

## ON EFFICIENCY OF WIND POWER USE FOR POWER SUPPLY OF THE ARCTIC DISTRICTS OF YAKUTIA

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### Abstract

*Efficiency of wind power stations (WPS) for power supply of settlements of the eastern Arctic area of Russia has been assessed in the article on the example of the Allaikhovsky district of the Sakha Republic (Yakutia), Russia. Authors consider using of wind power as an additive energy source, as the power supply of the district in the near future will remain autonomous, and the diesel power will be basic and a guaranteed source of energy. Therefore, exploitation of wind power could partly reduce the consumption of fossil fuels. The work takes into account the changes of indicators of wind potential during one year, fuel prices, and annual electricity consumption schedule with the aim of financial and different types of wind turbines applying economic assessment for an Arctic settlement isolated from energetic systems.*

**Key words:** Renewable energy, WPS, decentralized consumer, autonomous energy source, economic efficiency, payback period

In recent time, applying of the renewable energy sources for providing a capable energy supply of distant and arctic regions of the Sakha Republic (Yakutia), that are located on the area of decentralized energy supply with limited period of cargo delivery becomes more actual. In this regard, the necessity to evaluate the economic efficiency of renewable energy use for energy supply of consumers of the area increases.

The main reason of insignificant use of renewable energy sources on decentralized zones of Russia is its capital intensity and low coefficient of installed capacity use connected with unevenness and uncertainty of energy resources development, and the non-dense schedule of communal load of consumers isolated from energy system. Therefore, it should be talked about the rational balanced schedule to exclude some part of organic fuel from the traditional source of energy rather than replacement of the traditional schemes of energy supply of consumers.

Since wind power is the priority type of renewable energy sources in the Arctic regions, the article shows the evaluation of the effectiveness of their use on the example of the Allaikhovsky district settlements located in the Northeast of the republic in the lower reaches of the Indigirka River.

The main problems of providing power inherent in district, as well as all the decentralized zone of the republic, are caused by geographically dispersed consumers and their small power loads. Electricity is supplied by diesel power plants located in each village. In order to provide uninterrupted power supply to consumers sustainable in the harsh conditions of the North, installed capacity of diesel generators exceeds the maximum winter load 3-5 times.

Diesel fuel, oil and gas condensate is used as fuel on the energy sources of the district. Fuel delivery scheme is complex and multi-link, with the length of more than 5 thousand km: by railways, waterways on rivers and through the Northern Sea Route, motor transport. In this connection, there is the dependence on fuel supplies, limited seasonal timing of delivery and, consequently, more expensive and short supply of fuel, irregular power supply to consumers and the high cost of electricity on self-contained energy sources. In the modern conditions, the price of diesel fuel for power of the district is 41.4 thousand rubles/ton. Transportation component in the cost of fuel exceeds 50%. Due to the multi-tier scheme of delivery of fuel its loss amounts about 20% [3, 6].

Technical feasibility and effectiveness of the use of wind turbines (WT) of the unit up to 100 kW in the northern regions of the Sakha Republic (Yakutia) is considered by the authors in [6]. For the study it were selected the wind turbines that meet the requirements of cold climate to the maximum extent: horizontal axis wind turbine

SRC-Vertical with unit capacity from 0.75 to 10 kW, Northern Power (NP) 100 Arctic, Atlantic Orient Corporation 15/50 (AOC-15/50).

The initial data for analysis in the study are wind speed measurements conducted at meteorological stations of the republic from 2001 to 2012. In the analysis it has been assumed a linear variation between the wind speed measurements; thus, values of wind speed at each hour of the day were obtained. In addition, for systems with a unit capacity of 50 and 100 kW wind speed measured at a height of a wind vane of weather station was recalculated at the height of wind-tower of the wind turbine.

Potential power generation of wind turbines was calculated, for all 27 settlements of the Arctic regions of the Sakha (Yakutia) Republic, including the Allaikovsky district, using the «WindMC-Analyzer» to evaluate the technical efficiency.

