Study of Operation of Combined Power Supply System Based on Renewable Energy in Territory of Far East of Russia

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***Abstract*—This article is devoted to analysis and research of operation of combined power supply systems for electric supply of stationary and remote electric power consumers in the territory of the Far East of the Russian Federation. The article outlines the main advantages of low-capacity combined power plants, through which it is possible to reduce greenhouse gas emissions into the atmosphere and achieve savings in expensive diesel fuel, the transportation of which is also high cost against the background of a small level of development of transport infrastructure. The authors of this article dwell on the problem of determining and calculating the dependence of electric power parameters of a combined power plant from external environmental conditions, such as: illumination, wind velocity and others. It is important to note that during the study, the authors of the article developed mathematical programs for calculating a combined wind-solar power plant, taking into account the passage of state registration on of the Federal Institute of Industrial Property of Russia.**

Keywords—combined power supply, wind energy, solar energy, energy storage system, North, Arctic, diesel fuel, energy-saving and cost price

I. Introduction

Nowadays, supplying power to consumers located in the Russian Far East is generated through the operation of traditional energy sources, such as thermal, diesel and gas turbine power plants. However, burning fuels have negative consequences for the environment. For example, the value of carbon dioxide emissions from the combustion of diesel fuel is 3.15 t CO2 / t or 2.6–2.8 kg CO2 / l, this depends on the temperature of the fuel and its brand, summer is denser and winter is less dense. The carbon emission factor is 19.98 t_c/TJ in accordance to the Ministry of Natural Resources of Russia dated April 16, 2015, No. 15- "On the approval of methodological recommendations for conducting a voluntary inventory of greenhouse gas emissions in the constituent entities of the Russian Federation [1],[2],[3],[4].

At the same time, the fuel supply to the above generation facilities in the North-Eastern part of Russia is carried out with the help of the state programs for the transportation of fuel "Severny Zavoz". However, during the transportation of fuel and power plant components from point A to point B across the Lena River and the Laptev Sea, the delivery time is up to 2 years, and the cost increases up to 2 times. In addition, the installed capacity utilization rate is 10-11% [4],[5],[6].

In this regard, the introduction of energy-efficient technologies to save expensive fuel for the power supply systems of the Russian Far East is highly relevant. One of the best solutions is the design, construction and operation of renewable energy sources when working together with facilities of traditional energy sources.

In addition, according to the results of operating combined power plants in the circumstances of the Russian Federation, during the design, construction, installation, commissioning and operation, the following proportions are applied by sources of electricity generation:

- 65% of the specific power of generation from a conventional energy source + 35% of the specific power of generation from an unconventional energy source [7],[8],[9].
- 70% of the specific power of generation from a conventional energy source + 30% of the specific power of generation from an unconventional energy source [10],[11],[12].

Renewable energy sources in Russia[13] can be effectively used to supply energy to consumers, primarily in areas not covered by centralized energy supply. These zones include the vast territories of Russia [14], in which about 20 million people live, as well as remote areas of the Far North, Siberia and the Far East and rural areas in the central part of the country (Arkhangelsk, Vologda, Kirov, Yaroslavl and other regions).

Thus, it is necessary to prove the possibility of efficient operation of renewable [15],[16] energy facilities in the Far East.

In this regard, in order to compile a detailed analysis of the choice of the source of electricity, it is necessary to consider the solar activity map, presented in Figure 1 below.

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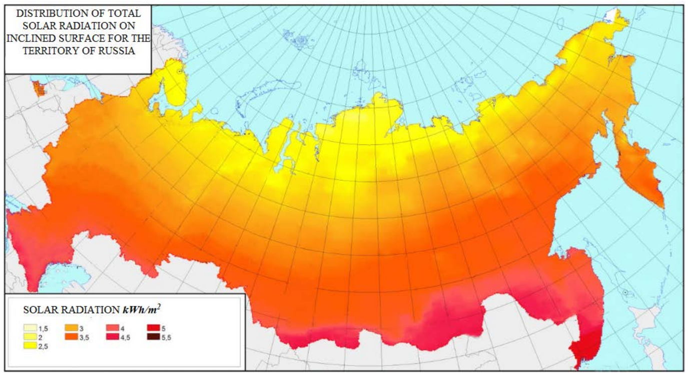

Fig. 1. Map of solar insolation in Russia.

