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CONTROL SCIENCES

Active Consumer: Optimization Problems of Power Consumption and Self-Generation

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Abstract—To solve problems of demand management in terms of smart energy systems (Smart grid), we need a mathematical model of active consumer decision-making. Existing models either do not consider important aspects of consumer behavior, or are too complex for use in multi-agent simulation. A mathematical model of an active consumer is proposed, based on which we formulate and solve the problem of optimization of electrical appliances and consumer equipment, as well as determine the loading conditions of self-generation, under which the consumer problem allows simple and effective solution. The proposed approach is illustrated by equipment optimization of a single household.

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1. INTRODUCTION

In recent years, Russia has begun the process of innovative conversion in the electric power industry development, named "Intelligent Power System of Russia," which is based on the concept of fundamental provisions of Smart Grid. Part of this concept is the "activation" of consumers, that is, enabling them to self-manage the amount of electricity obtained and its functional properties (level of reliability, quality, etc.) on the basis of the balance between their needs (to minimize energy costs and generate income from the sale of electricity and power) and power system features, using the information about the characteristics of the prices, volumes of electricity supply reliability, quality, etc. [1]. An active consumer should be able to perform the following functions in the integrated power system:

—manage own power in accordance with the need to fulfill their plans for production of goods or provision of energy to a household by optimizing the cost of purchasing electricity from external markets;
—define own power load conditions (if any) for participation in the purchase/sale of electricity on the wholesale and retail markets;
—determine the degree of own participation in the provision of additional services for controlled active and reactive loads (power) to be managed by the system operator.

Implementation of these functions requires creation of external conditions and tools that would enable consumers to realize their potential. Such instruments must meet the following requirements:

—reflect the economic interests of the active consumer;
—ensure the formation of optimum loading of appliances and equipment on the basis of projected consumer price signals, as well as consider the load distribution between different types of consumer equipment;

—ensure the formation of own consumer generation of power supply within the household/enterprise or deliver electricity to the grid.

In this paper we present a model of the active user, based on which we formulate and solve the electrical appliances optimization problem and consumer equipment mode, as well as determine the loading conditions of own generation. The model can be used either by a consumer to develop a strategy for effective energy utilization or by the power company and the regulators to develop mechanisms to influence active consumers.

In the second case, the proposed model represents the behavior of a control object, allowing to estimate consumer response to price signals, the main mechanism of action on the controlled system (on a set of active consumers), to estimate its desired behavior. An active consumer must participate in the optimization of the energy system, including smoothing consumption peaks in demand management programs (demand response) [2].

2. LITERATURE REVIEW

Management of the power consumer behavior were examined at previously in the literature, both by Russian scholars and abroad. In the 1980s, the main task of controlling the behavior of electricity consumers in the Soviet Union was to reduce uneven load schedule grid by requiring consumers to regulate electricity consumption in order to reduce the total households costs. Opportunity to participate in load management had been considered only for large industrial consumers (consumer regulators), who had the technological processes allowing the flexibility to adjust their load online. The problem considered by the authors can be summarized as follows:

—optimization of energy consumption for existing and projected enterprises to reduce the total costs of the enterprise while maintaining production plans, subject to restrictions on technologically allowable reduction of power consumption, with the electricity tariff differentiated by the parts of the day, days of the week and seasons of the year;

—optimization of energy consumption by minimizing total energy flow (electricity and other energy) given the constraints of fluctuating daily production plan;

—distribution of limited capacity (amount of electricity) under the conditions of deficits in the power system (including restrictions on the bandwidth of electrical networks) between different enterprises or technological installations of the same enterprise, which provides the minimum national economic damage from reducing power consumption.

Thus, V.V. Mikhailov in [3] proposes to solve these problems using nonlinear programming with continuous optimization techniques. The author does not consider the possibility of electrical disconnection, allowing only continuous mode change. This approach does not fully represent the interests of the consumers in the simulation of their behavior (because not all consumption schedules, allowing to fulfil the plans, are equivalent), and does not account for distributed generation. In addition, its application requires the identification of complex nonlinear dependencies.

