Efficiency research of free electricity (power) transfer zones integration by distributed generation

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Abstract. The possibility of combining free electricity (power) transfer zones by distributed generation is considered in this paper. The relevance of a subject is caused by the existing condition of network infrastructure and a high part of a network component in the final electricity cost, change of a fuel and energy landscape in territorial subjects of the federation, increase in ecological requirements and need of increase in power production efficiency. The object of the study is the second price zone of the wholesale market located on the territory of Siberia, where the task of increasing the availability of electricity is combined with the problem of reliable heat supply due to climatic conditions. It causes the presence of a large number of heating boiler houses. It is shown that the medium and large boiler houses transfer to the cogeneration mode of operation in the cities of the Altay Reginon and the Republic of Altai will allow to integrate the free electricity (power) transfer zones Altai and Siberia among other significant effects. Distributed generation was seen as an effective alternative to strengthening intersystem connections. It is obvious that the new network construction leads to an increase in the electricity transmission tariff and the transition to distributed generation leads to an increase in competition in retail regional markets, which reduces the cost of electricity.

Keywords. Free electricity (power) transfer zone, gasification, boiler house, distributed generation, gas-piston engine, cogeneration

1. Introduction

The concept of free electricity (power) transfer zone (FETZ) appeared in 2010, when the Federal Antitrust Service defined 29 FETZes, where competitive power selection is carried out using the power price limit.

The FETZ allocation is justified by the presence of technical restrictions on the transmission of power systems through intersystem connections. In each FETZ the generating power can be distributed without any restrictions. It's possible to conclude that there is internal competition with the absence of external competition due to restrictions on external connections load. Such zones may be both redundant and scarce.

Currently there are 21 FETZes. In the second price zone there are 5 zones, where the largest is Siberia (Figure 1). The reduction in the number of FETZes by integrating them increases competition among electricity suppliers [1]. Those suppliers are members of the wholesale electricity and power market (WEPM). Usually the integration is achieved by the construction and reconstruction of networks to remove network restrictions. This method requires large investments and consequently leads to an increase in the electricity transmission tariff imposed by the executive bodies of the federal entity state power.

Figure 1. Current map of the free electricity (power) transfer zones.

It is obvious that for scarce FETZes, network restrictions can be removed by planting new generating capacities. Construction of large power plants in recent years was carried out by power supply contracts, which were concluded by a system operator with unified and territorial generating companies [2]. However, this mechanism also resulted in an increase in the electricity cost for end-users, who are charged with the 12.5% return of investments through the power consumption payment mechanism [3].

The rise in the final electricity cost for consumers, compounded for industry by the existence of cross-subsidies in favour of the population, required them to seek an alternative to a centralized electricity system. As a solution to the problem, large and energy-intensive consumers have chosen the option of creating their own energy supply systems based on distributed generation. Much of them were made possible by scientific and technological advances that made distributed generation competitive and technically effective.

Efficiency of distributed generation allows setting and solving the problem of power engineering transition. It will lead to increase of availability, reliability and quality of power supply. The considerable length of the Russian territory, the heterogeneity of the population and the distributed placement of resource and production capacities require new methods on solving the problems of power engineering development. All the prerequisites and conditions for the restructuring of Russian power system on the basis of a combination of centralized and local power supply systems are appeared. It is obvious that distributed generation technology, as well as non-traditional and renewable sources of energy, will be widely used in local power systems.

The aim of the work is to explore the possibility of using distributed generation in integration of FETZes. To date, the literature hasn't met such theme, which makes it possible to say about the novelty of the obtained results for solving the tasks considered in the work.

2. Materials and Methods

2.1. Free electricity (power) transfer zones' boundaries and their integration effects

According to [2], the free electricity (power) transfer zone is a part of the Unified Power System of Russia. Electricity and power produced or planned for supply can be redistributed between the power plants located inside this zone in accordance with their technical characteristics, providing the flow of electricity and power restrictions between such zones.

The Regulation for free electricity (power) transfer zones parameters determination and updating of Unified Power System (UPS) states that the list of FETZes is determined in accordance with the "Pro-

cedure of free electricity (power) transfer zone determination". It's stated there that it is necessary to reduce the load of intersystem connections by 1/3 from the peak load to integrate FETZes.

