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Electricity in retail markets as a commodity in smart energy systems

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Abstract. Currently, the worldwide trend has been the transition of many countries to low-carbon energy sources. These changes are dictated both by external factors, such as the rapid growth of information and communication technologies, as well as the general policy of world powers advocating a clean environment and ensuring energy independence for the future. In Russia, the introduction of small generating capacities on renewable energy sources has great prospects due to the huge number of regions that are difficult to access for electricity supply. But the integration of generating capacities based on renewable energy sources requires not only the availability of special technical and legislative means, but also the competent selection of a tariff for a prosumer. This article presents the concept of an intelligent system that allows individual households to be involved in a progressive type of energy consumption and generation and creates a new type of energy system and market participant - prosumer. Two systems are offered for households equipped with solar panels. It is proposed to extend the practice of settlements at unregulated prices to individuals and households with the possibility of choosing the most favorable price category for the considered prosumer.

1. Introduction

One of the challenges of the energy security doctrine, approved by the Presidential decree 216 of May 13, 2019, is an increase in the share of renewable energy sources (RES) in the global fuel and energy balance. The challenge identified in the doctrine is a consequence of the commitment Russia made to reduce CO emissions by 2020. As an adequate response to the challenge, Russian manufacturers of equipment for renewable sources need to provide support and assistance in its implementation. To create a convenient platform and make appropriate amendments to the legislation for making settlements between the consumer and the producer, in one person, who will be called a prosumer and the already existing system in which payments for electricity are carried out now. Such a shift will be possible due to the development of intelligent technologies in the field of energy and the steady increase in the amount of renewable energy, which are the objectives of the above-mentioned doctrine.

Moreover, besides it is necessary not only to adopt the climate agreement and national legislative acts, but also to conduct an active policy in our state aimed at supporting the development of renewable sources by the population. All of the above requires the support of investment and venture funds, a flexible tax policy of the state, as well as the support of prosumers in the consumption and production

of clean energy [1]. Of great importance is the readiness of scientific organizations to develop competitive domestic equipment and local factories to begin production of equipment intended for the use of renewable energy sources.

The current trend facing the energy policy of any state is the search for optimal relation between the availability of electricity technically and from economic point of view. In most markets, both wholesale and retail, electricity demand has a low price sensitivity, since fluctuations in electricity prices that occur in the market hourly are not communicated to the retail consumer. Retail prices in Russia are regulated, and sales companies do not seek to use prices in real time and inform consumers of the household sector about the opportunity to save. Now, in the context of price regulation in retail markets, consumers of utility services, according to the annex to the Federal Tariff Service N 20-e/2, adopted in 2004, are charged at a fixed price, unlike commercial consumers with multi-rate tariffs. The government has repeatedly attempted to introduce different tariffs for the population and piloted them in several regions of the Russian Federation, but for the most part, payment for the tariff was made depending on the amount of energy consumed, and not on price fluctuations in the wholesale electricity market. Since in the short term, energy consumption is almost unchanged, and demand is variable, there is a shortage of it during peak periods and surplus at night. If the consumer is aware of real-time prices, then the price in the retail market will accurately follow the load level at the same time [2]. As a result of public awareness of tariff increases during the peak period, the need for generating capacity would be reduced by 10% with the help of only price factors. As a result, there would be an equalization of the demand curve for electricity, due to a decrease in its peak and an increase in the base parts of the daily schedule. If the consumer is informed of large fluctuations in electricity prices, this may lead to flattening of the consumption curve peak. To do this, it is necessary to amend the existing legislation and make calculations of the population at unregulated tariffs [3].

According to the International Energy Agency [4] the share of renewable energy sources is expected to grow by 20% and reach 12.4% of the total world consumption in 2023. Electricity generation at power plants using renewable energy sources has been showing steady growth in 170 countries for the past ten years, so in 2018 commissioning of capacities using renewable energy sources amounted to 181 GW, in 2017 - 8% less than in 2018, and a year earlier, only 85 GW [5]. Currently, hydropower industry remains the largest renewable source based type of generation in the world, with a share of 16% of global electricity generation, wind power is in the second place accounting about 6% and solar photovoltaic energy is in third place (4%).

