Czech Technical University in Prague
Faculty of Electrical Engineering
Department of Economics, Management and Humanities

DESIGN OF WIND-DIESEL OFF-GRID POWER SUPPLY SYSTEM

Master Thesis

Study Program: Electrical Engineering, Power engineering and Management
Branch of study: Management of Power Engineering and Electrotechnics
Supervisor: Ing. Martin Beneš, Ph.D.

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MASTER'S THESIS ASSIGNMENT

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II. Master's thesis details

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Design of wind-diesel off-grid power supply system

Guidelines:

1. Study the technology of wind power turbines, the power control methods.
2. Analyze the consumer requirements, load diagram.
3. Analyze wind potential in the given region.
4. Calculate parametres of the hybrid power system.
5. Evaluate and optimize the project from economic and financial view.

Bibliography / sources:

1. Lukutin B. V., Muravlev I. O., Plotnikov I. A.: Sistemy elektrosnabzheniya s vetrovymi i solnechnymi elektrostanciami [Power supply systems with wind and solar power plants], TPU, 2015
2. Brealey R. A., Myers S. C., Allen F.: Principles of Corporate Finance, 13th edition, McGraw-Hill, 2020.

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III. Assignment receipt

The student acknowledges that the master's thesis is an individual work. The student must produce his thesis without the assistance of others, with the exception of provided consultations. Within the master's thesis, the author must state the names of consultants and include a list of references.

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Declaration:

I hereby declare that this master's thesis is the product of my own independent work and that I have clearly stated all information sources used in the thesis according to Methodological Instruction No. 1/2009 – "On maintaining ethical principles when working on a university final project, CTU in Prague".

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ABSTRACT

This master thesis is devoted to the design of a hybrid power supply system based on a renewable energy source in the form of wind and diesel generator for a rural settlement in Russia which is not technologically connected to the United Energy System (UES). At the moment the power supply of Soyanskoye Rural Settlement (Archangelsk region) is provided by diesel generators, since due to the low population density in the north of Russia it is economically inefficient to build overhead lines and connect small settlements to the grid. Integrating a renewable energy source will make it possible to reduce the annual cost of consumed electric power and also to reduce emissions of diesel fuel combustion products into the atmosphere. The thesis contains the description of energy needs and requirements of a rural settlement, the analysis of wind energy potential in chosen area, designed scheme of a hybrid power supply system with the price list of necessary equipment and economic evaluation from a financial point of view.

KEYWORDS

Wind turbine generator, diesel generator, power control, load diagram, wind speed, hybrid power supply, power balance, economic evaluation, sensitivity analysis.

CONTENT

LIST OF ABBREVIATIONS

Abbreviation	In foreign language	In English
ASO	-	Automatic Switch Over
CAPM	-	Capital Asset Pricing Model
FTS	-	Federal Tax Service
GOST	Gosudarstvenniy Standart	Russian Technical Standart
HAWT	-	Horizontal Axis Wind Turbine
ISO	-	International Organization for Standardization
NPV	-	Net Present Value
POL	-	Petroleum, Oil and Lubricants
TNV	Teplotvornoe netto znachenie	Net Calorific Value
UES	-	United Energy System
WT	-	Wind Turbine
YMZ	Yaroslavskiy Motornyy Zavod	Yaroslavl Motor Plant

INTRODUCTION

The modern development of the energy sector in Russia is characterized by an increase in the cost of energy production. The greatest increase in the cost of energy is observed in decentralized areas of far North or far East of Russia, where power supply systems based on diesel generators operating on imported fuel are mostly used. This fuel is mainly delivered from far away due to poor weather conditions and geographical aspects [2].

With the constant development of technology in the electric power industry, renewable energy, which has a number of advantages, has become an urgent solution to the problem of providing distant areas with electricity. Affordability, widespread distribution, renewability, low cost of energy production for the foreseeable future, and environmental impact are the main aspects of why renewable energy is one of the main potential solutions to the examined problem [2].

The main target of master thesis is the development and economic evaluation of a decentralized power supply system using a renewable energy source and providing continuous power supply to a small rural settlement in the Arkhangelsk region of Russia.

In order to accomplish the aforementioned target, it requires:

- To analyze consumer requirements in terms of electrical energy consumption;
- To investigate the wind energy potential in chosen region;
- To define the scheme of the hybrid power supply system with the selection of electrical equipment;
- To create an economic model and examine it from a financial point of view.