In accordance with figure 1, the introduction of small solar power plants, according to the indicators of solar insolation, is possible in the territories:

1. Southern part of the Khabarovsk territor - 4.5 kW*h/ m^2;
2. Amur Region - 4-4.5 kW* h /m^2;
3. The main part of the Republic of Sakha (Yakutia) - 3-3.5 kW * h / m^2;
4. The main part of the Magadan region –[3-3.5] kW*h/m^2.

These regions were selected based on the availability of autonomous generation facilities and a decentralized power supply[17] system in the areas of the federal project "Far Eastern Hectare". The duration of sunny days per year, are presented in Fig.2 below [18],[19],[20],[21].

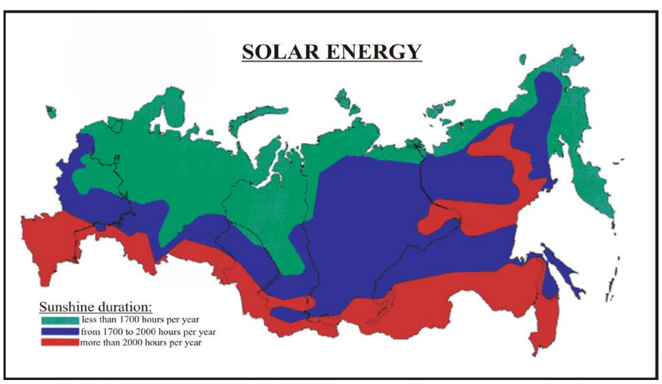

Fig. 2. Map of sunshine duration per year in Russia.

In accordance with figure 2, the introduction of small solar power plants, according to the indicators of the duration of sunshine, is possible in the territories:

1. Southern part of the Khabarovsk Territory-2000 hours /year;
2. Amur Region - 2,000 hours / year;
3. Northern and central part of the Republic of Sakha (Yakutia) - 1,700-2,000 hours /year;
4. The main part of the Magadan region –[1,700-2,000] hours /year.

The average annual wind speed in Russia is presented in figure 3 below:

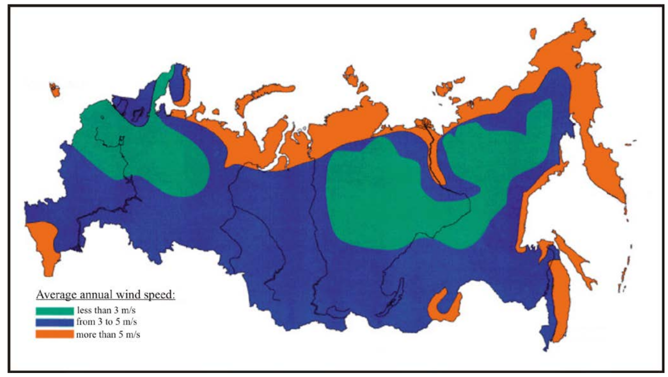

Fig. 3. Map of the average annual wind speed in the Russian Federation.

In accordance with figure 3, the introduction of small wind power plants, according to the indicators of the average annual wind speed, is possible in the territories:

1. Southern part of the Khabarovsk Territory –[3-5] m/s;
2. Amur region – [3-5] m/s;
3. Central part of the Republic of Sakha (Yakutia) - less than 3 m/s;
4. Northern part of the Republic of Sakha (Yakutia) - more than 5 m / s;
5. The main part of the Magadan region - 3-5 m/s.

The wind regions of Russia are presented in Fig.4.

