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Development of "Active Consumer" Concept on Energy Market

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ABSTRACT

The paper investigates a new approach to interaction of all participants on the energy market. An active consumer, as a participant of the energy market, has technical capabilities for optimization of their energy consumption, and determines whether "to produce" or "to buy" electrical energy on the market by themselves. The active consumer's profile reflects their ability to optimize the electrical energy consumption schedule to improve the economic efficiency of consumption and reduce the cost of the electrical energy consumed. In the concept proposed in this paper, the active consumer is considered as a partner of the energy market entities. This brings about a change in the market regulators and participants' behavior and their transition from the concept of cost management to the concept of interaction with consumers, involving them in the value chain. A significant difference in the cost of electrical energy for domestic and foreign industrial companies, due to the development of new technologies in the energy sector, leads to a change in the participants' behavior. Within the framework of the active consumer concept, we propose a process model for the participants' behavior in the energy market, which presents the economic benefits to all participants during a particular period of time.

Keywords: Active Consumer, Energy Market, Demand-Side Management, Economic Benefits
JEL Classifications: D24, Q43, M31

1. INTRODUCTION

Electrical and heat energy is a commodity whose parameters are initially defined. Participants of the energy market wish to actively manage not only production, but also distribution of electrical energy, which gives them the opportunity to take the part of both consumers and producers of electrical energy at the same time. Also, the consumers' behavior is influenced by the development of new technologies. The literature review made it possible to classify the main characteristics of the "active consumer:"

- Management of their own generating capacities: Assessment of the degree of capacity, the amount of electrical energy produced for their own consumption and supplied to the market (Haas and Loew, 2012)
- Availability of the processing systems capable of changing the capacity, own generation, energy storage (Zolotova, 2016)
- Management of the energy storage mode, including that generated by their own generating capacities (Ryapin, 2013; Jiang and Fei, 2011)
- Determination of conditions for loading their own capacity (if any), for submitting a bid to buy/sell electrical energy in the wholesale and retail markets (Rodin, 2011; Kunz, 2016).

Because of an active consumer appearance in the market, there are problems of providing consumers with the opportunity to change by themselves the amount of electrical energy they buy, to choose the level of reliability and the quality based on the balance of their needs and the capabilities of the energy system. These were reported by Volkova et al. (2011); Bushuev (2013); UNEP Collaborating Center, Frankfurt School of Finance and Management, Germany (2015).

The purpose of this article is to generalize the conceptual provisions of building a competitive active consumer and identify the main factors of the energy market, which has an impact on the active consumer's behavior.

2. THE CONCEPT OF AN ACTIVE CONSUMER IN THE ENERGY SYSTEM

The concept of the "active" consumer in the energy system is based on the energy consumption management mechanisms, which are divided into long-term and short-term actions (Scenario Forecasts for the Development of the Electric Power Sector for the Period up to 2030).

Mechanisms for improving energy efficiency are long-term and short-term. Also, such mechanisms are nominally divided into static and dynamic response.

Demand-side management, as an example of a static response mechanism, is currently a developed area. The program of action is aimed at stimulating energy-efficient consumption. The dynamic response mechanism is characterized by the consumers' reaction and includes planned or contracted actions, which contribute to the stability of the energy system and its balancing or are required in case of network failures. The main problem is consumer retention, as well as ensuring their motivation and ability to participate in the program.

Active actions allow consumers to react, for example, to high prices set in the market. In this case, consumers react to information coming from the market, and decide to change the model of their behavior in response to these signals.

The problem of an active consumer concept in the concentration of most energy markets is on the supply side, access issues and lack of information for participants from the demand side, which makes their participation difficult and unprofitable. Knyaginin (2010) was one of the first to investigate this problem.

Within the framework of the active consumer concept, we propose a process model for the participants' behavior in the energy market, which presents the economic benefits to all participants during a particular period of time.