CHAPTER 1. Technology of wind power installations

1.1 Technology of wind power installations

Horizontal-axis wind turbines (HAWT) have a rotational axis that is horizontal to the ground and nearly parallel to the wind flow. Most commercial wind turbines fall into this category. Horizontal-axis units have a number of undeniable advantages, such as low wind speeds at the inlet and ease of installation. However, the generator and gearbox of these turbines must be located above the tower, which makes their construction more complicated and expensive. Another disadvantage is the need for a tail or yaw drive to orient the turbine downwind [4].

Depending on the number of blades, horizontal-axis wind turbines are classified into one-blade, two-blade, three-blade and multi-blade. Single-blade turbines are cheaper due to the economy of blade materials. The drag losses of such turbines are also minimal. However, in order to balance the blade, a counterweight must be installed against the hub. Single-blade designs are not very popular because of balancing problems and visual acceptability. Two-blade rotors also have these disadvantages, but to a lesser extent. Most modern commercial turbines used for power generation have three blades. They are more stable because the aerodynamic load is relatively uniform. Machines with more blades (6, 8, 12, 18 or even more) are also available. The ratio between the actual blade area and the rotor span area is called strength. Therefore, multiblade rotors are also called high strength rotors. Such rotors are easy to start because the large rotor area initially interacts with the wind. Some designs with low solidity may require external starting [4].

The principal subsystems of a typical (land-based) horizontal axis wind turbine are shown in Figure 1.1. These include:

- The rotor, consisting of the blades and the supporting hub.
- The drive train, which includes the rotating parts of the wind turbine (exclusive of the rotor); it usually consists of shafts, gearbox, coupling, a mechanical brake, and the generator.
- The nacelle and main frame, including wind turbine housing, bedplate, and the yaw system.
- The tower and the foundation.
- The machine controls.
- The balance of the electrical system, including cables, switchgear, transformers, and possibly electronic power converters [3].

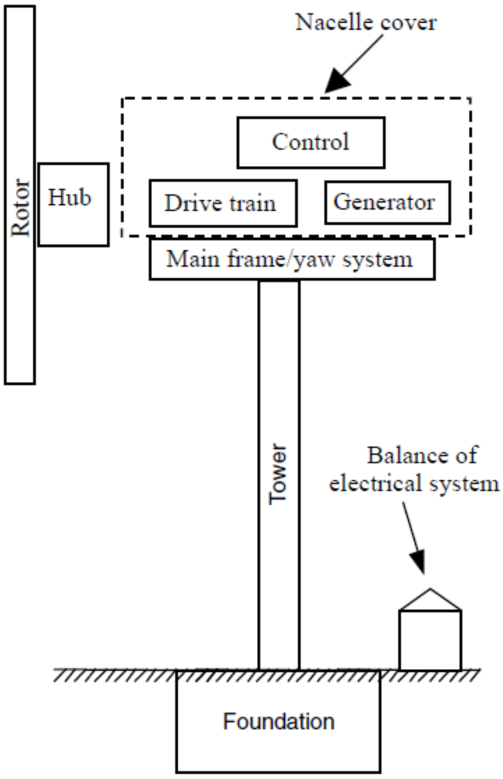


Figure 1.1 – Major components of a horizontal axis wind turbine [3]

The main options in wind turbine design and construction include:

- number of blades (commonly two or three);
- rotor orientation: downwind or upwind of tower;
- blade material, construction method, and profile;
- hub design: rigid, teetering, or hinged;
- power control via aerodynamic control (stall control) or variable-pitch blades (pitch control);
- fixed or variable rotor speed;
- orientation by self-aligning action (free yaw), or direct control (active yaw);
- synchronous or induction generator (squirrel cage or doubly fed);
- gearbox or direct drive generator [3].

The power output of a wind turbine depends on the wind speed, and each wind turbine has a characteristic power performance curve. With this curve it is possible to predict the energy production of a wind turbine without taking into account the technical details of its various components. The power curve represents the electrical power output as a function of wind speed at the height of the installation. Figure 1.2 presents an example of a power curve for a hypothetical wind turbine [4].