Results of comparing of the possible wind turbine power generation and consumers' demand show that Wind turbine "AOC-15/50" can be considered as the most appropriate for the settlements with a maximum electrical load a little more than 100 kW (for example, Olenegorsk, Russkoye Ustye), and Wind turbine SRC-Vertical 2, 3, 5 kW – for the small settlements (Chkalov, Nychalakh) [6]. The vast majority of settlements demand electricity from wind turbines up to 10 kW during the day. One of the main conclusions of the studies is the need for electricity accumulation from wind turbines with unit capacity more than a minimum load of the consumer, because in particular time generated electric energy is not in demand.

Since the choice of the optimal number and capacity of wind turbines for each settlement requires additional studies, for the largest settlement of the Allaikovsky district – Chokurdakh, where winter peak of electric load is 1.9 MW, and summer peak - 1.3 MW, studies to assess the economic and financial effectiveness of more powerful wind turbines with a predetermined optimum power of WPS were conducted. Method of determining the optimum capacity of renewable energy for the consumer isolated from the power system is described in details in [4].

Autonomous diesel power plant (DPP) with installed capacity of about 7.8 MW provides consumers of Chokurdakh village by electricity. Most of the units were installed in the early 80s and have been in operation for over 25 years. The annual demand for electricity is 9.6 million kWh. Minimum electrical load in the village in winter is 920 kW, in the summer - 290 kW.

Winds weaker than, for example, on the coast and islands of the Laptev and East Siberian Seas are typical for Chokurdakh. Wind speed of 4-5 and 6-7 m/s prevails during the year [5]. The average wind speed at a height of wind vane (11 m) on the Hydrometeorostation is 4.7 m/s. The strongest wind is observed during the summer period (June-July-August).

To evaluate the effectiveness of application the wind turbines of German companies Turbowinds and Nordwind with unit capacity of more than 400 kW were considered: Turbowinds T-400-34, NW 44-850 VN, NW 66-1600 NY-P. Based on the performance and the wind speeds distribution probability by gradations during the year, the potential of electricity generation by wind turbines was calculated. For more accurate power generation determination, recalculations of wind speed grades were conducted from the height of wind vane (on which measurements at the meteorological station were conducted) to the height of wind tower of the wind turbine. For the wind turbine of Turbowinds T-400-34 wind tower is 34 m; for NW 44-850 VN - 44 m; for NW 66-1600 NY-P - 66 m. Starting speed of wind turbines is 3-4 m/s, the speed of the nominal power output is 13-14 m/s [1,2,7].

Estimated electricity generation by wind turbines regarded under conditions of Chokurdakh is between 0.7 and 3.3 million kWh per year, the capacity factor - 20-23% (Table 1)

**Table 1.** Estimated electricity generation and capacity power use coefficient on wind turbines of various types

| Type of wind turbine | Electricity development of wind turbine, thousand kWh per year | Capacity factor, % |
|----------------------|----------------------------------------------------------------|--------------------|
| Turbowinds T-400-34  | 737                                                            | 21,0               |
| NW 44-850 VN         | 1510                                                           | 20,3               |
| NW 66-1600 NY-P      | 3297                                                           | 23,5               |

As with the use of the wind power it is assumed power supply of a settlement isolated from the power system, it is necessary to correlate the WPS annual power generation schedule with a different set of wind turbines to the consumption schedule.

The greatest development of wind power potential in wind conditions of Chokurdakh village, and hence the power generation from the WPS, can be observed in summer, while the maximum power consumption - in winter. Due to the generation graphs' mismatch and electricity consumption the actual capacity factor of WPS will be significantly low. Thus the cost-effectiveness of its use will decrease. Figure 1 shows the alignment of energy consumption schedules and, for example, the development of it by wind plant with a set of 6, 10 and 20 wind turbines Turbowinds T-400-34 with unit capacity of 400 kW that was accepted for consideration at the first iteration of the study by the method of determining the optimum capacity of renewable energy.

For WPS with a set of up to 6 units of 400 kW wind turbine the possible electricity generation is completely useful i.e. demanded by consumers. However, most of the year, especially the winter period, it is required to use diesel power station, which will provide more than 50% of the settlement demand in electricity.

When increasing the quantity of wind turbines the share of usable electricity generation reduces to 62% in the variant of maximum replacement of DPS with the set of 20 units each with power of 400 kW (Table 2). Thus, almost 40% of electricity generated by wind power with power of 8000 kW will be unclaimed.

