Demand Response on the Russian Retail Market

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***Abstract*—In this paper, the potential of reducing the electricity cost with the help of energy storage and controllable loads on the Russian retail electricity market is studied. The retail electricity market in Russia features different price categories, allowing consumers to reduce expenses with proper planning. Approximately 2/3 of the cost in flexible price categories is for the power consumption in specific hours, with the remaining 1/3 for the energy consumption itself. Because of the continued cost decrease of energy storage devices, they have become an increasingly more attractive investment, opening opportunities for economic savings combined with load shifting, which can occur either in a standalone manner or with the use of energy storage. In this paper, demand shifting is implemented in the Russian retail market, combined with the payback calculation for energy storage.**

***Index Terms*—Russian Power System, Demand Response, Energy Storage**

I. Introduction

The price of electricity in Russia depends on the price zone the consumer is located, whether it is wholesale or retail, and what price category the consumer has. When end-users do not satisfy the wholesale market's minimum consumption requirements (which is 20 MVA of cumulative power load), they need to purchase energy in the retail market. Consumers are classified as small industrial, commercial, and residential. Unless a consumer has a single-rate electricity tariff or does not have the resources to manage their consumption, it is always possible to optimize the electricity consumption profile to reduce the electricity bill. In this paper, we consider the possibility of reducing the electricity bill in two ways:

1) Redistribution of power consumption over time with the help of a controllable load, i.e., which can be rescheduled.
2) Storage charge and discharged in different hours.

Both methods are identical in terms of their effect on the power system since they reduce power consumption on expensive hours and shift it towards cheaper ones. The differences arise in the amount of energy managed and in the cost of such management. For the energy storage case, the management cost of interest is its payback time related to the electricity bill reduction. The manageable load does not usually have a marginal cost of utilization and little or null investment cost but is not always available.

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II. Literature Review

A. Energy Storage

There has been an abundance of studies on the price-dependent electricity consumption with energy storage for different national and regional markets, including a diverse array of storage technologies and regulation schemes. The trend increases its popularity since the energy storage prices continue to decline [1] and its use for load shifting and arbitrage becomes more attractive.

The use of load shifting for the China Southern Power Grid was studied in [2]. This work proposed an energy storage control strategy based on dynamic programming, where the number of charge-discharge cycles and depth of discharge were considered. The price forecasting was done via linear regression analysis.

Another load shifting case was studied in [3], where community energy storage was used. In particular, in this work, there was a comparison between different technologies, like lead-acid (PbA) and lithium-ion (Li-ion), and storage sizes for the UK NETA electricity market. It was claimed that despite PbA batteries seemed to be more attractive based on the optimal capacity to manage, in projection to 2020, the PbA and Li-ion will have comparable profitability since Li-ion will significantly decrease its capital cost per unit.

In [4], the electrical energy price arbitrage with the help of pumped hydroelectric storage (PHES) was studied for 13 markets of 11 countries. The study's main result was the optimal dispatching strategy, which allowed to profit from the use of energy storage. However, as the authors claim, it is only possible under the assumption that either the actual future prices are available or the dispatching operator has exact forecasts. In other cases, the profits can be significantly decreased or even turn into losses.

The use of compressed air energy storage (CAES) in Turkey's market was analyzed in [5]. This work implemented a mixed-integer linear programming (MILP) model and derived the price predictions based on a discrete-time Markov chain (DTMC). The study shows that energy storage could be implemented under the current energy price levels, but the payback period would be relatively high (11 years).

The Pennsylvania-New Jersey-Maryland interconnection (PJM) arbitrage study with the help of storage was conducted in [6]. The study was done for the day-ahead market (DAM) and real-time market (RTM) for 7 395 different locations throughout the PJM with the help of local marginal price (LMP) data of 2008-2014. The break-even cost for energy storage was determined, below which storage becomes unprofitable.

The storage study on the Iberian market, implemented in [7], reveals that with the current pace of technological progress in round-trip efficiency, the number of life cycles, and cost, will lead to energy arbitrage viability from 2024. But for now, as the economic analysis concludes, the arbitrage business profitability is negative. The model includes the deterioration of the storage capacity, assumed proportional to the number of cycles. The battery's useful life is taken as the number of cycles until the capacity reaches the 20% of its initial value.

