Integrated Infrastructural Energy Systems – Challenges for Russia

Nikolai Voropai, Valery Stennikov, Sergey Senderov, Evgeny Barakhtenko, Oleg Voitov, Lidiia Kovernikova, Tamara Oshchepkova, Liudmila Semenova
Melentiev Energy Systems Institute, ESI SB RAS
Irkutsk, Russia
voropai@isem.sei.irk.ru

***Abstract* - General framework of integrated infrastructural energy systems is presented. Elements of concept of integrated energy systems are suggested. The results of two illustrative study cases are shown and explained.**

***Index Terms* - Energy Systems, Integration, Critical Infrastructures, Elements of Concept, Challenges**

I. INTRODUCTION

Energy systems, especially electricity, gas and heat supply systems, have an infrastructural role which aims to supply energy to consumers efficiently with required reliability and acceptable quality of energy carriers. They have a developed transmission and distribution network infrastructure. These energy systems are normally divided into energy production- transmission systems – *Super Grids* (large power plants and cogeneration power plants, large boiler plants, gas fields, underground gas storages, and transmission electric and pipeline networks), distribution energy supply systems – *Mini Grids*, that encompass distribution electric and pipeline networks which until recently have not had energy sources, but in the last decades have included distributed generation, and local energy supply systems – *Micro Grids*, that include inside electric and pipeline networks of enterprises, homes, public buildings which can have local small energy sources [1, 2].

The energy production- transmission systems (Super Grids) are integrated to a certain extent as energy carrier from one system can be used in another one (for example, gas as a fuel for power plants and boiler plants, electricity at gas or heat water pumping units, etc.). Moreover, energy carriers are interchangeable, particularly in emergency conditions (for example, heavy oil instead of gas at power plants and boiler plants, etc.), primary energy carrier can be used for production of several final energy carriers (for example, gas as a fuel for combined generation of electricity and heat). This integration predetermines the leading role of the considered energy systems in the energy industry. At the same time, although optimization of the energy industry makes it possible to determine a rational extent of interaction and mutual influence of the energy production- transmission systems, further, their expansion, operation and control are studied usually independently. Energy production- transmission systems have large energy scales therefore they are paid increasingly greater attention to provide efficiency, reliability and quality of their operation, and rational expansion. The efficiency and reliability of these systems as well as the quality of energy supply are provided by different advanced control and automation technologies and devices intended for control of their operation [3, 4].

The energy supply systems (Mini Grids) are represented mostly by energy infrastructure of cities, industrial hubs and rural areas. These centralized systems are constructed either on the basis of cogeneration power plants with combined production of heat and electricity or on the basis of boiler plants and rural power plants with separate generation of these types of energy. Also, energy infrastructure of cities includes gas distribution systems that supply gas to definite consumers. The energy supply systems are often large in scale, have large capacity and unite tens and even hundreds thousands of consumers. At the same time they have simplified schemes of energy distribution, and are insufficiently furnished with control and automation devices, which makes it impossible to control them in real time and leads to high financial and material expenditures as well as considerable energy losses [3, 4].

The problems of expansion and operation of energy supply systems in cities, industrial habs and rural areas are separately by type of system without coordination each other [5-7, etc.]. Comprehensive consideration of energy supply problems in the regions [8, 9] is limited by optimization of design solutions within regional energy sectors without their complete optimization at the level of energy supply systems, and without research into their operation and control. Therefore, organization of a coordinated process of expansion and operation of these systems as well as consideration of different types of energy systems in the form of a a unified integrated energy supply systems will greatly enhance their security, reliability, cost effectiveness and environmental friendliness. Inevitable development of distributed generation on the basis of nonconventional and renewable energy sources both at the level of energy supply system and at the level of consumers, and their integration into the joint systems require implementation of new principles of the construction of these integrated systems and creation of systems to control them with well-developed information and communication tools. Integration of separate systems into a single technological complex will provide new functional ca-

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pabilities, enable the application of more advanced operation technologies and the creation of integrated, centralized-and-distributed Mini Grids with coordinated control of their operation and active participation of consumers in the energy supply process.

