Digital platform for management of the regional power grid consumption

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Abstract. One of the trends in the current energy transition is decentralization of power management and diversification of power generating facilities in terms of both the level and the amount of installed capacity. This puts forward new requirements for interaction of the consumer who owns the pool of electric power equipment with the power supply company. One of the foundations of this interaction is power management and monitoring. An increased number and type of receivers and sources of electricity, and significantly increased data flows on energy consumption necessitates an appropriate digital platform to solve problems of energy consumption management and monitoring. The digital platform determines an appropriate environment for interaction between the consumer and the power supply company, and most significantly, the conditions for improved energy efficiency of the entire process of generation, transmission and consumption of electricity.

1. Introduction

Advanced information technologies at the beginning of the 21st century shaped new directions for industrial and economic development. One of these directions is digital energy. It is conceptually based on phased transition to completely new technologies in the field of distributed generation, power grid facilities, renewable energy sources, energy storage, etc. In digital energy, much attention is paid to the conceptual aspects of the formation of digital energy platforms, energy services and active power grids, and decentralized management of functioning processes [1–5].

The study of regional power grid (RPG) in terms of the transition to digital energy identified a need to develop a software and hardware complex for monitoring power consumption, which includes services to ensure interaction of consumers with the power-supply system.

Despite the continuity of the processes of generation, transmission and consumption of power, their target setting is different. The purpose of power supply is to provide consumers with electricity of the required quantity and quality, i.e. maintaining the specified parameters of electricity at the point of intersection between the power system and the consumer. The purpose of the power consumption process is to reduce it to the minimum, while ensuring a normal mode of functioning of the consumer that does not go beyond the established norms. Different target settings require different methodological approaches [5, 6]. In the study of the process of power consumption, the focus is placed on the consumer that features availability of individual metering, and a control subsystem
represented by the person responsible for the power industry, the owner or another official. System-level optimization implies that an interconnected set of electricity consumers, which exhibits technocenological properties and functions in conditions of unified control systems and comprehensive support, forms a regional power grid [5].

Methodological differences between power supply and power consumption are reflected in the concept of the architecture of the Internet of Energy [7]. It describes the main ideas of the transition to new energy, which stems from digitalization, decarbonization, decentralization and diversification in terms of types and amount of installed power capacity of power sources. The main component in the architecture of the Internet of Energy is an energy unit, a pool of electrical power equipment, which has transaction (settlement of accounts for rendered services), information (transfer of control commands) and power interfaces. The study proposes forms of interaction between energy units when buying and selling electricity. In addition, the concept deals with service applications (avatars), which independently build interaction between users of the Internet of Energy, energy supplying companies among them. In this context, an obvious analogy can be found between the energy unit in the architecture of the Internet of energy and the object (consumer) of the regional power grid.

As a result of the study conducted by the scientific school of Professor V.I. Gnatyuk [5, 8, 9], the scientific and methodological foundations have been developed for the RPG power management platform based on the digital twin of the technocenosis (Figure 1) [9].

![Figure 1. Conceptual model of the digital platform.](image)

The key place in the proposed platform is occupied by the digital RPG twin based on the technocenosis model, and power consumption management implies the use of a static and dynamic power consumption model, difflex, ASR, GZ and ZP analysis procedures, and a system of quality indicators, costs and efficiency.

2. Subsystem for monitoring the regional power grid consumption
The power consumption monitoring subsystem includes a set of software modules that identify anomalies in data, implement short-term, medium-term and long-term forecasting, and construct
typical load profiles and highlight trends, rationing, analysis and planning (Figure 2).

![Figure 2. The structure of the power consumption monitoring.](image)

Each individual platform program fulfills its own tasks. Their order and interaction can be determined automatically or by users of energy units. The main theoretical provisions employed to develop programs for a digital platform include components of mathematical statistics, functional, combinatorial and vector rank analysis, as well as time series analysis [5, 8, 10].

The first program is designed to identify anomalous values – data with values significantly deviating from the distribution center (Figure 3).
This program should be used at the stage of initial processing and in case of slightest doubts about the correctness of the initial data. If the user (analyst) does not take measures to identify and correct outliers, he must be aware of the fact that estimates and subsequent conclusions may be distorted, and an erroneous managerial decision will result in an unaccounted ‘cheap’ outlier that will turn to be ‘costly’.