The modeling of electric energy storage units has been approached by multiple studies. In this study, we model the energy storage as generic and ideal, i.e., its performance is considered constant through time and operating conditions [8]. However, more detailed battery models that considers efficiencies and charging and discharging dependence with state-of-charge [9], [10] could be applied without loss of generality.

B. Manageable Loads for Demand Response

Shifting power consumption patterns can help reduce electricity charges; this can be done by relocating electricity usage from hours with high energy prices to those with lower ones. One possible tool to manage consumption is to use the equipment that must consume a given amount of energy with flexible usage time. Such type of load has been extensively studied; its definition and classifications can be found in [11]. The most promising examples of such load are heating, ventilation & air conditioning (HVAC) systems. Thermostatically controlled loads (TCL) can be turned on before starting the working day to cool the rooms for its subsequent shutdown during peak price hours while maintaining a comfortable temperature regime. Such principle can be used, for example, with underfloor heating, as in [12]. In this study, thermal inertia made it possible to switch off the heating for the peak load duration and turn it back on after the peak while maintaining the temperature within a comfort boundary.

In [12], the energy cut off during the peak has not been recovered during off-peak hours. Still, the approach related to load redistribution can be extended to those types of managed loads that strictly require a specific amount of energy consumed per day. An example of such a case may be a refrigeration system. A normal shutdown during peak hours without later energy compensation gives a noticeable deterioration in temperature conditions. The optimal HVAC dispatch modeling was done in [13], where the comfort temperature was maintained at an adequate level while the cost of dispatch was minimized.

III. Russian Electricity Market

A. Market Reforms

The electricity sector of Russia has been actively reformed since the '90s. The first separation on the wholesale and retail markets was done in 1995; then it was followed by two main reforms in 2003 and 2006. The industry itself had been almost entirely state-owned. With the dissolution of the monopolist "RAO UES" company in 2008, Russia's electrical energy industry privatization came to an end. The industry was divided into many companies, differing based on the types of activities and geographical location. In 2011 the most critical part of the pricing policy liberalization occurred when all the consumers (except for residential) were allowed to buy the electricity at unregulated prices; such reforms allowed to attract significant investment to the Russian electrical energy sector and increased its effectiveness. In 2012, a government decree introduced a new pricing policy for the retail market, which consisted of several price categories [14]. This policy made the electricity tariffs more time-depended, especially for large consumers.

B. Retail Market and Price Categories

In total, there are six price categories on the Russian electric energy retail market [15]. They range from the first category, a single tariff on electricity, to the sixth category, where the price consists of three time-dependent components: energy, capacity, and transmission. There is also a cost for not matching the hourly plan of the load profile in the sixth category. The total cost of electricity can be written as:

$$C = C_E + C_C + C_T \tag{1}$$

where C_E, C_C, and C_T are respectively the costs related to the energy, capacity and transmission price components. The example of the price distribution over the month is presented on the Fig. 1. For the flexible price categories the payment for power consumption in certain hours (capacity and transmission) represents nearly 2/3 of the electricity bill. As it will be shown in this work, load shifting is the main mechanism for cost reduction under the current structure of the Russian retail market.

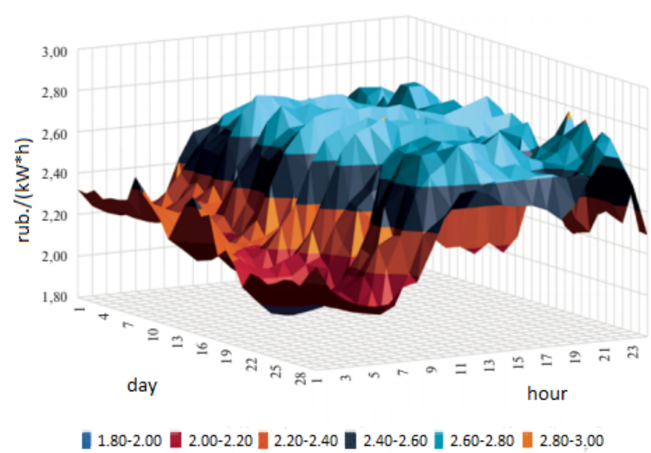

Figure 1: Typical hourly prices over a month [16].