The output of this wind turbine can be related to three key points on the velocity scale [3]:

- Cut-in speed: the minimum wind speed at which the machine will deliver useful power.
- Rated wind speed: the wind speed at which the rated power (generally the maximum power output of the electrical generator) is reached.
- Cut-out speed: the maximum wind speed at which the turbine is allowed to deliver power (usually limited by engineering design and safety constraints).

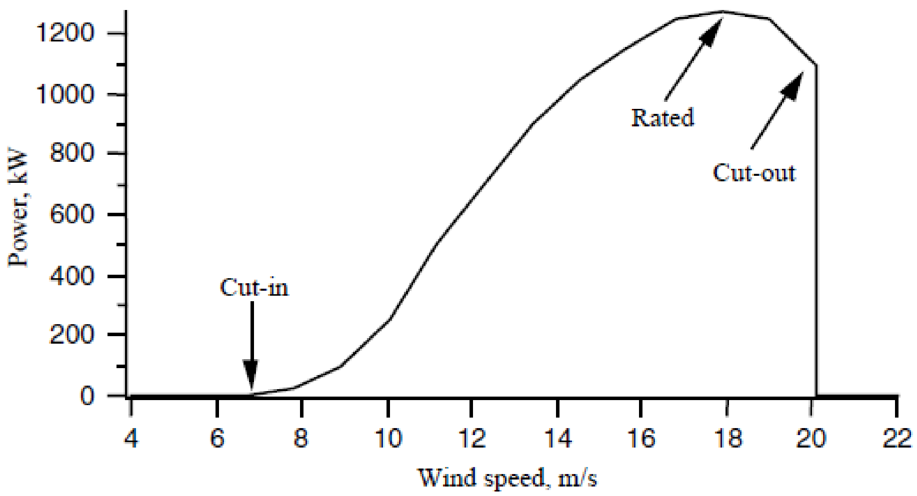


Figure 1.2 – Typical wind turbine power curve [3]

1.2 Operation in different conditions

Operation in severe climates imposes special design considerations on wind turbines. Severe climates may include those with unusually high extreme winds, high moisture and humidity, very high or low temperatures, and lightning [4].

Operation at low temperatures also involves certain design features. Experience has shown that cold weather can impose significant requirements on the design and operation of wind turbines due to icing of sensors and turbines, material properties at low temperatures, permafrost and snow [4].

Turbine icing is a serious problem in cold climates. icing comes in two basic forms: glaze ice and rime ice. Glaze is the result of rain freezing on cold surfaces and occurs at temperatures close to 0 °C. Glaze is usually clear and forms sheets of ice on large surfaces. Rime ice forms when supercooled droplets of moisture in the air come into contact with a cold surface. Rime ice accumulation occurs at temperatures colder than 0 °C. Ice buildup on aerodynamic surfaces impairs turbine performance, and on anemometers and wind wheels leads to either no information from these sensors or unreliable information. Ice can also cause rotor imbalance, aerodynamic brakes to malfunction, power lines to break, and personnel hazards due to falling ice. Attempts to solve some of these problems include special blade coatings (black paint) to reduce ice formation, heating systems, and electrical or pneumatic devices to remove accumulated ice [4].

Cold weather also affects the properties of materials. Cold weather reduces the flexibility of rubber seals, causing leaks, reduces clearances, reduces fracture strength, and increases lubricating oil viscosity. Each of these factors can cause mechanical failures or problems in everything from solenoids to transmissions. Most cold-weather turbines are equipped with heaters on a number of critical parts to ensure proper operation. Materials also become more brittle in cold climates. Cold-weather operation may require a reduction in component strength or special materials necessary for components to operate properly in cold weather or to provide sufficient fatigue life [3].

Installation and operation of wind turbines can be affected by cold weather climatic conditions. Access to wind turbines can be severely restricted due to deep snow. This can lead to increased downtime due to turbine problems or delays and costly maintenance. If installed in permafrost, the turbine installation season may be limited to winter when permafrost is complete and transportation is easier [3].

1.3 The power control methods

Nowadays there are several methods of regulating the power output of a wind power installation. Each of these methods has both advantages and disadvantages, which have been described below:

1) Power control at constant rotational speed

During operation of such a wind turbine the voltage at the output of generator and rectifier respectively changes when wind speed changes. Thus, at low wind speed and output voltage becomes lower than the voltage on the battery, the current in the battery stops flowing, which leads to a decrease in electromagnetic torque of the generator on the wind wheel shaft. As the wind speed increases, the generator speed tends to increase, which leads to an increase in generator output voltage and an increase in current to the battery. The increase in current leads to an increase in electromagnetic torque of the generator on the shaft of the wind turbine, which does not allow it to accelerate above a certain speed, thus achieving stabilization [2].