Last decades there are many research results concerning Micro Grids [10, 11, etc.]. This level in Russia has not practically been studied yet. In this context it is first of all necessary to make a thorough analysis of the international experience considered in brief in [1, 2] and adapt this experience to the Russian conditions. Then, based on these analysis and adaptation, it will be possible to formulate the important problems to be accomplished in the research.

II. ELEMENTS OF CONCEPT

Taking into account above mentioned ideas and the analysis of current status of the problem in [1, 2] the generalization and expansion of the understanding integrated energy system is suggested. Such an integrated energy system can be represented by a three-layer structure in three dimensions similar to Rubik's Cube (Figure 1).

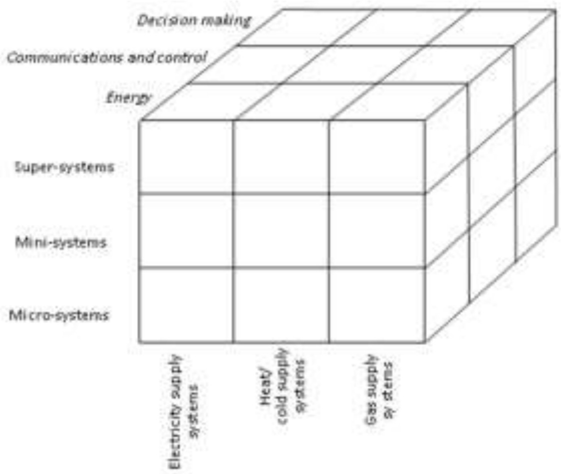

Fig.1. A tree-layer structure of integrated energy systems in three dimensions

Let us define this groups of layers as follows:

− The system layers – electricity, heat/could, and gas supply systems;

− The scale layers – super-, mini-, and micro-systems;

− The function layers – energy, communications and control, and decision making.

Let us consider in more detail the presented multi-layer structure.

The system layer do not require additional comments and specifications. As was said above these are the primary energy infrastructural systems. It is only necessary to note once again that there are technological interactions among these energy systems at different levels.

The scale layers are represented by the following interconnected systems:

• Super-systems include large power plants (termal condensing and cogeneration, hydro, nuclear), large boiler plants, gas fields, underground gas storages, transmission electric, gas and heat networks;

• Mini-systems include mini sources of energy that can be connected to distribution electric, heat and gas networks (mini-cogeneration plants, heat boiler plants, wind parks, mini hydropower plants, photovoltaic complexes, etc.), as well as the distribution networks themselves;

• Micro-systems include single wind units, gas microturbine plants, solar collectors and photovoltaic panels, micro-storages of electricity and heat, etc.), as well as house electric, heat and gas networks.

Figure 2 shows in a simplified manner the layers of super-mini-micro-grids as interconnected systems at different levels.

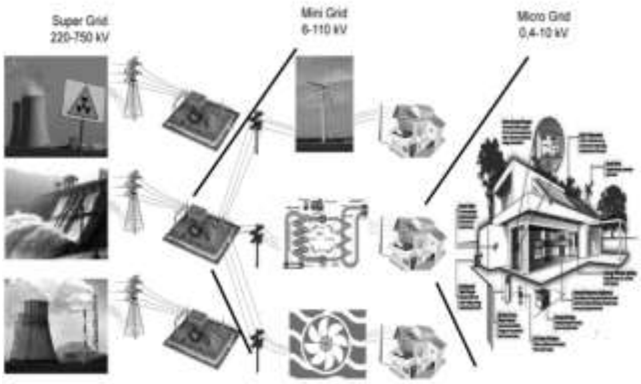

Fig. 2. Super-mini-micro grids

The function layers include the following functions:

➢ Energy functions – production, transmission, distribution and consumption of energy resources (electricity, heat/could, gas) at all levels of system layers and scale layers;

➢ Communications and control functions – measurement (acquisition) of data, its processing, transfer and representation, as well as the systems for control of operation of the integrated energy systems;

➢ Decision making functions include the models and methods of making decisions on the expansion of integrated energy systems and the systems to control them.

It should be noted that the interactions among the function layers are rather strong: the layer of communications and control employs the data from the layer of energy functions (current parameters of the structure and operating conditions of systems, forecast data, etc.) as well as the data obtained from the models and methods at the layer of decision making; the layer of decision making uses the data from the layer of energy functions and layer of communications and control, and based on these data generates decisions for the layer of communications and control.

