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ANALYSIS OF THE REQUIRED ENERGY STORAGE CAPACITY FOR BALANCING THE LOAD SCHEDULE AND MANAGING THE ELECTRIC ENERGY DEMAND OF AN APARTMENT BUILDING

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Abstract: The rapid and voluminous development of renewable generation, and its stochastic nature, creates problems in terms of maintaining frequency and balance in the power system. In this work, demand response management and the use of the concept of demand response are discussed in detail. The potential of using prosumers to maintain the power balance in the power system is considered. The analysis of prosumers was carried out on the basis of a study of load schedules of typical consumers with software that forms schedules taking into account socio-demographic characteristics.
Keywords: energy storage, Smart Grid, load schedule, household consumer, power system

1. INTRODUCTION

Nowadays, the most developed countries are rapidly increasing the volume of electricity production based on renewable energy sources (RES) (Fedorchuk et al., 2020; Keles, 2012), which firstly includes an increase in the share of energy generation by solar and wind power plants. An increase in the share of its generation causes problems with maintaining the balance (Miroshnuk and Tymchuk, 2013; Drabecki and Toczyłowski, 2022) of generation and load. The reason for this is the stochastic nature of the RES generation. There is a significant number of variants to compensate for these problems:

- maintaining balance through existing traditional power plants with a high rate of power change;
- installing energy storage system (Mohammadi-Ivatloo and Jabari, 2018; Al_Issa et al., 2022) (ESS) facilities at generation sites;
- disabling part of the generation capacity on renewable energy sources;
- real-time selling or buying energy from neighboring countries;
- using demand response management.

Demand response management (Merrad et al., 2022; Mishra et al., 2022), namely the use of the concept of prosumers, is the main study of this article.

Prosumers, as participants in processes in electric power systems, are able (Espe et al., 2018; Ikonnikova et al., 2022; Sioshansi, 2019; Padmanaban et al., 2022; Xia-Bauer et al., 2022) to function in contemporary traditional electrical systems, provided that additional opportunities for market operations are obtained, however the advantages of Smart Grid (Padmanaban et al., 2022; Khasawneh et al., 2021; Mahmood et al., 2017; Kuźniak et al., 2022) greatly increase their efficiency.

We considered the potential (Sioshansi, 2019; Xia-Bauer et al., 2022; Agwan et al., 2021; Medveď et al., 2021; Balázs et al., 2021; Antal et al., 2022; Zdonek et al., 2022; Pressmair et al., 2021; Weiß et al., 2022, Tutak et al., 2020) of using prosumers in order to align load graphs and sustain the balance of active power at the Power Grid. For this purpose, we examined methods and tools for analyzing the modes of operation of ordinary consumers and prosumers. Nonetheless, getting actual consumption graphs of a residential area or even an individual house is a difficult task that requires a significant number of approvals and at the same time gives information only about individual objects. That is why the analysis of the modes of prosumers operation is based on the research of load graphs of typical consumers based on software for generating load graphs (Mishra et al., 2022; Miroshnyk et al., 2023), taking into account the socio-demographic characteristics of households and international experience in managing demand response.

2. ANALYSIS OF CONSUMPTION GRAPHS

Consider prosumers as an element of the Power Grid and methods for studying the potential of their involvement in the tasks of maintaining power balance or aligning load graphs. A prosumer (Sioshansi, 2019; Tymchuk and Miroshnyk, 2015; Qawaqzeh et al., 2021; Parag and Sovacool, 2016; Jacobs, 2016, Ulewicz et al., 2021) is a relatively new term that combines "generation" and "consume". A prosumer differs from the traditional consumer in that they not only consume electricity but also have the ability to accumulate or generate it. There are several options for using excess energy by prosumers, namely selling it to the Power Grid and targeting it to individual consumers. The advantage for the Power Grid occurring out of prosumers is improving the efficiency of the Power Grid:

- maintain a local demand and supply balance for energy resources;
- reduce the load at distribution networks due to local changes in the consumption and operation of energy storage systems.

