system, elements of concept, intelligent integrated energy system control, mathematical modelling.**

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I. Introduction

Modern energy sector represents a complex infrastructural system, including fuel, electric, heating and cooling systems. Despite various types of services, they render, their common goal it to create comfortable working and living conditions for the population, and to effectively facilitate the development of the national economy. To perform their functions, each of them has their production, transportation and distribution structure connecting them with consumers. They often overlap and compete in the market for energy services. This, in particular, refers to the electric, heating, gas and other systems. Being functionally independent, these systems can interact with one another under normal and emergency conditions, through the interchange of primary energy and use of energy carriers. All this is indicative of their natural integration which grows increasingly stronger with the establishment and expansion of intelligent information and communications systems. Jointly, they represent a new structure, i.e. the intelligent integrated energy system [1, 2]. This structure combines certain independence of the systems involved with their coordinated participation in the accomplishment of the main goal of providing social and economic activities. The information system represents an infrastructural framework for the intelligent integrated energy system.

The intelligent integrated energy systems have a multidimensional structure of functional features and properties of development. They combine a great number of components; intelligence; efficiency; reliability; controllability; flexible use of energy conversion, transportation, and storage technologies, and active demand.

Technological structure of the intelligent integrated energy system should provide:

— Effective integration of renewable energy into the energy system;
— Use of alternative energy sources, the sources operating on hydrocarbon fuels and easily transportable fuels;
— Maneuverability of the system;
— Support of an effective integration of energy and fuel infrastructures.

Conceptually, the integration is performed in three

aspects, in terms of [2, 3]:
— System, representing the integration of systems by type, including electric, heating, cooling and gas systems; in each specific case, either all or some of them can be integrated;
— Space, reflecting the extent of the systems with differentiation into super-, mini- and microsystems;
— Functions, determining the system activity (its purpose). These include energy (technological), communications and control, and decision making functions.

Within the spatial (scale) structures, we consider the following interrelated systems [2, 3]:
— Super-systems, i.e. traditional centralized energy supply systems, including large-scale electricity and heat sources, gas fields, underground gas storage facilities, as well as electric, gas and heat networks;
— Mini-systems, i.e. decentralized (distributed) systems, including mini electricity and heat sources (including those unconventional and renewable) that are connected to the distribution electric, heat and gas networks, and these networks themselves;
— Micro-systems, i.e. individual systems with unconventional and renewable electricity and heat sources, as well as house electric, heat and gas networks.

The functions of the intelligent integrated energy system include:
— Energy functions representing, production, transport, distribution and consumption of electricity, heat/cooling and gas at all levels and scales;
— Communications and control functions representing measurement, processing, transmission, exchange and representation of data, control of operation and expansion of the metasystem;
— Decision making functions, i.e. intelligence of the metasystem, including models and methods for decision making on expansion of the integrated energy systems and adjustment of systems for their control.

All functional properties of the intelligent integrated energy system are strongly interconnected with one another in terms of input and output parameters of states, structure of forecasts, both at the level of operation and at the level of expansion. They form a totally new technological architecture that describes the organization of the metasystem, including the design solutions of its components, their interrelations with one another and external environment, as well as the principles of evolutionary development of such a multi-link structure.

The properties expected to be acquired by the intelligent integrated energy system are:
— Flexibility, i.e. the capability of a system to adapt to a current level of energy consumption, variation in the ambient temperature, considering general changes in the urban infrastructure system, and adequately respond to internal and external impacts;
— Intelligence, i.e. the capability of the system to respond to the consumer needs (reduce or increase energy generation).
— Integration, i.e. the system is integrated into an urban environment, both in terms of the city planning and allocation of energy facilities and in terms of interaction among all systems of life support services of a city (electricity, heat water, fuel systems; sewerage, etc.).
— Centricity, i.e. control based on a distributed communications network where each component of the system can interact with any other component. Telecommunications network underlies the control.
— Efficiency, i.e. the equipment used meets all the modern requirements of energy efficiency. The maximum efficiency of the system is ensured by an optimal combination of technologies, including the maximum involvement of local energy resources.
— Competitiveness, i.e. the technologies are cost effective and energy resources are available to the population. Consumers can manage their energy consumption to reduce payment for it.
— Reliability, i.e. the system meets a growing demand for energy, in particular, by using renewable resources and local fuels.