The presented three-layer structure of integrated infrastructural energy systems in three dimensions enables us to consider the problem from different sides and formulate the objectives of research in a more systematic manner.

III. TWO ILLUSTRATIVE CASE STUDIES

A. Emergency in Gas Transportation Network of Russia

Let us present the research of emergency situation at the level of Super Grids of energy system layers after the accident on pipeline of gas transportation network of Russia. This network is represented on Figure 3. We will consider main characteristics of gas transportation network and its influence on the other energy systems.

Fig. 3. Gas transportation network for Russia and EU

The length of pipelines of the gas transportation system of Russia has nearly 160 thousands km. A half of this length includes large diameter pipes – 1020, 1220, and 1420 mm. More than 90 % of Russia's gas is produced in one area – in the North of Tyumen region of Western Siberia, 2.5-3 thouthands km from main gas consumption areas of European part of country. The major gas transportation capacities are concentrated in multi-line transportation corridors outgoing from the fields of Western Siberia, which have gas pipeline crossings. There are more than 29 such crossings of main gas pipelines in the gas transportation network. An emergency on one pipeline can initiate a dangerous situation across the entire gas transportation corridor or at the crossing of the main gas pipelines, which can threaten with the complete disconnection of gas supply. The existing underground gas storages have limited capacities which are not sufficient to compensate for gas undersupply to consumers under extreme situation.

Thermal power plants (TPPs) including more than 50 % co-generation are the largest natural gas consumers in Russia. Gas consumption at TPPs in the country amounts to nearly 40 % of all gas consumption with the total gas share in the mix of the fuel consumed today is 78 %. Interruptions and limitations in the gas supplies to TPPs during extreme situation may negative affect to production of electricity and heat with their reduction in supplies to consumers.

The most severe consequences are possible in the winter period with the peak of electricity and heat consumptions when nuclear and hydro power plants operate at full capacity. Then the reservation of gas deficit is possible only through:

– Partial replacement of gas by another fuel type for the period of extreme situation (for TPPs with double fuel supply);

– Additional loading of TPPs with the other types of fuel;

– Supply of electricity to deficient region from neughbouring regions using interregional transmission network.

Above mentioned possibilities to compensate the consequences of gas deficit were studied by simulation flow model of Russian gas industry [12] and optimization model of fuel and energy sector of Russia [13] that reflect in detail the specific features of the integrated daily operation of different energy industries within the fuel and energy sector. These models represent all territories of Russia which are located in the service area of the Russian gas industry. The illustrative results are presented for one region – Northwest Federal District .

The scenario of emergency situation was created on the base of possible interruption in the operation one of important crossing of the main gas pipelines in the Yamal region (see Figure 3). The most difficult time of the year – January – was considered. Table 1 presents emergency conditions in the Northwest regions and the possibilities of compensating for gas undersupply to electricity and heat generation through the distribution of heating oil reserves available at the end of the year. It is possible to see that the share of Expected Energy Not Supplied is rather big in some regions and required heating oil volume during the emergency is more than its consumption before the emergency. Very important fact is that potential use of heating oil reserves located in Norwest regions does not enough for compensating of gas undersupply to electricity and heat generation.

Table 2 shows the possibilities of daily electricity and heat production in the entities of the Northwest Federal District during the emergency when gas shortage is compensated by heating oil. It is important to note that production of heat by co-generation TPPs and heat power plants is required without shortage because of local distribution of heating. Therefore the reserves of heating oil does not enough for electricity generation and there is a deficit of electricity in some regions (see Table 2) which can be compensated from neughbouring districts using transmission network.

Thus, interrelations between different energy systems due to their integration give good possibilities for reliable energy supply to consumers.

B. Emergency in Distribution Power Supply System of City District

Let us present the research of interdependency of power and heat supply Mini Grids in emergency conditions on the example of Novo-Lenino district of Irkutsk City.

The simplified diagram of heat supply system of Novo-Lenino district is shown on the Figure 4. It includes one coal boiler plant, two electric steam boilers and pipeline network. The total heat production capacity is 496 Gcal/h, the total heat load is 281 Gcal/h. The total length of heat pipelines is 169 km.

