

Impact of Grid Tariffs on the Competitiveness of Distributed Generating Sources in the Regions of Russia

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Abstract— The article focuses on the effectiveness of the distributed generating sources development as an economic choice of consumers under the existing electricity tariff regulation system in the regions of Russia. The existing impact of cross-subsidization in the distribution grid tariffs on the cost of electricity supply for the different types of industrial, commercial consumers and households is assessed and compared with the alternative levelized cost of supply from the local gas-fired generating sources. The paper also considers the profiles of the economically optimal grid tariff and electricity retail price structure and estimates the changes in the reasons to invest in the distributed generating sources for the same types of consumers – as well as for the households and municipal sector. Considering the set of regions, the paper provides an analysis of how the investment decisions at the retail level of the electricity market are sensitive to the tariff regulation policy.

Keywords— *tariff regulation; regulation policy; cross-subsidization; electricity retail price; economic choice; distributed generating sources; investment decisions; levelized cost of electricity*

I. INTRODUCTION

One of the key issues in shaping the future technological profile of the Russian electric power industry is the ratio of the scale of development of centralized and decentralized (distributed) generation. Historically, the Unified Power System (UPS) of Russia was based on the principle of high concentration of electricity and heat production. In the conditions of the previous technological profile and government-controlled economy, this allowed to maximize the economic effect from the scale of production.

However, changes in the market environment during the reform of the electric power industry and technological innovations that reduce the notorious scale effect for small-scale power plants [1] led to the emergence of the distributed generation (DG) segment in the UPS of Russia. In 2006, the total capacity of power plants of 25 MW and below was 10 GW, and in 2016 it increased to 13 GW. A significant part of DG operates in decentralized power supply area, although the volume of small power plants connected to the national grid has also increased by 1 GW. In addition, some consumers have "left" the energy system switching to their own DG sources.

Unlike many countries, Russian segment of distributed generation is dominated by thermal (diesel, gas reciprocating engine, gas turbine) power plants of small unit capacities, often CHP. This is due not only to the limited support of renewable energy in the country, but also to the real demand from consumers for combined electricity and heat supply in Russia. The economic choice between obtaining electricity and heat from own or remote sources (through power and heat grid) is determined by a number of factors. Some of them affect the possibilities of physical implementation of the project (for example, existing restrictions on gas supplies, available space for the facility, existing competencies for the new production management and maintenance). An important restraining factor is the need to send significant financial resources for the investment decisions that are not directly related to the core business of the electricity consumer (although they increase their competitiveness in the long term).

Other – the most important – factors are related to the alternative cost of electricity supply through the grid. If in the long term the aggregate costs of connection to the grid and the retail price of electricity for the consumer are higher than the levelized cost of electricity (LCOE) of his own generating source, this usually becomes a decisive economic argument in favor of its construction. The competitive choice between own and purchased electricity is greatly influenced by network tariffs which are determined by the regulation policy at the regional level [2]. The existence of cross-subsidization between consumer groups often strongly distorts retail prices from their economically justified level [3]. The purpose of this article is to assess the extent to which the existing level of cross-subsidization in the payment for network services affects the effectiveness of investment decisions related to the development of distributed generation as an opportunity of electricity supply to industrial and commercial consumers. This is considered for the existing consumers – for those who are facing the decision of switching to other mode of electricity supply, but not considering the possibilities and costs for connecting their energy consuming facilities to the power system.

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II. ESTIMATION OF THE ELECTRICITY COST FROM DISTRIBUTED SOURCES

The analysis of economic efficiency of DG sources requires that the consumer, first of all, estimates the cost of electricity production on such facilities. The methodological principles of such estimation correspond to the general practice of assessing the effectiveness of investment projects. The minimum required and constant in time price of electricity shall be determined ensuring the break-even use of the technology (i.e. equals the net present value (NPV) to zero) for the whole life cycle including the construction period (T_{con}) and the standard operating life (T_{op}), as in (1):

$$NPV(P, T_{con}+T_{op})=0, P=const \quad (1)$$

Based on condition (1) the value of the target price is the ratio of the total discounted capital and operating costs calculated for the entire life cycle of the technology to the total discounted electricity supply. In modern economic calculations, this indicator is defined as levelized cost of electricity or LCOE. Comparison of the LCOE value for DG technology with the actual or forecasted retail price of electricity, allows for the consideration of this technology competitiveness at the moment and in the future. In this analysis, the retail price of electricity, in accordance with [4], acts as a levelized avoided cost of electricity (LACE).