The advantages of the method of power control at a constant speed:

- this method does not require such units as a gearbox or a mechanism for changing the setting angle of the blades, which simplifies the design of the wind wheel, while increasing its reliability;
- the way provides the possibility of using the generator with excitation from the permanent magnets, which allows you to increase the efficiency of the generator and the entire wind turbine as a whole, since this generator does not require electrical energy to excite the magnetic field;

- the possibility of using a simple scheme of conversion of alternating electric current of the generator into direct current of the battery charge through a diode rectifier bridge allows you to simplify electrical equipment wind turbine and reduce the cost of the final product [2].

Disadvantages of this method:

- efficient operation of the wind turbine is provided only in a narrow range of wind speeds;
- it is necessary to apply special measures to protect against excessive power at wind speed exceeding the nominal one [2].

2) Power control by a step change in the rotor speed by switching the generator windings

This method is similar to the method of power control at a constant wind wheel speed, differing in the fact that depending on the wind speed, wind turbine design allows you to change the output voltage of the generator, which allows the wind wheel to operate at a variable speed depending on the wind speed, which allows efficient operation at multiple wind speeds [2].

Advantages of the method:

- the method makes it possible to significantly expand the range of wind speeds at which efficient operation of the wind turbine is possible;
- using this method allows you to save the simplicity of the electric wind turbine converter, shifting the functions of the executive device of wind turbine control system to the electromechanical switch of generator windings [2].

Disadvantages of the method:

- to ensure the functioning of such a method in the wind turbine control system, wind speed measurement with anemometer is required, or determination of this value by indirect evidence, such as the value of the angular acceleration of wind speed;
- use of generator winding switching device leads to a reduction in the reliability of electrical equipment of wind turbine;
- compared with the method of wind turbine power control at a constant wind wheel speed, there is a need to use special protective devices to limit the generator power at wind speeds higher than the nominal [2].

3) Power control by changing the gear ratio of the wind turbine gearbox

Another way to adjust the rotor speed of the wind turbine to varying wind speed is to use a mechanical gear between the shaft of the wind turbine and the shaft of the electric generator with a variable or step change gear ratio. An example of such devices is a gearbox with several gears.

This method makes it possible to significantly expand the range of wind speeds, while allowing the use of fairly simple synchronous generators designed for a fixed speed [2].

Advantages of the method:

– the use of a mechanical transmission with a variable gear ratio allows to significantly expand the range of wind speeds at which the efficient operation of the wind turbine is possible;
– use of such a method allows to save simplicity of electric converter of wind-power plant by transferring functions of executive device of wind-power plant control system to controlled gear-box [2].

Disadvantages of the method:

– the use of a gear changer leads to reduced reliability of the mechanical transmission from the wind wheel to the generator of a wind turbine;
– the use of a gear changer leads to an increase in mechanical losses in the path "wind wheel - generator", reducing the overall efficiency of the wind turbine;
– there is still a need to use special protective devices to limit the power of the generator at wind speeds higher than the nominal [2].

CHAPTER 2. Consumer requirements. Analysis of wind potential in the given region

2.1 Information about object of research

This paper deals with the design of a hybrid power supply system for the northern Russian village. Soyanskoye rural settlement (Soyana village) is located in the western part of Mezensky municipal district of Arkhangelsk region. According to the map of the Soyana village settlement [9], it was roughly assumed that the number of houses in the settlement is 196 buildings. Thus, if 401 people live in the village [10], then an average of 2 people live in one house. Distance from the administrative center - the city of Arkhangelsk 408 km. [10].

According to [11], there is no central heating system in the village of Soyana, the heating of houses in the village is carried out mainly by burning wood and coal, which are purchased personally by each resident. In addition, there is no lighting on the streets of the settlement. Currently, power supply to the Soyanskoye rural settlement of Mezensky municipal district is provided by diesel power plants through a system of high-voltage line 35 kV and the corresponding distribution substations. The total capacity of diesel generator is 400 kW.

