ESTIMATION PROCEDURE FOR APPLICATION EFFECT OF WIND-DIESEL POWER SYSTEMS FOR STAND-ALONE USERS

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Abstract. The paper presents a calculation procedure of application efficiency of wind-diesel complexes in the rural electric supply system. Electrical capacity of a wind-powered generator (wind turbine) depends upon the air flow rate through the wind-wheel plane and is determined on the basis of weather data supplied by the nearest meteorological station. Under sufficient wind flow the wind turbine takes over a part of electrical load thus allowing for lower diesel fuel consumption and for disengagement of several diesel generators. The number and capacity of wind turbines are chosen according to the current electrical loads and parallel operation with diesel generators. The main aim of wind turbine application within the wind-diesel systems is diesel fuel economy. The fuel amount saved under the given power of the wind-driven generator depends upon the average annual wind speed at the height of the wind-wheel axis. Yearly economic effect of wind turbines is calculated by multiplying the annual energy output by the fuel factor in the prime cost of one kWh of electric energy with due account of the yearlong maintenance costs. The presented calculation procedure is verified by the fact that application of wind-driven power plants allows for diesel fuel economy. Other prime cost factors, such as auxiliary energy of diesel power stations, line losses, repair and maintenance costs are unaffected by the presence or absence of a wind turbine in the system. The presented procedure has been tested when designing an autonomous electric supply system for a settlement in the Arkhangelsk Oblast.

Key words: renewable energy sources, wind turbine, diesel power station, diesel fuel economy, investment payback period.

Introduction

Wind power is the most widespread renewable energy source in the world, and in Russia as well, since it features the lowest capital investments for construction of wind-driven power plants (wind turbines).

Application effect of such equipment is considered on the basis of the case study of an autonomous hybrid wind-diesel power system designed for the Dolgoschelje community in Menzenskij District, Arkhangelsk Oblast.

Choosing procedure of a wind-diesel power system

1. Justification of wind turbine capacity

The number and capacity of wind turbines are specified by the existing electrical loads and parallel operation with diesel generators.

Calculations and field experience show that steady operation of a wind-diesel power system is secured when the nominal output of a wind turbine does not exceed 60 % of the capacity of a parallel diesel-powered generator. According to the technical reports of the Dolgoschelje community maintenance service under the minimal loads one 160 kW diesel generator is working in the settlement. The output of commercial wind-turbine Vestas V19 (Denmark) is 90 kW that is 56 % of the output of the engaged diesel generator. The next dimension type is a 100 kW wind turbine (ex. Vestas V20), the capacity of which is 63 % of that of the diesel generator.

Another recommendation is that the average consumer load does not exceed the maximum capacity of the wind turbine. In this case the generated energy will be utilized almost fully. According to the above technical reports the average wattage of power generation by the diesel generator is around 90 kW. So a 90 kW wind turbine satisfies this condition as well.

So for electric power supply of the Dolgoschelje community a wind-diesel power system, which includes a renovated wind generator of V19 type manufactured by Vestas Company (Denmark) [1], has been chosen.

Basic performance specifications of the wind turbine are as follows: capacity – 90 kW, voltage – 400 V, wind wheel diameter – 18.8 m, tower height – 23.4 m.

The wind turbine is supposed to be installed on the site next to the diesel generator in the Dolgoschelje community. It should be kept in mind that the parallel operation with wind generators is a heavier duty for diesel generators against their autonomous operation or parallel work with other diesel generators. Wind turbine makes the load on diesel generator more variable, and that, in its turn, makes the requirements to voltage regulators and rpm governors stricter. To provide the reliable performance of the wind-diesel system it is advisable to replace those diesel plants, which have reached, or nearly reached, the end of their service life.

2. Description of wind resources

The nearest to the Dolgoschelje community weather stations are Abramovskij Majak (37 km) and Mezen (36 km). The data of Mezen weather station are preferred for application since Mezen and Dolgoschelje communities have similar landscape (flat country, river bank). Abramovskij Majak weather station is located on the White Sea shore.

Wind conditions are described by the data supplied by the Mezen weather station [2] located 36 km from the Dolgoschelje community in latitude 65°54′ North, and at longitude 44°12′ East. Observations were made during 1974 to 1988 at the measurement height of 12.8 m. Table 1 presents the wind speed distribution in various ranges.