C. Demand Response Program

The demand response (DR) program appeared in the Russian electricity sector in 2017 as a pilot project. Since then, it has attracted significant attention from the industry sector and other electricity consumers. Smaller consumers who cannot participate in the wholesale market participate in the program via aggregators representing them. In this program, consumers are paid based on the amount and number of hours of power reductions. The program's operation consists of the following actions: the system operator (SO) notifies the consumers about the load reduction requirements, the consumer confirms availability, and the next day it satisfies the undertaken responsibilities. To confirm the fulfillment, the SO builds a baseline, a load profile that the consumer would have if there were no DR event, and compares it with the actual load.

IV. Mathematical Model

A. Objective Function

To represent the benefits of demand response usage in the Russian electricity market, we consider consumers belonging to the 4th pricing category with hourly energy tariff, capacity tariff (based on peak hour consumption), and a two-rate transmission tariff [15]. The hourly energy payment is calculated as the sum of the products of cost and consumed kilowatt-hours. The capacity fee is defined as the product of the capacity rate for the average monthly consumption during peak hours of a guaranteed supplier (GS). The two-rate transmission tariff is the direct payment for the transmission of a certain amount of power, calculated hourly and paid based on hourly costs. The transmission tariff also includes the power grid maintenance fee, defined as the defined charge multiplied by the average monthly value of the maximum daily consumption during planned peak load hours (PPLHs). PPLHs are monthly defined by the System Operator (SO). These rules allow to write each component of (1) as (eqs. (2) to (4)) [16]:

$$C_E = \sum_{t=1}^{24} \sum_{d=1}^{m} W_{td} c_{Etd} \tag{2}$$

$$C_C = \sum_{t=1}^{24} \sum_{d=1}^{m} P_{td} \tau_{td}^{P} c_C \tag{3}$$

$$C_T = \sum_{t=1}^{24} \sum_{d=1}^{m} P_{td} \tau_{td}^{T} c_T \tag{4}$$

where m is the number of days in a month, W_{td} and c_{Etd} are energy consumption and its price per MWh at hour t and day d respectively, P_{td} is power consumption at t and d, τ_{td}^{P} is a binary parameter representing the peak hours of GS, similarly τ_{td}^{T} represents the have maximum daily consumption within the range of PPLH (once per day) and 0 for all other hours. c_C and c_T are the capacity and transmission prices per MW, divided by the number of days. The power consumption per hour is given by:

$$P_{td} = P_{td}^{0} + x_{td}, \quad \forall t \in (1, 24), \quad \forall d \in (1, m) \tag{5}$$

where P_{td} is the actual power consumption at the hour t of a day d, P_{td}^{0} is the scheduled power consumption, and x_{td} is a corrective value, which results either from manageable loads or energy storage.

B. Constraints

There are also several constraints for the value of x_{td}, for the integrated manageable load they are the following:

$$\sum_{t=1}^{24} x_{td} = 0, \qquad \forall d \tag{6}$$

$$\underline{P}_l \leq x_{td} \leq \overline{P}_l, \qquad \forall t, d \tag{7}$$

where $\underline{P}_l$ and $\overline{P}_l$ are the manageable load's lower and upper bounds. Constraint (6) represents the integrated nature of the managed load: the reduced electricity consumption during peak hours, must be compensated during other hours.