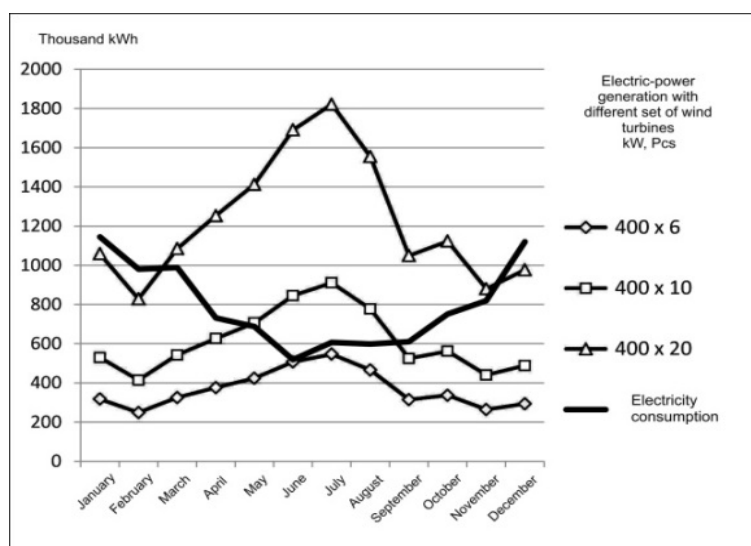


**Figure 1.** The combination of consumption schedules and possible WPS power generation with a different set of wind turbines Turbowinds T-400-34

**Table 2.** Estimated electricity generation of WPS with different set of wind turbines Turbowinds T-400-34

| Number of wind turbines of 400 kW, units             | 1    | 6    | 10   | 20    |
|------------------------------------------------------|------|------|------|-------|
| The installed capacity of WPS, kW                    | 400  | 2400 | 4000 | 8000  |
| Generation of electricity, thousand kWh              |      |      |      |       |
| - possible                                           | 737  | 4420 | 7367 | 14734 |
| - useful                                             | 737  | 4420 | 6539 | 9176  |
| Capacity factor for the development of useful energy | 21,0 | 21,0 | 18,7 | 13,1  |

Depending on the power of the WPS, not only the proportion of energy requirements coating changes but also its cost, and the volume of fuel, displaced with diesel power. The main technical and economic indicators of options of WPS with a different set of wind turbines of 400 kW are shown in table 3.

**Table 3.** Technical and economic indicators of WPS with different set of wind turbines Turbowinds T-400-34

|                                               |     |      |      |      |
|-----------------------------------------------|-----|------|------|------|
| Number of wind turbines of 400 kW, units.     | 1   | 6    | 10   | 20   |
| The volume of the displaced DPS fuel, t.c.e.* | 236 | 1415 | 2093 | 2936 |
| Fuel cost, mln. rub.                          | 6,8 | 40   | 60   | 84   |
| The cost of WPS, million rubles.              | 52  | 312  | 520  | 1040 |
| Payback period, years                         | 7,7 | 7,7  | 8,7  | 12,4 |

\* ton of coal equivalent

Optimality criterion in the selection of power at this stage of the technique is simple payback period. In all cases, with a set of up to 6 pieces of wind turbines of 400 kW while all electricity worked out by the wind plant is useful the payback period will be the shortest - 7.7 years. With further increase in power of WPS the payback period increases due to increased share of unclaimed energy.

In subsequent iterations of the study, the calculation of all the technical and economic performance of WPS with the wind turbines NW 44-850 VN and NW 66-1600 NY-P of unit capacity of 850 and 1600 kW, respectively are carried out with a power output of approximately equal to the energy produced by WPS optimum power selected on the first iteration.

Fig. 2 shows the alignment of the graphs of power consumption and its possible development by WPS with a selected set of wind turbines of various unit capacities. Number of wind turbines, power of wind plant and calculated technical and economic parameters are given in Table 4.

According to the research results the optimal capacity of WPS for Chokurdakh of the Allaikhovsky District of the Sakha Republic (Yakutia) is 1600 kW, the construction project of which is characterized by the shortest payback period (6.4 years). At the same time, from the point of operation and reliability, and taking into account the complexity of the current and capital repairs, the most attractive for construction is the variant of 2250 kW including WPS of three 850 kW wind turbines: the payback period of 7.1 years. Meaning of optimum WPS power as defined in the study is comparable with the maximum load of a consumer.

