Methodology for Assessing Meteorological Observation Data to Account for Wind Potential in The Design of a Wind Power Plant

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Abstract: The development of clean renewable energy sources is a strategic task to ensure the balance of energy supply to territories. When implementing a policy of reducing dependence on or abandoning fossil fuels, the use of renewable energy sources is an obvious competitive solution. And for territories remote from power supply networks, the development of renewable energy sources is generally the only alternative. Wind energy is increasingly being used to generate electricity. In this sense, accurate accounting of the influence of wind potential on the energy balance is the basis of energy-saving architecture. From a thermodynamic point of view, wind is a high-quality source of energy. Its high efficiency makes it possible in principle to convert into other types of energy. However, the wind energy flow is unstable – the performance of wind power plants is due to their extremely high sensitivity to the conditions of their location. In this situation, the reliability of the initial data on wind energy resources is a criterion of paramount importance. Therefore, the development of a methodology for evaluating data from long-term meteorological observations of wind speed and direction is of important empirical importance. To design a wind power plant, it is not enough to enter ready–made data on the value of specific power and specific wind energy in the territory into economic calculations - the data deviation is too large. It is necessary to calculate the technical potential of the wind power plant for each prospective location option. Both the approach to accounting for wind potential and the approach to scaling the data of the observation station to remote territories ensure the reliability of the initial data for the design of a wind power plant. The proposed methodology highlights all these aspects and offers an algorithm for evaluating the data of long-term ground-based meteorological observations on the territory of Russia.

Key-Words: Renewable Energy Source (RES), Wind Energy, Meteorological Observations, Wind Potential, Wind Power Plant (WPP), Wind Generator, Data Model for Wind Potential Assessment

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1 Introduction

Russia has a significant wind potential, wind energy resources are estimated at 10.7 GW, and the technical potential of wind power plants is estimated at 2,469.4 billion kW per year. At the same time, based on the energy balance data, these opportunities are implemented insignificantly [1].

The area for which the technical potential of wind power is calculated is determined by the formula:

$$ST = q \times S, \quad (1)$$

where ST - the area on which the technical potential is calculated, m^2; q is the area as a percentage of the total area of the territory of Russia, where the required wind speed prevails, %; S - the total area of the territory of Russia – 17,125191x109 m^2.

Energy wind zones in Russia are located mainly on the coast and islands of the Arctic Ocean from the Kola Peninsula to Kamchatka, in the areas of the Lower and Middle Volga, Don, on the coast of the Caspian, Okhotsk, Barents, Baltic, Black and Azov Seas. Separate wind zones are located in Karelia, Altai, Tuva, and Baikal [2].

According to JSC "SO UES" (the System Operator of the Unified Energy System) - a specialized organization that single-handedly carries out centralized operational dispatch management in the Unified Energy System of Russia - the installed capacity of wind power plants for 2022 is 0.83% (in 2020 – 0.4%) of the total capacity of all power plants of the Unified Energy System of Russia) [3]. Despite the fact that now the share of wind power plants in the UES (Unified Energy System) Russia does not exceed 2%. For comparison, the installed capacity of solar power plants is 0.8%, and hydroelectric power plants – 20.25% of the total capacity of all UES power plants.

Despite the impressive resources of the wind potential, investments in wind farms need state support and patronage [1]. And we are talking about direct investments and benefits not only at the construction stage of wind farms. At the operational stage, such support measures are applied as compensation for losses of grid organizations in power grid facilities and competitive selection, following which the investor receives the right to build renewable energy facilities of any kind with a guaranteed return on investment. Similar measures are being taken by the governments of the USA and China [4, 5]. The Russian Government has determined the limits of capital and operating costs for renewable energy facilities [6]. This indicates the presence of state interest in the development of renewable energy. But the context of the support measures themselves indicates that the development of renewable energy as a defining vector of the country's energy is not considered. Today, the interest in renewable energy is no longer just a tribute to the fashion of "green" technologies, but it is also not comparable to the amount of financing of traditional energy.

In terms of the development of "green" generation in the period from 2021 to 2027, it is planned to put into operation 2863.1 MW of wind and solar power plants as part of the first stage of the renewable energy development support program. Currently, the Russian Government has approved a new program to support the development of renewable energy until 2035, the cost of which can amount to about 360 billion rubles for the period from 2025 to 2035 and ensure the commissioning of about 6.7 GW of renewable energy capacity [7].

What prevents an increase in the share of wind energy in the installed capacity of UES power plants? In our opinion, technical and technological features play a more significant role here than the immaturity of state support.

The technical condition of the equipment (its structural defects, wear), non-compliance with the performance of the installed capacity equipment create significant risks for investments in wind energy.

It is also necessary to consider the increased environmental restrictions on the conditions of protection of air basins.