II. Literature Review

Various energy supply systems, such as electric, gas, heating and other systems were normally designed and operated independently of one another. The advances in technologies and equipment, the emergence of new conditions and opportunities, however, make the interaction between different types of energy systems much stronger, which leads to a considerably increasing interest in the research on joint operation of these systems. A widely applied approach to study the integrated systems is based on consideration of such systems in the form of an energy hub. For example, in [4] the authors suggest a method for optimal energy generation and conversion in an integrated energy system with different energy carriers, which involves the energy hub conception. This method is widely applied in the studies related to optimal operation and design of integrated energy systems [5, 6].

The determination of an optimal load of generating equipment implies obtaining an optimal schedule of generating equipment startup and shutdown to meet the expected demand, given costs and constraints of a system. In the context of the integrated energy systems, this refers to the optimal startup and shutdown of each generating unit to meet the demand for several types of energy. The authors of [7] propose a solution to the problem of optimal loading of generating equipment based on the energy hub conception. For solving this problem, it is very important to consider the energy storage possibility. The authors of

[8] consider planning of electricity and heat storage as part of the problem of optimal loading of generating equipment. The authors of [9] compare energy and exergy approaches to solve the problem of optimal use of generating equipment.

The problem of the integrated energy system control can also be solved by determining optimal power flow. The determination of optimal power flow is reduced to the load distribution among energy sources, which meets the constraints of the energy transmission system in terms of cost minimization. Solving the problem of optimal power flow in the integrated energy system requires the consideration of the need for several energy types, which is met by using several energy sources and devices for energy conversion, and satisfaction of the transportation system constraints for each energy carrier. The optimal power flow in an integrated electric and gas system was investigated in [10]. For solving this problem, the authors developed a mathematical model in which the objective function is determined by a set of points for various components that are characterized by the minimum operation cost of the electric and gas systems and do not violate the constraints of the electric and gas transportation system. A method for calculation of optimal power flow for the integrated electricity, gas and heating system is presented in [11]. The method is focused on the power flow and optimality condition of Kuhn-Tucker for the case with several energy resources.

The calculation of the optimal power flow for several periods of time is related to the planning of the energy system operation for a set time horizon. In [12], the study is focused on modeling of an optimal power flow coordinated in time for electric and gas system for the case of distributed energy resources. Due to relatively slow flow speeds and specific features of storage in the gas and heating systems, it is important to take into account the dynamic behavior of these energy systems during several periods of time to solve the problems of control and scheduling of the systems. The authors of [13] study a method for calculation of optimal power flow and scheduling for integrated electric and gas systems with a transient model for the natural gas flow. The calculations were performed to compare the solutions obtained with steady state and transient models of natural gas transmission systems. A model of optimal power flow for several time periods was developed to study combined electricity and gas networks in Great Britain [14, 15].

Some studies are focused on centralized and decentralized control of integrated systems. In [16], the authors present the findings of the research into the centralized control, which involves an approach to the control with projection models for integrated energy systems. The central controller determines the actions for each energy hub to ensure better efficiency in terms of stability of transportation system, use of storage devices and forecasts of loads and prices. In [17], the authors propose a hierarchical centralized control of an integrated microgrid. The controller receives the data on transient characteristics of the natural gas flow and operation of energy converters. To take into account the dynamic characteristics of different systems, the controller was divided into three layers: slow, medium-speed and fast. The study is focused on the control of executive mechanisms when the renewable generation fluctuates, start of a conditioner, start of a microturbine, demand response and charge of energy storage. Further, the results of this research were extended to the control of an integrated energy system [18]. A strategy of real-time control of the integrated electric and heating system was proposed in [19]. The strategy of control has a hierarchical centralized architecture and is designed to maintain frequency of power supply system at a level of 50 Hz and a temperature of district heating water equal to 100^0C. An approach to solving the scheduling problem is presented in [20], where optimization is performed for a time period of 24 hours, and a strategy of real-time control compensates for a gap between a scheduled load and a real load by control actions.