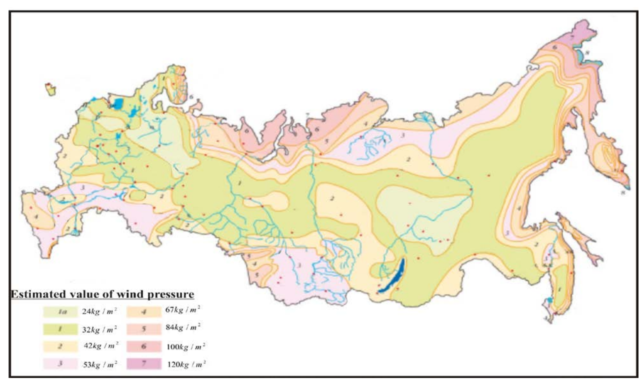

Fig. 4. Map of wind regions of Russia

In accordance with figure 4, the coastal part of the Russian Far East is included in the 4-6 wind regions, where the design wind pressure ranges from 67 kg / m2 to 100 kg / m2, which is also a positive parameter, which creates a full possibility of operating wind energy facilities on the territory Of the Far East [22].

Thus, the introduction of combined power plants based on the parallel operation of wind and solar energy is possible along the northern part of Yakutia along the Lena River and the coast of the sea of Okhotsk, Magadan region and Khabarovsk territory.

The northern part of Yakutia, the Lena River and the coast of the sea of Okhotsk, Magadan region and Khabarovsk territory shown in figure 5 below.

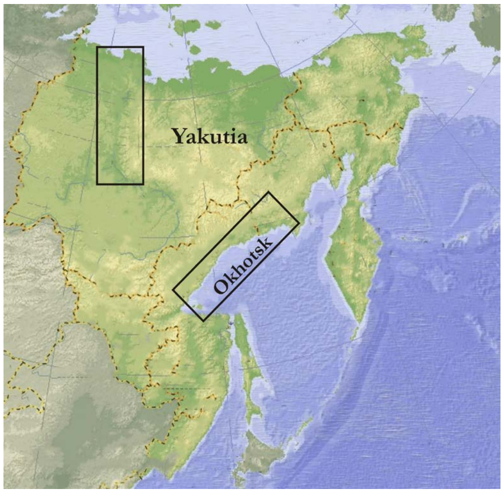

Fig. 5. Map of the possible implementation of hybrid stations in the Far Eastern Federal District.

In accordance with figure 5 above, it is proposed to introduce a hybrid power plant through a combination of wind and solar energy at the micro-power level.

In this regard, a prototype of a combined power plant of the KE-650 model was designed and assembled in the department of Power Supply of the North-Eastern Federal University.

The prototype KE-650 is shown in figure 6 below.

Fig. 6. Picture of the KE-650.

In the course of technical approval based on the farm "Neleger", the Republic of Sakha (Yakutia), certain physical and mathematical dependences on the illumination indicator (lx), wind speed (m / s) and the area of the illuminated surface of the solar panel (m2) were established.

Taking into account the data of the established dependencies, a nomogram is presented in Figure 7 below.

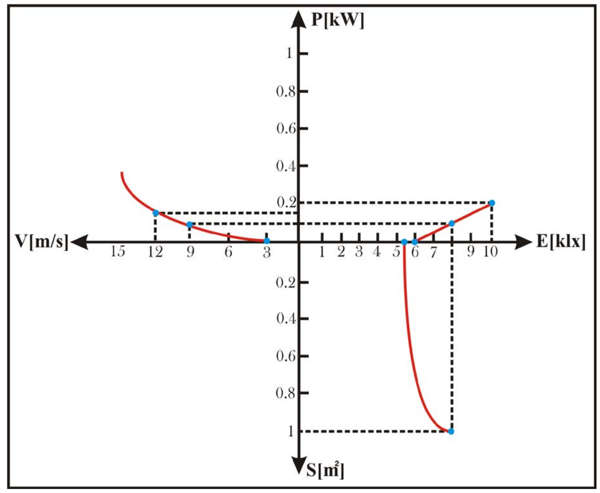

Fig. 7. Nomogram for KE-650.