Table 1

Wind speed distribution

Ranges of wind speed, m/s	Wind speed frequency, %	Ranges of wind speed, m/s	Wind speed frequency, %
0-1	7.6	7-8	5.6
1-2	10.2	8-9	3.0
2-3	15.1	9-11	2.8
3-4	16.9	11-13	0.6
4-5	15.9	13-15	0.2
5-6	12.8	15-17	0.1
6-7	9.1	>17	0.0

Average annual wind speed at the height of the weather station vane is 4.25 m/s. The maximum registered wind speed is 29 m/s.

3. Estimated cost of equipment

Estimated cost of renovated 90 kW wind turbine Vestas V19, including 23.4 m tower, on FOB Hamburg terms is around EUR 80 000. It does not include the following costs, which are calculated from the FOB Hamburg terms: custom clearance (for Russia it is 18 % VAT + 5 % duty), transportation to the river port of the Dolgoschelje community (around EUR 4000), assembly (15 %) and the crane leasing (terms of the Customer), the cost of the base (10 %). Thus the estimated turnkey cost of a 90 kW wind generator (without transportation costs) might be as high as EUR125 000. The above figures may be considered only as reference data on the draft proposal phase, and they are subject to adjustment on the engineering design phase.

THE OFFERED WIND-DIESEL SYSTEM EFFICIENCY

1. The amount of fuel economy

The main aim of wind turbine application within the wind-diesel power system is to save the diesel fuel. The amount of fuel economy under the set capacity of the wind turbine depends upon the average annual wind speed at the wind wheel height.

The average annual wind speed in any locality depends upon the height of wind turbine tower and the surface roughness class. The site next to the diesel generator was suggested for the wind turbine construction. After the preliminary site survey the first class surface roughness was taken for calculations. This class corresponds to the flat, possibly slightly wavy, surface with some occasional obstacles for the wind flow, such as detached buildings, trees and bushes. The power generated by the wind turbine was calculated following the procedure from [2].

The initial data for calculations were as follows:

- wind speed frequency as shown in Table 1;
- z_0 index (roughness of underlying surface) for the first class surface is taken 0.1 m [2];
- the height of Vestas V19 tower is 23.4 m;
- the height of the weather vane is 12.8 m;
- correlation between the Vestas V19 wind turbine capacity and wind speed is taken from [1].

Calculation results are as follows: annual power generation – 1.05 MWh, capacity factor – 13 %, average wind speed at the tower height – 4.75 m/s.

Under the parallel operation of wind and diesel generators the power of the former is consumed in the first place. At the same time the power generated by diesel generators drops by the amount of the wind-generated energy. This is true in case the average power consumption capacity exceeds the total installed power of wind turbines. Otherwise there will be a certain amount of waste energy. In 2006 the average output of the diesel generator installed in the Dolgoschelje community was 93kW. At the same time the capacity of Vestas V19 wind turbine is 90kW that is slightly less than the average capacity of the diesel generator. So it seems very likely that the wind turbine energy will be fully utilized.

The amount of consumed fuel is proportional to the diesel-generated energy – E_D (kWh):

$$M = E_D\, r, \tag{1}$$

where M – amount of consumed fuel, t;
E_D – diesel-generated power, kWh;
r – amount of fuel per one kWh generated.

The average fuel rate for the operating diesel generator r=0,33 kg/kWh (average of two months indices).

The amount of fuel saving may be calculated as follows:

$$M = E_{WT}\, r, \tag{2}$$

where E_{WT} – wind-generated power, kWh.

$$M = 105.000 \cdot 0.33 = 35.000 \text{ kg} = 35 \text{ t} \tag{3}$$

The forecast of power generation in the Dolgoschelje community was made by the available data (Fig. 1).