Later, in [4], the authors considered a problem of controlling the consumer behavior in order to smooth the load curve grid, contributing to the achievement of maximum economic efficiency units, reduce harmful emissions, and other purposes. While the above problems involve changing operation modes of the enterprise to achieve the effect of reducing costs or energy consumption, in this paper we propose a method of calculating the electricity tariff, taking into account consumer behavior and motivating different groups of consumers to allocate their load during the day, so that the actual load in the power system corresponds to the maximum economic efficiency, or the inflection point of energy characteristics, and the average rate for each group and the amount of energy produced remained unchanged. The developed method takes into account, first, the energy characteristics of the generating equipment, and second, the consumer daily load curve.

Proposed in [4], the method of tariffs calculation, based on consumer behavior, solves the problem of motivating consumers to equalize the daily schedule while maintaining the average tariff of the power system load unchanged. The above approach takes a greater focus on the generation and control, as it reflects the technological characteristics of the various modes of generation, and considers only the generalized form of the load curve without assessing consumer tolerance to changes in its configuration.

The new interest in energy management concept originated with the development of Smart Grid, part of which, as mentioned above, is the "activation" of consumers. Demand management problem is currently a widely researched topic worldwide. However, to date, mostly the mathematical models of domestic consumers (households) were being considered [5–9].

In [5], the authors propose a mathematical model that takes into account the following key parameters: the cash equivalent consumption profitability, the cost of buying electricity from the network, as well as the benefits derived from the sale of electricity from own generation. Using the results of ongoing optimization, minimizing the cost of energy consumption, the authors generate the load schedule of each consumer appliance (with the defined operating characteristics, such as the operation duration). The authors suggest a genetic algorithm as an approximate solution of the planning and consumption problem of own generation in the day ahead, with the possibility of rapid rescheduling, and are testing this algorithm on the example of households located in Zaragoza (Spain).

In [9] there is a similar problem of an optimal energy consumption profile, but unlike the monetary equivalent of profitability used in [5], the model uses the waiting time before the appliance starts operating. The authors propose to solve the problem using the convex programming algorithm. Results are tested on conditional data for individual households, but using real prices, taking into account inflation indices.

In addition to the task of creating the optimal graphics hardware load in [7], the authors add a problem of efficient distribution of electricity generated by renewable energy sources (RES) located at the consumer sute, changing between electrical energy consumption and electrical appliances. In contrast to papers [5, 9]. The authors of [7] did not consider the level of customer satisfaction. The authors propose to solve the optimization problem using metaheuristic algorithm and are testing the proposed algorithm on conventional data.

In [6] the authors consider combination of multiple users whose generating source is shared. A key feature of the proposed approach is the assumption that consumers interact favorably in order to maximize their individual results, since the payment for electricity for each user depends on the schedule of other energy consumers, which leads to the existence of game-theoretic behavior among participants. The authors consider two problems, in general, for all consumer associations: minimizing irregularity factor of the load curve and minimizing energy costs. Since both problems are interrelated, the authors consider the problem of minimizing energy costs and propose an algorithm solution using game theory, i.e., a power profile of each participant is defined, and they arrive at Nash equilibrium. Results are tested on conditional data.

Authors of [8] also address the problem of minimizing energy costs for all MicroGrid—combination of several households. In contrast to [7], they do not assume any interaction between consumers in the way of forming the graph of power consumption. The authors propose a sequential algorithm to optimize energy consumption. In the first phase, we solve the problem similar to that discussed in [5, 7, 9] to determine the schedule for electrical power consumption of each household regardless of the mode of other households on the basis of minimizing the cost of energy consumption, taking into account the admissibility coefficients reflecting the level of customer satisfaction from a given energy consumption graph, as well as penalties for interruption of electrical appliances. In the second phase, the management of distributed generation (which in contrast to

[5, 7, 9] is common to all grid) solves the problem of maximizing the use of distributed generation and minimizing the cost of energy for the entire MicroGrid. In the third phase, management of the electric energy storage device is performed based on the technical characteristics of the device, as well as external parameters defined in the first two phases: power consumption and RES volume. The authors propose to solve this problem using a metaheuristic algorithm. Results are tested on conditional data. All the above approaches provide reduction in energy costs from 8 to 25%.