Nevertheless, the last three years, the leaders in commissioned capacities on the basis of renewable energy sources have been accounted for the solar stations, which is explained by the desire of investors to invest in an acceptable payback period. This is due to scientific and technological progress in the development of materials for photo panels and, as a result, to a decrease in their cost, which has continued over the past decade.

In many developed countries, as well as places where centralized power supply is unavailable, for example, islands or, as is typical for Russia, a huge number of regions that have difficulties with access to power supply, in which RES will be competitive, it is necessary to pay attention to the development of distributed power supply to consumers [6]. To meet this energy need, 77% of global demand refers to buying a home solar system. Therefore, the use of distributed renewable energy, intellectualization of infrastructure and the transition of consumers to active, prosumer behavior patterns is obvious [7, 8]. At the same time, effective tariff setting for the prosumer will allow to get additional profit and adjust its consumption.

2. Materials and methods

To solve the problem of effective tariff setting for the prosumer in Russia the current system of retail tariffs was researched. According to clause 5 of Decree of the Government of the Russian Federation dated 04.05.2012 No. 442, there are six price categories of electricity in the retail electricity markets.

Based on this document, the Federal Tariff Service, the Ministry of Economic Development of the Russian Federation, the Ministry of Energy of the Russian Federation and the Federal Antimonopoly

Service developed rules for the application and determination of unregulated electricity prices (capacity) by guaranteeing suppliers. These rules are approved in the Decree of the Government of the Russian Federation dated December 29, 2019 No. 1179.

In accordance with these documents, the choice of the category according to which the calculation will be made between the legal entity and the sales organization is the duty and right of the consumer of electric energy (power) itself. Let us to consider the pricing principles and calculation methods which are applicable for each of the categories, according to the above regulatory legal acts.

The first price category includes small consumers with a maximum power of less than 670 kW. This article discusses the object of energy consumption, which can be classified in this category, due to the fact that the amount of electricity consumed by it is relatively small. Payment for electricity in this category is carried out at the same price for the whole amount of electricity consumed per month. The price already includes costs for the purchase of electricity in the wholesale market and for its transmission through networks of the corresponding voltage. In the invoice for payment for electricity, there is only one item at a single-rate tariff, and this category is one of the simplest, since hourly planning of energy consumption is not carried out, but it is often the most expensive for legal entities.

It is worth noting that in relation to legal entities (industries) that did not notify the guaranteeing supplier of the choice of a category on time, the calculation is made according to the first category. But it is possible to automatically transfer the price category used in the previous year to the current year.

The only difference of the second price category from the first one is that when calculating within this category, the division into zones is carried out to account for electricity consumption. The control zone is day and night consumption - two-zone consumption, as well as periods of peak, base and half-peak load, which are related to the three-zone consumption metering system. The object considered in the article has its own energy source - the solar panel, so the calculation of the two zones will be relevant for this article, since the solar panel operates in the mode of power output only in the daytime. As well as for the first price category, the cost of power and transmission costs are inherent in the price and consumer power does not exceed 670 kW.

When using the third price category, the electricity charge is hourly, therefore, appropriate metering of electricity is necessary. The transfer tariff is considered single-rate, as in the first and second price categories. Starting with the third, the range of application of price categories is expanding: they can be applied to legal entities that consume both less and more than 670 kW. Based on these factors, the third price category as well as the first and second ones may be applied to the object in question.

Common to the fourth, fifth and sixth price categories is that the electricity consumed by a legal entity is charged every hour at a different price. The main distinguishing feature between them is the need for consumers to plan their hourly consumption a day ahead (for the fifth and sixth). In case of deviations, the legal entity is obliged to pay for them (they are included in the price of electricity). This is not always feasible, therefore we will not calculate the fifth and sixth categories for calculating the consumption of electric energy by the object under consideration.