Figure 2.1 – Location of the Soyanskoye rural settlement, based on data from [8] and [9]

2.2 Analysis of consumer requirements

Objects of decentralized power supply differ in great diversity in terms of installed capacity, power consumption modes, and power quality requirements. A characteristic feature of decentralized consumers is a sharply variable electric load graph. To supply consumers under such conditions, a simple, reliable, economical, maneuverable power supply source is required, which has the ability to be designed for a wide range of installed capacities [2].

It was decided that the energy consumption model will be created only for one house, then after calculating the energy consumption for one house, the results will be multiplied by 196, which will show the relevant information about the energy consumption of the entire rural settlement.

It was assumed that an average rural resident has the following electrical equipment at home: electric kettle, iron, refrigerator, microwave oven, lighting, TV, stove. The power consumption graphs were built based on the following considerations: for example, the stove is most often used in the morning and in the evening. In addition, the power consumption of the stove depends on the cooking zones that are switched on as well as on the position of the power toggle switch of each cooking zone. The kettle with the microwave oven can be used during the day, especially during meals. The refrigerator has its own operating mode; it turns on automatically for 20 minutes every 3 hours to keep food cold. The stove and iron are automatically turned off from time to time to avoid overheating. The kettle, microwave and lighting do not change the power consumption during use, it remains constant and depends only on the operating time.

Table 2.1 – The average power consumption values of typical appliances [21]

Electrical equipment	Average Power, W
Electric kettle	1800
Iron	2500
Refrigerator with freezer	400
Microwave oven	1500
Lighting	Up to 160
TV set	150
Stove	2000-3000

Figures 2.2 – 2.8 below show graphs of power consumption for each appliance for one day (24 hours = 1440 minutes).

