Analysis of schedules and load indicators for the choice of the generation composition in the wind-diesel complex

J E Shklyarskiy and D E Batueva

Saint-Petersburg Mining University, 2, 21st Line, Saint Petersburg, 199106, Russia

E-mail: dasha-batueva4@rambler.ru

Abstract. The energy consumption of villages in the Arctic is characterized mainly by household consumers. The load schedule of such consumers has a characteristic shape and is determined by the heating season in the winter and a sharp change in external climatic conditions in the spring and autumn. The load graphs of a village in the Arctic are analyzed in an article, maximum average consumption is 369 kW in January-February. We study such indicators of load graphs as average load, rms load, variance of the load graph and standard deviation of the load from the average. As a result, it was found that the standard deviation of the load has large values precisely in the winter months and the spring-autumn period, when energy consumption changes significantly, and, therefore, this indicator must be taken into account when choosing the composition of the generation in the wind-diesel complex.

1. Introduction

Developing resource-rich countries face vital challenges related to economic diversification, resource replenishment, air quality, health problems, and rapidly growing domestic demand for cheap energy and water resources, which are critical factors for energy and the environment. Therefore, in order not to be vulnerable, it is necessary to take appropriate measures in the direction of developing policies and practices to promote sustainable development by harmonizing economic growth, protecting the environment and social integration.

Power supply of facilities in the Russian Arctic is carried out mainly in isolation from the Unified Energy System of Russia. The source of electricity is diesel generator sets, characterized by a large motor resource (diesel generators are oriented to long continuous operation) and low operating costs.

The maximum diesel fuel consumption in 2018 was noted in the Republic of Sakha (Yakutia) - 69.3 thousand tons among all regions of the Far North and the Arctic of Russia. An indicator such as “unit actual costs for the production of 1 kWh of electric energy at a generating facility, rubles/kWh” characterizes the cost of production of 1 kWh of electricity at the generating facility. The specified indicator takes into account fuel costs, expenses on the wage fund, maintenance and repair of fixed assets and other expenses. The maximum value of this indicator in 2018 reached 42.66 rubles/kWh in the Republic of Sakha (Yakutia). This means that the average actual cost of generating 1 kWh of electricity is higher than the single-rate tariff for consumers by 37 rubles [1]. Also, the share of fuel costs varies from 30–40% in the structure of expenses for electricity generation in the Republic of Sakha (Yakutia), which is mainly related to the remoteness of these territories from large fuel production and storage centers, complex logistics and the presence of seasonality of fuel supplies, which leads to higher fuel prices than the Russian average.
Therefore, more and more often in the scientific community and in the production companies the issue of using wind power plants (wind turbines) as the main source of power supply for these territories is being discussed, which will reduce the volume of deliveries and diesel fuel costs, reduce the cost of electricity generated and, moreover, reduce the impact of emissions greenhouse gases to the environment.

The demand for the introduction of renewable energy in the regions of Russia with decentralized electricity supply was formed against the backdrop of the transition to digital energy and intelligent electric networks, one of the prerequisites for which were various global and local reasons [2]. They are:

- Economic - an annual increase in energy tariffs and population expenses for their payment; low energy efficiency of the Russian economy; industry dependence on foreign technology and equipment [3].
- Environmental - electricity is the source of 42% of anthropogenic greenhouse gas emissions (decarbonization trend); an increase in the risk of accidents by 2030 to 80% due to the deterioration of the technical condition of the equipment because of insufficient capital investments.
- Technological - power shortage; the need to develop innovative technologies, devices and materials; large-scale development of distributed energy and electric transport (the trend towards decentralization); distribution of technological capabilities for the formation of the concept of an active consumer; infrastructure obsolescence (depreciation of the fuel and energy complex reaches 66%) [4,5].
- Legal - the need to combine the efforts of state authorities and the industry business community, research and educational organizations [6].

1.1. Electricity consumers

Renewable energy facilities operate in only a few regions of the Russian Arctic (Murmansk Region, Nenets Autonomous Region, Republic of Sakha (Yakutia)), and foreign companies are manufacturers of components for these facilities. But it is worth noting that research in the field of application of wind turbines in the Arctic, and especially in coastal areas, is extremely popular [7, 8].

The climatic conditions in these territories are very variable, the wind speed is almost always sufficient for the operation of wind turbines (at least 3-5 m / s depending on the region), it is also necessary to consider the possibility of accumulation of excess electricity.