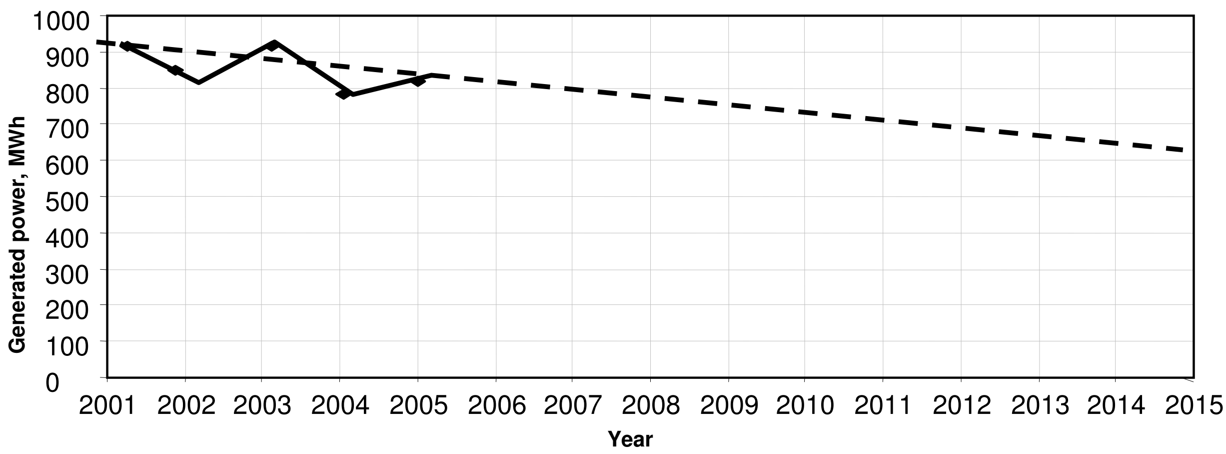

Fig. 1. **The forecast of power generation in the Dolgoschelje community:** — actually generated power; – – – forecast of power generation

The wind turbine was expected to be set in operation in autumn 2007, and the revenue service was to start in January 2008. This year the planned electric power generation would be 750 MWh. In the absence of the wind turbine the fuel consumption would be:

$$M = E_D\, r = 750.000 \cdot 0.33 = 248.000 \text{ kg} = 248 \text{ t} \quad (4)$$

With the wind turbine in use the fuel economy would be 35/248 = 0.14 or 14 %. On the basis of year-by-year calculations the following fuel economy forecast in percent was made (Fig. 2).

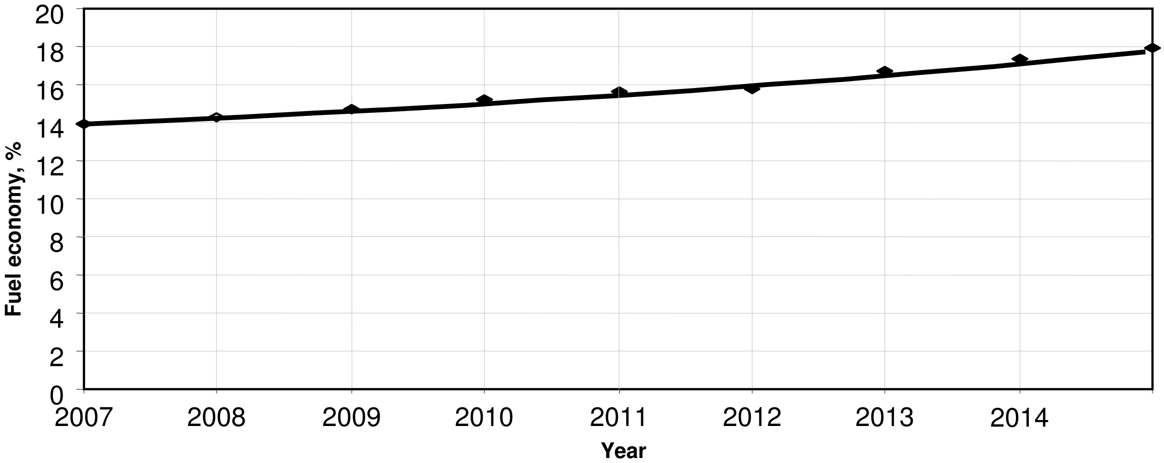

Fig. 2. **Fuel economy forecast**

2. Economic effect

Yearly economic effect of wind turbine application is easily calculated by multiplying the annual power output E_{WT} by the fuel factor ($C_{1\,fuel}$) in the prime cost of one kWh of electric energy (C_1) with due account of the yearlong maintenance costs (C_M):

$$E_{annual} = C_{1fuel}\, E_{WT} - C_M \quad (5)$$

The presented calculation procedure is verified by the fact that application of the wind turbine allows for diesel fuel economy. Other prime cost factors, such as auxiliary energy of diesel power stations, line losses, repair and maintenance costs are unaffected by the presence or absence of a wind turbine in the system.

The prime cost of electric power in the Dolgoschelje community in 2006 was C_1 =12.83 roubles/kWh (VAT included). The fuel factor in 2006 was around 60 % or 7.7 roubles/kWh. Based on the available data the forecast of the growth of energy prime cost and fuel factor was made (Fig. 3).