Thus, to the best of our knowledge, no one has developed a model of consumption control and active consumer generation that would be appropriate to describe households, allow to take into account the loss of the consumers in case of different load profiles, including managing their own generation, and at the same time, computationally simple enough to form the basis of the agents' behavior within the consumer multi-agent system. The main focus of the model is a solution to the problem of demand management through tariff regulation. Such a model is described below, with a simple and effective solution to the consumer problem. We show that such solution has conditions which allow us to describe a significant proportion of cases occurring in the simulation of the individual households behavior, at least in the framework of solving the problem of the rational electricity tariff definition.

3. LOAD MANAGEMENT AND SELF GENERATION MODEL

3.1. General Model of an Active Consumer

In [10], the authors proposed a general economic and mathematical model of the active consumer. It is believed that the active user minimizes function of operating costs, taking into account:

—price for purchased electricity from the market;
—power consumption profile;
—losses due to the deviation of the current energy consumption profile (electricity demand) from the desired one;
—the cost of reconfiguring generating capacity of the consumer;
—the price of the electricity transmitted to the network from own generation;
—the volume of own generation transmitted to the network;
—the cost of electricity from own generation.

This model allows us to identify the main economic factors that influence the behavior of the active user, helps to assess the order of magnitude of these factors in financial terms, and can be used to describe the consumer behavior in the development of consumer motivation to participate in management and control demand mechanisms. This article details and adapts this model to describe the behavior of an active user in order to address the problem of demand management.

3.2. Model of an Active Consumer Behavior

A model of an active consumer, reflecting consumer's economic interests in the time interval corresponding to the operational activities of [10], is detailed as follows.

We divide the time interval for which we are planning for T periods (for certainty—24 periods of the one-hour length). Let the consumer have the N units of energy-consuming equipment. Operation of a typical piece of equipment is modeled by load curve defining the power consumed by equipment in each of the 24 scheduled periods.

Matrix A_n of all possible load curves for equipment $n \in \{1, \ldots, N\}$ is formed for each hour of the next day. Matrix contains T columns and R_n rows (the number of possible load curves of equipment is n). The appearance of zeros in a row means that the equipment is turned off at appropriate times.

Example (transposed) matrix of the conditioner load curves

		Time																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Possible	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
load	2	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
curves	3	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$\alpha_2 = 1, \ldots, R_2$	4	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
													...												
	α_2^i	0	0	1	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
													...												
	$\alpha_2^{R_2}$	0	0	0	1	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Example of matrix A_n for an air conditioner ($n = 2$) is shown in table:

—can operate either continuously during predetermined time period or intermittently at predetermined intervals;

—operating parameters:[1] serial number of the equipment $n = 2$, power consumption of the equipment (nominal capacity) $P_2 = 1$ kWh.

We denote $a_n^\alpha(t)$ element of A_n matrix, corresponding to the row (operation mode $\alpha \in \{1, \ldots, R_n\}$) and to the column $t \in \{1, \ldots, T\}$. Thus, if for equipment n, a user chose a load curve $\alpha_n \in \{1, \ldots, R_n\}$, then the total consumption at time t can be written as

$$a(t) = \sum_{n=1}^{N} a_n^{\alpha_n}(t).$$

Not all of equipment load curves are equally preferable for the user. The cash equivalent for the user's benefit from consumption graph $\alpha_n \in \{1, \ldots, R_n\}$ of equipment object $n \in \{1, \ldots, N\}$ is denoted by d_n^α. If, among the modes of the equipment there is a mode corresponding to its complete blackout, it is logical to consider this variable to be equal to zero, and then for the other modes, d_n^α denotes the amount of money the consumer is willing to pay for the opportunity to exploit the electrical equipment n in mode α compared with the situation of when this equipment is not used.[2]

In practice, the assessment of monetary equivalent of value is a complex socio-economic objective function identifying consumer preferences. In economic theory, this is equivalent to a quantitative assessment of the utility. Cash-benefit assessment of a consumption schedule is extremely individual and subjective: for a person who does not work and stays home, the time of watching TV may not matter (cash equivalent of profitability may be the same throughout the day), whereas for a person who works during the day, the value of watching TV for a couple of hours before bedtime is higher than for the rest of the day (cash equivalent of value during the day will be zero, and only two hours before sleep may have a positive value). It is assumed that only a specific user can assess the cash equivalent value of electricity consumption for a specific type of electrical equipment, and to determine such value, a labour-consuming survey is needed.[3] As part of an approximate, but a more practical approach, all technically feasible load schedules are divided into acceptable and unacceptable to the consumer. Invalid graphics excluded from the matrix A, and all admissible schedules are assigned the same utility.

