Prospects for the Wind Energy Use for Power and Heat Supply to Decentralized Consumers in the Western Sector of the Russian Arctic

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Abstract. An issue of the possible involvement of wind turbines in the power and heat supply of remote dispersed consumers in the Arctic (meteorological stations, lighthouses, border outposts, army and navy facilities, hunting seats, fishermen and geophysical explorers’ bases, etc.) is considered. The need for the functioning of the consumers remains in the long term. The study of the wind energy potential in the western sector of the Russian Arctic showed emerging prerequisites to be favourable for the efficient use of this renewable energy source in the coastal areas of the Barents and White Seas. Average annual wind speed at a height of 10 m in the areas mentioned are 6-8 m/s. There is a pronounced seasonal wind intensity maximum, which coincides with the seasonal maximum of the consumer’s demand for power and heat. Exemplified by facilities located in the coastal Kola Peninsula, it is shown that it is possible to save a significant amount of expensive imported fuel combusted at diesel power plants and boiler rooms, and thereby to reduce the generated electricity and heat costs by 25-40%, when implementing wind turbines.

1. Introduction

Increased attention has been given to the development of the Russian Arctic during the past few years. This is due to the natural resources development of this region (including oil and gas reserves), the provision of year-round navigation along the important transportation envelope - the Northern Sea Route, and to the need to maintain the defensive potential across the country’s northern territories and due to other factors. Thus, it ultimately remains necessary to operate in the North such relatively small isolated energy consumers as meteorological stations, lighthouses, border outposts, special facilities of the army and navy, collective fisheries, reindeer farms and others. These facilities are power supplied from diesel power plants (DPPs) with overall 10-50 kW to 300-500 kW of installed capacity. Boiler rooms with a capacity of 58.1 to 2326 kW operating on fossil fuel are used for heating. The remoteness and disunity of the consumers, poor transport links significantly hamper their power supply [1-6].

As of July 2021, based on an 1 USD = 74 rubles exchange rate of the US dollar to the Russian Federation ruble, diesel fuel prices in the Murmansk region are 703-743 USD/tonne, for instance. Taking into account the delivery to coastal areas, its cost may increase to 1081-1216 USD/tonne, the
DPPs power cost rises to 0.4-0.54 USD/kWh, and heat energy at boiler rooms - up to 1.2 $e^{-4}$-2.8 $e^{-4}$ USD/kWh.

In view of this, researches aimed at involving renewable energy sources (wind, solar, hydropower of small rivers, etc.) into the power supply systems of decentralized Arctic consumers seem important and relevant. This paper deals with an estimation of the prospects for the wind energy use in the western sector of the Russian Federation Arctic zone - in the coastal Kola Peninsula (Murmansk region).

2. Wind potential in the coastal areas of the Barents and White Seas
The general characteristic of wind energy potential is determined by average annual wind speed (Fig. 1). Processing of long-term wind speed observation series at meteorological stations in the western sector of the Russian Arctic enabled the compilation of an average annual wind speed distribution map over the region territory [7-12] and establishing that the greatest wind potential takes place in the coastal areas of the Barents Sea. On the Kola Peninsula northern coast the average long-term wind speed is of 6-8 m/s, on the southern coast – 5-6 m/s [13-14]. The strongest winds are observed in winter, and this is a favourable precondition for the wind turbines use for energy supply to consumers in the North, especially for heat supply.

![Figure 1](image.png)

**Figure 1.** Average long-term wind speed (m/s) at a height of 10 m above the open flat ground level conditions.

3. Concurrent operation of wind (WPP) and diesel power plants (DPP)
The economic estimation of the concurrent operation of WPPs and DPPs can be made using the concept of net present value (NPV). Funds for the WPP construction can be obtained in terms of a bank loan. Further repayment obliged to be made taking into account the current inflation rate. Assuming the possibility of obtaining a loan at an annual percentage rate $n_r = 10-12\%$ and an inflation rate $b = 3-5\%$ (as for 2019-2020), the so-termed real interest rate $r$, determined by the expression $r = (n_r - b)/(1 + b)$ is to be about 7-9%.
Net present value is defined \([15-19]\) as the sum of current effects for the entire calculation period, reduced to the initial step:

\[
NPP = \left[ \frac{B_1}{(1+r)^1} + \frac{B_2}{(1+r)^2} + \ldots + \frac{B_n}{(1+r)^n} \right] - I_0
\]

where \(B_1, B_2, \ldots, B_n\) is the current income from the WPP operation for relevant year during the entire service life \(n\); \(r\) is the real interest rate.

Investments in the object construction are determined by the expression:

\[
I_0 = k_{DPP}^N_{DPP} + k_{WPP}^N_{WPP}
\]

where \(k_{DPP}\) and \(k_{WPP}\) are the specific capital investments in DPP and WPP, \(N_{WPP}\) and \(N_{DPP}\) are the power outputs of DPP and WPP.

The effect of the “DPP and WPP” complex use for the \(i\)-th year is to be determined as the difference between the heat energy sales income according to the \(f_i\) tariff and the salary cost, fuel cost and other costs:

\[
B_i = Wf_i - (1.2 \cdot P_{DPP}^N_{DPP} \cdot \Pi_{DPP}^N + \frac{W(1-\alpha^3)g_1^T}{\eta_{ix}}),
\]

where \(W = N_{DPP} \cdot h_{max}\) – annual energy consumption; \(P_{DPP}\) – normal-mode ratio for DPPs; \(N_{DPP}\) – boiler room power output; \(h_{max}\) – maximum capacity utilization hours; \(\Pi_{DPP}\) – annual salary; \(1.2\) – correction coefficient that takes account other expenses; \(\alpha^3\) is a wind turbine (WPP) participation in power-load curve provision; \(g\) is the specific fuel consumption; \(s_1^T\) – fuel cost; \(\eta_{ix} = 0.95\) – correction coefficient that takes account fuel losses during transportation and storage.