The simplified diagram of power supply system of Novo-Lenino district is presented on the Figure 5. This system includes four supply substations 110/6 kV which connect to regional power system and distribution electric network 6and 0.4 kV. The number of transformer substations 6/0.4 kV is 242. The total length of the cable lines is 188 km.

TABLE 1

Possibilities of compensating for gas undersupply to electricity and heat generation sources through the distribution of heating oil reserves available at the end of the year

RF entity	Gas shortage during the emergency, tse/day	Expected Energy not Supplied, %		Heating oil consumption before the emergency, tse/day	Required heating oil volume during the emergency, tse/day	Potential use of heating oil reserves in Jandary, tse/day
		Electricity	Heat			
Northwest Federal District	70.70			5.39	76.09	20.30
Republic of Karelia	3.55	16.6	8.2	2.14	5.69	2.13
Republic of Komi	0.00	0	0	1.10	1.10	3.03
Arkhangelsk region	0.00	0	0	6.82	6.82	7.12
Vologda region	11.83	28.3	10.0	0.07	11.90	2.01
Kaliningrad region	5.11	60.8	22.7	0.69	5.80	1.21
Leningrad region	62.01	40.4	13.0	2.17	64.18	15.57
Novgorod region	0.03	0.2	0	0.10	0.13	0.43
Pskov region	0.00	0	0	0.29	0.29	0.29

TABLE 2

Possibilities of daily electricity and heat production in the entities of the Northwest Federal District during the emergency when gas shortage is compensated by heating oil

RF entity	Heat			Electricity		
	Demand	Production	Shortage	Production before the emergency	Production during the emergency	Decrease in production
	Thousand Gcal		%	mln. kWh		%
Northwest Federal District	683.7	683.7	0	293.5	248.3	15
The Republic of Karelia	39.7	39.7	0	14.0	11.8	15
The Komi Republic	88.4	88.4	0	30.9	30.9	0
Arkhangelsk region	104.8	104.8	0	26.8	26.8	0
Vologda region	70.6	70.6	0	26.3	17.7	33
Kaliningrad region	20.8	20.8	0	10.5	6.9	34
Leningrad region	310.8	310.8	0	177.8	147.0	17
Novgorod region	28.8	28.8	0	2.3	2.3	0
Pskov region	20.0	20.0	0	4.9	4.9	0

Total active and reactive loads of consumers are 50 MW and 12 MVAr.

The emergency conditions were studied by load flow simulation using softwares for power [14] and heat [15] load flow calculations for maximum heating during winter period. The scenario of the cascading emergency in integrated power and heat supply system is considered through following stages:

1) Power outage for the electric substation Novo-Lenino with loss of power supply to electric boiler Novo-Lenino and heat deficit about 80 MW (heat).

2) Required heat load is distributed between two other sources.

3) Operated heat sources and network do not provide the redistribution of heat loads because of network congestions and boiler limitations, as the result heat shortage is about 10 MW (heat).

4) Many consumers are starting to use electric heaters.

5) Electrical load is increasing on 7 MW.