Although, the centralized architecture of control can provide the best total energy system performance, its complexity limits its wide practical application. The distributed control architecture divides the common optimization and control problem into subproblems that are solved with individual models. The local control action to be performed, however, depends on the actions of neighboring controllers and should be coordinated. In [21], the authors propose a distributed control system for combined electricity and natural gas systems. The system consisting of several interrelated energy hubs was controlled by corresponding control agents. In [22], these results were extended to the studies of distributed control based on projection models and the use of storage devices in gas systems.

The integration of electric and heating systems is most pronounced in cities and populated areas, and manifests itself in: the combined electricity and heat generation; the use of energy storage systems to ensure flexibility of cogeneration operation; and the use of electric equipment for heat production, transport and distribution. The joint operation and scheduling of electric and heating systems based on cogeneration are discussed in [23]. The interaction between electric and heating systems in the view of the need to ensure the required demand response is considered in [24]. Various electricity and heat supply options were compared when solving the problems of operation and scheduling in terms of techno-economic and environmental indices in [25, 26]. In [27], the authors consider trigeneration systems (combined production of electricity, heat and cooling power).

The sources of combined electricity and heat generation interconnect electric, heating and gas systems. In [28], the authors applied Sankey diagrams to illustrate energy flows through the electricity-heat-gas networks when considering several scenarios for the involvement of cogeneration power plant and heat pumps. The research was also focused on the impact of different technologies on operation of each network. The implications of switching from hydrocarbon fuel to renewables in the electric system for the district heating systems and gas network were studied in [29, 30].

III. Specific Features Of Intelligent Integrated Energy System Control

Control of an intelligent integrated energy system, including electric, heat and gas systems represents a challenging task. The urban infrastructure of centralized energy supply has interacting dispatching services ensuring on-line control of electric and heating systems. The centralized energy supply can be backed up by autonomous energy plants for short-term use in emergencies that can lead to interruptions in the energy supply to consumers.

Operating conditions of heating systems are static and determined by variable heat consumption characterized by inertia. This is a precondition for the consideration and scheduling of heating system operating conditions during some time period (for example, 24 hours long). Unlike heating systems, electric power systems are characterized by dynamics and simultaneity of electricity production and consumption processes. Their operating conditions should be scheduled in real time.

It is convenient to divide electricity consumption into direct and indirect in the case of joint operation of heating and electric systems. The direct electricity consumption is determined by the load of power and control equipment of heating system (pumping stations and electric boiler plants) under normal operating conditions. The indirect electricity consumption is determined by variation in the load of consumers in electric system in case of changes in the operating conditions of heating system. For example, forced disconnection of a heat source or unexpected cold spell can lead to an increase in electricity consumption to compensate for heat shortage. Normally, the increase in electricity consumption occurs due to interruption in the heat supply to consumers. Thus, the electricity consumption level is connected with the level of heat production.

In order to describe electricity consumption we should identify the nodes with direct electricity consumption and the nodes with indirect electricity consumption in the heating system. Since the operating conditions of consumers determine the operating conditions of both electric power system and heating system, it is assumed that the level of consumption with the accuracy to a single consumer is known (based on projection, normative framework, direct measurements and processing of measurements). Under the known consumption, the state variables are calculated with standard software intended for the calculation of load flow and flow distribution in respective networks.

The basic elements for the interface (interaction) between electric and heating systems within the intelligent integrated energy system are heat and electricity consumers as well as power and control equipment of electric and heat networks. A list of attributes of the heat and electricity consumer is presented in Table 1.

A list of attributes of power and control equipment (electric boiler plants, pumping stations, etc.) is presented in Table 2.

An algorithm for the combined calculation of electric

Table 1. Attributes of a Heat and Electricity Consumer

No.	Attributes of Consumer as a Component of Electric System	Attributes of Consumer as a Component of Heating System
1.	City address	City address
2.	Code of node number (number of a contract)	Code of consumer (number of a contract)
3.	Feeder code	Feed pipe code
4.	Supply transformer substation code	Pumping station code
5.	P_{max}, MW(contracted power of consumption)	Heat consumption curve (MW)
6.	P_{comp}, MW (power compensating for heat shortage)	Heat undersupply volume (MW)