3. LITERATURE REVIEW

The main solutions to the above problems in the concept of the active consumer were considered by both foreign and Russian researchers:

- Demand processes and distributed generation control, management of the energy storage regime, including that generated by generating capacities (Jiang and Fei, 2011)
- Energy conversion influence on energy markets and capacity management (Haas and Loew, 2012)
- Cross-subsidization in the electric power industry (Rodin, 2011; Zolotova, 2013; Ryapin, 2013; Kunz, 2013; NP "Market Council," 2016)
- Provision of science-driven growth of the electric power industry with the participation of an "active" consumer (Volkova et al., 2011; Bushuev, 2013; Lujano-Rojas et al., 2015)
- Processes of energy harvesting into energy system and transition to the creation of "microgrids" on the consumers' side (Grebenyuk and Solov'ev, 2004; Bresler, 2009; Chubais, 2009; Knyaginin, 2010; Govorov, 2012; Bushuev, 2013).

These studies have tended to focus on its aspects rather than the problem of an active consumer of electrical energy. The analysis of theoretical studies and best practices shows that the problem of an active consumer of electrical energy is very acute and is the subject of economic and technical research.

4. MATERIALS AND METHODS

During the study the following methods were used:

- Theoretical methods: System analysis, synthesis, generalization, theoretical analysis of scientific, methodological and technical literature on the problem studied
- Empirical methods: Analysis, monitoring, questioning, experiment.

Experimental work took place in several stages.

At the first stage of the research (2017), the purpose and objectives of the study were defined and literature was selected and reviewed.

At the emerging stage (2017), the analysis of the electrical and heat energy market was carried out, and the subject matter and the scope of the research were determined.

The purpose of the control stage (2017–2018) was to develop proposals on the concept of an active consumer and evaluate the effectiveness of this concept.

At the emerging stage (2017), the analysis of the electricity and heat energy market was carried out, and the subject matter and the scope of the research was determined.

The objective of the control phase (2017–2018) was to develop proposals on the concept of an active consumer and to assess the effectiveness of this concept.

5. RESULTS

The electrical energy market develops on the basis of protecting all participants' interests, which is feasible provided that energy companies interact with active consumers by offering them load rate tariffs for electricity, capacity utilization and grid connection.

Tariffs help control the participants' behavior in the energy market, which allows to create economic incentives for the formation of their behavior. For example, in order to stimulate necessary actions, tariffs are reduced, to prohibit unwanted behavior, they are increased. Energy companies need analyze the

active consumer’s behavior in the market in order to manage their demand. Demand-side management is an integrated approach to interaction with the consumer, based on its active participation in the formation and regulation of the load including incentives for the “active” consumer (Bushuev, 2013). Demand-side management in the electrical energy market includes load flow control and accounting system, as well as pricing policy, i.e., the modification of tariffs and prices. In the world practice, several methods of load management have been developed, which are described in the works of foreign authors such as Bresler (2009); Davito et al. (2010) and in the report prepared by National Energy Technology Laboratory Demand “Dispatch-Intelligent Demand for a More Efficient Grid” (2011), which reflect such aspects of demand-side management:
- Direct load control
- Load demand (supply) program or short covering program
- Time-of-use tariff
- Commercial/industrial options
- Interrupt programs
- Load-shedding
- Real-time pricing.

There are a number of programs for load management. Load demand programs or short covering programs are used in cases where the consumer can refuse to consume electrical energy at a high price. Participation in this program allows the active consumer to obtain information about the prices for online purchases and to take appropriate decisions to manage peak loads by selling the unused energy back at current prices. Currently, the program is being modernized to make it possible to send price signals and prevent speculation by active consumers through overstating planned loads and then re-selling intentionally excess electrical energy.

The next type of programs are compulsory programs that are designed for whole segments of consumers, and all consumers are obliged to participate in them. For example, all consumers with a certain level of consumption may be are charged using time-of-use rates. The supplier’s income may not depend on compulsory programs, if the indicators are developed properly and the consumers’ behavior varies within reasonable limits. The whole system is built in such a way that active consumers who save money on time-of-use tariffs are compensated at the expense of consumers who pay more. If the peak demand decreases and the capacity servicing factors improve, all tariffs can be reduced in due course relative to their level without taking into account time-of-use tariffs.