![Figure 2](image)

**Figure 2.** Dependence of the income earned for each dollar of investment on the power output ratio of WPP and DPP.

For example, we can consider a DPP with the following parameters: power output \(N_{DPP} = 200 \text{ kW}\), maximum capacity utilization hours \(h_{max} = 3000 \text{ hours}\), normal-mode ratio \(P_{DPP} = 0.035 \text{ person/kW}\),
specific fuel consumption $g = 25.5 \, e^{-2} \, \text{kg/kWh}$ (364 $e^{-6} \, \text{tonne of coal equivalent/kWh (tce/kWh)})$, plant depreciation rate $b_{DPP} = 0.1$. Based on an 1 USD = 74 rubles exchange rate of the US dollar to the Russian Federation ruble, annual salary $I_{DPP} = 8110 \, \text{USD/person}$, fuel cost $\gamma_f = 1.22 \, \text{USD/kg (850 USD/tce)}$, specific capital investments $k_{DPP} = 216 \, \text{USD/kW}$. Thus, the power plant generating cost is to be about 0.46 USD/kWh.

For the WPP operating in conjunction with a DPP following initial data were taken: specific capital investments $k_{WPP} = 1350 \, \text{USD/kWh}$, plant depreciation rate $b_{WPP} = 0.05$ (based on the 20 years of WPP service life). When implementing the WPP, a question inevitably arises as to what its capacity should be in relation to the DPP capacity. To answer it, we turn to the net present value attributable to each invested US dollar. Fig. 2 shows the dependence of the ratio on the power output ratio of WPP and DPP $\beta^3 = N_{WPP}/N_{DPP}$. The calculations were performed at an annual inflation rate $b = 4\%$, real interest rate $r = 9\%$, electricity tariff $f_i = 0.46 \, \text{USD/kWh}$. Fig. 2 shows high return level on invested funds is achieved when $\beta^3$ changes in the range from 0.2 to 0.8.

**Figure 3.** NPV generating for a 20 years of WPP service life.

With the initial tariff is 0.46 USD/kWh, then the full cost recovery is achieved in 4 years, and after another year an income of about 30% of the initial investment is formed. After that, it seems possible to switch over to the tariff 0.32 USD/kWh and continue the power supply at this lower tariff. Thus, in consequence of the WPP implementation, it is possible to reduce the electricity tariff by 25-30%.

4. Concurrent operation of the wind turbine with the boiler room
For estimating the effectiveness of the wind turbines implementation into traditional heat supply networks, the researches [20-23] were used. As an example calculations were performed for a boiler room with following characteristics. Power output $N_k = 0.2 \, \text{Gcal/h (0.24 MW)}$, efficiency $\eta_k = 0.7$, maximum capacity utilization hours $h_{max} = 3000 \, \text{hours}$, normal-mode ratio $p_k = 25 \, \text{person/kW}$, plant depreciation rate $b_k = 0.1$, maintenance personnel annual salary $I_{b_k} = 8110 \, \text{USD/person}$, fuel cost $\gamma_f = 1220 \, \text{USD/tonne (850 USD/tce)}$, specific capital investment $k_k = 92.8 \, \text{USD/kW}$. With these initial data, the cost of heat energy is to be about 0.23 USD/kWh.
The following parameters were taken for the wind turbine: specific capital investment $k_{WPP} = 1350$ USD/kW, plant depreciation rate $b_{WPP} = 0.05$. Further calculations were carried out based on: annual inflation rate $b = 4\%$, real interest rate $r = 9\%$, initial tariff $f_0 = 0.23$ USD/kWh. When the boiler room and the wind turbine operate concurrently, the highest profitability takes place in a wide range of the power output ratio of WPP and boiler room – from 0.2 to 0.8. As for the concurrent operation of WPP and DPP, further calculations were carried out with $N_{WPP} / N_b = 0.8$, which enables to increase the WPP contribution to heating load curve provision and the volumes of displaced fossil fuel. As a result, the cost of the heat energy generated is reduced to 0.15 USD/kWh.

Figure 4 shows NPV varying using the upper dotted curve at the initial tariff of 0.23 USD/kWh, the lower dotted curve – at 0.15 USD/kWh. In the first case, the investments are paid off in 4 years. After another 2 years, a profit of about 40% of the initial investment is achieved. And then it becomes possible to reduce the tariff for the consumer to 0.15 USD/kWh, that is by 35%.

Figure 4. NPV varying during the boiler room and a wind turbine concurrent operation.

5. Conclusion

In remote coastal settlements of the western sector of the Russian Arctic zone the cost of electricity generated reaches 0.40-0.54 USD/kWh, and heat energy - up to 1.2 $e^{-4}$ -2.8 $e^{-4}$ USD/kWh. The coastal Arctic areas have the increased wind energy potential. Average long-term wind speed at a height of 10 m are of 6-8 m/s and more. The highest wind intensity is observed in the cold season, being the main prerequisite for the wind energy successful use for the power and heat supply needs of consumers. Wind turbines implementation into the energy sector of coastal areas can bring about significant savings in imported fossil fuel and the cost reduction of electricity and heat by 25-40%.

6. References

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