Table 2. Attributes of a Power and Control Equipment

No.	Electric System Component Feeding Heating System Power Equipment	Heating System Equipment Component
1.	Equipment code	Equipment code
2.	Code of supply feeder	Code of supply line or transformer substation of electric system
3.	Code of supply transformer substation	Codes of adjacent pipes
4.	City address	City address
5.	P_{max}, MW(contracted power of consumption)	Electricity consumption curve (MW)
6.	P_{comp}, MW (power consumption under change in operating conditions of power equipment in heat network)	Change in the electricity consumption under change in operating conditions (MW)

power and heating systems for some time instant, for which the electric loads of heating system equipment are known, is reduced to the determination of values of state variables (nodal capacities and voltage, transformer ratios, and their functions) based on the calculation of feasible load flow in electric power system, given the loads of the other electric system consumers. For formalization, it is convenient to introduce individual nodes, where the load of heating system equipment is connected.

The calculated scheme of electric power system in terms of heating system operation is demonstrated in Fig.1. Under normal operating conditions, the amounts of electricity consumed by heating system are determined and they are assigned to the electric system nodes, according to the city addresses. To this end, the above tables associating the heat consumption nodes with the electricity consumption nodes are used.

Change in the heating system condition is analyzed, and the volume of required additional electricity, if necessary, and its distribution among nodes of the calculated electric system scheme are determined. If the problem is solved for the time interval, whose duration is taken equal to an hour, an increase in electricity consumption is numerically equal to load. Change in loads of the electric boiler plants and pumping stations also influences electric system operation, because they are electricity consumers. The feasible condition of the electric system is determined for the specified loads of heating system equipment and the loads of remaining electric system consumers. Calculation of power flow in terms of the corrected loads makes it possible to determine the degree of loading of transmission lines and transformers. The regulatory documents indicate that in the short run the overloading of transformers should not exceed 40% of the rated transformer capacity and that of cable lines should not exceed 25% of their rated transfer capability [31]. If the feasible solution does not exist, organizational and technical measures should be developed to eliminate causes of such a situation. Otherwise, the values of current state variables are used or corrected.

IV. Model Of Intelligent Integrated Energy System Control

The considered model of the steady state control of the intelligent integrated energy system can be applied to any time period divided into *t* intervals.

The suggested approach to steady state control of IIES is to ensure that this system operates with the minimum costs at the considered time interval. Therefore, the costs of energy system operation and maintenance should be minimized. The objective function has the form:

$$\min F_{obj2} = C_f + C_{dep} + C_m + C_{net}, \quad (1)$$

where

$$C_f = \sum_{i=1}^{N}\sum_{t=1}^{T} c_f^i (F_w^{it} + F_q^{it}), \quad (2)$$

$$C_{dep} = \sum_{i=1}^{N}\left(f_{dep}^i K_i \sum_{t=1}^{T} (P_i^t / P_{i\max}) \right), \quad (3)$$

$$C_m = \sum_{i=1}^{N}\sum_{t=1}^{T} f_m^i (W_i^t + Q_i^t), \quad (4)$$

$$C_{net} = \sum_{t=1}^{T} (f_{net}^e W^t + f_{net}^h Q^t), \quad (5)$$

subject to:

$$E_{k\min} \le E_k^t \le E_{k\max}, \quad k \in N_{par}^e, \quad t = 1,...,T, \quad (6)$$

$$H_{k\min} \le H_k^t \le H_{k\max}, \quad k \in N_{par}^h, \quad t = 1,...,T, \quad (7)$$