In accordance to figure 7 above, it is possible to determine the required power for hybrid power plants of micro-power performance "Wind + Sun" in the geographic and climatic conditions of the Arctic.

In addition, the main indicators and parameters of the technical and economic assessment of the KE-650 hybrid power plant are calculated.

In the example below, the hybrid power plant KE-650 is operating in parallel with a 2 kW diesel generator, in an Arctic agriculture facility.

TABLE I. RESULTS OF THE TECHNICAL AND ECONOMIC ASSESSMENT

Cost of IES-650, in rubbles	90 000.00
Specific power, in W	650.00
Generation source	Wind and Sun
Hourly generation volume, in W * h	570.00
Daily generation volume, in W * h	5 130.00
Annual generation volume of KE-650, in kWh	923.40
Specific fuel consumption for generation, l / W	$3.63*10^{-4}$
Annual fuel saved, in litres	335.74
The amount of annual savings, in rubbles	33 574.82
Payback period, in years	2.70
Discounted payback period, in years	4.00

II. EXPERIMENTAL PART

Besides, the experiments were carried out according to the procedure described in section I. Experiments with a solar panel having an area of 0.9916 m2 were carried out on a sunny day from 12:00 to 13:00 hours. The results are shown in Table 4.1.

TABLE II. RESULTS OF THE TECHNICAL AND ECONOMIC ASSESSMENT

E, [lx]	I, [A]	U, [V]	P, [W]
7750	7.14	14.23	101.60
7870	7.38	14.4	106.27
8120	7.71	14.8	114.11
8300	8.14	14.88	121.12

Processing and synthesis of the results was carried out in the computer program Microsoft Office Excel as a result of which dispersion and regression analyses of these experiments were carried out.

Based on the results of variance and regression analysis, a graphical interpretation of the dependence of current strength on illumination was obtained (Figure 8) and a regression equation describing this dependence:

$$P = 279,13 \ln E - 2398,1 \quad (1)$$

where P - power, W; E - indicator of illumination, lm.

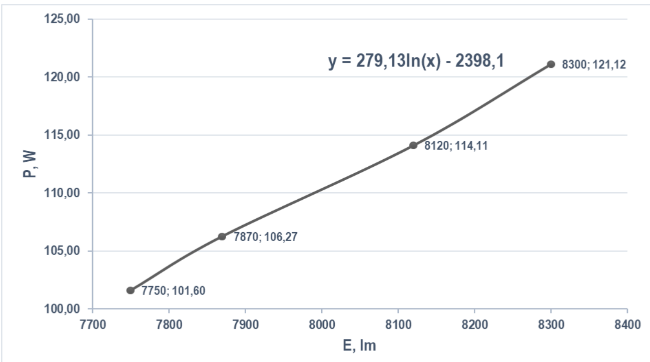

Fig. 8. Picture of the KE-650.

Analysis shows that with an increase in solar illumination, generation naturally increases, while this pattern is a logarithmic dependence. With an increase in illumination of 6.3%, power increases by 16.2% within (7750 lx; 8300 lux). However, it should be noted that due to the limited time of experiments (1 hour) during the educational process, a reason is created about the probability of changing the obtained patterns with a longer time of experiments. Such experiments are one of the promising areas of future research in priority for whole light-days of observation.

Experiments with the wind generator were carried out on a clear day from 13:00 to 14:00 hours at an average wind speed of 7 m/s. The results are shown in Table III.

TABLE III. RESULTS OF THE TECHNICAL AND ECONOMIC ASSESSMENT

V, [m/s]	I, [A]	U, [V]	P, [W]
3.20	1.52	7.06	10.73
5.30	2.02	8.06	16.28
7.58	3.81	10.58	40.31
7.69	3.87	12.10	46.82

Processing and synthesis of the results was carried out in the computer program Microsoft Office Excel as a result of which dispersion and regression analyses of these experiments were carried out.