In addition, we should not forget about the factor of reducing the use of installed capacity of power plants. The maximum value of the Capacity Utilization Factor (CUF) is 1. But in life and for traditional power plants, it ranges from 0.4 to 0.8. The highest CUF is for nuclear and geothermal power plants (0.7-0.8), the lowest is for hydroelectric power plants, since they are charged with removing load peaks (4-5 hours a day). As for wind farms, their CUF in Europe and Russia averages 0.2-0.3. But it depends mainly on wind conditions. There are examples of wind farms where CUF is 0.4 and higher. Due to technical features for wind and solar power plants, there is no guarantee of using power per hour of maximum power consumption. After all, the available capacity of wind and solar power plants during the passage of the maximum power consumption is assumed to be zero.

All of these are stress factors of the environment, the study of which is a primary task for the development of wind energy and investment in the design of wind power plants.

It is not enough to be guided by the wind potential data – they have many deviations. The main reason is that the wind potential is determined according to meteorological observations, and the distance between observation stations in many regions of Russia is 300 km or more. Yes, according to the recommendations [8], in order to track every change in the weather, the distance between observation stations should be 50 km in rural areas, forests, steppes, deserts; in the suburbs of megacities - 20 km; in cities - 5 km (it is possible and more often, but it will be necessary not to clarify the forecast, but to study the microclimate of the city). But the current situation with the number and distribution of observation stations is very far from the recommended one.

Since there are no other reliable data to assess the wind potential, the methodology for assessing meteorological observations of wind speed and direction is a popular solution. On its basis, it is possible to objectively consider the wind potential of a separate territory for deciding on the design of a wind power plant.

The methodology will be based on data from long-term ground-based meteorological observations in Russia. That is, the technique will use pure data accumulated by observation stations. In the absence of open databases and widely available algorithms for assessing wind potential, the methodology will be a source of reliable data for an informed decision on the design of a wind power plant.

The initial parameters for the design of a wind generator are presented in Table 1.

Table 1 – Specification of the wind generator

Wind turbine class	Power range, kW		Range of diameters of the wind wheel, m		Range of rotation speeds of the wind wheel, rpm	
	0,025	1	0,5	2,5	2000	500

Very small	1,5	10	3,0	9,0	500	200
Small	20	60	10	15	140	92
	75	150	18	24	60	40
Medium	200	300	26	30	40	40
	400	500	35	40	35	30
Large	600	750	43	48	30	30
	900	1300	50	64	32	20
Very large	1500	3000	70	90	20	15
	4000	6000	105	124	15	13

The need to compile a methodology for evaluating data based on ground-based meteorological observations is also determined by the fact that the reliability of the NASA SSE[1] (Surface Meteorology and Solar Energy) data array in Russia is minimal. This is due to the fact that more than half of the territory of Russia is located in latitudes above 60°. This conclusion was made based on the results of work with the RETScreen International[2] climatological information database containing data from NASA SSE and ground observations.

2 Development of Methodology for Evaluating Meteorological Observations of Wind Speed and Direction

The totality of wind characteristics in terms of its use for the production of mechanical or electrical energy is called a wind energy cadaster.

The main components of the cadaster are:

(1) Average annual wind speed. The annual and daily course of the wind, i.e. its changes by day and month of the year.

(2) Speed repeatability, types and parameters of speed distribution functions, i.e. how long a certain wind speed lasts during the year.

(3) Maximum wind speed.

(4) Distribution of wind periods and periods of calm.

(5) Specific power and specific wind energy.

(6) Wind energy resources of the region, i.e. how much energy can be generated from a certain area.

The last two components of the wind energy cadaster are, in theory, a data source for solving the problem of the feasibility of designing a wind generator. It is these data that can be used as the basis for the calculation part of the project (Table 2). They are a guideline when choosing a site for the construction of a wind farm of nominal capacity.

Table 2 - Dependence of the specific power of a wind generator on wind speed

Class number	Class characteristics	Specific power, W/m2 at a height of 50 m	Average annual speed, m/s at an altitude of 50 m
1	Poor	0-200	0,0-5,6
2	Marginal	200-300	5,6-6,4
3	Fair	300-400	6,4-7,0
4	Good	400-500	7,0-7,5
5	Excellent	500-600	7,5-8,0
6	Outstanding	600-800	8,0-8,8
7	Superb	> 800	> 8,8

The current procedure for making decisions on the construction of a wind farm involves the following mandatory steps:

(1) Selection of the location of the wind farm (wind generator park) depending on the type and market of electricity (wholesale/retail).

(2) Determination of the wind energy cadaster at a pre-selected location based on data from the nearest observation station.

(3) Determination of preliminary main technical and economic indicators of a wind farm.

(4) Installation of a weather mast at the site of a future wind farm and continuous observation

1https://power.larc.nasa.gov/data-access-viewer/

2https://www.nrcan.gc.ca/maps-tools-and-publications/tools/modelling-tools/retscreen/7465 of wind speed in the directions of parts of the world for at least a year.

(5) Determination on the basis of measurements of normative technical and economic indicators of a wind power plant and deciding on its construction.