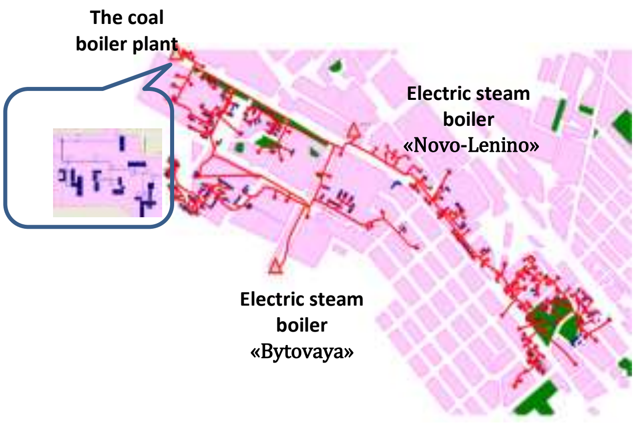

Fig.4. Novo-Lenino district heat supply system, Irkutsk

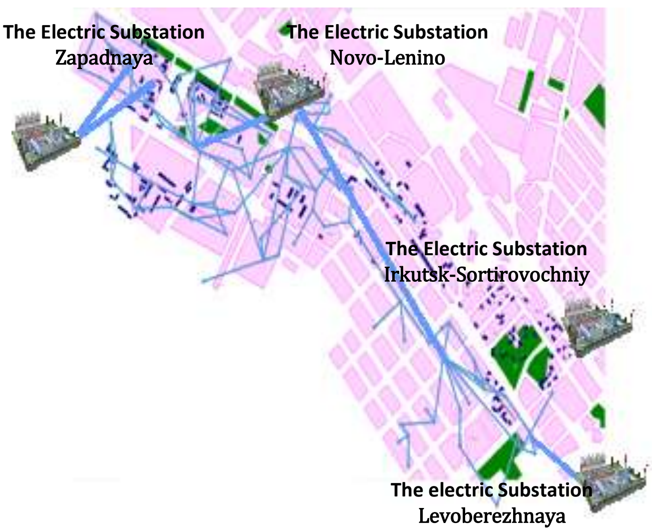

Fig.5. Novo-Lenino district power supply system, Irkutsk

6) Electrical network and substations can not provide total power supply because of overloading of cable lines and transformers. Some consumers have the loss of power supply because of protection system operation against overloadings.

The results of study are shown on the Figure 6 for heat supply system and on the Figure 7 for power supply system. Three areas with heating problems are marked on the Figure 6, one of them has the most value of heat shortage – 6.3 Gcal/h. Therefore this area has the problems with using electric heaters because of overloadings of cable lines and transformers (see Figure 7), what leads to loss of power supply to consumers in addition to heating problem.

IV. CONCLUSIONS

The research results of this paper show that consideration of the integrated infrastructural energy systems as a technological platform for the energy sector of the future, and control of these systems are important goals that require intensive study. This paper provides a general framework of integrated infrastructural energy systems using the introduction of three-layer structure in three dimensions, what is useful for the problem understanding.

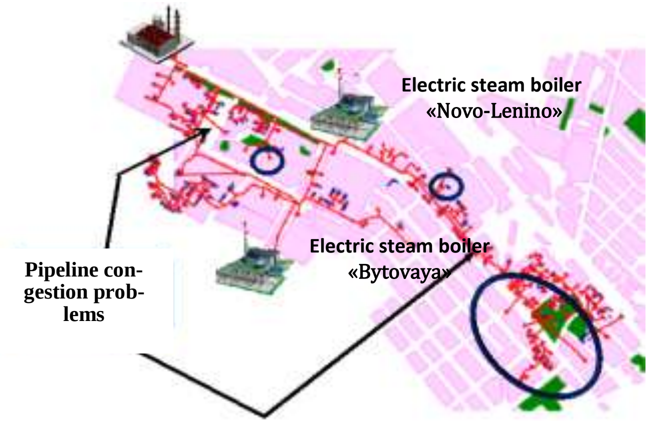

Fig. 6. Novo-Lenino district heat power supply system after emergency, Irkutsk

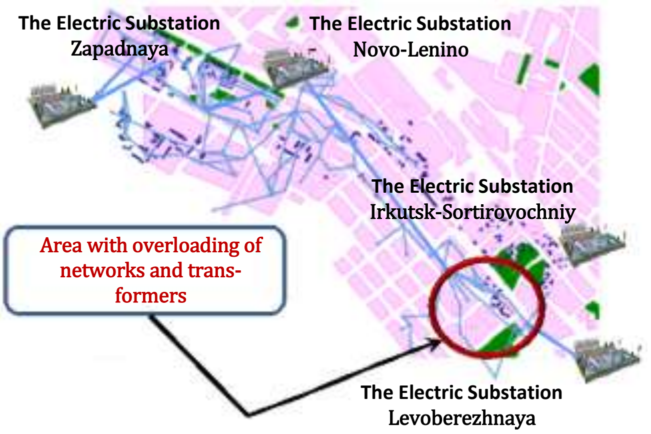

Fig. 7. Novo-Lenino district power supply system after emergency, Irkutsk

Two examples of strong interdependence among Russian electricity, heat and gas supply systems show that the integration factor of these systems is very important for consideration, especially in emergency conditions.

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