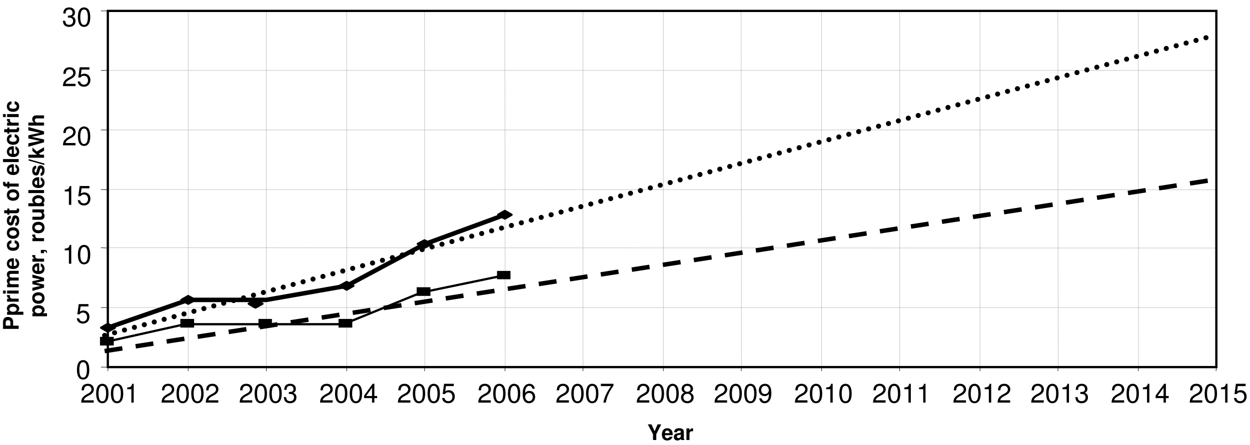

Fig. 3. **Growth dynamics of energy prime cost and fuel factor in roubles:** – actual growth of energy prime cost; – actual growth of fuel factor; – forecast growth of energy prime cost; – forecast growth of fuel factor

According to the forecast of oil processing industry in the Russian Federation [3] by 2015 the diesel fuel price will be 1.6 to 2.5 fold higher against that in 2007. As shown on Fig. 3 the fuel factor will redouble within this period.

The annual output of Vestas V19 wind turbine will be 105 000 kWh. The yearlong maintenance of the turbine will be around EUR 4000 [2], or 135 000 roubles at 2007 values. Thus the annual economic effect in 2008 might be

$$E_{annual} = 7.7 \cdot 105.000 - 135.000 = 675.000 \text{ roubles} \tag{6}$$

Taking into consideration the forecast growth of diesel fuel price the economic effect of wind turbine use will be increasing each year (Fig. 4).