As for the tariff for the transmission of electricity, the fourth and sixth price categories can be combined into one group. They are different from other categories. Only in the calculations for these price categories the two-rate transmission tariffing is applicable. Calculation of payment by price categories between legal entities and guaranteeing suppliers is established by the law - the use of other mechanisms is not legal now in Russia. The real price of electric energy and capacity for each guaranteeing supplier is published before the 14th day of the month following the estimated one on the website of the «Administrator of the Trading System of the Wholesale Electricity Market», Joint Stock Company. Tariffs for transmission services and marketing premiums for guaranteeing suppliers are set annually by the regional energy commissions. Thus, having information on the data of actual and planned consumption, it becomes possible to verify the cost of electricity production, which is set by the guaranteeing supplier for the month, with the highest degree of probability [9].

What to do if, when checking the expediency of using a category, it proved to be unprofitable? The answer is switch to another category. The transition in the framework of the first, second, third and

fifth categories is possible once a month for one year. Similarly, between the fourth and sixth. For the transition, it is necessary to notify the guaranteeing supplier at least 10 working days before the start of the settlement period. The company can only switch from the first, second, third and fifth to the fourth or sixth categories once a year. For the transition, it is necessary to inform the guaranteeing supplier and replace the tariff for the transfer of electric energy within one month after the publication of tariffs for a new period. Usually, updated information is available at the end of December.

Thus, a legal entity can choose between a single-rate or two-rate tariff for the transfer of electric energy only once a year [10]. As for the choice within this division, the situation is much better. You can change the price category on a monthly basis if it meets the requirements of economic feasibility.

For our object - a residential building in the city of Kazan - we assumed the choice of one of several price categories: first, second, third and fourth, and also performed a calculation for each of them. Based on the data received, recommendations were made for the electricity consumer. The choice fell on these categories of data not accidentally. The price categories for which independent planning of consumption by the enterprise is provided (fifth and sixth) are not beneficial to the vast majority of consumers, because it is impossible with 100% probability to plan hourly consumption for the day ahead, resulting in deviations from the declared volume, which are necessary pay to a legal entity [11]. Thus, for consumers with a maximum power of less than 670 kW, the determination of the price category is reduced to the first, second, third or fourth, which differ in the tariff option for electric power transmission services, as well as taking into account electric energy. Unlike the second, the first is characterized by a more “ragged” load profile. According to this characteristic, in accordance with the schedule of electrical load, a residential building can be attributed to the first price category.

3. Results

In view of the foregoing, a technical solution should be developed for the integration of renewable energy sources into the energy system, which takes into account market signals and is accessible not only to large industrial facilities, but also to single households or housing societies. Then each person can be involved in a system of progressive energy consumption. The main components of this system are smart metering devices with built-in data transmission devices, communication lines, a hardware-software complex for data processing and computing, and user applications. The structural diagram of the system is shown in Figure 1.

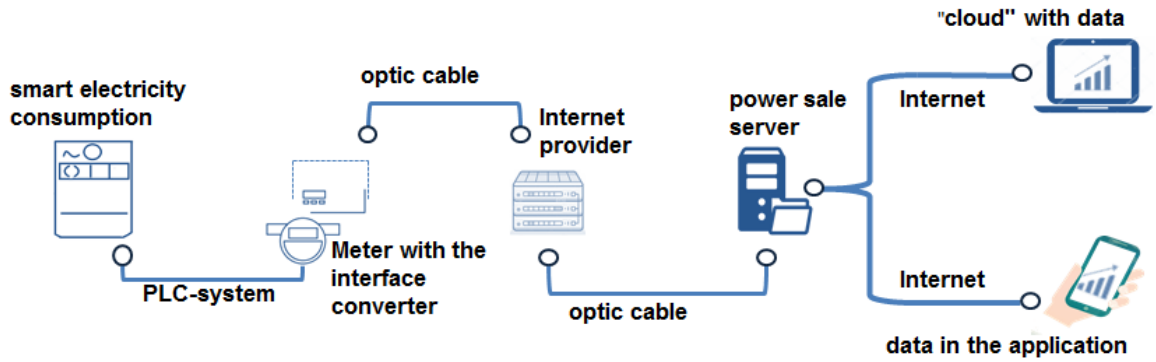

Figure 1. Diagram of a smart billing system.