Despite the existing logic of the presented procedure, the risks associated with the reliability of the source data are significant.

In particular, a risk factor that can negate all efforts is the determination of the wind energy cadaster in a pre–selected location based on the data of the observation station closest to this location. And since the distance between them can be very significant, the deviation of the solution is large. Of course, the results of continuous observations for at least a year will answer the question whether it is worth placing a wind farm in this place. That's just a negative answer leads to the starting point, from which it is again necessary to determine the wind energy cadaster for the newly selected location and take meteorological readings again for at least a year.

That is, considering the fact that the reliability of the initial data is a determining factor of economic and energy efficiency, the choice of the location of the weather mast for continuous observations should be made on the basis of an assessment of data from long-term observations of wind speed and direction.

This leads to the following question and the following risk factor – what initial meteorological data should be used to decide about the location of the weather mast? Meteorological data requires verification. For example, the data of the NASA SSE database, when compared with the measurement data of ground observation stations, show a deviation of no more than 15%. However, this is an acceptable deviation only if the projected wind farm is located in the immediate vicinity of the meteorological observation station. In other cases, when calculating the wind potential of a particular location, such a deviation is significant.

In this regard, the idea of symbiotic use of satellite and ground-based observations should be abandoned. The logical solution would be to focus only on the use of long-term ground-based observations. Accordingly, the data of the weather station for the wind energy cadaster in the pre-selected location and the zones of neighboring observation stations will be used to carry out optimization calculations and substantiate the efficiency of the projected wind power plant.

Having determined the source of meteorological data for the assessment of wind potential, it is necessary to answer the following question, which also includes a risk factor. Namely, for what period is it advisable to accumulate data? A non-stationary time series of data should have a sufficient and acceptable duration so that its probabilistic characteristic contributes to the identification of a trend and deterministic periodicity.

We proceed from the dependence of the wind potential on actinometric data, since the very existence of wind is due to solar origin [9]. Therefore, it is proposed to use a binding to the cycles of solar activity based on the direct dependence of wind, as a natural phenomenon, and its speed, as a consequence of the effects of temperature changes, on solar activity. The application of the Schwabe-Wolf cycle [10] will provide the necessary duration of the time series of meteorological data and will make it possible not only to link the cyclicity of actinometric data and wind potential, but also to compare data between Schwabe-Wolf cycles to identify dependencies. As a result of the assumptions made, the developed methodology is based on actinometric data of the 23rd cycle (May 1996 - December 2008) and the 24th cycle (December 2008 – December 2019).

The next risk factor is associated with the determination of the main technical and economic indicators of the projected wind power plant. Unlike other types of power plants, the generation of electricity by a wind turbine cannot be regulated. It is possible to stop the turbine and stop the production, but to increase it, and in general it is impossible to precisely adjust. Therefore, the CUF of wind power depends on the characteristics of the unit itself and its location. In this regard, the decision on the location of the wind farm becomes even more responsible. The application of a methodology for evaluating meteorological observations can improve the characteristics of deciding on the positioning of a wind farm. This will increase the CUF.

As a conclusion, recognizing these risk factors as significant, it is impractical to decide only on the basis of open data from observation stations, since we have no idea about the deviations inherent in the calculations, nor about the method of scaling the data to the territory of the entire region. It is important to understand for what period to evaluate the data, by what parameters to form a sample, how to consider meteorological data at a distance from the location of the observation station.

We propose a methodology that reproduces the calculation of the wind potential step by step with reference to a separate territory for making an informed decision on the design of a wind power plant. Such a technique will make it possible to decide based on objective primary data, having a holistic view of all possible options and alternatives for considering wind potential in the selected territory.

The methodology is based on a sequence of several stages. At the first stage, the initial (primary) data of meteorological observations are accumulated and a database is developed. At the second stage, a data model is built to assess the wind potential. At the third stage, the model is interpreted and the boundaries for deciding on the design of a wind farm are determined.

2.1. Development of a Database of Meteorological Observations of Wind Speed and Direction

The sources of obtaining the initial information for the meteorological observation data model are:

(1) Weather stations that measure all climatic parameters, including wind speed, usually four times a day. At modern weather stations, measurements are carried out on 8 points, i.e. directions relative to parts of the world: north, south, east, west (4 directions) and between them: northeast, etc. (4 directions).

(2) Continuous observation weather stations, as a rule, constructed at the proposed sites for the installation of wind power plants.

(3) Probes and balloons launched periodically to different heights from certain stations, called areological.

Since the decision on the sufficiency of the wind potential should be based on data from long-term observations, then, first of all, data from the network of observation stations are in demand. Operating with regular observation data will ensure the objectivity of the data model. Continuous observation weather stations are not a data source for the model, since their network is much smaller. But their data helps to calculate the magnitude of the error of the initial series of daily values of wind speed and direction. After all, 4 standard measurements of weather metrics are made during the day.