Several positive effects can be distinguished from FETZ integration. The integration will allow to reduce the load of some generators and put them into reserve [4]. It will increase reliability of power supply in the zone. There are more competing supply participants of electricity and power to the WEPM in integrated zones. Those generators that have lower power price and energy production costs compared to others will pass on the market for the day ahead and competitive power selection. Production prices, which are about 50% in the final cost of electricity for the consumers, can be expected to decline due to the increase in the number of bidders for electricity and power.

However, this positive effect will be reduced if the FETZ is combined by network construction. It is obvious that operating costs increase with the increase in investment in the network complex. Therefore it leads to an increase in the electricity transmission tariff. The size of this tariff is largely determined by the costs of maintaining the network in working condition.

With the advent and development of distributed generation, there is an alternative to network construction to solve the problem of combining the FETZes.

2.2. Local power systems and effects of their integration with Unified Power System

First of all, it is necessary to point out not only the high technical efficiency of distribution generation [5], but also the existence of imperfect market relations in retail markets, which they relay to as the main prerequisites for the emergence of local power supply systems.

For small and medium-sized businesses covered by the cross-subsidization mechanism, centralized energy supply was largely becoming a critical factor, often forcing them to leave the law field and seek illegal routes for power supply [6]. With the advent of distributed generation (DG), they have the opportunity to become subjects of the local power supply system, where DG is being the main source of power. The cost of electricity in such systems is usually lower, since being in the immediate proximity of the supplier and user of electricity significantly reduces the network component [7].

The development of local power systems is facilitated by achievements in the implementation of the program of gasification of the country. To date, the level of gasification in Russia has reached 68.6% [8]. It indicates a radical change in the fuel and energy landscape on the territory of the European part of the country and partially in Siberia. But in the near future, with commissioning of the pipeline gas supply system "Power of Siberia" and "Power of Siberia 2" the situation will change [9]. This program promotes the conversion of boiler houses to an ecological fuel and creates the prerequisites for their conversion in cogeneration operating mode. It is stimulated by the Government to improve their energy efficiency, energy saving and non-volatile regional power supply systems.

These prerequisites and other factors create investment attractiveness for private capital and the expediency of creating local power systems that have a positive impact on the social and economic development of the federation entities. It should be noted that distributed generation leads to a reduction of network construction volume for the development of the regional power supply system. It also has a positive impact on the size and growth rate of the network component of centralized power supply [10].

It is obvious that if the part of DG in the regional power and energy balances included in the scarce FETZ increases, it can lead to intersystem connections unloading. And therefore it will lead to fulfilment of the conditions necessary for their integration. But to do this, there is a need to find the answer to the question: How many and where is it needed to install distributed generation objects to ensure the integration of FETZes?

2.3. Research object

The second price zone of the wholesale market was chosen as the research object. This zone is located in Siberia so there is a need for affordable heat and electricity. Therefore, a large number of boiler houses located on the territory of Siberia are operating on various types of fuel. Often they are subsidized from the federation entity budget. It's caused due to very high cost of released heat. The only

possible way to reduce the cost is to put the boiler house into cogeneration operating mode [11], which provides combined generation of heat and electricity, i.e. leads to the emergence of mini thermal power plant.

Cogeneration can be carried out by any kind of fuel, but the most effective is the usage of gas and the technology based on gas-piston and gas turbine engines [12]. The gasification program of regions contributes to this transfer and also the growth of environmental requirements gives acceleration to this process. It should be noted that gas-piston engine is more effective than gas turbine engine by the following indicators:

- Higher electrical efficiency and its little change while load changing (40-47% against 17-36%);
- Advantageous ratio of heat generation to electrical (1/1.5 versus 1/2.5, suggesting more efficient fuel use);
- Price per 1 kW is two times lower (400-600$ versus 1000-1400$);
- Motor resource of such engines is higher (40-100 thousand hours of work until failure for gas-piston and 30-60 thousand for gas turbine engine);
- Gas-piston engine can use close to domestic low pressure gas, while gas turbine engines can only operate at high pressure (near 16-20 bars).

"Altai" is the best suited research zone among all FETZes from the second price zone. It's the part of power system located on the territory of Altai Region and the Republic of Altai. The part of thermal power plants reaches 99% of all generation capacities in that zone (it's 1163 MW of installed power). Also there are 5 solar power plants with power of 40 MW which don't participate in power balance. It causes the coverage of load schedule peaks due to the flows from FETZ "Siberia". The presence of intersystem connections allows to ensure reliability of power and energy balances.