Information about the consumption or generation of electricity on various devices of the facility is collected in a single smart settlement system located on the server of the energy supplying organization or guaranteeing supplier. This server carries out financial calculations for electricity. One of the requirements for the system is to support the cloud storage function to provide users with access to information about their consumption and the state of the electricity bill. The user will be able to view

data in a mobile application that supports communication with cloud storage at any time of the day. In Figure 1, the implementation of communication channels is shown by PLC technology and optical communication lines, but it is possible to use twisted pair or wireless data transmission methods.

The financial calculations carried out by the system are carried out according to two models. The first model is the energy credit model. When choosing this model, the prosumer gets the opportunity to take into account the electricity generated and delivered to the network on his account in the form of marketable products. In periods when own consumption exceeds generation, it can be used to offset the consumed electricity from the network. The second model is called energy billing. In energy billing, the electricity generated and consumed from the network has its own set prices. The consumer sells electricity generated in excess of his own consumption and takes it into account in monetary terms.

An energy credit model requires a bi-directional meter, which, when the electricity is consumed from the grid, will add its volume to the value recorded in the meter, and when the electricity is generated, it will subtract its amount. The prosumer pays in monetary terms only for the purchase of electricity from the grid at a retail price.

Energy billing requires two meters that separately measure the energy consumed and delivered to the grid. In this model, a prosumer buys electricity from the grid from a utility at a retail price and sells its own produced energy at a wholesale price. At the same time, in order to track real-time pricing, the meter must take into account the current market price so that the prosumer has up-to-date information for choosing a retail tariff [12, 13].

In order to assess the economic feasibility of the proposed calculation models, we carried out calculations of the estimated generation obtained from the solar panels installed on the roof of a residential building in the city of Kazan, and the income from their use. Realization of the generated energy was carried out according to the two models described above.

According to the model of energy credit, energy was consumed by a residential building, both from the network and from its own sources of generation. In periods when the generation of electricity by solar panels exceeded the needs of a residential building, the surplus was given to the network at the expense of future consumption. According to the energy billing model, surplus energy generated by solar panels was sold to the network for money.

The rightmost column in tables 1 and 2 displays the monthly status of the prosumer payment. The amount in the payment is determined based on the average consumption rate of electricity by the household (the base cost for the tariff in Russia is 170 rubles), and the amount of electricity sold or additionally consumed. Electricity consumption is paid at a price of 170 rubles/kWh, sale at a price of 3.015 rubles/kWh.

Table 1. Calculation for energy credit model.

Month	Solar panels generation, kWh	Building consumption, kWh	Consumption from/to the grid, kWh	Credit of energy, kWh	Payment, Rubles
January	100.335	581.742	-481.407	0	-170-3.015×481.407
February	268.457	644.071	-375.614	0	-170-3.015×375.614
March	470.323	581.742	-111.419	0	-170-3.015×111.419
April	788.400	601.133	187.267	187.267	-170
May	1051.000	581.742	469.258	656.525	-170
June	1283.000	601.133	681.867	1338.392	-170
July	1106.000	581.742	524.258	1862.65	-170
August	919.742	581.742	338.000	2200.65	-170
September	511.920	601.133	-89.213	0	-170
October	242.477	581.742	-339.265	0	-170
November	108.000	601.133	-493.133	0	-170
December	52.258	581.742	-529.484	0	-170
Total	**6901.912**	**7120.797**	**-218.885**	**6245.484**	**-2700**

Table 2. Calculation for energy billing model.