$$0 \le P_i^t \le P_{i\max}, \quad i = 1,..., N, \quad t = 1,...,T, \quad (8)$$

$$F_{w\max}^{it} \ge F_w^{it}, \quad (9)$$

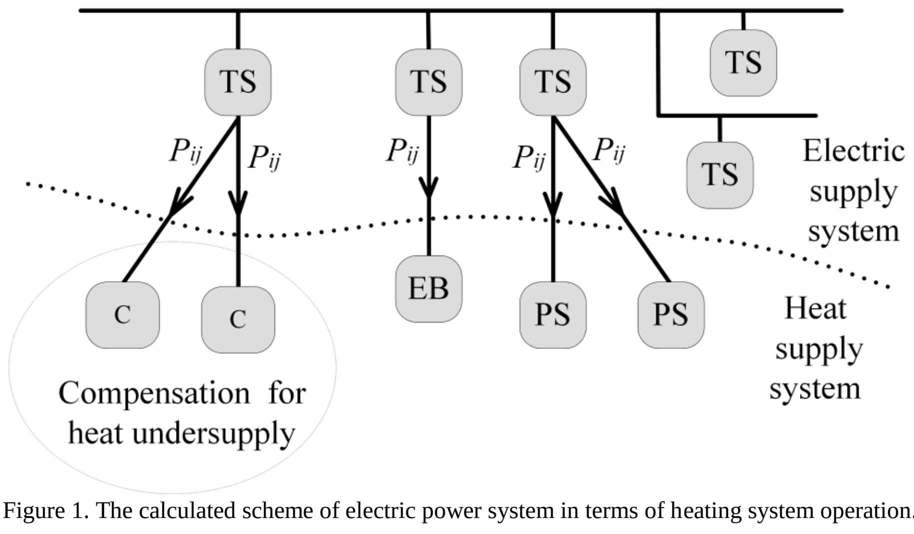

Figure 1. The calculated scheme of electric power system in terms of heating system operation.

$$F^{it}_{q\max} \geq F^{it}_{q}, \qquad (10)$$

and balance between electricity and heat production is:

$$\sum_{t=1}^{T}(W^t + Q^t) = \sum_{i=1}^{N}\sum_{t=1}^{T}(W_i^t + Q_i^t) = \sum_{t=1}^{T} P_i^t \Delta t, \qquad (11)$$

where C_f – fuel costs; C_{dep} – depreciation costs of energy sources; C_m and C_{net} – operating costs of energy sources and networks, respectively; c_f^i – cost of the fuel used at each source *i* out of the total number *N*; F_q^i – volumes of fuel used at source *i* for heat production; F_w^i – volumes of fuel used at source *i* for electricity production; f_{dep}^i – capital recovery factor; K_i – capital investment in source *i*; P_i – used (installed) capacity of source *i*; $P_{i\max}$ – maximum (installed) capacity of source *i*; f_m^i – specific values of operating costs of source *i* (maintenance, semi-fixed costs, consumption of other primary energy resources except for fuel, etc.); W_i – supply of electricity from source *i*; Q_i – supply of heat from source *i*; f_{net}^e – specific values of operating costs for electric networks; f_{net}^h – specific values of operating costs for heat networks; W – total values of electricity outputs in the system; Q – total values of heat outputs in the system; E_k – parameters of the current state of electric network; $E_{k\min}$ and $E_{k\max}$ – technically admissible limits of operating parameters of the electric network; H_k – parameters of the current state of heat network; $H_{k\min}$ and $H_{k\max}$ – technically admissible limits of operating parameters of the heat network; P_i – used (installed) capacity of source *i*; $P_{i\max}$ – maximum (installed) capacity of source *i*.

The operating parameters (6) and (7) are determined from the calculation of operating conditions of electric and heat networks by using special mathematical models of load flow which are based on the known network laws of Kirchhoff.

Electricity consumption in the system W_{cons} is related to its supply as follows:

$$W_{cons} = W(1 - l_w), \qquad (12)$$

where l_w – a share of power losses in the system.

The amount of electricity consumed in the system can be divided into three parts:

$$W_{cons} = W_{cons(e)} + W_{cons(h)} + W_{pump}, \qquad (13)$$

where $W_{cons(e)}$ – electricity used to cover electric loads of consumers; $W_{cons(h)}$ – electricity consumed by electric heaters to cover part of heat (heating) load; W_{pump} – electricity used in the motor drive of pumping stations in the heat network.

Based on (12) the heat consumption in the system Q_{cons} is related to its supply as follows (we make an assumption that the electric energy consumed by electric heater is completely transformed into thermal one):

$$Q_{cons} = Q(1 - l_q) + W_{cons(h)}, \qquad (14)$$

where l_q – a share of heat losses in the system.

The amount of fuel consumed at source *i* for electricity or/and heat production, respectively, can be determined as follows:

$$F_w^i = W_i / \eta_e^i, \quad i = 1,...,N, \qquad (15)$$

$$F_q^i = Q_i / \eta_h^i, \quad i = 1,...,N, \qquad (16)$$

where F_w^i – volumes of fuel used at source *i* for production of electricity; F_q^i – volumes of fuel used at source *i* for production of heat; η_e^i = factors of fuel efficiency at source *i* for electricity production; η_h^i = factors of fuel efficiency at source *i* for heat production.