The research object is dominated by non-productive consumers, such as tourist facilities. It should be noted that Altai is a sanatorium and resort area with a large number of nature reserves and the presence of agricultural industry, which determinates the importance of ecology for the region. Due to distributed consumption, networks have a large length and it leads to high losses. The prospect of gas pipeline "Power of Siberia-2" construction allows to count on changes in the fuel landscape, where natural gas will become the main resource.

In addition, the interest of the executive power in increasing the availability of electricity is obvious, as in FETZ "Altai: even the value of electricity cost for the population [13] is higher than in the nearest FETZ "Siberia" for 1.5-2 times [14]

Nowadays there is not enough installed power of power plants in FETZ "Altai" for independent load coverage, so the part of this power comes from other system. In table 1 the power balance for FETZ "Altai" is shown.

Table 1. Power balance for FETZ "Altai"

Generation, MW	Load, MW	Losses, MW	Summary consumption, MW	Flow from the over systems, MW
1163	1560	36	1596	433

It's necessary to reduce the flow by 1/3 (145 MW) according to the "Procedure of free electricity (power) transfer zone determination" to integrate FETZ "Altai" with "Siberia". It will remove network restrictions that limit the social and economic development of the regions included in the FETZ "Altai".

2.4. Data for calculations

2.4.1. Determination of cogeneration plants locations. In order to determine the installed power that can be obtained during the installation of cogenerating plants, it is necessary to identify boiler houses

which are possible to transfer to mini thermal power plants. The composition of the houses is specified in the heat supply schemes of cities, where it is possible to choose suitable one according to such criteria as:

- Installed capacity (not less than 5 Gcal/h and not more than 50 Gcal/h, which characterizes boiler rooms of average capacity);
- Performance of heating functions.

2.4.2. Choice of the cogeneration units. Cogeneration units of the company GazEcos with 1 MW and 2 MW capacity were chosen as the main units. According to the manufacturer, these units have the highest electrical efficiency - 44%, and the total reaches 82%. These installations are produced in Russia in Ivanteyevka. Plants are characterized by high maneuverability (70-80% of load drop/surge in 2 seconds), possibility to operate at low gas pressure (600 mbar) and their warranty service life reaches 20 years [15]. Chosen units are shown in the table 2.

Table 2. Characteristics of chosen units

Unit name	Installed active power, MW	Rotation speed, rpm	Electrical efficiency, %	Total efficiency, %
GazEcos 16GDG49	2	1000	44	82
GazEcos 8GDG49	1			

2.4.3. Operation modes calculation. For mode parameters analysis the section connecting FETZ "Altai" and "Siberia" was determined, and for more accurate assessment it was divided into 4 separate sections: Novosibirsk – Altai (1), Kuzbass – Altai (2), Rubtsovsk – Altai (3), Omsk – Altai (4). These sections are shown on figure 2.
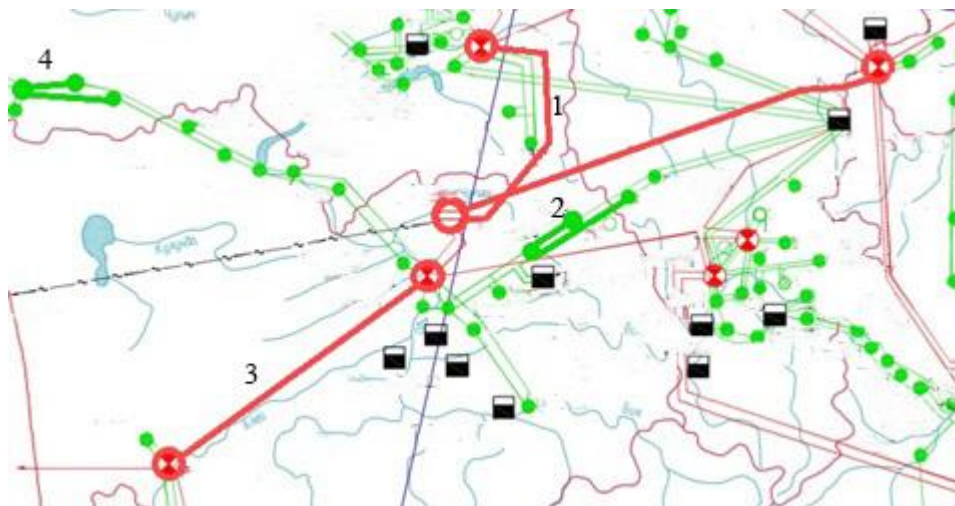

Figure 2. Highlighted controlled sections.