Based on the results of variance and regression analysis, a graphical interpretation of the dependence of output strength on wind speed was obtained (Figure 9) and a regression equation describing this dependence:

$$P = 3,5973 \times e^{0,315V} . \quad (2)$$

where P - power indicator, (W), V - wind speed indicator (m/s).

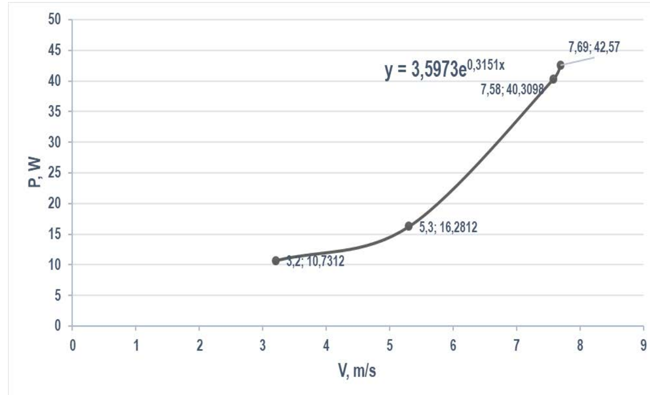

Fig. 9. Picture of the KE-650.

Analysis shows that with an increase in wind speed in the blades of the wind generator, generation naturally increases, while this pattern is also an exponential dependence. With an increase in wind speed of 240.31%, power increases by 436.36% within (3.2 m/s; 7.69 m/s). However, it should be noted that due to the limited time of experiments (1 hour) during the educational process, a reason is created about the probability of changing the obtained patterns with a longer time of experiments. Such experiments are one of the promising areas of future research in priority for the whole day of observation.

In addition, based on the above electric power patterns of wind and solar power generation, the author of the article developed a mathematical model on the program MathCad 14, with the help of which we obtain:

- Daily and annual power generation from hybrid power supply system.
- Required number of wind generators and solar panels based on power consumption.
- Autonomous period of power supply through renewable energy sources without the use of traditional energy sources.
- Daily and annual diagrams of power generation from hybrid power supply system.
- Value of annual diesel fuel economy under the condition of hybrid power supply system operation.

This mathematical model is designed to calculate the main electric power indicators of the Wind and Sun hybrid power plant, giving the main parameters of the station in Arctic conditions, which can be used as part of design and survey work.

Also, the author of the article on the basis of the above electric power laws of solar energy generation developed a mathematical model on the program MathCad 14, with the help of which we obtain:

- Daily and annual power generation from a solar power plant in Yakutia.

- Required number of solar panels based on power consumption.
- Autonomous period of solar power supply without application of traditional energy sources.
- Daily and annual diagrams of power generation from a solar power plant in Yakutia.
- Currently, the mathematical programs have received 2 registering documents, such as [23],[24]:
- Certificate of state registration of the program for computers dated 21.12.2020 No. RU-2020667205
- Certificate of state registration of the program for computers dated 23.12.2020 No. RU-2020667411.

Thus, at the moment, the author of these mathematical models is planned to come up with a proposal for cooperation and joint work with energy companies of the North and the Arctic, private electricity companies and enterprises of the private sector of the economy.

Of course, there are various analogues of programs for calculating the electric power parameters of hybrid power supply systems, but the above mathematical models use patterns that are obtained from laboratory data in accordance with this article.

III. Conclusion

Based on the above, during the study of the KE-650 hybrid power plant, the following conclusions were obtained:

1. Operation of a hybrid micro power plant of “Wind + Sun” performance in the Arctic is the most possible and expedient.
2. A nomogram has been developed for the design of hybrid micro power plants of the "Wind + Sun" design.
3. The results of the feasibility study show positive parameters for the project payback.

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