Month	Solar panels generation, kWh	Building consumption, kWh	Consumption from/to the grid, kWh	Payment, Rubles
January	100.335	581.742	-481.407	-170-3.015×481.407
February	268.457	644.071	-375.614	-170-3.015×375.614
March	470.323	581.742	-111.419	-170-3.015×111.419
April	788.400	601.133	187.267	-170+3.015×187.267
May	1051.000	581.742	469.258	-170+3.015×469.258
June	1283.000	601.133	681.867	-170+3.015×681.867
July	1106.000	581.742	524.258	-170+3.015×524.258
August	919.742	581.742	338.000	-170+3.015×338
September	511.920	601.133	-89.213	-170-3.015×89.213
October	242.477	581.742	-339.265	-170-3.015×339.265
November	108.000	601.133	-493.133	-170-3.015×493.133
December	52.258	581.742	-529.484	-170-3.015×529.484
Total	**6901.912**	**7120.797**	**-218.885**	**-103.0949**

In this case, the total consumption is 7120.797 kWh, the total electricity generation is 6901.912 kWh. At the same time, according to the results of the month, the user's debt to the supplying organization under the credit system amounted to 2700 rubles, and under the billing system 7213 rubles. Similar calculations for households with different ratios of generation and consumption showed that an energy credit is beneficial for those who generate less than they consume. And energy billing is appropriate for prosumers with generating capacities, the generation of which often exceeds the amount of household needs.

In the above calculations, fluctuations in the price of electricity in the retail market were not taken into account. However, as mentioned above, for the full inclusion of all consumers in a progressive consumption model, the financial settlement system includes the function of translating market price signals. Thus we consider and evaluate several models of calculations using price categories that are currently valid in Russia for legal entities, and the essence of which is proposed to be transferred to the financial calculations of prosumers.

Electricity generation from renewable energy sources is inconsistent, so the consumer has to combine power from the network and renewable energy sources [14]. If the apartment building is not equipped with batteries or other sources of alternative energy, except for the sun, that is, consumption from the network will be made every day at night, the comparison chart of the selected categories will look like shown in Figure 2.

For the case when the calculation is carried out by category, but the consumer does not give "surplus" to the network, the comparison chart of the selected price categories will look like shown in Figure 3. Figure 4 shows a comparison of the third and fourth price categories.

4. Discussion

It can be seen from Figure 2 that the use of a two-rate transmission tariff compared to others is more profitable by 1,310 rubles. Thus, under these conditions, it is more profitable to use the second price category, when electricity is calculated in two zones of the day.

In the period from April to August, the amount of electricity consumption from the network is zero. The diagram in Figure 3 shows that when comparing these categories, the first turned out to be the most profitable. The price of electricity for the first price category is calculated according to the residual principle. That is, all the expenses of the guaranteeing supplier after subtracting of the bills of all consumers in categories from second through sixth, the remaining money is distributed evenly among consumers using the first price category.