The use of the LCOE indicator for this task has a number of features that are important to consider when calculating its values. Traditionally, the forecasts of the development of national energy sector, energy strategies and other documents shaping the state energy policy, consider the power system development from the point of view of social investment efficiency. Accordingly, the LCOE indicator used here includes only direct material costs: capital, fuel, other operation and maintenance (O&M) costs including wages [5, 6].

A correct assessment of DG investment projects competitiveness implemented in a real retail market should be guided by commercial rather than social investment efficiency estimation. Accordingly, LCOE, in addition to direct material costs, should take into account investor's key financial and taxation expenses. This methodical approach is most common in corporate planning practice, in particular in the USA [7, 8], and its general formula assuming that fuel prices and O&M costs remain unchanged, can be statistically presented as (2):

$$LCOE=(F+OM+PT+K \cdot A/(1-Tax))/W \quad (2)$$

where F, OM – annual fuel and O&M costs;

PT – annual tax payments (except for income tax), first of all – property tax);

Tax – income tax rate;

K – discounted capital investments distributed over the years of construction (3):

$$K=\sum_{t=-T_{con}}^0 K_t/(1+WACC)^t \quad (3)$$

K_t – capital investment by years; this value may also include additional costs for the construction of electrical and gas grids (or connection to them);

T_{constr} – construction period in years;

$WACC$ – weighted average cost of invested capital;

A – annuity factor which ensures equal annual payments for the return of initial investments within a given period ($T_{payback}$) taking into account the value of invested capital. In fact, this constant in time payment is calculated using a formula (4) similar to that used by banks when giving loans:

$$A=1/\sum_{t=1}^{T_{payback}} 1/(1+WACC)^t \quad (4)$$

$T_{payback}$ – return on investment period taken for the calculation purpose. As a rule, it is set lower than the lifetime of the power plant in order to estimate the necessary price level providing a positive NPV for the whole life cycle.

Cogeneration technology providing combined production of electricity and heat is a fairly widespread and effective solution for distributed generation not only in Russia, but also globally. The availability of the second product (heat) makes it possible to improve the competitiveness of distributed cogeneration units in the retail electricity market, since the total costs are partly offset by the savings from heat purchase in the local market (5):

$$LCOE=(F+OM+PT+K \cdot A/(1-Tax)-P_{heat} \cdot Q)/W \quad (5)$$

where P_{heat} is the heat price in the local market;

Q – the amount of heat received by the consumer from his own DG source.

To assess the effectiveness of investment decisions on the transition to distributed generation for different groups of consumers in the power system, the LCOE indicators for different types of gas-fired plants were estimated: gas turbine and gas reciprocating engine. Several ranges of unit capacity of these plants were considered: from dozens of kilowatts to several megawatts (Table 1).

The calculations were carried out at the existing level of gas prices for the regions of central Russia (about 5000 RUR/toe), with a real WACC of 10 % and a capacity factor of DG sources corresponding to the typical load factor for the small industrial or commercial consumer (near 60 %). Taking into account the established regulation practice of keeping the gas prices stable in the real terms, these estimates will remain relevant, at least in the medium term.

The analysis of the initial, technical and economic indicators for DG sources considered, shows that in the range of small unit capacities, the scale effect remains strong enough, especially this is noticeable for units below 1 MW. Smaller capacity units have higher capital costs and lower efficiency (especially for gas reciprocating engine).

TABLE I. KEY CHARACTERISTICS OF DG PLANTS

	Gas reciprocating engine			Gas turbine		
	0.06-0.2	1	6	0.2	1	6-12
Unit capacity, MW						
Capital cost, \$/kW	1230-1910	750-940	520-650	1530-1840	1100-1320	660-910
Efficiency, %	32-40	41-42	42-44	29-31	30-32	31-33
LCOE, RUR/kWh	6.9-10.3	4.8-5.6	3.8-4.3	7.6-8.7	5.9-6.8	4.3-5.2

Another important specificity of the initial data is the high uncertainty in the capital costs for each capacity range. This is due to large differences in the equipment composition, and amount of design and construction works included into the total plant cost. An important role is played by the fact that most types of equipment are imported, and the exchange rate fluctuations introduce additional and significant uncertainty.

The calculated values of the cost of electricity from own sources show that for each class of DG sources there is a fairly wide range of LCOE. For the smallest units (up to hundreds of kW), the price of electricity is 6.9 – 10.3 RUR/kWh. For sources with units of about 1 MW, this range will be approximately 30 – 35 % lower and will reach 4.8 – 6.8 RUR/kWh. For larger units (over 5 MW), the cost of electricity will be another 25 – 30 % lower – about 3.8 – 5.2 RUR/kWh.