For the energy storage the constraints (6) and (7) become [7]:

$$x_{td} \leq (K - L_{(t-1)d})/(1 - r) \quad \forall t, d \tag{8}$$

$$x_{td} \geq -L_{(t-1)d}(1 - r) \qquad \forall t, d \tag{9}$$

where K is the battery capacity, r is the loss of energy factor due to the power electronics and the conversion process and $L_{(t-1)d}$ is the battery charge level at the previous hour:

$$L_{(t-1)d} = \sum_{i=1}^{t-1} x_{id} + \sum_{i=1}^{24} \sum_{j=1}^{d-1} x_{ij} \tag{10}$$

The constraints reflects the capacity of the storage, that is assumed to be constant along the time of modeling. Constraint (8) implies, that it is not possible at the hour t to store more, than the capacity left unused, assuming the conversion loss. Constraint (9), instead, implies, that no more energy can be withdrawn, than that stored, again, including the unit's losses.

V. Experimental Results

Model implementation was done Python language in the Google Colab environment. Optimization was carried out using the cvxpy library with ECOS (embedded conic solver). To be able to represent both the capacity and transmission expenses, the time frame of analysis was set for one month.

The consumer is an industrial building with 5 working days and 2 weekend days. Its daily peak load reaches 40 MW. The manageable load cap P_l was assumed to be the same for all hours at 6 500 kW. This value was chosen based on the ratio of underfloor heating shear load to full load at peak time in [12]. The storage capacity was chosen as 1 MW power and 4 MWh capacity at a cost of 63 million rubles.

The result of solving the optimization problem with objective (1) and constraints (6)–(7) for the case with manageable load is shown in Fig. 2.

Electricity consumption was reduced during the day and increased during the night, according to the behavior of the electricity price. It can be seen that consumption during PPLHs and HP peak hours was reduced, but was compensated in the

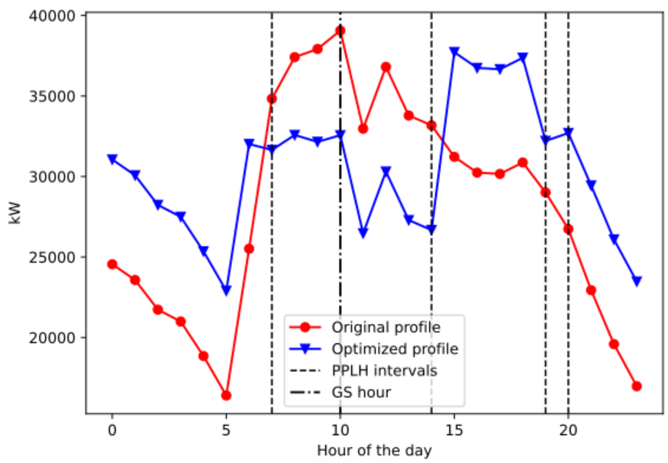

Figure 2: Real and optimized profiles for the manageable load.

TABLE I: RESULTS FOR THE MANAGEABLE LOAD.

	Energy, mln. rub.	Capacity, mln. rub.	Transmission, mln. rub.	Total, mln. rub.
Real profile	21.650	32.306	36.655	90.613
Optimal profile	20.981	26.190	30.905	78.077
Difference	0.668	6.115	5.750	12.535

rest of the time by increased consumption in other hours. Electricity fees and their components before and after the operation optimization are presented in Table I. As seen in the table, savings can be significant, but this method is suitable only for those cases where the consumer has a load with properties allowing to distribute its consumption over time.

Payment for different cases were compared in the Fig. 3. We can see, that the most part of savings comes exactly from avoiding capacity and transmission payments. This is explained by the reduction of power consumption during peak hours, since the consumed energy does not change between scheduling modes.

Load shifting with the storage is more universal in terms of technical execution, but this method, as will be seen later, has problems with payback. In addition, the storage has an efficiency that is associated with inverter and power electronics losses, assumed at 10%. In addition to the usual shifting, the current demand response mechanism was used during optimization. In the considered month of May in 2020 there were only two such cases, on May 15 and 29, the median cost of 1 MW of responsive load capacity is approximately 300 thousand rubles, this value will also be included in calculation of profit and payback time for the storage unit.

The energy storage charges during the night (second to fifth hours) at maximum capacity, when there are no PPLHs and GS hours. Then it discharges during the tenth hour as it is the most expensive: it is both GS hour and maximum PPLH hour. After this, the storage charges to the maximum to maintain the DR event, since it will last for 4 hours. The remainder of the time, the storage performs price arbitrage.