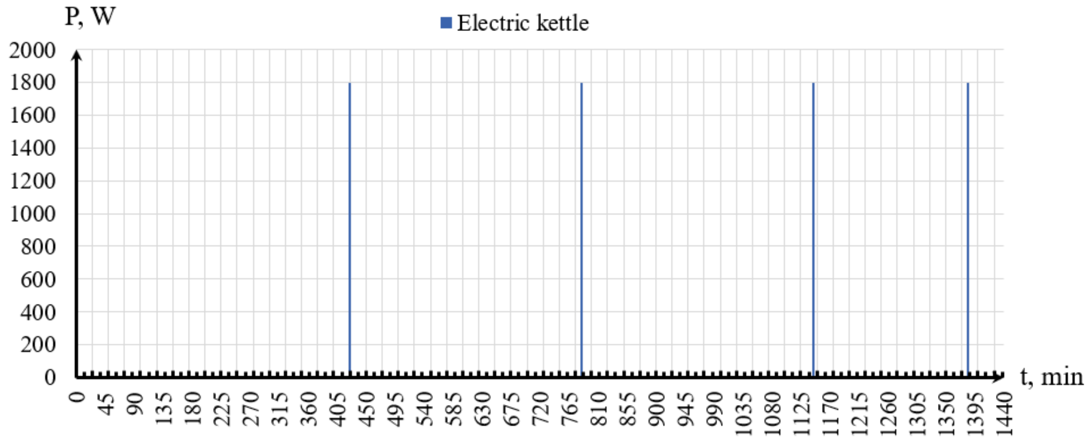


Figure 2.2 – Power consumption graph of the electric kettle

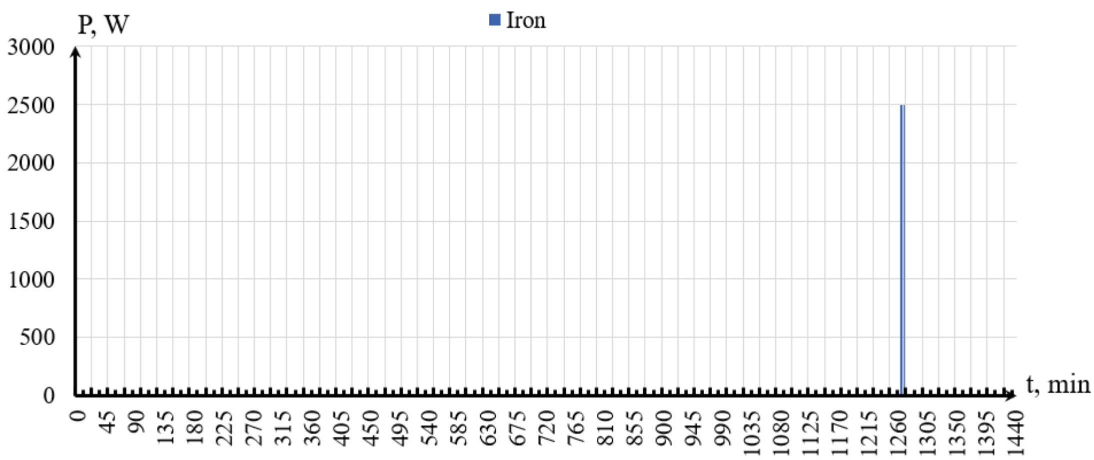


Figure 2.3 – Power consumption graph of the iron

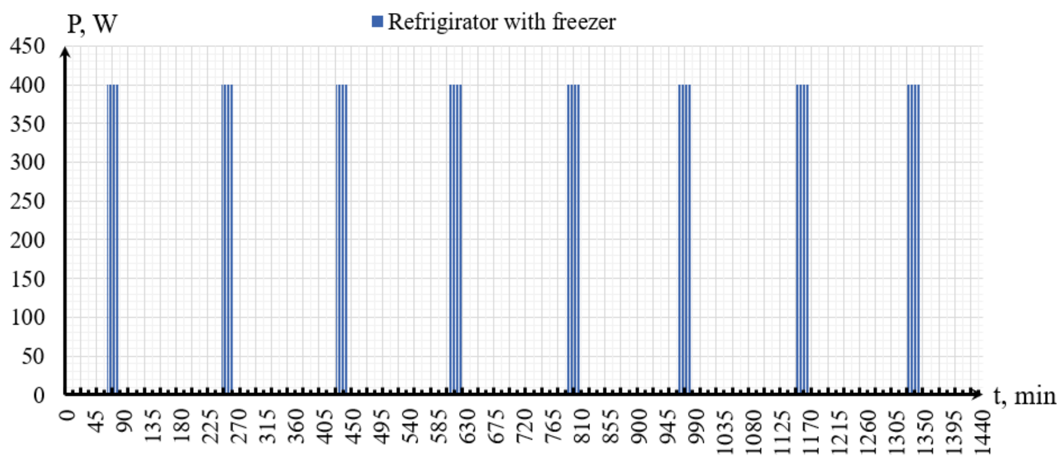


Figure 2.4 – Power consumption graph of the refrigerator with freezer

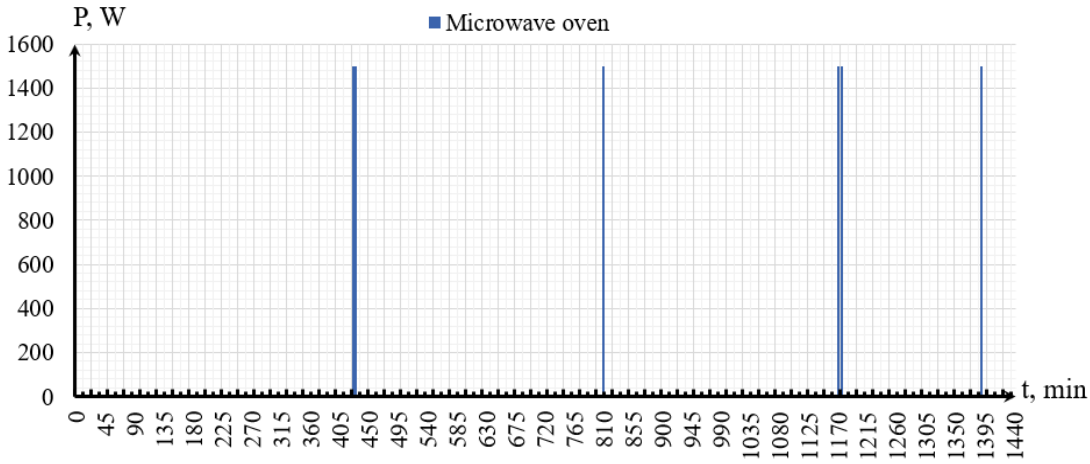


Figure 2.5 – Power consumption graph of the microwave oven

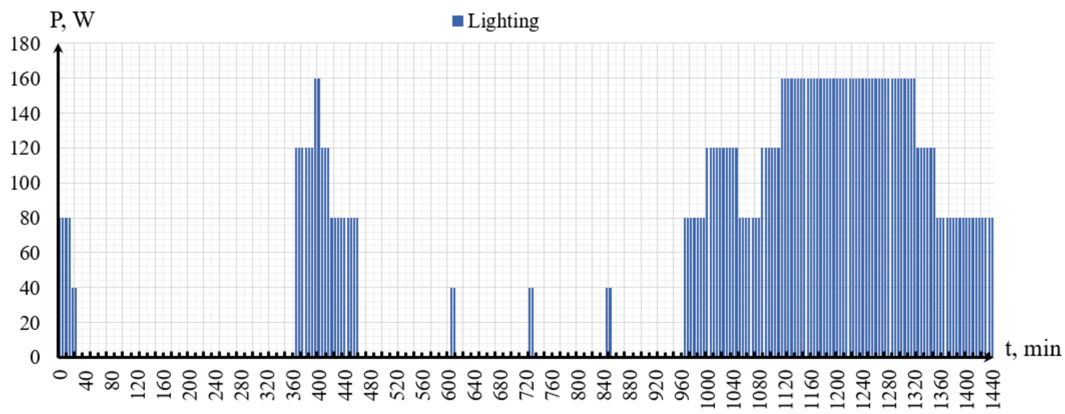


Figure 2.6 – Power consumption graph of the lighting in winter period