III. ANALYSIS OF DIFFERENCES IN THE STRUCTURE OF ELECTRICITY PRICES TAKING INTO ACCOUNT ECONOMICALLY JUSTIFIED NETWORK TARIFFS

The cost of electricity supply for retail market consumers (except for households) is a sum of several components:

- wholesale electricity market spot price and capacity price in a mixed competitive-tariff pricing model;
- government-regulated tariffs for electricity transmission and distribution (T&D) services or grid tariffs and fees for system and commercial operators services;
- sales premium which is also regulated by the government for guaranteeing suppliers.

Electricity prices for households are fully subject to the government regulation: the relevant decisions of the executive bodies approve not only retail prices for this category of consumers, but also their certain components, including the cost of electricity and capacity purchase in the wholesale market.

Grid tariffs play a major role in the structure of retail prices. In each region, their values are set by local regulators in 4 groups, according to the voltage levels: high voltage (HV), 1st medium voltage (MV1), 2nd medium voltage (MV2) and low voltage (LV). A so-called "uniform tariffs" pricing principle is applied here to ensure the equality of tariffs for consumers connected at the same voltage level, regardless of the consumer economic activity type and his organizational and legal form.

According to the Market Council database, in Russia the average share of the grid tariff in the retail price for MV2 consumers in late 2017 was 54 %, and for smaller consumers

(LV) – 57 %. Thus, the price of electricity for most final consumers is at least doubled compared to the price at the wholesale market. New consumers have to pay additionally for the technological connection to the power system.

Distribution of consumers by tariff groups depends on the capacity of power receiving units. As a rule, large industrial enterprises are HV or MV2 consumers. Non-industrial and agricultural consumers, as well as transport infrastructure are usually medium voltage consumers. Electricity supply to households and some budget and commercial consumers is carried out at a low voltage level.

Based on economic logic, the grid tariff should increase significantly as the level of the network voltage, to which the consumer is connected, decreases. However, the regulator balances the economic and social consequences of tariff decisions, and often changes the economically justified distribution of costs attributable to different categories of consumers. In Russia, this phenomenon of cross-subsidization is aimed at reducing the electricity prices for households. According to current estimates, at present this volume in Russia as a whole makes 283 billion RUR excl. VAT per year, or 20 % of the total cost of power transmission and distribution services.

Due to regional specifics in grids structure and length, their functioning in certain regions, and also due to the peculiarities of local regulatory decisions, the price for T&D services differs considerably for consumers located in different administrative regions of Russia but connected to the same voltage level. Even bigger is the difference in the grid tariffs for households and other LV consumers (Table 2). As households are connected to the grid at low voltage, based on economic logic, tariffs for T&D services must be equal to the tariff levels for other consumers connected at this voltage level. However, in fact, the corresponding tariffs for households are lower than the tariffs for other consumers by 30 – 70 %.

Different levels of grid tariffs also determine the difference in the level of retail prices for households and other (industrial and commercial) consumers, i.e. taking into account the wholesale price, tariffs of the system and commercial operators and the sales company. The analysis of the situation in several regions of the Central Russia shows a general trend in the country: compared to the average retail price for power for industrial consumers (including large ones), the price for households remains noticeably (up to 40 %) lower (Table 3).

Given the unequal level of cross-subsidization in grid tariffs, the elimination of this practice will lead to a different scale of changes in retail electricity prices for households and other consumers when switching to an economical tariff profile [3]. Estimates made for a number of regions for the 2017 conditions show that – with the simultaneous elimination of cross-subsidization – the general trend is an increase in electricity price for households by at least 30 % and a decrease in electricity prices for other consumers by at least 5 % (Table 3).

TABLE II. GRID TARIFFS FOR DIFFERENT TYPES OF CONSUMERS IN 2017 BY REGIONS OF THE CENTRAL RUSSIA, ROUBLES/KWH

Region	Households	Other consumers, RUR/kWh				LV to household tariffs ratio
		HV	MV1	MV2	LV	
Belgorod	1.64	1.80	2.24	1.86	2.66	0.6
Ivanovo	1.50	1.49	2.00	3.28	4.15	0.4
Kaluga	2.11	1.76	2.48	2.74	3.51	0.6
Lipetsk	1.31	1.54	2.76	2.93	4.06	0.3
Ryazan	1.95	1.25	2.16	2.35	2.71	0.7
Tambov	1.61	2.32	2.47	2.61	3.13	0.5