Savings from profile redistribution are expected to be lower

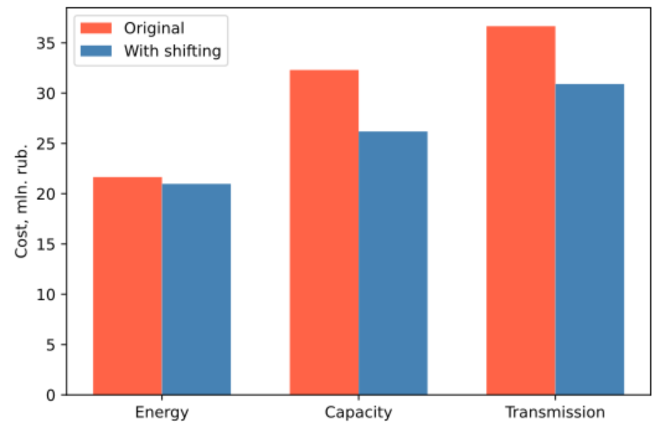

Figure 3: Bar chart with cost shares for different cases.

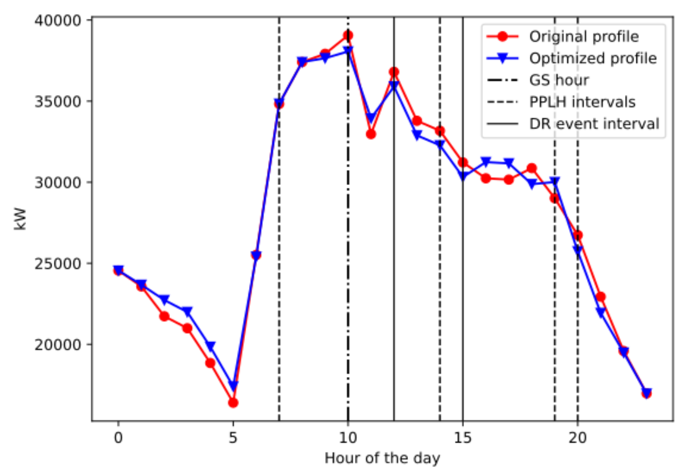

Figure 4: Real and optimized profiles for the storage.

due to the limited storage capacity, Table. To assess the profitability of energy storage installation, we assume the storage price to be 325$/MWh (26 815 rubles/MWh)[1] [1]. Thus the overall capital cost for a 4-hour battery system is 107.26 million rubles. The total monthly profit from using a storage unit would be about 2 million rubles. Thus, purchasing the pay-back time for a storage unit is about 53 months or 4.4 years.

VI. CONCLUSIONS

We have presented an economic analysis of the potential benefits of employing demand response in the Russian retail markets and tested two possible cases: controllable loads and energy storage usage.

Controllable loads that can be shifted at peak hours are an effective tool to decrease electricity payments. As reported, the consumption shift to hours with less expensive energy tariffs does not bring significant benefit (approximately 5% out of overall savings), which means that most of the benefit comes

[1]The exchange rate on 25 October 2020 is 1 US dollar = 76.18 Russian rubles

TABLE II: RESULTS FOR THE ENERGY STORAGE.

	Energy, mln. rub.	Capacity, mln. rub.	Transmission, mln. rub.	Total, mln. rub.
Real profile	21.650	32.306	36.655	90.613
Optimal profile	21.589	31.370	35.906	88.866 - 0.27
Difference	0.061	0.935	0.749	1.746 + 0.27

from avoiding consumption at capacity-penalized hours. In the studied case, this period coincided with the building's load peak and with the maximum consumption within the PPLH interval.

The analysis showed that a storage unit is a profitable investment for a large consumer with a presence of highly sharp peaks. We also have demonstrated that such benefits can be enhanced by the participation in the mechanism of demand response proposed by the system operator. As with the controllable load, the benefit from the hourly energy price difference was minor, and it is not profitable to use energy storage for this particular term of the cost function.

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