[1] Here and later the data from [5] is used as an example of equipment parameters.

[2] In the original model [10] similar functions were performed by a so-called "losses due to deviations from the consumption needs." Here the terminology slightly changed for easy comparison of results with other models.

[3] An interesting idea is that of automating this survey by studying consumer behavior in terms of information signals from a "smart electricity meter" on cash equivalent of undertaken decisions (if the user switches on a dishwasher, after receiving information on the cost of electricity at any given time, we assume naturally that for him or her the cash equivalent of utility exceeds these costs). After a period of "consumer fitting," the need for signals disappears.

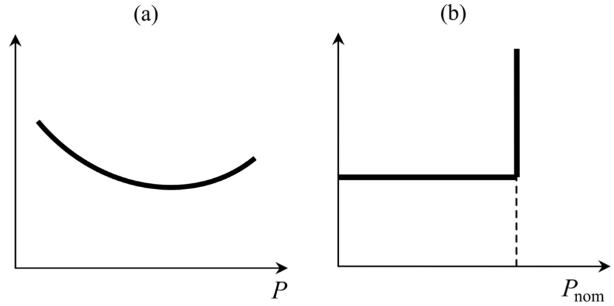

Fig. 1. Examples of graphs of electricity generation cost for (a) a diesel generator and (b) a solar panel.

Suppose further that the consumer has its own M generation sources—solar and/or wind turbine, diesel or gas-electric generator. Given the possibility of different modes of generators for each oscillator $n \in \{1, \ldots, M\}$, one can plot the cost of generating electricity unit $c_n(g_n)$ produced at each moment of power g_n. The point on the graph corresponds to a minimum cost, at which required power from given power plant can be produced.

Examples of appropriate graphs for solar installation and diesel generator are presented in Fig. 1.

If we denote with generation of plant capacity $n \in \{1, \ldots, M\}$, then $g(t) = \sum_{n=1}^{M} g_n(t)$ is a full amount of generation over the time period which is divided between internal consumption $g^I(t)$ and the amount of electricity $g^E(t)$ transmitted in the network, a $C(t) := \sum_{n=1}^{M} c_n(g_n(t))$ is the production cost for the active consumer to deliver the amount of electricity g in time t. To simplify the calculations, the cost to start/stop generation facilities is considered to be zero. Let ζ_g be the parameters for charging electricity transmitted in the network; for example, accumulated in the cumulative consumption rates depending on that transmitted from the beginning of the reporting period, the volume of electricity, including stipulated in the contract with the utility constraints on generation. The composition and functions of these parameters will be specified below. Similarly, we denote by ξ similar pricing options for electricity consumption, including the contractual restrictions on the consumption. We denote by η the external conditions on the planning horizon, such as the average daily temperature and day length.

Denote with $p_a(t, a(t), \xi_a, \eta)$ the price of the electricity consumed, depending on the time period, the volume of consumption and other parameters; with $p_g(t, g^E, \xi_g, \eta)$—the price of the electricity transmitted in the network, depending on the time period, the volume of external generation, and other parameters.

With this notation we can write the objective function of the active user

$$f = \sum_{n=1}^{N} d_n^{\alpha_n} - \sum_{t=1}^{T} p_a(\cdot) \left[\sum_{n=1}^{N} a_n^{\alpha_n}(t) - g^I(t) \right] + \sum_{t=1}^{T} \left[p_g(\cdot) \times g^E(t) - \sum_{n=1}^{M} c_n(g_n(t)) \right]$$

as the sum of "profit" from consumption (the difference in benefits from the consumption and value of electricity from the grid) and profit from own generation (difference in income from the sale of electricity to the grid and the cost of generation).

Formally, the problem of active user (problem of optimizing consumption and own generation) is to maximize the objective function f once for each object of electrics $n = 1, \ldots, N$ with consumption schedule $\alpha_n \in \{1, \ldots, R_n\}$, for each of the existing generators $n = 1, \ldots, N$, with generation graph (i.e., for each of the periods $t = 1, \ldots, T$ choice of non-negative number—generation capacity $g_n(t)$), as well as volume of electricity transmitted to the network

$$g^E(t) \leq g(t) = \sum_{n=1}^{M} g_n(t).$$

3.3. Classification Problems

In general, the formulated problem is an example of a challenging mixed optimization. The main purpose of this article is to identify important cases when this problem has simple and often even analytic solutions. For this purpose, we introduce the following classification of specific problems. The classification is based on the complexity of its various components.