The coefficient f_{dep}^i is determined by the following equation:

$$f_{dep}^i = [r(1+r)^{n_i}] / [(1+r)^{n_i} - 1], \qquad (17)$$

where *r* – a discount rate which can be represented by the cost of funds; n_i – depreciation rate of equipment at source *i* as a result of its wear due to operation.

The indices f_{dep}^i, r and n_i are normally assumed annualized.

Model (1) – (11) makes it possible to control the operating conditions of the integrated intelligent energy system during any period of time, considering changes in the electric and heat loads during this period. The efficiency of energy production at the sources also changes, hence for each source *i* there is an efficiency characteristic according to which the coefficients η_e^i and η_h^i take certain values depending on the time interval *t*. Thus, the fuel consumption at sources in equation (2) is determined considering the time-variable efficiency:

$$F_w^{it} = W_i^t / \eta_e^{it}, \quad i = 1,...,N, \quad t = 1,...,T, \qquad (18)$$

$$F_q^{it} = Q_i^t / \eta_h^{it}, \quad i = 1,...,N, \quad t = 1,...,T . \quad (19)$$

Requirements for reliability of the integrated intelligent energy supply system operation can be specified by the following conditions which should supplement equations (6) – (11):

$$R_j^e \geq R_{0j}^e, \quad j \in J , \quad (20)$$

$$R_j^h \geq R_{0j}^h, \quad j \in J . \quad (21)$$

Reliability is normally assessed by several indices that characterize its different properties. Here for each index we should set condition (20) or (21) depending on the type of supply (electricity or heat). The assessment of the reliability involves two main nodal reliability indices – availability factor and probability of failure-free operation.

V. Study Of Intelligent Integrated Energy System Operating Conditions

The algorithm of calculating conditions of joint operation of electric and heating systems subject to their integration comprises the following stages [32]:

1. Physical layout of sources on the terrain plan and assignment of their parameters.
2. Generation of schemes of heat and electric networks.
3. Determination of time period and step.
4. Calculation of flow distribution in the heating system for the determined time step.
5. Estimation of condition feasibility of the heating system.
6. Assessment of reliability indices of the heating system.
7. Determination of consumers of power and control facilities of the heat network, whose power demand changed.
8. Determination of consumers with unserved heat load, and the volume of undersupplied heat.
9. Determination of transformer substations supplying electricity to power and control facilities of the heat network, whose power demand changed.
10. Determination of transformer substations supplying electricity to the consumers with undersupplied heat.
11. Change in capacity of the transformers determined in steps (9) and (10).
12. Calculation of conditions of the electric system.
13. Estimation of condition feasibility of the electric system.
14. Assessment of reliability indices of the electric system.
15. If the feasible solution exists, then calculation of costs on energy system operation and transition to step 3), otherwise, development of organizational and technical measures to eliminate causes of the formed situation.

Consider some results of the studies on joint operation of the electric and heating systems by the example of one of the districts of Irkutsk city with centralized electricity and heat supply.

A graphical model of the integrated energy system is presented in Fig. 2. It contains an electric system (blue lines in Fig. 2) and a heating system (red lines in Fig. 2).