The industrial programs are peak load management programs, which are also available to industrial and retail consumers. The majority of participants in such programs are industrial consumers, who can interrupt operations for several hours or postpone them. Besides, there are also consumers using standby generators that can withstand all or significant parts of the load. These include: Systems interrupt program for hands-on integrated reliability; Load-shedding programs “low-power mode;” real-time pricing program; load demand (supply) program or Short Covering Program.

Experienced active consumers can include the supplier’s pricing scheme for the electrical energy in their energy management system. Large price differences between periods with high and low prices can automatically cause large changes in electricity consumption. It should be noted that unlike existing real-time pricing (Faria and Vale, 2011), the transition to a smart grid also implies a decrease in the planning horizon in the spot market: For a balancing energy market - the maximum approach to real-time mode (while the balancing energy market is now held every 4 h).

Active consumers’ voluntary participation in some technologically advanced smart grids can be stimulated by lower payments for participation. The incentive scheme for consumers depends on several factors, including:
- Type of the controlled equipment
- Level of control
- Average level of load reduction
- Level of load reduction.

Bonuses are paid through monthly loans to accounts for consumed services. Installation of the necessary equipment and subscriber line charge is effected at the expense of the electrical energy supplier, at the expense of the consumer (both grid-connection one-time payment and in the form of interspaced in time charge), and jointly in the agreed proportion. Discounts for the installation of equipment can be a significant factor stimulating the participation of the population in the program.

The concept of an active consumer in making a decision to “buy” or “generate by themselves” electrical and heat energy has the following selling points: Firstly, an important factor is the price for the electrical energy consumed from the grid and the formula for calculating it (type of tariff); secondly, availability of the own generation; thirdly, transmissibility of the own generation to the power grid; fourthly, the money equivalent of the profitability of the energy mode and, fifthly, the portability of time load equipment. The conceptual provisions for the construction of a competitive electrical energy market based on the capabilities of the IPS AAG (Intellectual Power System with Active Adaptive Grid) of Russia were spelled out by Dorofeev and Kuz’min in 2013. The developed range of tools is executed on the basis of MS Excel, which makes it possible to carry out multiple calculations to evaluate the effectiveness of the active consumer in terms of the cost of consumed electrical energy in the case of its purchase from the wholesale energy market or in the case of own production. Table 1 shows an example of the components of these tools.

The calculations are made with the help of MS Excel spreadsheet “calculations и result output.” During the calculation, the unit cost of electricity for the consumer is calculated without taking into account the elimination of cross-subsidization and taking into account the elimination of cross-subsidization.

We examined the model of economic benefit to the active consumer of the energy market, which contains the following elements:
- Interval time of the load scheduling (a daily-load curve is built, T = 24 h per day)

Table 1: Composite blocks of model tools

Name	MS Excel	Sequence
Information on transmission service tariff, straight-line rate from the wholesale energy market (capacity) (hereinafter referred to as the wholesale market for electricity and power), energy supplier’s retail markup, as well as the volume of net electrical supply and the current level of cross-subsidization in entities by levels of voltage	“Source data”	Determined by model statement
Data on forecast indicators: Annual average rate of inflation (CPI), the gas price growth rate (in accordance with the wholesale prices growth rate for all categories of consumers, except for the general public), the electricity prices growth rate of over the long-term	“Indices+const”	Determined by model statement
As the parameters of the electrical energy consumer’s work, the consumer’s location is included - the power receivers (electric consumers) in MW, utilization time per year, the voltage level of the electrical grid from which the consumer is powered, the choice of the power supply for the electric consumer - from “own generation” or when working in the system. Also there is an input of the cost of “own generation” in this block, as well as the annual amount of operating expenses required for the operation and maintenance of “own generation”	“Control terminal”	Determined by model statement/ automated settlement
Computed values. The calculation parameters are the choice of the payment period for capital investments made when creating an object of own generation, as well as the rate of return on invested capital provided by the investor. Within the framework of this block, there is also an optional choice of the period for which the existing amount of cross-subsidization in the selected entity of the Russian Federation is to be liquidated	“Calculations и result output” “CAPEX”	Automated settlement

Source: Authors’ processing

- The amount of equipment in pcs, included in the calculation of the loading schedule and the power consumed by this equipment per day;
- Loading matrix A_n (columns of the matrix - loading of equipment, and lines - options for loading the equipment included in the schedule).