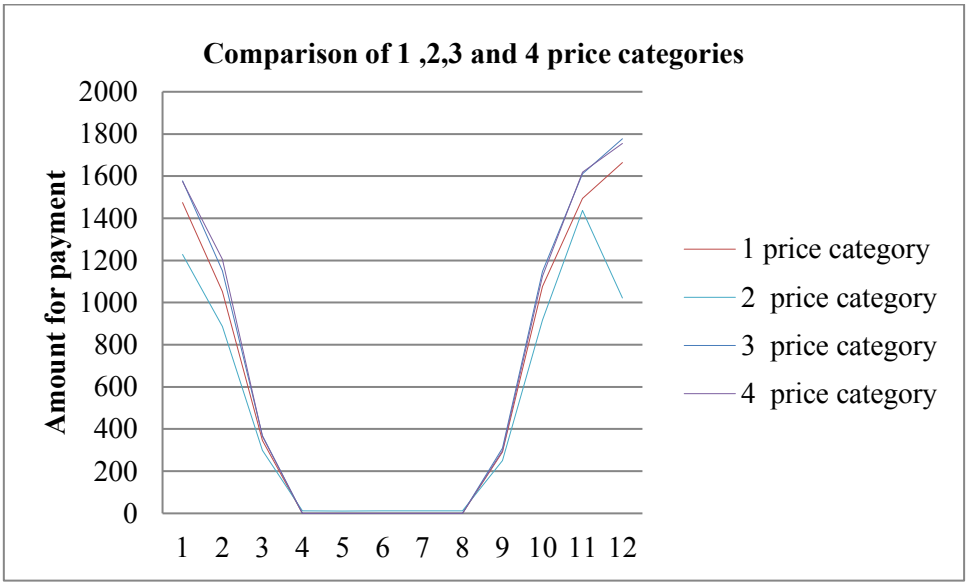

Figure 2. Comparison of annual payment amounts for settlements for the first, second and third price categories for the energy credit model.

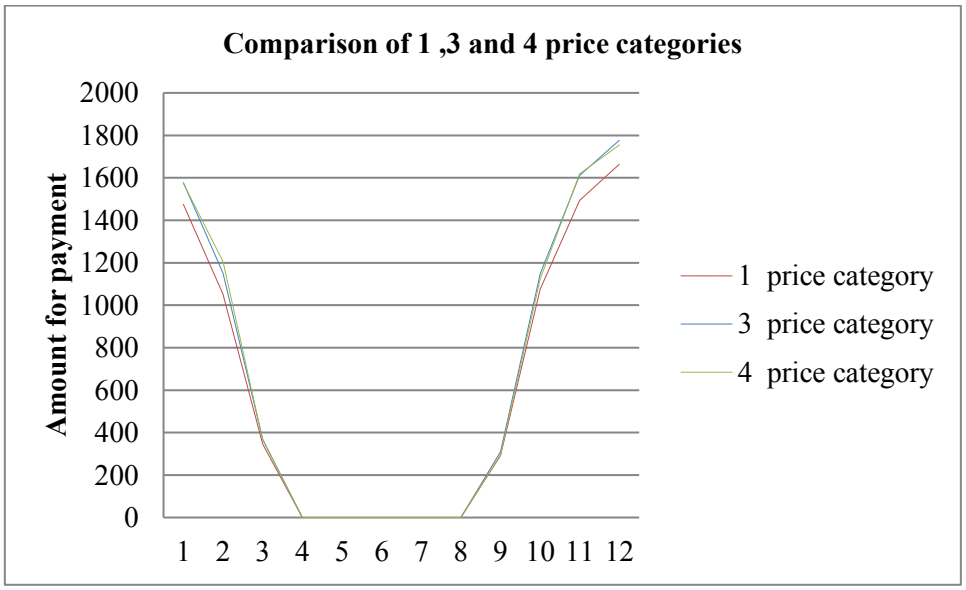

Figure 3. Comparison of annual payment amounts for settlements in the first, third and forth price categories for the energy billing model.

The first price category should be more expensive than the others, should encourage consumers to install hourly metering devices and choose other price categories with more accurate methods for determining actual consumption. However, due to the residual mechanism for calculating the price of the first price category, in some regions there are “distortions” at which it is the cheapest category for consumers. When using the first category, the consumer benefits for the year compared to the third and fourth, respectively, 545 and 544 rubles, respectively.