The data obtained during continuous registration are compared with the data of regular observations and help to determine the deviation of daily measurements. When comparing, the margin of deviation and the confidence coefficient are established. For the presented methodology, the error value of the initial series of daily values for regular measurements is 8-12%. The confidence coefficient is 0.8.

The request for meteorological data is sent to an organization that performs research and operational and methodological functions in the field of hydrometeorological forecasts. In Russia, these functions are performed by the Federal State Budgetary Institution "Hydrometeorological Center

n/a	Index	Station name	Station coordinates		Height of the weather site	Beginning of observations	Note
			latitude	longitude			
1	20046	**Hydrometeorological observatory n.a. E.T. Krenkel**	80°37′	58°03′	21	1957	
2	20069	**Vize**	79°30′	76°59′	10	1945	
3	20087	**Golomyanny**	79°33′	90°37′	7	1940	
4	20107	**Barentsburg**	78°04′	14°15′	22	1940	
5	20289	**Russky**	77°10′	96°26′	9	1940	Closed in 1999
6	20292	**Hydrometeorological observatory n.a. E.K. Fedorov**	77°43′	104°18′	12	1932	
7	20476	**Sterlegov**	75°25′	88°54′	10	1940	
8	20667	**Hydrometeorological observatory n.a. M.V. Popov**	73°20′	70°03′	4	1940	
9	20674	**Dixon**	73°30′	80°24′	42	1916	
10	20744	**Small Karmakuly**	72°22′	52°42′	18	1876	
11	20891	**Khatanga**	71°59′	102°28′	31	1906	12/01/1951. transfer to 800m to the South-Southwest
12	20946	**Hydrometeorological observatory n.a. E.K. Fedorov**	70°27′	59°05′	13	1959	
13	20982	**Volochanka**	70°58′	94°30′	37	1933	
14	21432	**Kotelnyi**	76°00′	137°52′	10	1933	
15	21611	**Terpyai-Tumsa**	73°33′	118°40′	12	1961	Closed in 1997
16	21647	**Shalaurov**	73°11′	143°14′	21	1928	It was mothballed in 2000
17	21802	**Saskylakh**	71°58′	114°05′	16	1935	
18	21824	**Tiksi**	71°35′	128°55′	6	1932	
19	21908	**Dzhalinda**	70°08′	113°58′	61	1942	
20	21921	**Kyusyur**	70°41′	127°24′	30	1940	
21	21931	**Yubileinaya**	70°46′	136°13′	23	1961	
22	21946	**Chokurdakh**	70°37′	147°53′	44	1939	05/20/1955. transfer to 800m to the North-Northeast
23	21982	**Wrangel Island**	70°59′	181°31′	2	1926	Transfers in 1934 from the shore to the spit
24	22003	**Vaida Bay**	69°56′	31°59′	8	1940	
25	22019	**Polyarnoe**	69°12′	33°29′	32	1936	
26	22028	**Teriberka**	69°12′	35°07′	33	1914	Transfer in 1936 to 2 km to the North
27	22095	**Kolguev Severnyi**	69°32′	49°05′	23	1933	
28	22101	**Yaniskosky**	68°58′	28°47′	98	1959	1965 - the station burned down; 1969 - opened 7 km to the Northeast
29	22113	**Murmansk**	68°58′	33°03′	57	1918	Transfer in 1934 2.5 km to the South
30	22140	**Svyatoi Nos**	68°09′	39°46′	12	2001	
31	22165	**Kanin Nos**	68°39′	43°18′	48	1915	
32	22204	**Kovdor**	67°34′	30°27′	246	1959	Transfer in 1965 to 1 km to the Northeast
33	22217	**Kandalaksha**	67°09′	32°21′	26	1912	Transfer in 08.1958 to 5 km to the Northwest
34	22235	**Krasnoshchelye**	67°21′	37°03′	155	1940	
35	22249	**Kanevka**	67°08′	39°40′	149	1959	
36	22271	**Shoyna**	67°53′	44°08′	5	1932	
37	22292	**Indiga**	67°41′	48°41′	3	1923	
38	22324	**Umba**	66°41′	34°21′	39	1940	
39	22355	**Sosnovets Island**	66°29′	40°41′	15	1862	

of Russia". The request is formed considering the following features.

For further processing, the data is requested in symbolic form (in a table). The data structure corresponds to the SYNOP (surface synoptic observations) observation methodology. The sample is based on observations over the past 30 years (from 1990 to 2020). The network of observation stations includes all weather stations on the territory of Russia located within meteorological zones 1 to 5. The Hydrometeorological Center of Russia provides data from 600 observation stations, at the moment the number of operating stations is 585, 15 are closed or mothballed.

Figure 1 shows a fragment of the list of observation stations, which includes stations located on the Arctic coast from the Kola Peninsula to Chukotka.