The presence of a control system based on two-way connections, intelligent measuring staff, and remote control means is one of the key conditions for using the concept of prosumers. Integration of prosumers into the Power Grid provides the following advantages:

- the ability to maintain a balance of electricity consumption at the local level;
- the involvement of household consumers in direct or indirect participation in the electricity market;
- the reduction of the load on medium and low voltage distribution networks, which allows to prevent their overload and reduce losses on energy transmission;
- the reduction of emissions of harmful substances from traditional power stations through the use of prosumers RES.

The use of prosumers to solve the problem of maintaining the specified parameters in Power Grid has certain limitations. The first limitation is the low efficiency of involving individual consumers. This limitation is due to the significant unit cost of equipment and low capacity to change the power level. The second limitation is based on the significant complexity of analyzing and managing a large number of prosumers. It was decided to analyze the potential of using a multi-storey building as a prosumer with common energy storage. For this purpose, an analysis of socio-demographic indicators of the Kharkiv region was carried out. The economic level of people who could live in such a house was also taken into account.

3. SOCIO-DEMOGRAPHIC AND ECONOMIC ANALYSIS

To form a load graph, it is necessary to take into account a significant amount of information. Domestic load is characterized by a much greater variety of influence factors and internal features in contrast to industry, agriculture, and utilities. In addition to weather conditions, the composition of consumer families, housing characteristics, and electrical appliances used, the level of energy consumption is decisively influenced by human behavior. An apartment multi-storey building in the city of Kharkiv was chosen as an object of the research. The class of the house is chosen "business" since the prosumers belong to the category of wealthy citizens. The parameters in table 1 (Karaiev et al., 2021) correspond to this house. The number of families in the house is determined as 100, according to the above parameters.

Table 1
Building options

Parameter	Characteristic
Technology of construction	monolithic frame, brickwork
On the new building material	silicate ceramic brick
Number of apartments in the building	more than 100
Number of apartments on the floor	up to 8
Minimum area per 1 inhabitant	more than 40 m^2

For the selected 100 families, it is important to determine the composition and take into account the number of working family members. The data from the State Statistics Service of Ukraine show that 52.5% of households are in large cities and the average family size is 2.42 people [www.ukrstat.gov.ua]. Table 2 shows the social demographic characteristics of Ukrainian households in 2020.

Table 2
Social demographic characteristics

Family composition	Share of households
One person	**21.2%**
Two persons	**35.3%**
Three persons	**27.7%**
Four or more persons	**15.8%**
Families with children under 18	**33.9%**

Based on the above data, the composition of families in the house: 21 out of one person, 35 out of two, 28 out of three, 16 out of four.

4. LOAD GRAPHS

Existing methods of modeling household consumer load involve the use of long-term data by consumption information or data about installed equipment. It is possible to analytically evaluate or predict the basis of these data. The methods of modeling household energy consumption can be divided into two categories, conventionally indicated: "from top to bottom" and "from bottom to top".

The first method involves a primary study of the energy consumption of the region with the subsequent transition to individual consumers using additional parameters. Typical load graphs are one of the main examples of this method.

The second method extrapolates the graphs of individual consumers to the country level. This method requires much more information but increases the accuracy of calculations.

