Effect of local power systems integration on the distribution network functions

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Abstract. The Russian energy industry today needs an “energy transition”. The key link is the Regional Electric Network Companies as the basis of regional power supply system. There are significant changes in the industry, such as changes in legislation, the emergence of new requirements, changes in the regional fuel landscape. The mass appearance of distributed generation as the basis of local power systems has a great influence on the changes. This has led to new functions for Regional Electric Network Companies. The paper studies the effect of local power systems integration on the expansion of the functions performed by distribution network. Particular attention is paid to demand management for electricity; mutual reservation, multi-agent voltage regulation, functions of local energy systems integration with distribution networks.

1. Introduction
Raise of safety, reliability, quality, availability, environmental friendliness of power supply will ensure high competitiveness of domestic power engineering and its efficiency consequently. The new power engineering transition and digital transformation are aimed at this. The large Regional Electric Network Companies play an important role there as the basis of regional power supply.

Regional Electric Network Company (RENC) is a commercial organization that provides power distribution services using electrical network facilities related to united national (all-Russian) electric network. I.e., RENC provides the transmission and distribution of electricity in the regional power supply system. Wherein, [1] reflects that campaigns have the missions to providing services at an affordable price by carrying out the final consumer’s power supplying functions:

• transmission and distribution of electricity;
• maintaining of structural and functional reservation;
• technological connection of new consumers.

These functions are provided by RENC since the creation of network companies. Nowadays the relevance and necessity of marked functions hasn’t changed in the Russian power engineering. But new RENC functions have appeared due to the industry development, changes in law, emergence of new requirements, change of fuel-energy resources landscape and other factors. Implementation of them is accompanied by the extraction of new effects, both for network companies and for other subject of power engineering industry.

As result have new way – setting up local power systems based on distributed generation and using non-renewable (traditional) and renewable energy resources (alternative), integration which the greatest influence on the expansion of the functionality of region's network companies.
Thereby the actual tasks are:

- identifying and structuring new functions and effects related to the integration of the local and regional power systems;
- models development for assessing the technical and economic effects of integration.

The objective of the work is to identify new functions for regional electric network companies and their impact on efficiency of power supply.

2. Factors affecting new functions

2.1. Local power system

The efficiency of Russian centralized power supply system is reducing by its existing contradictions. That’s why local power systems are emerging. The main factors causing this process are:

- technical and economic inexpediency of centralized power supply in isolated power systems while the availability of effective power plants usage of local or imported fuel;
- high growth rate of the electricity cost and the impossibility of its forecasting in region's systems power supply. In this case is not possible long-term planning of the business subjects’ activities. On the other hand, there are modern technologies for efficient energy production on competitive price;
- appearance of new types of fuel, recycling of which is necessary by environmental and other requirements (associated gas, solid household and industrial waste, etc.) and the implementation of the total gasification strategy of the country are getting open up new ability to small business subjects. Important factor is availability technologies for using renewable energy sources;
- changes in the composition and structure of consumers while combined with the lack attract investments in the development of regional electrical networks, has led to a decrease in the reliability of electricity supply.

The above reasons have forced consumers to look for ways of reducing dependence of regional power supply systems. At the present time, about 10% of the installed capacity of power plants in Russia accounts for distributed generation of low power with an installed power source capacity up to 25 MW and a generator voltage of 10 kV.

The trend of appearing of local power supply systems is enhanced by the state policy in the energy conservation and energy efficiency. According to [2], the reconstruction of existing medium and large boiler houses should be carried out with the compulsory installation of cogeneration equipment. Consequently, the boiler house is turning into a mini-TPP (Thermal Power Plant) and in addition to the electrical supply of its zone; it will provide electricity to consumers, ensuring an increase in the energy efficiency of the heat and electricity production in the region.

The existing centralized power supply system has alternative options in modern conditions. It is caused by the possibility of making a choice for the consumer: to connect to a regional power supply system, to use its own power supply systems or to connect to local power systems.

In most cases, local power systems operate under conditions of self-balance and have excess (backup) capacities, which follow from the reasons of their appearance [3]. According to the genesis of the Russian power system development, which began in 1920 with known as the GOELRO plan, it may be concluded that the current development of the power industry in Russia is at a new stage of the development spiral (Figure 1).