Basis of classification 1. Formula for calculating the flexible tariff $p_a(\cdot)$

- *Zone tariff* (Time-Of-Use Pricing), $p_a(t)$ at which the price of electricity consumed depends only on the time of day, usually including two to four price periods (see Fig. 2).
- *Zone tariff subject to the limitation on the maximum power*, $p_a(t, a(t), \xi_a)$, involves not only the dependence of the price on time, but also on the power consumption $a(t)$, specifically,

$$p_a(t, a(t), \xi_a) = \begin{cases} p_a(t), & a(t) \le \xi_a \\ +\infty, & a(t) > \xi_a. \end{cases}$$

  Such dependence of price on power actually prohibits the consumer from exceeding the norm ξ_a of volume of electricity consumed simultaneously. In practice, such tariff is realized through a combination of zone tariff and automatic breaker of power.
- *Tariff with consumption norms (social norm of consumption)* implies dependence of price on total consumption for the period.
  In [11], the authors have shown an approved a package of measures aimed at the transition of the establishment of utilities' consumption social norms in Russia, that is, some consumption norms will be approved, within which electricity will be consumed at regulated tariffs (now considered various options from 50 to 100 kWh) and beyond those norms, at market price.
- *Complex pricing.* As a part of demand management programs, more complex pricing formulas can be used. The most common examples are (see Fig. 3) establishing discounts with increasing electricity consumption and pricing for each range of consumption when prices are set for specific ranges of electricity, with the transition to a new range of consumer price increases.

Basis of classification 2. Own generation

- No possibility of using distributed generation.
- Possibility of sale of the electricity generated by consumer at market price ($p_g(\cdot) \equiv p_a(\cdot)$).
- Possibility of using distributed generation for own consumption (without transmitting to the network).
- Opportunity to sell electricity generated by consumer distributed generation network at a price different from the market.

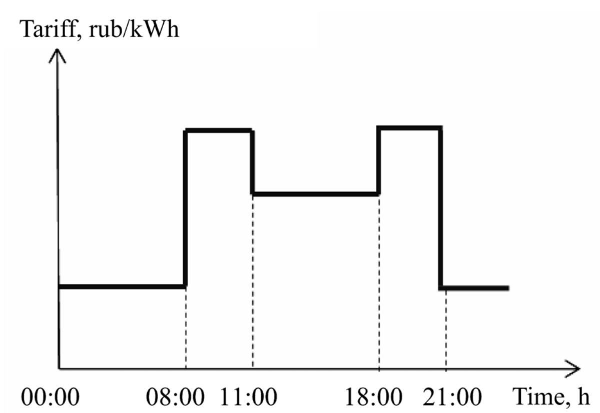

Fig. 2. Example of zone tariffs (time-of-use tariff).

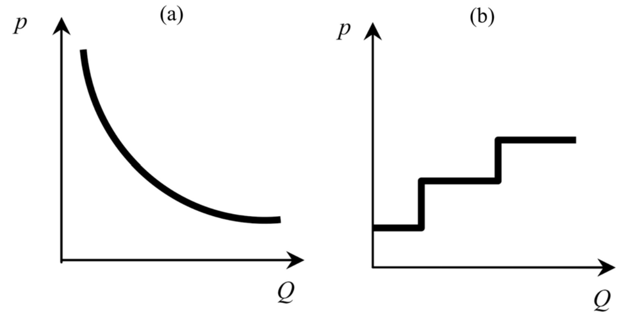

Fig. 3. Modifications of price p chart, depending on the pricing conditions with the application of demand management programs: (a) Graph of price when discount rates for increasing consumption Q are applied; (b) Graph of price set for each range of consumption.

In this paper we studied a model where the rate depends on the time of day (Time-Of-Use Pricing) with no limit on power consumption, and distributed generation allowing to sell electricity produced at the market price. It appears that in this case, the problem of optimizing consumption schedules and generating own electricity separate, and they can be solved independently. It is also clear that the situation when there is no distributed generation is a special case of the problem.