We carried out the analysis by the second method. An "LPG electric load generator" was used for this purpose. This method allows you to get a load graph based on family composition, available appliances, and the behavior of each member of the household. Each person receives an adjust with tasks and deadlines. For example, cooking should take place twice per day and take a total of 1.4 hours per day. Load graphs are generated for each family type using LPG (Miroshnyk et al., 2023). At the same time graph regeneration gives each time a new look of the loading graph, however, keeps characteristic features. For the study, the number of graphs according to the number of families was generated and processed. This allowed us to create typical graphs for each type of family. They are presented in Figure 1 (working day) and Figure 2 (weekend day). The information received was processed at the level of individual consumers and the house as a whole. For this purpose, annual data was used in increments of fifteen minutes for each of the families. During the analysis, the maximum, minimum, and average consumption levels were found for individual consumers and the building as a whole. The amount of energy required for balancing was chosen as the maximum daily consumption above the average level. The highest level of consumption was observed in winter and spring. The results of the research are reflected in Table 3. It should be noted that a bigger level of consumption in three people’s apartments is due to existing electrical appliances and behavioral features.

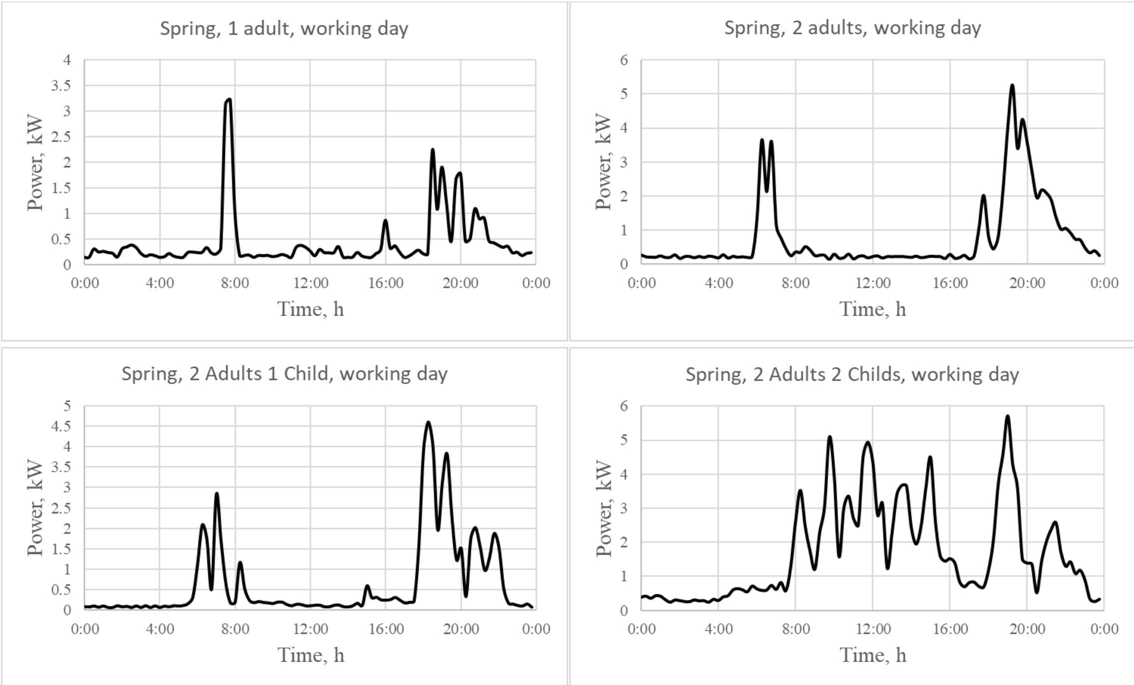

Fig. 1. Load Graphs of Typical Consumers (working day)