TABLE III. CHARACTERISTICS OF UNEVENNESS IN RETAIL POWER PRICES FOR INDUSTRY AND HOUSEHOLDS

Region	Prices for industry RUR/kWh			Prices for households, RUR/kWh		
	Current policy	No cross-subsidization	Change, %	Current policy	No cross-subsidization	Change, %
	Russia	3.00	2.69	-10%	2.36	4.09
Ivanovo	3.71	2.95	-21%	2.64	5.11	94%
Kaluga	3.85	3.45	-10%	2.56	4.63	81%
Lipetsk	2.81	2.51	-11%	2.06	5.25	155%
Ryazan	3.51	3.35	-5%	2.90	3.85	33%
Tambov	3.87	3.29	-15%	2.29	4.34	90%

In general, for Russia, the electricity prices for households with economically justified regulation should increase 1.7 times, with the corresponding reduction in prices for other consumers by 10 %. These estimations on the growth of retail electricity prices for households consider only elimination of cross-subsidizing "embedded" in grid tariffs. In addition, a similar mechanism is applied in regulating prices for electricity and capacity in the wholesale market for the supplies to households. The elimination of this policy as well will lead to an additional increase in retail tariffs for households.

More detailed model calculations for changing the profile of retail prices for consumers connected to different voltage levels were performed for several regions of the Central Russia with different levels of cross-subsidization (Table 4).

The current profile of retail prices was taken into account in terms of voltage levels, and its change was assessed when moving to economically justified regulation with a complete elimination of cross-subsidizing. The analysis of the results shows that in most cases the most significant effect will be felt by industrial consumers connected at the HV and MV2 levels, for whom electricity prices is often critical for the competitiveness of their main products. Depending on the structure of electricity consumption in the regions (the ratio of industrial, commercial and communal load), the increase in prices for households can vary from more than 2-fold to a relatively small rise (about 30 %).

IV. EVALUATION OF CHANGES IN DG DEVELOPMENT EFFECTIVENESS WITH THE REDUCTION OF CROSS-SUBSIDIES IN THE ELECTRIC POWER INDUSTRY

The above regional features of tariff regulation, existing levels of retail electricity prices for different categories of consumers strongly affect the efficiency of switching (in

whole or in part) to own source of generation or continuing to get all the power from the grid [9]. The comparison of actual retail prices and LCOE of gas turbine or gas reciprocating engine power plants was carried out for several regions of central Russia with a comparable level of gas prices. This allows comparing the actual profiles of retail prices and electricity price ranges (LCOE) from different types of DG sources (Fig. 1).

TABLE IV. CHANGE IN THE TARIFF PROFILE FOR RETAIL CONSUMERS AT DIFFERENT VOLTAGE LEVELS IN CASE OF CROSS-SUBSIDIZATION ELIMINATION, RUR/KWH

Region	HV	MV1	MV2	LV households
Ivanovo				
current policy	3.49	4.00	5.28	2.64
without cross-subsidization	2.68	3.30	4.09	5.11
Same as % of current	-23%	-18%	-23%	94%
Kaluga				
current policy	3.76	4.48	4.74	2.56
without cross-subsidization	3.28	4.06	4.30	4.63
Same as % of current	-13%	-9%	-9%	81%
Lipetsk				
current policy	2.69	3.91	4.08	2.06
without cross-subsidization	2.47	3.72	3.82	5.25
Same as % of current	-8%	-5%	-6%	155%
Ryazan				
current policy	3.25	4.16	4.35	2.90
without cross-subsidization	2.99	3.75	3.83	3.85
Same as % of current	-8%	-10%	-12%	33%
Tambov				
current policy	3.82	3.97	4.11	2.29
without cross-subsidization	3.27	3.65	3.83	4.34
Same as % of current	-14%	-8%	-7%	90%

As the analysis shows, under existing conditions the development of large DG sources (having unit capacity of several MW) is competitive for MV1 and MV2 consumers in most of the regions considered. For HV consumers, the use of these sources is at the edge of efficiency compared to the retail price. The use of DG with a smaller unit capacity has a smaller efficiency zone – for MV2 consumers in regions with the greatest regulatory distortion of retail prices through cross-subsidization. For households, the current low electricity price makes the centralized grid supply a preference without any alternative.

A similar comparison with the estimated level of retail prices in case of elimination of the current cross-subsidization and a significant reduction in the grid tariff for other consumers, other than households, shows a significant change in DG competitiveness.