The obvious next step will be the integration of local and regional power supply systems. “Pilot” integration projects are already being observed in Russia in a several regions. For example, the integration of local power system, providing electricity and heat supply for the “Berezovoe” residential community at Novosibirsk.
Figure 1. Genesis of power engineering development in Russia.

In general, power systems based on distributed generation are the solution of many problems for the consumer: starting from the need for reliable power supply to ensure the safety of technological processes during production, to fulfilling environmental requirements and solving the problem of reducing the expenses of electricity costs in the cost of their products. The last is most acute today for small and medium-sized businesses, where the cost of power supply makes their products non-competitive, due to their unbearable cross-subsidizing in the power industry [4].

2.2. Demand Side Response Aggregator (DSR Aggregator)

In 2019 in Russia a new subject of electric power industry appeared due to the insufficiency of the controlled resource and the need to electricity demand management – Demand side response aggregator in the UPS [5]. DSR Aggregators are organizations that identify and coordinate the ability of a group of end users to manage their workload and convert it into goods and services in the electricity, power and system services markets. Essentially they are actively involved in maintaining the balance of production and consumption of electricity. The main objectives of managing the demand for electricity are to reduce the peak load in the power system, what should be accompanied by a decrease in prices on the electricity market and the prevention of excessive capital-intensive construction of power plants and electrical networks.

Conducted field experiments on the coordinated management of reduced electricity consumption have demonstrated their effectiveness, carried out in three regions of the Russian Federation with the participation of nine retail market consumers [6].

This subject is an analogue of operating abroad Demand response [7], where demand management has become a full-fledged tool to ensure the balance of supply and demand in power systems over the past decade. Nowadays, about 20 GW of controlled demand are involved in Europe, while the European Commission estimates the current potential at 160 GW in 2030. The usage of this resource in the US energy system allows avoiding investment of $ 270 billion (in prices of 2016) in the development of energy infrastructure [7].

In Russia, according to preliminary estimates, the potential of demand management can be 6–10 GW for the first price zone and 2–3 GW for the second price zone, which totals up to 13 GW.

The aggregator contracts the services providing with the subjects of the retail market for changing the load of their equipment by a specified amount a certain number of times according to a notification given in advance. Aggregator receives payment in the wholesale electricity and power market for reducing electricity consumption. In turn, the subject provides the aggregator with services for changing the load and receives payment from it.
The project of DSR Aggregators fully complies with the global trend of digitalization of the industry and the transition to a more sophisticated intelligent power engineering industry.

Any electric power industry entities or electricity consumers that have entered into an appropriate agreement will be able to become one of the aggregators. The important point is that as an adjusting resource, the aggregator can use the power of distributed generation and electrical energy storage systems. However, local power systems should be legislatively consolidated as a subject of the power industry, by amending the relevant legal acts. This status actualizes the begun processes of integration of local power systems with regional ones.

3. Functions acquired by the network company

Changes acquired by the emergence of local power systems and their integration allow the RENC to significantly expand the functions performed, including the functions of the energy supply company.

The subject of energy that receives the greatest number of functions, including the “hidden” effects from performing the function of a DSR aggregator, is precisely network companies. Performing the functions of an aggregator opens up the possibility for network companies to form a generalized adjusting resource and ultimately to obtain a significant effect due to participation in the retail and wholesale electricity market. And the most effective resource for managing the demand of electricity is generating capacity of local power systems connected to the networks of the network companies.

RENC will be able to determine in which places of the network it is advisable to emerge and connect local power systems from the standpoint of their interests, primarily to level the network load and control reliability and quality. Reducing the peak loads at the feeding centers make it possible to expect an increase in the durability of network equipment by increasing the irregularity factors and filling (density) of the load curve attached to the feeding center.

Creating an aggregator based on the network organization will allow solving a number of tasks specified in the concept of digital transformation of PJSC “ROSSETI” [8] related to improving the reliability characteristics of the power supply to consumers; increasing the efficiency of the company; increasing the availability of network infrastructure; diversification of the company's business through additional services.

In order to achieve maximum efficiency in the integration of local power systems, the RENC may receive an additional function - the integration of local power systems aimed at improving the efficiency and extracting new system effects that ensure the development of regional power engineering industry. Essentially it says about the emergence of regional power systems.