The second program is designed to identify long-term stable properties in the data on power consumption, i.e. a trend (Figure 4). This approach should be used to plan the relationship between the energy unit and the power supply company.

For example, it will be useful to consider the trends of the energy unit and trends of the economic development of the distribution grid. Within the module, a trend is identified and detected only. The task of automatic selection of the mathematical model of the trend is not considered, and the analyst has to resort to his experience and creativity to fulfill the task.

The third program provides the predictive values of electricity consumption or other resources (Figure 5). When developing the program, the ability of forecasting algorithms to select the parameters of predictive models with the best predictive properties without user participation was considered. The algorithms of forecasting methods implemented in the module are divided into two groups: technocenological methods that consider systemic properties of the distribution grid and energy units, and classical methods that take into account statistical properties of the time series. The choice of methods depends on the tasks the user faces. When solving problems related to medium-term or long-term forecasting of power consumption of the distribution grid or energy units, technocenological methods should be used. For operational forecasting issues with regard to the daily load profile, classical methods should be employed, which are based on time series analysis techniques, regression models, artificial neural networks, etc. In addition, short-term forecasting considers many contributing factors, primarily meteorological ones, such as wind direction and speed, temperature, humidity, atmospheric pressure, and light intensity (cloudiness).
**Figure 4.** Fragment of the workstation for constructing a trend.

- Selecting methods of constructing a trend and typical load profiles
- Actual consumption
- Trend

**Figure 5.** Fragment of the workstation for forecasting energy consumption.

- G-methods selection panel
- Upper limit of a 95% variable confidence interval
- Accounting for meteorological factors
- Lower limit of 95% variable confidence interval
- Forecast

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The fourth program enables constructing a typical load profile based on the available statistics (Figure 6).

Grouping of daily profiles uses the hypothesis of their compact location in the multidimensional space of characteristics. Within the framework of the issues being solved, the characteristics are defined as the value of the power consumption for the daily profile at a fixed time point. After reducing the length of the initial data, the images are grouped based on the analysis of the principal components by methods of cluster analysis. A typical profile is formed for each cluster based on averaging the daily load profiles. It is assumed a priori that the division of typical load profiles in the RPG is associated with working days and weekends (holidays). Due to this, images are divided into two clusters. If necessary, the user can change the number of clusters and build the required number of typical load profiles.

Thus, the service application of the digital platform of power consumption management to monitor RPG power consumption completes application tasks and serves as a tool for interaction between the RPG, energy units and users (owners) of power equipment.

3. Implementation of digital programs for power consumption management of the regional power grid
The digital programs for power consumption management of the RPG were implemented using modern programming tools. The C# language was employed to develop CAD workstations shown in Figures 3–6.

Based on the data of regional statistics [11], trends in electricity consumption in Russian regions were identified for a quarter and for a year in the period from 2012 to 2019. In addition, images of typical monthly electrical load profiles were obtained.

When forecasting power consumption for the medium and long-term period, the obtained values were estimated with respect to absolute and relative errors. The technocenological method with a fixed first point (FFP) and the method without a fixed first point (WFFP) were used as forecasting methods. To assess the forecasting accuracy, the annual electricity consumption data from 2017 to 2019 were taken as validation data. Forecast was made using annual data on electricity consumption in 2012–2016. When comparing the predicted values for three years ahead (2017–2019) with those verified, the
total absolute error (sa) and the average relative error (so) were calculated (Table 1).

### Table 1. Assessment of the accuracy of forecasting.

| Parameter     | WFFP | FFP |
|---------------|------|-----|
|               | 2017 | 2018 | 2019 | 2017 | 2018 | 2019 |
| sa, $10^4$ kWh| 4.4  | 4.2  | 4.8  | 3.1  | 3.8  | 4.0  |
| so, %         | 3.3  | 3.9  | 4.2  | 2.9  | 3.3  | 3.6  |

### 4. Conclusion

Thus, implementation of the digital programs for management of electricity consumption of RPG yielded the development of CAD workstations for users of the software and hardware complex. The workstation was tested based on the data of regional statistics in Russia, trends in the power consumption of Russian regions were determined for a quarter and for a year, and monthly typical load profiles and forecast values were obtained for the medium and long-term period.

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