In particular, HV consumers in all considered regions, in case of retail price decrease, have no more reasons for DG development even based on largest DG units. For MV1 and MV2 consumers, building power plants with units for several MW each, remains efficient albeit closer to the edge of competitiveness (Fig. 2). DG sources with smaller unit capacities (about 1 MW) are losing appeal to MV2 consumers, but they are becoming an effective solution in the communal utility sector, taking into account a noticeable increase in retail prices for households. At the same time, DG sources of even lower power (dozens and hundreds of kilowatts) are still too

expensive alternative to grid supply even after the elimination of cross-subsidization. The most likely area of their application is power supply to new consumers, when DG use avoids additional connection fees, often calculated by deep charge rate model.

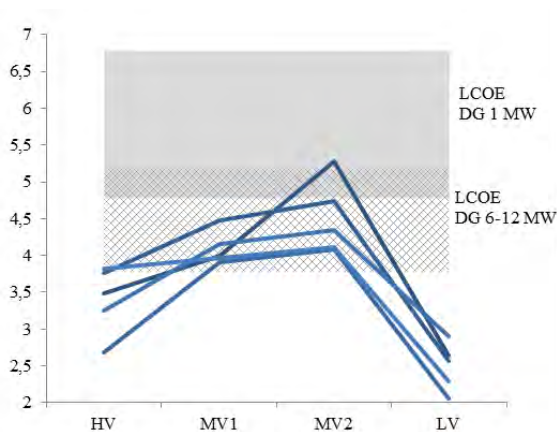


Fig. 1. Competitiveness zones for different classes of DG sources with the existing retail prices profile.

It should be noted that the above examples of assessing the change in the effective use of DG by different types of existing consumers depend not only on the scale of regulatory distortions in the tariff profile in specific regions. With the emergence of a critical mass of consumers building their own power plants, while maintaining physical connection to the energy system, another question will inevitable arise – the regulation of the price for maintaining such a connection, for example, as a charge for reserve capacity. The introduction of such a payment, based on the connected capacity of the consumer, is a fair mechanism preventing the emergence of new types of cross-subsidization (between active consumers developing their own generating capacities and other "passive" consumers). The size of such a payment and its uniformity for different types of consumers is subject to future research and justification. However, the inevitable rise in the cost of DG projects will be an additional factor potentially limiting the growth of this new technological segment in the energy system.

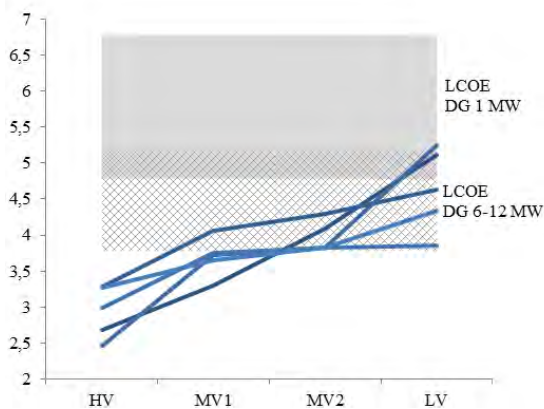


Fig. 2. Competitiveness zones for different types of DG sources with an economically justified retail prices profile (in case of cross-subsidization elimination in network tariffs).

V. CONCLUSION

The strategic assessment of the prospects for restructuring Russian electric power industry in favor of distributed generation should certainly take into account the existing distortions in the profile of retail prices associated with the regulatory policy aimed to keep the prices low for households. As a result, in some cases, the effectiveness of DG is "artificial" especially for existing industrial consumers connected at high and medium voltage. In this case, as a rule, competitive are facilities with unit capacity of several MW, in some cases – about 1 MW.

The change in the regulatory policy will significantly change the profile of retail prices reducing them for industrial and commercial consumers by 5 – 20 % or even more depending on the structure of electricity consumption in the region and cross-subsidization activities. At the same time, in many regions the efficiency of switching to own generation for consumers at high voltage will decrease, and it will worsen somewhat for consumers at medium voltage. And, due to a significant increase in prices for households, the efficiency of using smaller units (about one MW) for power supply in the communal sector will increase.

Thus, the DG economic potential – competitive in the retail market – is quite sensitive to the changes in regulatory policy. However, other factors contributing to the reduction of power generation at consumers' power plants, will influence a lot. The most important of them is lower prices for equipment which will require an active industrial policy for the import and localization of technologies of these classes, as well as the influence of the price effect on the scale of production.

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