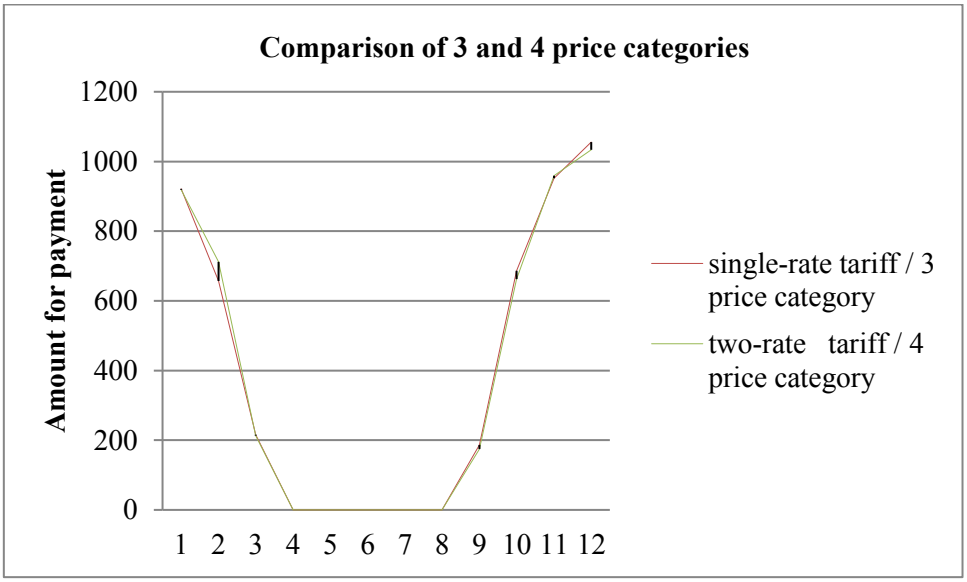

Figure 4. Comparison of annual payment amounts for settlements for the third and fourth price categories.

The diagram in Figure 4 shows that the two-rate tariff turned out to be, although not by much, but more profitable than the single-rate one. Consumer savings in this case amounted to 117 rubles.

If the facility has an accumulator of unlimited capacity, with the help of which accumulation is carried out, it is possible to assume the possibility of selling excessively generated electricity to the network during peak hours in a balancing market.

However, it should be noted that the profitability of any price category is variable. It cannot be said unequivocally that any one specific category will be beneficial for all regions. Moreover, for each prosumers within the region various price categories are beneficial. Therefore, in order not to fall for an increase in price, it is necessary to periodically analyze the conditions of energy supply of the consumer and, if necessary, make changes. It is worth considering that if the period of maximum electricity consumption occurs at night, it is more profitable to use the second price category. If from an economic point of view it is more profitable to use two-rate tariffing for energy transfer, then a fourth or sixth price category should be used. But we must not forget about the need for consumption planning in the calculation of the fifth and sixth categories.

5. Conclusion

As a first step towards the implementation of the proposed concept of the energy trade system, amendments should be made to the tax legislation, which will be aimed at stimulating the development of renewable energy sources. Such measures, in relation to prosumers, may include the introduction of tax benefits on value added for the transportation of solar panels, their purchase and installation, property tax, tax holidays for the first years of use of equipment, and introduce state subsidies for interest rates on loans in in relation to renewable energy facilities [15].

The next step is to agree on the procedure for technological connection to the network object. Here, the technological process of integrating renewable energy generation should be supported by network equipment and the capabilities of the network operator. After this, the principles of contractual relations with the sales organization are established. In general, this means choosing a billing model for the user. To implement this step, it is necessary to extend the practice of settlements at unregulated prices to individuals and households with the possibility of choosing the most favorable price category for the considered prosumer and make changes to paragraph 5 of the Resolution 442 issued by the Government of Russian Federation and equate the population with consumers who pay for electricity at unregulated prices.

Today, the degree of RES integration in the energy system is an indicator of the technological and industrial development of the state. Renewable energy is the driver of economic development, science and education. In the context of the transformation of global energy systems with a deep decentralization of electricity production, the introduction of energy conservation practices, digital technologies and intelligent control systems, cloud technologies, block chain and other new financial technologies will determine the face of the electric power industry of the future. It is important for Russia to stay on the wave of development and transition to a new technological structure in order to maintain competitiveness on the world stage.

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