The main consumers of electricity in the Arctic are either large industrial complexes operating in extreme climatic conditions, such as the Yamal-LNG natural gas production, liquefaction and supply plant, and hydrocarbon production on the Arctic shelf on an offshore ice-resistant stationary Prirazlomnaya platform and others [9]. Their power supply is carried out from their own sources of electricity. However, there are examples when wind turbines are additional sources in industrial facilities in auxiliary power supply systems. For example, in the Khabarovsk Territory, a wind power installation with a rated power of 100 kW (at an output voltage of 380/400 V with a frequency of 50 Hz) is integrated into the existing power supply circuit of the Unchi base of the Svetloye company to save diesel fuel and engine life of diesel generator sets.

The remaining consumers are small settlements with poorly and moderately developed production. Such facilities have characteristic load schedules, for example, in winter consumption increases because heating systems are used, in summer electricity consumption is less, but this time of year lasts in the Arctic only from late June to early August. In the spring and autumn periods, energy consumption changes significantly due to abrupt climatic changes. There is also an increase in power consumption on holidays and weekends. These patterns are basic for these consumer groups, but should be investigated more accurately at a specific object when predicting energy consumption [10,11].

Further work will be aimed at developing a method for short-term forecasting of the electric energy consumption of an industrial enterprise or facility with a household load depending on climatic conditions and weather factors, which includes a wind turbine in the power supply system, which will
be possible and justified with the gradual introduction of digital technologies, such as intelligent sensors and intelligent metering, followed by the subsequent collection and processing of Big Data, demand response systems and the formation of a MicroGrid and a Smart Grid systems.

2. Materials and methods
The purpose of this study is to analyze the graphs and load indicators, which will subsequently affect the choice of the composition of the generating equipment in the wind-diesel complex for power supply of villages with public utility load.

2.1. Theoretical methods
In the work, theoretical methods were used, consisting in a scientific analysis of trends in the volume of electricity consumption depending on changing factors, methods of computational mathematics and mathematical statistics, statistical samples, factors and data from the weather service.

2.2. Load graph analysis
Modern approaches to modeling and forecasting power consumption are based on the application of methods for analyzing electric load graphs based on multidimensional mathematical models that allow you to find implicit relationships and patterns that exist in the process under study. The most common and studied mathematical model of power consumption over time is a model of a random process or a random graph of electrical load.

As an object of study, we consider a village in the Republic of Sakha (Yakutia), mainly with a household load of consumers. Analysis of the load curves showed that the average value of the electric load varies from 209 kW (in July) to 336 kW (in January), and its maximum and minimum value falls to January and February (369 kW) and July (201 kW), respectively.

The implementation of random graphs of electrical load obtained from the testimony of existing metering and control systems for power consumption is presented by discrete models of a real process of step type. Typical graphs for February and July are shown in Figures 1 and 2:

![Figure 1. Daily power consumption of electric load in February.](image)

Continuing to analyze the load schedules, we distinguished the characteristic base (white), peak (black) and semi-peak (gray) zones, which allows us to characterize the rate of change in consumption, for example, the duration of the peak zones is from 2 to 4 hours per day. The shape of the graphs in winter has a more noticeable peak zone due to the inclusion of heating devices, the power compared with the summer period increases 1.5 times.
3. Results and Discussion

The most important probabilities of the characteristics of a random process of electric load are the distribution function, distribution density and power variance for each moment of time.

The average load is calculated for a step graph according to formula 1:

$$P_a = \frac{1}{T} \sum_{i=1}^{n} P_i t_i,$$

where $T$ is the considered time period, $t_i$ is the duration of the section with power $P_i$.

The rms load is calculated by formula 2:

$$P_{\text{rms}} = \left( \frac{1}{T} \sum_{i=1}^{n} P_i^2 t_i \right)^{1/2}.$$

Variance is an important feature when choosing the composition of generating equipment, it shows how much the average values of the sample deviate on average (the average square of the deviations of the power consumption from their average value in the studied time range).

The variance of the load curve is calculated by formula 3:

$$D_P = \frac{1}{n-1} \sum_{i=1}^{n} (P_i - \bar{P})^2.$$

The standard deviation of the load from the average value is calculated by the formula 4:

$$\sigma = \sqrt{D_P}.$$

The calculated indicators by formulas (1-4) based on averaged data for each month of the year are presented in table 1.