It is known that the connection of the local power system on the basis of distributed generation is accompanied by an increase of quality of power supply through the implementation of the principles of multi-agent voltage regulation [9]. Maintaining the voltage level in the nodes increases the stability of the motor load, both in normal conditions and in case of remote short circuit faults at high voltage classes.

Due to the adjusting capabilities of generators’ automatic excitation control, it is possible to optimize the loss of active power in the networks to which the local power system is connected and to extract energy saving effects.

The integration of local power systems is generally associated with an increase of the reliability of power supply for both consumers of the local power system and consumers connected to the networks of the RENC. The main effect is the appearance of the function of mutual reservation. In [10] it’s shown that with the integration of a self-balancing or redundant local power system, the power supply of consumers actually becomes two-way and the frequency and time of consumers' power-off are reduced.

4. Features of integration of local power systems

In accordance with certain functions, it is possible to highlight 3 main sections (cut sets) of networks of integrating the local power system (Figure 2):
1. used to separate the energy source according to the technological conditions and provide power supply to the consumers of the local energy system from the external network and control the energy produced by the energy source;
2. used to isolate the local power system for work in the island mode and control the energy supplied to the network;
3. used to regulate the requirements of the load aggregator in the mode of excess power of the local power system.

The technical conditions for connecting the local power system are different from the conditions for connecting distributed generation, in accordance with which a power plants’ system of power output is being developed. That’s why the connection of local power systems assumes the presence of appropriate automation, performing a number of functions, including:
- voltage regulation in parallel operation;
- prevention and elimination of interruptions of regime restrictions on the loading of network equipment at the feeding center in case of transformer failures at 110/10 kV substation and supplying it 110 kV grids.

An automatic control system for the parallel operation of low-power power plants with their direct connection to the networks of powerful power systems is developed by Novosibirsk State Technical University. Its production is carried out by two Novosibirsk companies: LLC “Modular Systems Tornado” and JSC “IAES”.

The following idea and method are proposed for integration: advanced balanced division of the system according to a priori fixed cut sets of the network in interruption of the normal mode with the transition to the island mode with the subsequent automatic restoration of synchronism and normal mode with the required equipment load [9–11].

The proposed method of parallel operation with advanced balanced division of the system is aimed at limiting short-circuit currents, ground-fault currents. It helps to prevent interruptions of the stability of parallel operation with the emergence of asynchronized modes, eliminating shock moments on the shafts of synchronized machines and the need to coordinate external network protection with the protection and automation of the network being connected with plant [11,12].

**Figure 2.** Controlled sections (cut sets) of network during integration.
The usage of this kind of automation for the integration of local and regional power systems will allow to fully implement the control and management of all concerned sections to perform new functions by the RENC.

5. Effects of energy saving and mutual reservation
A distribution network scheme (Figure 3), consisting of two energy districts, was selected to analyze the effectiveness of the implementation of new functions by the network organization. The right part of the scheme is the local power system connected to the external network of the RENC. There is mainly domestic consumption (70%) with an insignificant amount of non-production enterprises related to the service sphere (30%) in the structure of load of the local power system. The summary load is 3 MW. The generating capacities are represented by three 2 MW generators.

Section 1 allows to determine the output in the local power system. Cable communication lines between the local power system and external network form a section 2. Section 3 is formed by connections between the 110/10 kV power supply feeding bus and the external network power system region.

Proposals to assess the effect of mutual reservation of connecting local power systems were proposed by the authors at [10]. The values of structural and functional reliability of network are proposed to be determined on the basis of the failure frequency and the recovery time of the main network equipment, its structure and topology, incorporated in the engineering of reservation capabilities for determining the indicators according to the current order of incentives to improve reliability [13].

![Figure 3. Estimated scheme for a 10 kV network of two power system regions.](image_url)

Based on the values of reliability indicators and the restoration of network equipment, the structure and composition of the load, the values of indicative indicators of reliability of power supply of the...
areas before integration and after were determined (table 1). A multiple improvement in the reliability of power supply consumers is obvious.