Figure 1 – A list of observation stations of the Arctic coast, the data of which are used to build the model

Recall that promising energy wind zones in Russia, according to experts, are located mainly on the coast and islands of the Arctic Ocean from the Kola Peninsula to Kamchatka. For example, the estimated capacity of the Kola wind farm under construction (Enel Green Power) is 210 MWh, and the project is considered highly profitable.

Having formed a data model of meteorological observations of wind speed and direction, we will be able to verify the correctness of the conclusions.

The request must include a list of climatic parameters for data sampling:

(1) Average wind speed in m/s at an altitude of 50 m. above the earth's surface (during the observation period - a month, a year), regardless of the method of its determination.

(2) Maximum wind speed at gusts in m/s at an altitude of 50 m. above the earth's surface (during the observation period - a month, a year).

(3) The average wind direction at an altitude of 50 m. above the earth's surface (during the observation period - a month, a year).

(4) The repeatability (percentage of time) of wind directions and calms having a speed in the intervals of 0-2 m/s, 19-25 m/s (January, July, year).

(5) Wind speed, the probability of exceeding which is 5%.

(6) The highest wind speeds of varying probability (wind speed possible 1 time in 5 years, 1 time in 10 years, 1 time in 15 years, 1 time in 20 years).

(7) Especially dangerous phenomena associated with physical processes in the atmosphere.

Figure 2 shows a fragment of the map layer, on which the locations of the observation stations of the Arctic coast are plotted with geometrics. The geometries contain the following data: the name, the coordinates of the station, the height of the weather site (the height of taking weather readings).

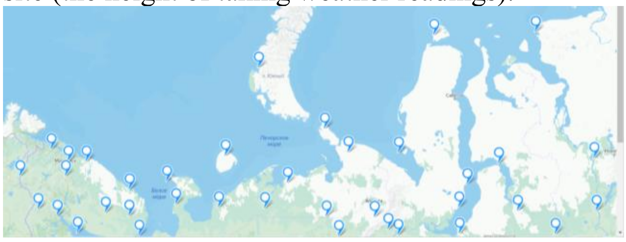

Figure 2 – Fragment of the map layer with the applied geometries of observation stations

The monitoring data of all stations are combined into a single SQL Server database. Forming a query to the database, the analyst can set the boundary values of the average and maximum speed, wind direction, can select data on the repeatability of wind direction.

With the help of a query, the analyst has the opportunity to form map layers and visualize the geometries of observation stations corresponding to the sampling parameters. In addition, layers with geodata can be loaded into the map, which will help to correct the decision about the location of the wind farm. For example, to load a layer on which the locations of energy-deficient areas, or territorial zones with a special economic status, or critical infrastructure facilities are located.

2.2. Data Model for Estimating wind potential

The data model is by its nature a simulation model, since it reproduces the work with parameters for deciding on the design of a wind farm. To build the data model, we proceeded from the basic conditions for designing a wind farm based on the results of the wind potential assessment.

First, the data model considers the following wind parameters:

(1) The starting wind speed at which the wind generator starts rotating is in the range from 2.5 to 4.0 m/s.

(2) The nominal wind speed at which the power of the wind generator reaches the nominal value is from 10 to 14 m/s.

(3) The maximum wind speed at which the wind generator is disconnected from the grid and stops is in the range from 20 to 25 m/s.

(4) The wind speed of the storm (the speed at which the stopped wind generator should not collapse) is from 60 to 80 m/s.

These are the boundary parameters of wind speed, according to which a request will be made to the database and a list of observation stations will be displayed, the location of which provides the starting conditions for the design of a wind power plant.

The wind energy flow is very unstable. At a wind speed of 10m/s, the specific power of the wind flow is about 100 watts per 1 m^2 of the area swept by the blades of the wind generator, and at a speed of 5 m/s, this power is 8 times less [9]. If this parameter is applied in the data model to estimate the wind potential, then the sample of locations recommended for the design of a wind power plant will include those for which the average wind speed is at least 8 m/s (ideally, at least 10 m/s).

Further, the data model considers that there is no constant wind direction in the interior of the continent. Since different parts of the land are heated differently at different times of the year, the seasonality factor is the determining factor for the "wind direction" parameter. In addition, the data model considers that the wind behaves differently in the interior of the continent at different heights. And, since yawing flows are typical for heights up to 50 meters, the solution generated by the data model mainly relies on climatic readings recorded at an altitude of 50 meters and above. For observation stations located on and near the coast (up to 40 kilometers), the factors of seasonality and the height of the weather site do not have a determining value in the data model.

Secondly, the data model considers such a parameter as the rated power of the wind generator. In general, the power range is from 0.025 kW to 6,000 kW, based on the classification of wind generators [11]. When designing a wind farm, the data model considers that the wind generator operates with rated power only if the wind speed is equal to or greater than the nominal. The rest of the time, the wind generator operates with less than nominal power. Therefore, in the data model for estimating wind potential, the calculation is based on the nominal average annual wind speed and nominal power.