4. PROBLEM SOLUTION

4.1. Optimization of Own Generation

Assume that the electricity tariff depends only on the time and energy that the company purchases from the consumer at the same price that it sells the power back to the consumer, i.e., $p_a(t) = p_g(t) = p(t)$.

In this case, the user objective function can be written as

$$f = \sum_{n=1}^{N} d_n^{\alpha_n} + \sum_{t=1}^{T} \left[p(t) \times g^E(t) - p(t)(a(t) - g^I(t)) - C(t) \right]$$
$$= \sum_{n=1}^{N} d_n^{\alpha_n} + \sum_{t=1}^{T} [p(t) \times (g(t) - a(t)) - C(t)].$$

The formula shows that from the economic point of view, the consumers are indifferent between generation of electricity primarily for their own needs and transmission to the network. Thus, we can assume that $g^E(t) = g(t)$, $g^I(t) = 0$.

Then,

$$f = \sum_{n=1}^{N} \sum_{t=1}^{T} \left[\frac{d_n^{\alpha_n}}{T} - p(t) a_n^{\alpha_n(t)} \right] + \sum_{n=1}^{M} \sum_{t=1}^{T} [p_g(t) \times g_n(t) - c_n(g_n(t))].$$

In the problem itself, there are no restrictions linking the choice of variables α_n and $g_n(t)$, thus we can carry out separately both the maximization of the part of the objective function associated with consumption

$$f_a = \sum_{n=1}^{N} \sum_{t=1}^{T} \left[\frac{d_n^{\alpha_n}}{T} - p(t) a_n^{\alpha_n(t)} \right], \tag{1}$$

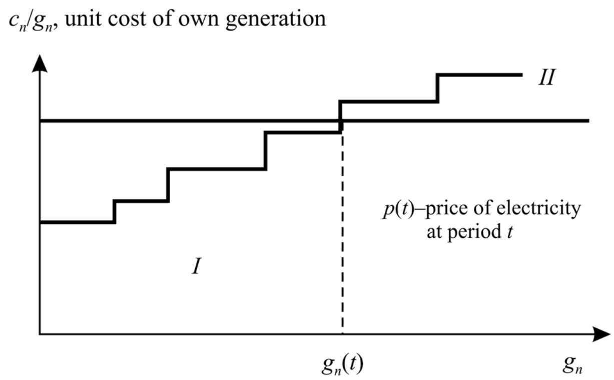

Fig. 4. Selecting the generator mode.

and the part associated with own generation

$$f_g = \sum_{n=1}^{M}\sum_{t=1}^{T}[p_g(t) \times g_n(t) - c_n(g_n(t))].$$

This means that in the presence of own generation with the opportunity to transmit the power to the network, the purchase price does not affect the consumer's desire to reduce its own maximum power consumption during periods of high prices (which is usually assumed by tariff demand management programs)—the cost of electricity replaced by lost profits as not all electricity transmitted to the grid.

If, as assumed above, the user can independently control the power sources of own generation, the problem of maximizing function f_g also splits into M independent tasks of selecting the output power for each of the M existing power plants.

Output power selection $g_n(t)$ of own generation of plant $n \in \{1, \ldots, M\}$ at time t is carried out based on the price of electricity in this period.

Thus, if the marginal cost of own generation $c_n(g_n)/g_n(t)$ increases (which corresponds to an increase of expenditure on the scale), the optimal power is determined from the equation $c'_n(g_n(t)) = p(t)$, i.e., $g_n(t) = [c'_n]^{-1}(p(t))$.

Figure 4 shows a typical plot of marginal cost of electricity of own generation, which has a stepped form, where each new step is the inclusion of less economical mode of generation. On phase I, where the marginal cost of electricity of own generation $c_n(g)^{\mathrm{I}}$ is below the market price $p(t)$, consumers make benefit by downloading their own generation (in volume, g_n^{I}), both to cover their own load and for the sale of electricity to the network. Marginal cost of electricity of own generation on phase II is above market price $p(t)$, and therefore, it is not economically feasible for the consumer to load the corresponding generating capacity at a given market price.

If the cost of the increase in power changes in a more complex way, in particular, if there is an economy of scale effect, abrupt change in the cost etc., the problem reduces to a one-dimensional nonlinear optimization, remaining the type of problem typical for production economics [15].