Table 1. Calculation data of average load, rms load, variance of the load curve and standard deviation of the load from the average, kW

| Month | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| $P_a$ | 350.1| 339.0| 310.3| 275.9| 273.5| 234.3| 216.8| 327.5| 271.7| 315.3| 324.8| 353.3|
| $P_{\text{rms}}$ | 344.5| 333.3| 304.5| 271.1| 268.8| 230.2| 213.2| 322.8| 267.0| 310.1| 319.4| 347.5|
| $D_P$  | 1262.7| 961.2| 480.1| 595.5| 577.0| 387.9| 437.7| 1464.2| 563.6| 972.4| 934.5| 1201.0|
| $\sigma$ | 35.5| 31.0| 21.9| 24.4| 24.0| 19.7| 20.9| 38.3| 23.7| 31.2| 30.6| 34.7|
Based on the calculations, it is worth noting that the standard deviation of the load, showing the real average value of the deviations from the average value in the sample, is larger in the winter months and spring-autumn period, when energy consumption changes significantly due to sharp changes in external climatic conditions. For example, the largest standard deviations were found in January ($\sigma = 35.5$), February ($\sigma = 31.0$) and August ($\sigma = 38.3$). The autumn period begins in the Arctic in August and there is a sharp change of climatic conditions in the direction of lowering temperature and increasing gusts of wind. This indicator must be taken into account when choosing the composition of generation in a wind-diesel complex.

The methodology for modeling load schedules [12] using formulas (1)-(4) is widely used in applied research due to the relative simplicity and the impossibility of obtaining a sufficient number of realizations in a limited time.

The second reason for the widespread use of modeling methods based on individual implementations is a simpler model when summing up random plots, i.e. modeling a group graph $P(t)$ according to the known characteristics of its constituent processes $p(t)$.

4. Conclusion

As a result of the study, it was found that the prerequisites for the use of renewable energy sources in the Arctic were formed under the influence of the need to consolidate efforts to promote sustainable development by achieving economic growth, environmental protection and social integration.

Wind power plants have great potential for use in the Arctic together with the diesel generator sets. The article analyzed the load graphs of the village mainly with household consumption, the maximum average consumption of which is 369 kW in January and February. We studied such indicators of load curves as average load, rms load, variance of the load curve and standard deviation of the load from the average. As a result, it was found that the standard deviation of the load has large values precisely in the winter months (January, February) and the spring-autumn period (especially in August), when energy consumption changes significantly, and therefore, this indicator must be taken into account when choosing the composition of generation in wind-diesel complex.

References

[1] Generation facilities in isolated and inaccessible territories in Russia. Analytical report. March 2020, available at: https://ac.gov.ru/uploads/2-Publications/analitika/генерации_в_ИТТ.pdf
[2] Zhukovskiy Y L, Starshaia V V, Batueva D E and Buldysko A D 2019 Analysis of technological changes in integrated intelligent power supply systems Innovation-Based Development of the Mineral Resources Sector: Challenges and Prospects ed V Litvinenko (London: CRC Press) 249-258
[3] Ulanov V L and Ulanova E Y 2019 Impact of External Factors on National Energy Security Journal of Mining Institute 238 474-480 DOI:10.31897/pmi.2019.4.474
[4] Vostrov K, Frolov V and Safonov E 2017 Development of current limiting device for short and autonomous networks 22nd Symposium on Physics of Switching Arc ed Milada Bartlová (Mesto na Morave: Curran Associates, Inc.) 182-185
[5] Frolov V Y, Neelov A A, Zhiligotov R I and Bystrov A V 2018 Identification of the protection parameters of the local electrical network taking into account the detuning of the inrush current Proceedings of the 2018 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering, ElConRus ed S Shaposhnikov (Saint Petersburg: Saint Petersburg Electrotechnical University “LETI”) 626-628
[6] Lipina S A, Bocharova L K, Belyaevskaya-Plotnik L A 2018 Analysis of government support tools for mining companies in the Russian Arctic zone Journal of Mining Institute 230 217 DOI: 10.25515/pmi.2018.2.217
[7] Berdin V K, Kokorin A O, Yulkin G M and Yulkin M A 2017 Renewable energy sources in off-grid settlements in the Russian Arctic (Moscow: WWF)
[8] Kirsanova N Y, Lenkovets O M and Nikulina A Y 2018 The Role and Future Outlook for
Renewable Energy in the Arctic Zone of Russian Federation European Research Studies Journal XXI Special Issue 2 356-368

[9] Litvinenko V S and Sergeev I B 2019 Innovations as a Factor in the Development of the Natural Resources Sector Studies on Russian Economic Development 30(6) 637-645 DOI: 10.1134/S107570071906011X

[10] Mustapha M, Mustafa M W, Khalid S N, Abubakar I and Shareef H 2015 Classification of electricity load forecasting based on the factors influencing the load consumption and methods used: An-overview IEEE Conference on Energy Conversion (CENCON) ed Abdul Halim Mohd Yatim (Johor Bahru: Institute of Electrical and Electronics Engineers Inc.) 442-447

[11] Ummuhan B F, Gerek O N and Kurban M 2011 A novel modeling approach for hourly forecasting of long-term electric energy demand Energy Convers. Manag. 52 199-211

[12] Bozhkov M I and Kostin V N 2017 Analysis of load graphs of substations on the basis of the Automated Energy Control and Metering System Industrial Energy 1 13-18