Table 1. Values of indicative reliability indicators.

| Region | Indicator | Before integration | After integration* |
|--------|-----------|-------------------|--------------------|
| LPS    | SAIDI     | 1.43E-03          | 5.01E-05           |
|        | SAIFI     | 1.78E-04          | 1.25E-06           |
| DNet   | SAIDI     | 4.42E-04          | 2.05E-06           |
|        | SAIFI     | 5.53E-05          | 5.12E-06           |

* - under the assumption of full mutual reservation

Improving the reliability of power supply is an effect for RENC whose monetization mechanism is known and used in Russia. According to Resolution of the Government of the Russian Federation of 31.12.2009 N 1220, reaching certain values of reliability and quality indicators can lead to increase the tariff for electric power transmission by 2%.

The same monetization mechanism allows extracting the economic effect of improving the quality of power supply in the implementation of the principles of multi-agent voltage regulation. Calculations of electric modes show a decrease in the standard deviation of the voltage at the nodes of the 10 kV network as the result of multi-agent voltage regulation by attracting the aggregates’ automatic excitation control in performing both the functions of mutual reservation and the DSR Aggregator, table 2.

Table 2. Mode indicators at peak load.

| Indicator                          | Before integration | Performing functions |
|-----------------------------------|--------------------|----------------------|
|                                   | DNet   | LPS    | DNet   | LPS    | DNet   | LPS    |
| Standart deviation of the voltage at the nodes, % | 1.418  | 4.014  | 1.441  | 0.611  | 1.214  | 1.002  |
| Power losses in network, MW       | 0.142  | 0.054  | 0.139  | 0.062  | 0.122  | 0.116  |

It is modeled that the power reserve available for isolated operation in the local power system is used as a control resource when the network company is performing functions of DSR Aggregator in UPS. It’s accepted that the removal of peaks is carried out for 4 hours per day (Figure 4).

Non-used power of distributed generation at the local power system is provided to the power district of the external network in cut set 2 to achieve energy efficiency and energy saving. It allows to reduce power losses in the network by 1.71 MW × h per day. The division of generating capacity of the local power system by purpose is shown in Figure 5.

The mode of peak load of generation equipment of distributed generation of the local power system is giving the highest efficiency in terms of improving energy efficiency, energy saving, quality and reliability of power supply. That’s why this mode is recommended to consider as the main one in justifying technical solutions for integration with the regional power supply system [14].

It is obvious that the maximization of installed capacity ratios will accompany various economic effects. These effects are significant for owners of distributed generation and don’t reduce the level of reliability of power supply to consumers in the local power network relative to available during isolated work.
For the RENC it’s accompanied by the redistribution of power flows in the 35–110 kV network, removal of restrictions from the “closed” feeding centers and new technological connection of consumers.

An important aspect of the integration process of local and regional power systems is the coincidence of interests of all subjects - owners of distributed generation and consumers of both regional and local power systems, and territorial grid organization.

6. Conclusion
Integration of local power systems with regional power systems is the pattern of development of the power industry in Russia, which coincides with global trends. RENCs are an integral element of the regional power supply system, traditionally performing the functions of transmission and distribution of electricity and power to end consumers. The development of the industry provides opportunities to expand the functions of network companies. New functions are emerging with the advent and connection of local power systems to the networks. These include: demand management for electricity; mutual reservation; multi-agent voltage regulation. It increases energy safety, energy independence, energy efficiency and energy saving, because the integration of local power systems leads to the emergence of a competitive regional power system based on distributed generation.
However, it is important to note that in order to implement most of the functions, local power systems should receive a fixed status of a power engineering subject and a retail market subject.

The most important function for territorial grid organizations, by existing commitments to implement digital network transformation, is the demand management function implemented by the DSR Aggregator in the UPS of Russia. Network organizations will be able to streamline the process of integrating existing local power systems and the emergence of new ones, determining the necessary place in the network, which will be reflected in the development of “Schemes and programs of the perspective development of the power industry of the regions”

Obviously, the integration will be accompanied by significant systemic technical and economic effects while reducing the expenses into region's networks development of higher and medium voltage, including in terms of improving the reliability and quality of power supply, reducing losses in networks, improving energy efficiency and energy saving. The number and size of system effects will be largely determined by the circuit-mode conditions in which new functions and their combinations are implemented.

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