4.2. Selection of the Optimal Consumer Load Profile

If, as expected, the user can operate independently with consumption of various devices, then, from formula (1), the maximization of the objective function is

$$f_a = \sum_{n=1}^{N}\left[d_n^{\alpha_n} - \sum_{t=1}^{T} p(t) a_n^{\alpha_n}(t)\right]$$

decomposed into N problems of optimal equipment loading option (rows of the matrix A_n) for each device $n = 1, \ldots, N$.

To do this:

1) each row of the matrix A_n is multiplied by the vector $[p(1), \ldots, p(T)]$—graph of price changes throughout the planned period of time;
2) all elements of each row are summed separately, giving a column $[c_n^1, \ldots, c_n^{R_n}]$ of energy costs for each alternative equipment loading;
3) from the column $[d_n^1, \ldots, d_n^{R_n}]$ of option benefits we substract column with cost of electricity $[c_n^1, \ldots, c_n^{R_n}]$ element by element, and we get a column $[\varphi_n^1, \ldots, \varphi_n^{R_n}]$ of options evaluation;
4) option with the maximum score is selected, $\varphi_n^1, \ldots, \varphi_n^{R_n}$.

According to the calculation results, we generate hourly schedule of consumer equipment and load of own generation.

Thus, the problem is solved when the price depends on the time period (time of day), there are no restrictions on capacity, sales of electricity of own generation is possible at the market price. It is clear that the above algorithm solves the problem in the absence of the consumer features of distributed generation.

5. NUMERICAL EXAMPLE

Testing of the proposed model without optimization of own generation was carried out using partial data [5] and was based on the conditional data.

The operation of the following devices was considered:

—Air conditioning: serial number of the equipment $n = 1$, power consumption (nominal power) $P_1 = 1$ kW;
—Electromobile: serial number of the equipment $n = 2$, power consumption (nominal power when charging) unevenly (based on average data [5]) $P_2 = 0.79$–3.56 kW , charging time 19 h;
—Washing machine serial number of equipment $n = 3$, power consumption (nominal power) $P_3 = 0.95$ kW;
—TV: serial number of the equipment $n = 4$, power consumption (nominal power) $P_4 = 0.3$ kW.

We take as given the price of electricity for retail customers of "MosEnergoSbyt" approved for the first half of 2013 (multirate accounting by applying the tariff differentiated by zones of the day). Cash equivalent consumption of profitability d_n adopted on the basis of conditional data.

Input data for calculations and the final calculation of the optimal load schedules are available online (http://www.mtas.ru/upload/library/VGS2013.xls). In particular, the optimal option for the consumer schedule is:

—air conditioner: option 3 (operate from 11.00 to 12.00, from 15.00 to 16.00 and from 19.00 to 20.00);
—electromobile: option 4 (operate from 16.00 to 10.00);
—washing machine: option 3 (operate from 3.00 to 5.00);
—TV: option 5 (operate from 11.00 to 15.00).

6. CONCLUSION

The developed model of active consumer can be used to automate the management of consumer load (for the category "active—passive" consumers who manage their loads using the automatical programs). Furthermore, the use of the developed model allows us to estimate the economic effect for the consumer from participation in demand management. It is shown that, at least for households with a suggested realistic model of optimal behavior of active consumer, which adequately describes the main reasons for the decision-making power consumption and own generation. It is also shown that in many important practical situations (zone tariffs in the conditions of uncritical constraints of power consumption at the same time, equivalent prices of consumed energy and energy transmitted to the network) optimization problem of consumer allows an extremely simple solution, significantly more efficient in terms of computation than general methods proposed in the literature.

This algorithm of an individual consumer behavior, just because of its simplicity, can be taken as a basis for multi-agent simulation of consumer response to the tariff demand management mechanisms. During the simulation in the population of agents relevant to individual consumers, with described in the article by a decision algorithm, but with different parameters (preference profiles, set of appliances and their operation modes, local generation capacity) are plugged in the general conditions of tariff policy. The simulation revealed rescheduling of total consumption for a fixed menu of tariffs. This "demand response" is then used to find the optimal tariff policy by, for example, local search algorithms (Newton's method or gradient descent). In general, this simulation allows making reliable predictions about the effectiveness of planned tariff regulation measures.

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