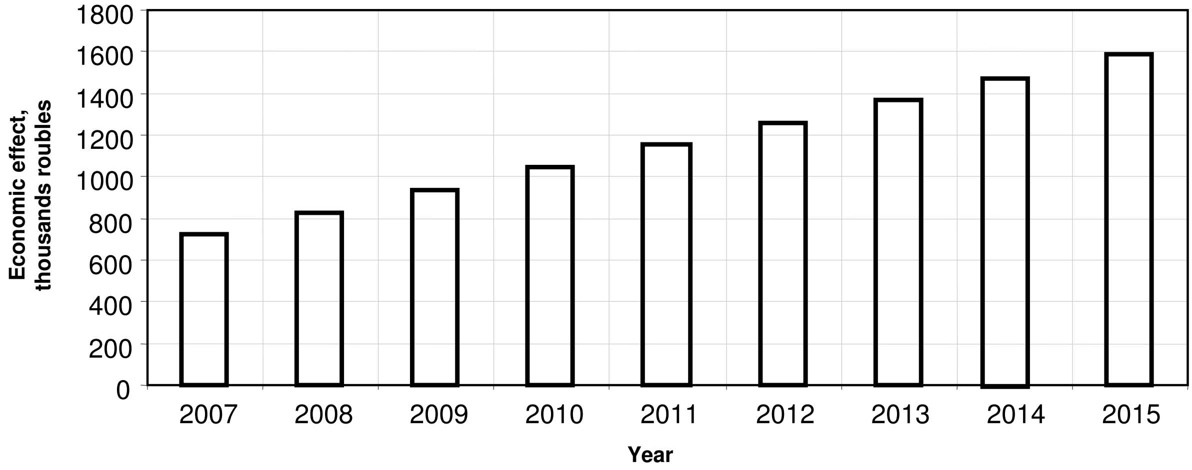

Fig. 4. **Forecast annual economic effect of Vestas V19 wind turbine use**

3. Pay-back period

The payback period is determined by the time when the total economic effect exceeds the capital investments for the wind turbine construction, which for Vestas V19 turnkey construction are estimated in EUR 125000 or 4250000 roubles at 2007 values. Fig. 5 presents the total economic effect of the wind turbine use, the horizontal line showing the capital investments.

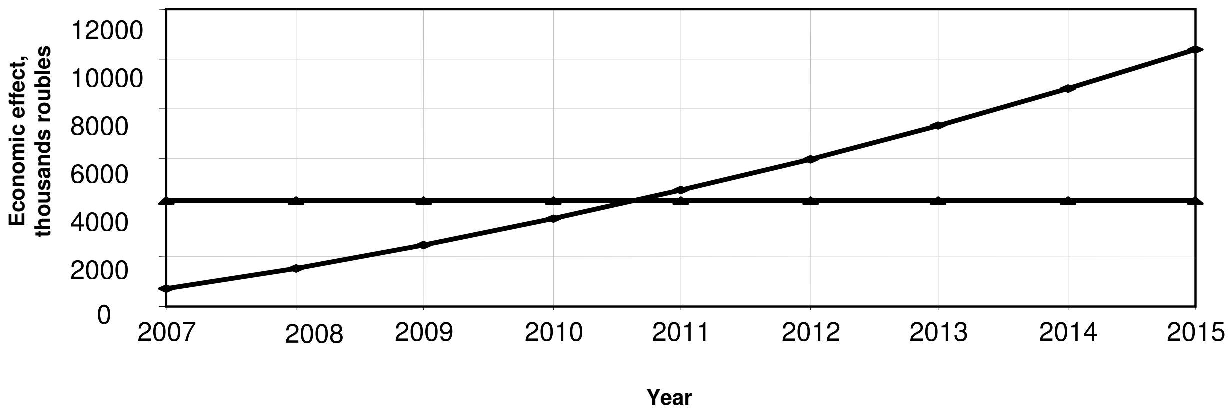

Fig. 5. **Graphical calculation of the payback time for the wind turbine use in thousand roubles:** – forecast of total economic effect; –capital investments in the wind turbine construction

As Fig. 5 shows, the payback time is found between 2010 and 2011, so the payback period will be 3.5 years.

4. Electric energy cost

The prime cost of electric energy generated by the wind turbine Vestas V19 may be calculated in the following way:

$$C_{1\_WT} = (C_{Total} - C_M\, T)/(E_{WT}\, T), \tag{7}$$

where C_{Total} = EUR 125000 – the turnkey construction cost of the wind turbine;
C_M = EUR 4000 – the yearlong maintenance cost of the wind turbine [1];
T = 15 years – the service life of the renovated wind turbine;
E_{WT} = 105000kWh – the annual energy output of the wind turbine under the wind speed of 4.75 m/s.

$$C_{1\_WT} = (125.000 + 4000{\cdot}15)/(105.000{\cdot}15) = 0.12 \text{ EUR}$$

Thus the prime cost of one kWh of energy generated by the wind turbine is estimated in approximately 4 roubles at 2007 values.

Conclusions

The parallel operation of wind and diesel generators, with the wind turbine capacity being below 60 % of that of the diesel generator, provides 14 % diesel fuel economy. Furthermore the stable electric power supply of consumers is guaranteed.

By 2015 the predicted diesel fuel price will be 1.6 to 2.5 fold higher against that in 2007. The calculations made by the offered procedure show that the fuel factor of the electric energy prime cost for diesel electric power stations will redouble from the year 2007 to 2015. Economic application effect of the wind turbine working together with the diesel generator will increase nearly 2.5 times. The payback period of the wind turbine will be 3.5 years. The prime cost of electric energy generated by the wind turbine will be approximately 4 roubles/kWh that corresponds to the grid energy cost in the region under consideration. As a result the calculations made by the offered procedure prove the feasibility of the wind turbine installation for parallel operation with the already functioning diesel generators aimed at the diesel fuel economy.

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