The studies were performed on the basis of multivariate

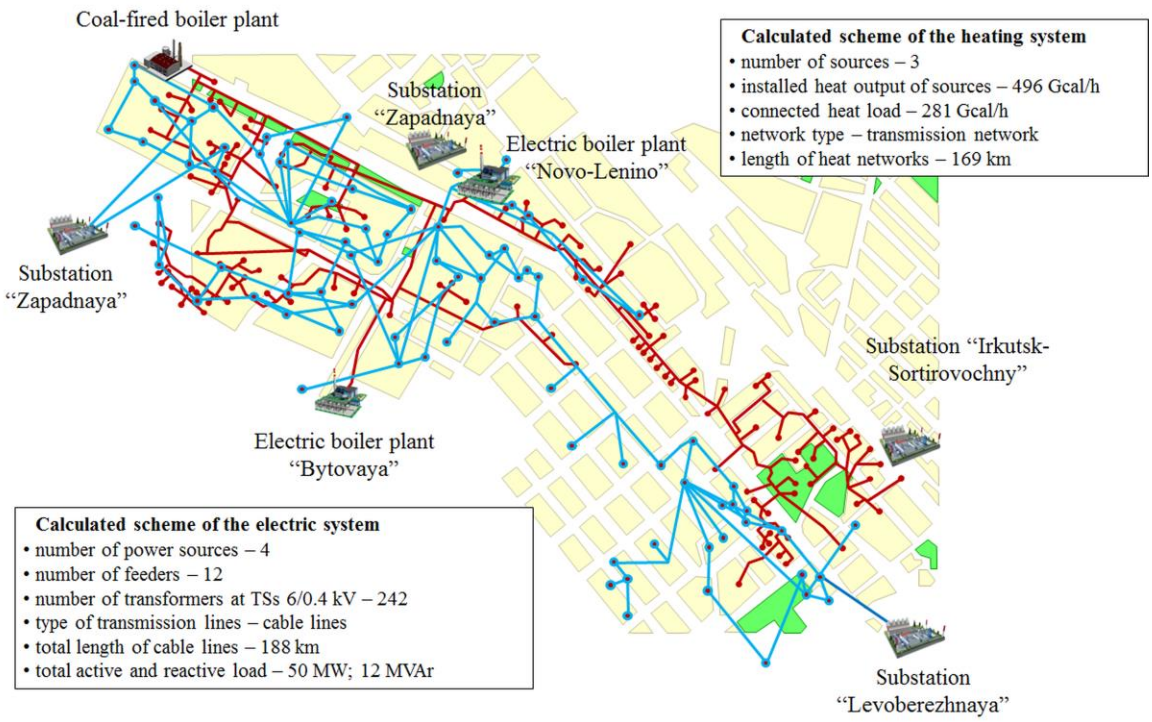

Figure 2. A scheme of the integrated energy system.

calculations of operating conditions of the electric and heating systems and generalization of their results using the corresponding software designed at ESI SB RAS. The calculated loads of the energy system of the district corresponded to winter loads. A day with a step equal to one hour was taken as a time period.

When the electric and heating systems operated independently, the costs of energy supply amounted to 359,122 RUR/day. In accordance with the above model of IIES control, joint operation of the electric and heating systems allows their energy flows to be distributed so that the operation and maintenance costs are minimized integrally for both systems. The energy supply costs in this case decreased and made up 298,071 RUR/day. Operation of the systems as a single integrated entity considerably decreased the costs, improved the technological potential of mutual redundancy and fuel diversification, enhanced the comfort level, etc. At the same time, the studies also revealed shortcomings caused by the need of separate development planning of the electric and heating systems. This fact was confirmed by calculations of conditions with increased consumer demands due to abnormal fall of ambient air temperature, in emergency situations, unforeseen repairs and so on.

An increase in electric load because of abnormal cold snap, for example, by about 30 MW, which seems quite real, made it impossible to supply 14 MW of electricity to consumers even with the available capacity reserve and led to overloading of transformers at 18 transformer substations. Load decrease in the heating system could improve the situation and reduce load of the electric system to 4 MW. However, this measure was not implemented because of the absence of automatic and intelligent control of conditions of the electric and heating systems. All of these things show that transition to operation of electric and heating systems as an integrated entity leads to essential saving of costs and a set of technological effects and at the same time requires certain engineering modifications of the systems, their substantiation and implementation.

VI. Conclusion

Intelligent integrated energy systems have versatile functions and a developed technological structure which includes a heterogeneous configuration of basic components: production systems, systems for transportation of energy carriers, systems of load-controlled consumer, systems of energy storage, integration tools, information-communication platform, metering and measuring systems and also intelligent control systems. These facts essentially complicate coordination and control of conditions of such a metasystem. The suggested model and algorithm of calculating the conditions make it possible to perform studies, plan operating conditions of IIES and generate recommendations on their implementation. At the same time, the conducted studies reveal unavailability of the existing energy systems to joint operation. Hence, they should be transformed to create a proper structure and provide with required parameters.

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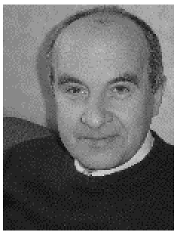

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