When designing a wind farm, the wind generator is calculated for a certain power, for example 800 kW. With an average annual wind speed of 6 m/s, the wind generator will produce 1,500,000 kW/hours of electricity per year, with an average annual wind speed of 5 m/s – 1,100,000 kW/ hours of electricity. A 2,000 kW wind generator with an average annual wind speed of 6 m/s will produce 3,700,000 kW/hours of electricity per year, with an average annual wind speed of 5 m/s - 2,300,000 kW/hours of electricity.

If it is necessary to increase energy production, for example, by 1.5 times, then in addition to the option of changing the location of the wind farm, the data model also considers the option of increasing the height of the mast to 22-25 meters. This makes it possible to increase the average annual wind speed at the axis height by 20-30%.

The data model will form the same solution when the average annual wind speed is less than 4 m/s. It should only be noted that the model has a parameter for bridging the gap in the distribution of wind speed frequency. Such a gap occurs when data on zero and low speeds are entered into the model. And the solution is to use not the Weibull distribution, but a polynomial regression model as a probability density function for the wind speed frequency [12].

Thirdly, the data model calculates for the projected wind farm and the diameter of the rotor of the wind generator. It is selected based on the average annual wind speed. The rated power of the wind generator is determined by the diameter of the rotor squared. Here the data model manifests itself as follows. With winds up to 6-7 m/s, the data model shows that the output of a rotor with a diameter of 5 meters is higher than that of a rotor with a diameter of 4.2 meters. At average annual wind speeds of more than 10 m/s, the output is leveled.

In addition to the parameter of the nominal power of the wind generator, the data model also considers technical limitations. For example, it is considered that at a wind speed of 12-13 m/s, the power of the wind generator reaches a nominal value of 1 MW and remains constant in the range of 13-25 m/s. It turns out that a significant power of the wind flow is not used. But no other solution is possible, since it is impossible to overload the wind generator above its rated capacity.

The expansion of the operating range in the data model is considered impractical for the following reasons. Firstly, the average annual wind speeds of more than 25 m/s were not recorded by observation stations during the study period. Secondly, the wind pressure on the wind wheel during its rotation is proportional to the area of the swept surface. And, so that the pressure force does not overturn the wind farm, it is necessary to strengthen the foundation and its attachment to the tower. Such a decision would be economically wrong.

Combining all the above parameters considered when designing a wind farm, the wind potential assessment data model generates a solution. The solution can be generated based on the nominal average annual wind speed, and offer options for the nominal power of the wind generator of the projected wind power plant. Or the opposite situation is possible, when, based on the nominal power of the wind generator available in the project, a decision is generated on the options for the location of the wind power plant, considering the range of values of the nominal average annual wind speed.

The rated power of the wind generator (RWPPs) depends on the measured in m/s, air density (p=1.225kg/m^3), wind energy utilization coefficient (Avg=0.45), gearbox efficiency coefficient (ηred), diameter of the wind wheel squared (D^2), wind speed in cube (V^3), coefficient the efficiency of an electric generator (η_{gen}), or in other words, the coefficient of conversion of mechanical energy into electrical energy.

The following formula is used [13]:

$$\mathrm{P}_{WPPs} = 0{,}3925 \times \rho \times Avg \times D^2 \times V^3 \times (\eta_{red} \times \eta_{gen})[Watt] \quad (2)$$

The total efficiency of the mechanical and electrical elements of the power path of the wind turbine is 0.9.

In Russia, the average air density at the earth's surface is 1258 g/m^3; at an altitude of 5 km - 735 g/ m^3, 10 km - 411 g/ m^3, 20 km - 87 g/ m^3. At the equator, the density values in the troposphere are less, and in the stratosphere - more than in Europe. In winter, the air density is greater than in summer. In the proposed model, the air density is assumed to be 1.225 kg/m^3, considering the average values of the height of the location of meteorological sites at observation stations.

The capacity factor (CF) of wind power depends on many design features, but ultimately on the profile of the blade and the degree of its roughness, as well as on the ratio between the speed of rotation of the blades and wind speed. This coefficient ultimately determines the efficiency of the wind generator. The maximum value of the CF coefficient is 0.593 [14, 15]. On land, the throughput coefficients range from 0.26 to 0.52 [16]. In the proposed model, the value of the CF coefficient is assumed to be 0.45. This corresponds to the characteristics of high-speed wind turbines with streamlined aerodynamic blades.

2.3. The Order of Interpretation of the Data Model for the Assessment of Wind Potential and Scaling of Meteorological Observations

Even with meteorological observations from the stations at your disposal, you need to answer one important question. Namely, whether it is possible to use these data to assess meteorological conditions in territories remote from the location of the observation station. There are also related questions. At what distance from the station and under what conditions does the data remain valid? What approach should I use to scale the data?