Elements of matrix A_n, $c^n_{rt} \in \{0;1\}$ - correspond to the work mode, for $r \in \overline{1,R}$ and time $t \in \overline{1,T}$, can be denoted as $A^n = \left(c^n_{rt}\right)^{r\in\overline{1,R}}_{t\in\overline{1,T}}$.

Then the active consumer has an estimated total energy consumption at each time t as $w_t = \sum_{n=1}^{N} c^n_{tz_n} * P^{consum}_n$,

Where $\overline{z} = \left(z_1,.....z_N\right)$ is a vector of variables, corresponding to a set of equipment operating modes, $n \in \overline{1,N}$; $z_n \in \overline{1,R_n}$;

P^{consum}_n is a power capacity (kW) consumed by the n^{th} unit of the equipment.

It is important for an active consumer to express each equipment operating mode in the form of a money equivalent of costs or economic benefits ($Э_{rn}$) for purchasing electrical energy at a schedule $r \in \overline{1,R}$ and selected objects $n \in \overline{1,N}$. In zero operation mode, when the equipment is completely off $Э_{rn} = 0$. In other cases $Э_{rn}$ will show the required amount of energy costs for the amount of operating equipment *n* and its operating mode r. The money equivalent in the form of a sum of costs $Э_{rn}$ will show the value of the work of each additional piece of equipment in the mode r.

The active consumer can also calculate the money equivalent as the mathematical expectation of the price c_i at the moment of time *t* according to the probability distribution P:

$$Э_n(t) = \sum_i c_i * P(c_i,t) \quad (8)$$

Where c_i is the i^{th} element of set C.

Expressing the operation mode as a set of time modes, we obtain:

$$Э_n(r) = \sum_j Э(r_j) \quad (9)$$

Where j is the time interval r.

However, it is important to understand that the monetary evaluation of the economic benefits of any schedule of electrical energy consumption is individual and subjective. For example, it can depend on the operating schedule of the enterprise, the type of the products made and the specific type of equipment.

An economic benefit can be estimated in various ways. However, in our opinion, the estimation based on the maximum possible volume of energy consumption per hour is of much interest. It is calculated as the nominal power consumed by the equipment multiplied by the number of days of the given period T.

The ratio $\frac{R^t_i}{R_{max}}$ will be an option of the price for the electrical energy c_i in given the period T, and the money equivalent of the energy costs will be equal to the ratio:

$$d^t_n = \sum_{i=1}^{I} \frac{C_i * \frac{R^t_i}{R_{max}}}{I} \quad (10)$$

If the active consumer has the opportunity to produce electrical energy, it is necessary to calculate and estimate the economic benefit of energy production using the own generation units (distributed generation). The number of such units will be denoted by N, whose operating mode is $g \in \overline{1, G}$. Assuming that the operating modes of the generators are different, it is possible to build the relationship between the unit cost of electrical energy produced by means of own generation c_m (T_{mt}) and the power output at every instant T_{mt}. Having drawn a graph of such a relationship, one can find the point of the minimum cost of electrical energy produced by using own generation unit.

The total amount of generation of electrical energy $W_t = \sum_{g=1}^{G} q_{mt}$ produced by own sources is divided into the quantity of electrical energy for own consumption and the quantity of electrical energy transferred to the energy grid $q_t^E \left(\overline{q^E} = \left(q_t^E\right)\right)$. Costs of generating electricity by own generation source are calculated according to the formula $W(t) = \sum_{g=1}^{G} c_m (t, q_{mt})$.

The cost of electrical energy transferred to the energy grid will be denoted by Q_g, and the cost of the consumed energy by Q_f. External conditions, such as the length of the light day and the mean daily temperature, will be denoted by F.