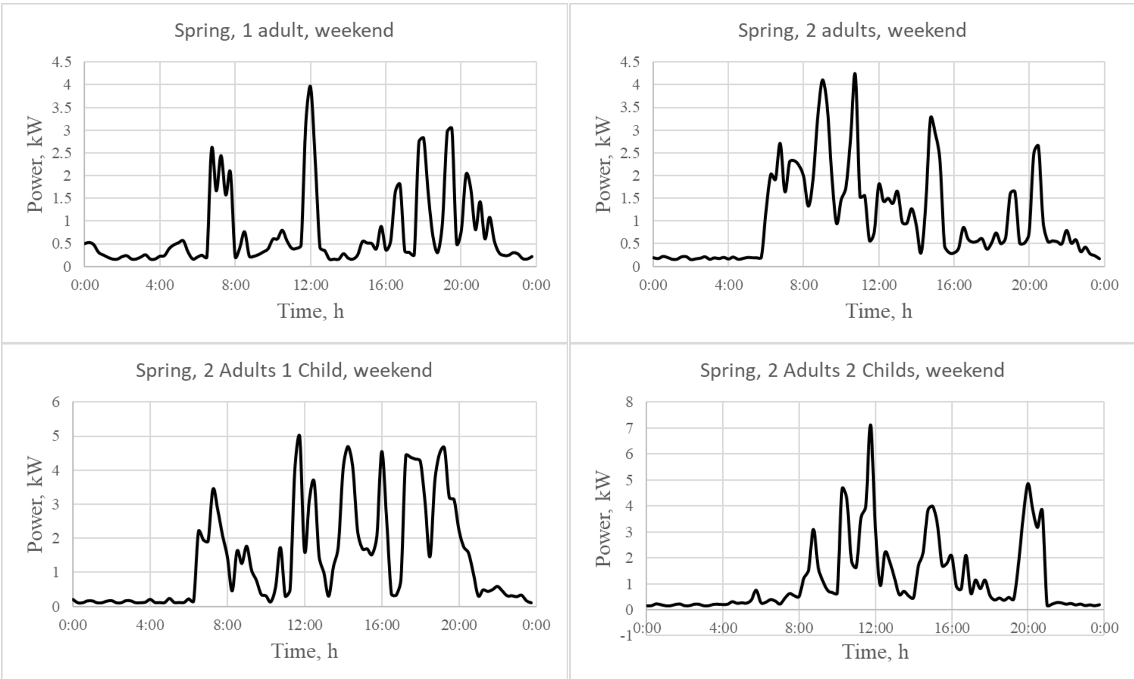

Fig. 2. Load Graphs of Typical Consumers (weekend day)

Table 3

The amount of energy required to align daily load graphs, kWh

Object	Winter	Spring	Summer	Autumn	All year round
One person	45.6	29.12	22.5	26.1	45.6
Two persons	43.9	38.6	48	32.7	43.9
Three persons	54.2	59.3	55.1	56.6	59.3
Four or more people	42.8	51.5	46.5	50.71	51.5
Building	5191	4861	4353	4515	5191

Based on the obtained annual data, it is determined that the required amount of energy to equalize the load graph of the whole building is 5191 kWh. However, the depth of the discharge greatly affects the duration of storage system use. For lithium-ion ESS, it is recommended a discharge of no more than 20%. Thus 5191 kWh is 80% of the required charge. According to that ESS volume should be increased to 6490 kWh. Additional consideration of the minimum charge-discharge efficiency factor of 80% increases the required ESS volume to 8113 kWh. It should be noted that the actual required parameters of the ESS will differ from those obtained due to the mismatch of load peaks. However, a more accurate calculation requires a significant amount of additional information and long-term data collecting. The installation of such ESS will allow you to fully balance the load graph and further unload the power supply network. Thanks to the analysis, it is also possible to find out the required ESS capacity for each individual consumer. This solution is less efficient than connecting the whole building because specific consumption of energy increases with decreasing capacity. ESS with the calculated volume can not only be used to balance the load graphs, but also provide additional services for additional services electricity market. This is possible because ESS was selected by peak parameters. In this scenario, the residents of the building become active consumers.

5. CONCLUSIONS

The article analyzed the load graphs of a multi-storey apartment building based on modeling taking into account the living standard and behavioral characteristics of residents. The data obtained in the research allow you to determine the necessary parameters of the energy storage system to align load graphs and perform the function of a prosumer. Further steps in the study will be the analysis of real data and the assessment of the economic efficiency of using a common energy storage device for the whole building.

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