According to the results of the research of the leading Russian scientific center in the field of actinometry of the A.I. Voyekov, measurement data with an acceptable deviation can be extrapolated to a distance of no more than 130 km from the weather station [17]. Accordingly, as one of the parameters of the data model for estimating the wind potential, scaling of data to a radius from 80 to130 km from the observation station is accepted. The exact value within the interval is determined considering the terrain – for homogeneous terrain, the value is assumed to be 130 km. The inhomogeneity of the terrain reduces the data scaling radius, as the accuracy of wind speed and direction readings decreases. The greatest volatility of data characterizes wind resources in areas with mountainous and foothill terrain [18].

The order of scaling in the methodology for evaluating meteorological observation data is as follows.

The calculation is based on a number of parameters and using several approaches. The physical parameter is comparable terrain conditions. The second parameter is the distance between the observation stations. The third parameter is the distance from the station location. And then three approaches are used: calculation of average indicators of weather stations connected to a network; data extrapolation method; data interpolation method. And a combination of approaches is also used, for example, the method of extrapolation of averaged values.

The determination of the average values of the climatic characteristic is reduced to the calculation of the average values recorded by the network of observation stations. The selection for subsequent calculations depends on the number of stations – a small number of weather stations leads to the fact that all available stations are included in the network. It is clear that the greater the number of monitoring stations in the network, the more accurate the calculations of the average values.

The average long-term values reflect the patterns of wind propagation in the territory. It remains to make sure that they can be trusted. As a positive factor, we have the homogeneity of the available observations and an unchanged instrumental base installed at the observation stations. The error of the initial series of daily values of wind strength and direction obtained during continuous recording is 8-12%. Based on a confidence probability of 0.8, the required length of the time series is 18-25 years. Calculations have shown that the length of the time series in 20 years gives an error of 5.5% - that is, it does not go beyond the error of the original series. This allows us to state the accuracy of the average long-term ground observations for the selected averaging period of 22 years (two Schwabe-Wolf cycles).

To improve the quality of data in the processing of meteorological observations, methods of extrapolation and interpolation of data from observation stations are used.

The extrapolation method based on the average value of the time series is used if the distance between the observation stations in a straight line is more than 260 km – the square of the maximum allowable extrapolation distance with an acceptable deviation. With a smaller distance between observation stations, the extrapolation method based on the average value of the time series is used if the relief between the stations is not uniform and the difference between wind directions is more than two points (recall that the wind direction measurement is carried out by 8 points).

Extrapolation formula based on the average value of the time series:

$\hat{Y}_{t+l} = \overline{Y}$, where (3)

$\overline{Y}$ – the average value of the time series levels in the past; $\hat{Y}_{t+l}$ - extrapolated level value; L – lead time; Y_t – the level taken as the extrapolation base.

The confidence bounds for the mean are defined as follows: $\hat{Y}_{t+l} = \overline{Y} \pm t_a S_{\overline{y}}$, where (4)

t_a – tabular value of Student's t-statistics with n-1 degrees and probability level p; $S_{\overline{y}}$ – the average square error of the average value.

The total variance associated with both the fluctuations of the sample average and the variation of individual values around the average will be $S^2 + S^{2/n}$. Thus, the confidence intervals for predictive evaluation are equal to:

$\overline{Y}_{t\_l} = \overline{Y} \pm t_a S\sqrt{1 + 1/n}$ (5)

The data interpolation method is applied according to Newton's formula. This formula is convenient when interpolating functions for values of x close to x_0. Newton's formula has an advantage over Lagrange's interpolation formula – when using it, the number of nodes can be increased without repeating all calculations again. This corresponds to the requirements of the methodology for estimating meteorological observation data for cases when a decision is made to interpolate data across several locations to scale the data.

Newton 's interpolation formula:

$P_n(x_0 + th) = y_0 + \frac{t}{1!}\Delta y_0 + \frac{t(t-1)\ldots t(t-n+1)}{n!}\Delta^n y_0$ (6)

At the same time, it is necessary to consider the calculation deviation. The deviation affects the accuracy of the design of a wind farm, the choice of equipment, the choice of operating mode and the forecast of the amount of energy received. The deviation increases as the radius of the distance from the observation station increases. Extrapolation or interpolation of averaged values carries a smaller deviation, which speaks in favor of using these approaches for data scaling.

When extrapolating the daily values of wind strength for 100 kilometers, the deviation is 11%, for 200 kilometers – 17%, for 300 kilometers – 25%, for 500 kilometers – 42%.

When interpolating by two points of the location of observation stations, the value of interpolation to the middle of the distance between the points (up to 500 kilometers) reduces the error by a factor of 1.5 in comparison with extrapolation. The interpolation error is comparable to the averaging error for an observation station at a distance of 100-120 kilometers between stations. If the distance between the points exceeds the specified value, interpolation is performed on three or more points. At a distance greater than or equal to 500 kilometers, the interpolation deviation is such that it makes it impractical to use the approach to scale the data of meteorological observations of wind speed and direction.