The price of energy consumed is C^I (t, V_t, Q_f, F), and the price of the generated energy is C^E (t, q^E, Q_g, F).

The active consumer's behavior should be aimed at maximizing their goal by selecting the appropriate consumption schedule $r \in \overline{1,R}$ for each type of equipment $n \in \overline{1,N}$, for each generation unit $m \in \overline{1, M}$, the schedule of its operation for each period of time $t \in \overline{1,T}$, the choice of the positive amount of power output, and the amount of electrical energy transferred to the energy grid.

Restriction on the amount of power consumption can be expressed as

$$\forall t \sum_{n=1}^{N} V_t \times P_n^{consum} \le V_{max}$$

The active consumer when forming the generation operating mode based on the price signals coming from the market, must take into account the following elements: Time-of-use tariff, their own generation capacity; unit cost of their own generation; the best option for loading facilities.

Based on the above model of the active consumer's behavior in the energy market, a strategy for their behavior is proposed, which includes the following stages. The first stage is to select the necessary parameters and technical characteristics of the operation of each unit of each type of equipment. The second stage is to forecast and form possible operating modes for each unit of each type of equipment during the day and build a matrix of equipment loading. The third stage includes determining the economic benefit of electrical energy consumption for each equipment operating mode. Then the price parameters of the selected operating modes are determined, such as: The cost of purchased electrical energy, the working cost of own energy production, the cost of supplying electrical energy to the energy grid. The next step is to choose the most optimal option. We propose to consider from a large number of criteria the following ones: Optimality criteria, which are set according to the parameters of working costs and costs. For example, if the costs of energy generation exceed its purchase cost from the grid, the participant of the energy market should choose the option of buying electrical energy and not load their own generation, and vice versa, if the cost of own generation is lower than the price for electrical energy, the maximum possible amount of electricity should be produced independently, and the remaining energy should be consumed from the energy system. If the price of electrical energy supplied to the grid is lower than the production costs, it is necessary to limit the energy production to one's own needs.

Practical implementation of the active consumer model will be based on their own decisions to "buy" or produce electrical energy by themselves.

6. DISCUSSIONS

The active consumer's functions in the energy market are to purchase electrical energy from the shared energy grid, to choose the quantities of electrical energy purchased from other participants in the energy market and to sell it.

The change in the behavior of energy companies when active consumers appear on the market is to make it possible for the consumer to change the amount of the purchased electrical energy on their own, and to choose the functional properties (reliability level, quality) based on the balance of their needs and the capabilities of the energy grid.

The concept of an active consumer in the energy grid is implemented through a system of mechanisms (demand-side management), which includes demand-side management programs (demand response) and energy efficiency.

For making optimal decisions by the business consumers of the electrical energy with regard to "buy" or "produce by themselves," we have developed a model that includes the formation of an energy consumption schedule and a loading mode of own generation that reflects consumers' economic interests and allows them to implement their functions.

The proposed model for active consumers in the energy market can be used by various entities to solve different problems: Consumers - to formulate a strategy for their energy consumption and to automate consumer load management; power supply companies and a regulator - to model a multi-agent system providing consumers' response to tariff mechanisms of demand-side management and to evaluate the economic benefit to the consumer from participation in demand-side management.

7. CONCLUSION

The change in the role of participants in the energy markets led to the formation of the concept of an "active consumer," who is understood as an energy market participant, who has technology access to maneuver their energy consumption and participation in demand-side management. The main characteristics of the "active" consumer are: Availability of the processing system capable of changing (transferring) the load; availability of own generation (distributed generation); availability of power storage; availability of the processing system capable of changing the load, own generation, energy storage units; demand-side management: Reduction in the load, time transportation based on the principle of economy of energy consumption; management of their own generating capacities: Determination of the loading efficiency, the quantity of electrical energy produced for their own consumption and the quantity of electrical energy supplied to the energy market; management of the energy storage mode, including that generated by their own generation capacities; sale of accumulated electrical energy; determination of conditions for their own capacity loading (if any) and for submitting an application for participation in buying/selling electrical energy in the wholesale and retail markets.

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