During calculations in calculation program complex RastrWin it is necessary to determine the flow rate for each of the sections and the limit for static stability. The maximum allowable flow rate is estimated to provide a static aperiodic stability margin factor of 20% for active power in normal mode and for each section was determined by the following formula:

$$P_M = 0{,}8 \times P_L - \Delta P_{IF} \qquad (1)$$

here P_P – limit flow value when static stability is maintained,

ΔP_{IF} – Value of amplitude of irregular fluctuations in the controlled section, calculated as:

$$\Delta P_{IF} = K \times \sqrt{\frac{P_1 \times P_2}{P_1 + P_2}} \tag{2}$$

here K – coefficient characterizing the method of active power flow control in the controlled section (1.5 for operational dispatching control),
P_1, P_2 – active power consumption from the power system at each side of controlled section.

For estimation of cogeneration efficiency, the calculations were made in the mode of winter peak load and the limits on distributed generation power in dedicated circuit nodes were taken into account:

$$\begin{cases} \sum P_{DG} \leq P_{Tr} \\ \sum P_{DG} \leq 0{,}5 P_{Load} \\ P_{DG} \leq 25 \; MW \end{cases} \tag{3}$$

here P_{DG} – installed power of cogeneration plants of the forming local power systems,
P_{Tr} – active transformers power with the condition of n-1 (n – quantity of transformers),
P_{Load} – load power in the node where local power systems are formed.

3. Results

The heat supply schemes analysis of such cities as Barnaul, Biisk, Kamen-na-Obi, Gorno-Altaysk, Slavgorod and Belokuricha showed that there are 42 suitable boiler houses in the region with a total installed power of 790 MW. Taking into account the specifics of the region, where the ratio of heat consumption to electricity consumption is 2:1, which, taking into account the emergency reserve of 20%, causes 280 MW of available capacity.

Accordingly, the maximum allowable flow was calculated and the load of each section was determined for the cogeneration efficiency estimation. These calculations are shown below in the table 3.

Table 3. Highlighted sections and their load

Section	Flow, MW	Maximum allowable flow, MW	Load, %
Novosibirsk – Altai	-63.5	233	41
Kuzbass – Altai	310.6	380	82
Rubtsovsk – Altai	18	92	19
West (Omsk) – Altai	141	566	25

According to calculations the most loaded section Kuzbass – Altai was selected as the main one. Therefore, the calculations for cogenerations efficiency estimation were made according to calculation methods and there are results below. Calculations for efficiency estimation are placed in table 4.

Table 4. Calculations results

Parameter	The value before cogeneration usage, MW	The value after cogeneration usage, MW	Decrease, %
Flow from the other systems	432.7	224.8	48
Kuzbass – Altai section load	310.6	174	36
Losses	36	27	24.9

4. Discussion

According to results, there are more boiler houses suitable for reconstruction in the region than necessary for combining FETZes. But it is obvious that there will be known problems associated with their connection to high-voltage networks. These problems can be solved if local power systems with 10 kV network will be built on their basis. According to [16], such systems should operate on the principle of self-balance, but integrated into regional power supply systems, which is effective from the point of view in increasing the fuel efficiency, the utilization factor of installed power, reliability, quality, reliability of power supply and performing the multi-voltage regulation [17].

Also, the calculations show that cogeneration usage allows to reduce various parameters and generally the flow from the other systems more than by 1/3. According to "Procedure of free electricity (power) transfer zone determination" FETZ "Altai" and "Siberia" can be integrated without network construction.

5. Conclusion

This research has indicated the effectiveness of using distributed generation for integration of free electricity (power) transfer zones. In addition to integration of the free electricity (power) transfer zones, the use of distributed generation makes it possible to create local power systems, which will improve the reliability and quality of power supply and reduce the cost of regional distribution network building. Also the use of distributed generation leads to increased persistence, energy efficiency and independent power supply to consumers in the investigated region. It's necessary to note that the occurrence of distributed generation does not increase the electricity transmission tariff. In general, it was obtained that the price determined for the long-term capacity market for 1 MW can be halved (up to 100 thousand rubbles). As a result, it is possible to expect a decrease in the cost of electricity and power for the end-users in the Altai free electricity (power) transfer zone.

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