The interpretation of the data model for the assessment of wind potential includes a set of indicators reflecting the average values of long-term meteorological wind measurements by parameters. The complex includes the following indicators:

(1) Coefficient of variation of seasonal (annual) values of wind speed (wind direction), which reflects the degree of variability of the regime.

(2) The number of hours in a day with an average (acceptable) wind speed (wind direction) in a set of indicators for the month (year) to consider the features in the daily data.

(3) Type of distribution of daily wind speed data (wind direction) - prioritization order – negative asymmetric island-top distribution; negative asymmetric distribution; normal distribution; bimodal distribution; positive asymmetric distribution; positive asymmetric island-top distribution.

3 Conclusions

The proposed methodology for evaluating meteorological observations data to account for wind potential can be used in the design of a wind power plant of any type and any rated power of a wind generator.

Actually, the methodology itself is a ready-to-use solution and can be developed by increasing the number of parameters on the basis of which a decision on the design of a wind farm is generated. The methodology can be integrated into the structure of the feasibility study of the project and be included in the calculation part of the assessment of the payback of the investment project and the energy efficiency of the wind farm.

We emphasize that considering the wind potential to determine its location is a mandatory and very important stage of design. The proposed method not only increases the reliability of decision-making, but also significantly reduces the risks associated with determining the location of the projected wind farm.

References:

[1] Energy strategy of the Russian Federation for the period up to 2035. URL: https://policy.asiapacificenergy.org/node/1240

[2] Decree of the Government of the Russian Federation No. 1209-r dated 09.06.2017 (General layout of electric power facilities for the period up to 2035). URL: http://www.consultant.ru/document/cons_doc_LAW_218239/

[3] Unified Energy System of Russia: Interim results, Information Review, March 2022, URL: https://www.so-ups.ru/fileadmin/files/company/reports/ups-review/2022/ups_review_0322.pdf .

[4] Center for Sustainable Systems, University of Michigan, 2021, *Wind Energy Factsheet*, Pub. No. CSS07-09.

[5] Jun Li, Decarbonising power generation in China - Is the answer blowing in the wind?, *Renewable and Sustainable Energy Reviews*, Volume 14, Issue 4, 2010, Pages 1154-1171

[6] Decree of the Government of the Russian Federation No. 1-r dated 08.01.2009 "On approval of the Main directions of state policy in the field of improving the energy efficiency of the electric power industry based on the use of renewable energy sources for the period up to 2035". URL: http://government.ru/docs/20503/

[7] Order of the Ministry of Energy of the Russian Federation No. 88 dated 02/26/2021 "On approval of the Scheme and Program for the Development of the Unified Energy System of Russia for 2021-2027"). URL: http://www.consultant.ru/document/cons_doc_LAW_384492/

[8] Laurencas Raslavičius, Vytautas Kučinskas, Algirdas Jasinskas, Žilvinas Bazaras, Identifying renewable energy and building renovation solutions in the Baltic Sea region: The case of Kaliningrad Oblast, *Renewable and Sustainable Energy Reviews*, Volume 40, 2014, Pages 196-203

[9] Hydrometeoizdat, *Instruction to hydrometeorological stations and posts*, issue 3, part 1, Leningrad, 1985.

[10] *Climatic data for renewable energy in Russia (climate database): Textbook*. – M.: MIPT Publishing House, 2009. - 58 p.

[11] R.M. Wilson, *A Comparison of Wolf's Reconstructed Record of Annual Sunspot Number with Schwabe's Observed Record of 'Clusters of Spots' for the Interval of 1826–1868*, Sol Phys 182, 217–230 (1998). https://doi.org/10.1023/A:1005046820210.

[12] Set of rules, *SP 267.1325800.2016. High-rise buildings and complexe*s. Design rules https://docs.cntd.ru/document/456044284 .

[13] Lingzhi Wang, Jun Liu, Fucai Qian, Wind speed frequency distribution modeling and wind energy resource assessment based on polynomial regression model, *International Journal of Electrical Power & Energy Systems*, Volume 130, 2021, 106964

[14] P.P. Bezrukikh, *Wind Energy: Reference and methodological manual*, Moscow, "ENERGY", 2010.

[15] A. Betz, *Introduction to the Theory of Flow Machines*. (D. G. Randall, Trans.), Oxford: Pergamon Press, 1966.

[16] N.E. Zhukovsky, *NEZH type windmill*, Proceedings of TsAGI, 1920 (lithographed edition).

[17] U.S. DOE, NREL (2015) "*Transparent Cost Database: Capacity Factor" Open Energy Information*.

[18] V.Y. Okorenkov, *Methods and means of verification of meteorological information and measuring systems and measuring instruments*, Publishing House of the Central Research Institute "Asterion", St. Petersburg, 518 p.

[19] Juchuan Dai, Yayi Tan, Wenxian Yang, Li Wen, Xiangbin Shen, Investigation of wind resource characteristics in mountain wind farm using multiple-unit SCADA data in Chenzhou: A case study, *Energy Conversion and Management*, Volume 148, 2017, Pages 378-393