**Table 4.** Technical and economic indicators of WPS with wind turbines of different types

|                                         |      |      |      |
|-----------------------------------------|------|------|------|
| Unit capacity of wind turbines, kW      | 400  | 850  | 1600 |
| Number of wind turbines, units.         | 6    | 3    | 1    |
| The installed capacity of WPS, kW       | 2400 | 2250 | 1600 |
| Useful development of WPS, thousand kWh | 4420 | 4529 | 3297 |
| Volume of displaced fuel on DPS, t.o.e. | 1415 | 1449 | 1055 |
| Fuel cost, ml. rub.                     | 40   | 41   | 30   |
| Cost of WPS, million rub.               | 312  | 293  | 192  |
| Payback period, years                   | 7,7  | 7,1  | 6,4  |

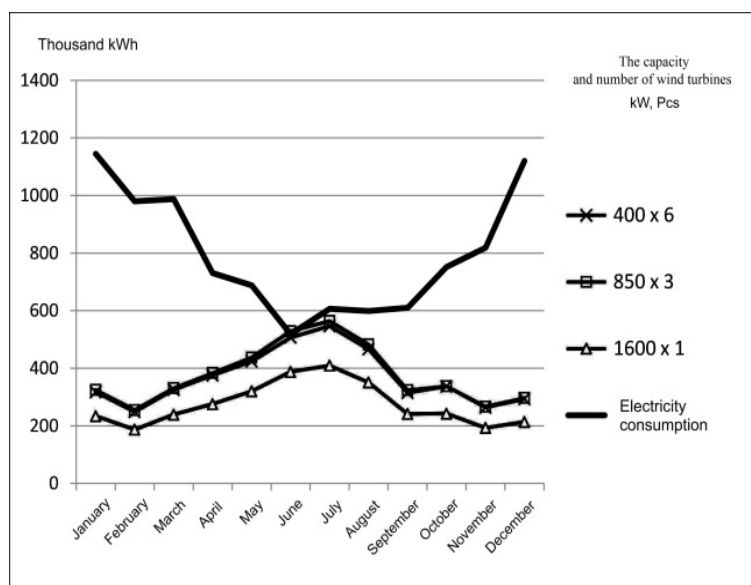


**Figure 2.** The combination of consumption graphs and possible WPS power generation with wind turbines of different types

To assess the financial and economic efficiency of wind power stations for electric-power supply of Chokurdakh, production and financial model describing the dynamics of cash flow during the operation of WPS in addition to the existing diesel power station had been used. The project budget effectiveness was assessed, i.e. the fuel delivery and energy sources budget costs for the selected options of wind power capacity in comparison with the traditional scheme of power supply were analyzed.

Despite the significant single investment, payback of WPS construction projects under conditions of Chokurdakh were provided by decrease of annual energy costs compared to that of a single DPS due to the displacement of fuel which is estimated on the options as 1.1-1.5 thousand t.c.e. per year.

The graphs of the cumulative discounted costs for electricity supply on the traditional scheme and joint operation of DPS and WPS showed that projects for the construction of WPS in Chokurdakh with settings of unit capacity over 850 kW would be financially attractive: the discounted payback period amounts to 8-10 years.

Thus, the studies to assess the economic efficiency of wind turbines for electricity of settlements of the Allaikhovsky District of the Sakha Republic (Yakutia) lead to the following conclusions:

1. Construction of WPS in addition to the existing DPS in the arctic regions of the republic in the current price environment is cost-effective.
2. Basis for the use of wind power for each settlement requires a separate case study to assess the financial and economic efficiency with a predetermined optimum power of WPS.
3. The following factors affect the magnitude of the optimum power of WPS: the distribution of wind potential during one year, the performance of wind turbines, a graph of electricity consumption, distance and accessibility of the territory and, therefore, equipment and fuel delivery cost parameters.
4. The value of optimum capacity of wind power for electricity supply of a consumer in the eastern Arctic zone of the Russian Federation isolated from the power system is comparable with the maximum load.
5. To use the electricity that is unclaimed from wind power during the day, it is necessary to conduct additional studies to evaluate the effectiveness of its daily accumulation.

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