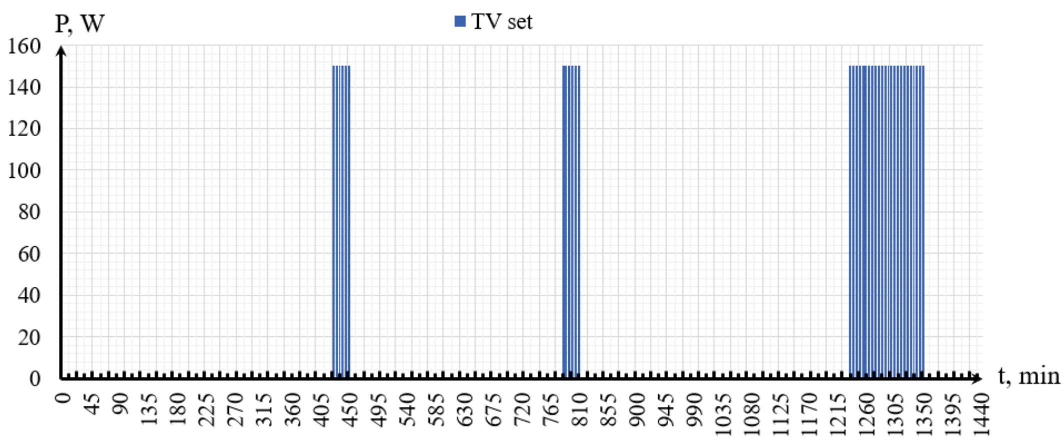


Figure 2.7 – Power consumption graph of the TV set

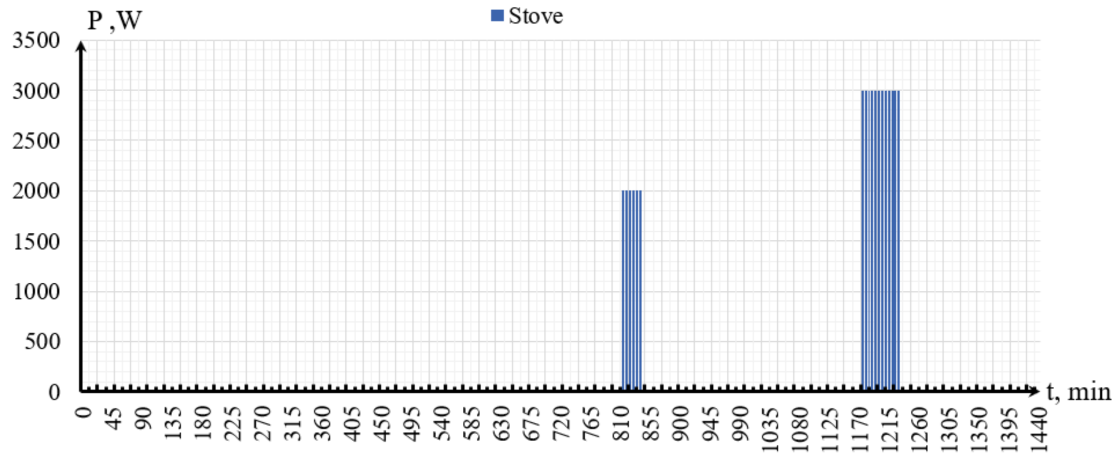


Figure 2.8 – Power consumption graph of the stove

In the course of calculations, it was found that the total electricity consumption for one residential house for one day in winter season is 8.231 kW. Further, it makes it possible to find the total amount of electricity consumed in one day for the entire village of Soyana:

$$P = 8.231 \cdot 196 = 1\,613.325\ kW. \quad (1)$$

Dividing the obtained value by 24 hours makes it possible to obtain the consumed electrical energy for 1 hour, which is 67.22 kW·h.

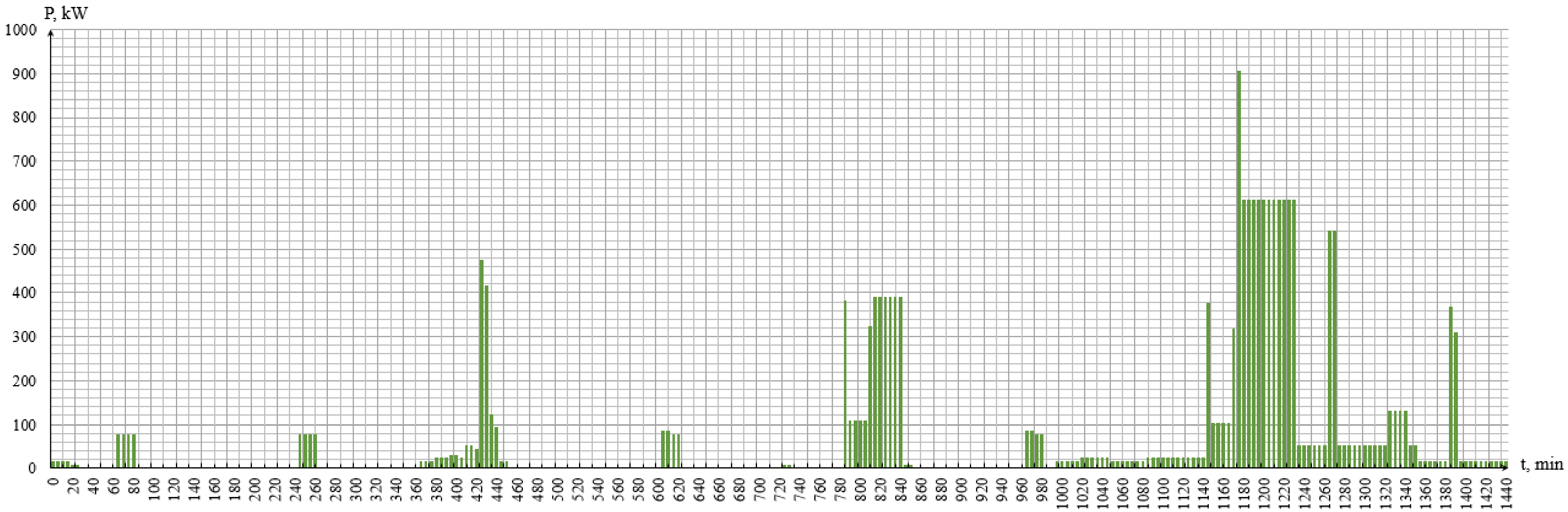


Figure 2.9 – Daily load graph for Soyana village

As can be seen from the Figure 2.9 the ranges of maximum power consumption in the Soyanskoye rural settlement are during the periods of working day from 6 to 7:30 a.m. And then, from 7 p.m. to 9 p.m.

Table 2.2 contains the seasonal coefficients for each month. The seasonal coefficient is the coefficient of change in electricity consumption depending on the time of the year.

Table 2.2 – Seasonal coefficients for annual load graphs of decentralized consumers [2]

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Seasonal coefficient	1.0	1.0	0.9	0.85	0.8	0.75	0.7	0.75	0.8	0.85	0.9	1.0

In order to compile a power balance in an autonomous power supply system with a wind-diesel power plant, an annual graph of electricity consumption in the settlement is required. The calculated graph of annual electricity consumption in Soyanskoye rural settlement is shown in the Figure 2.10.

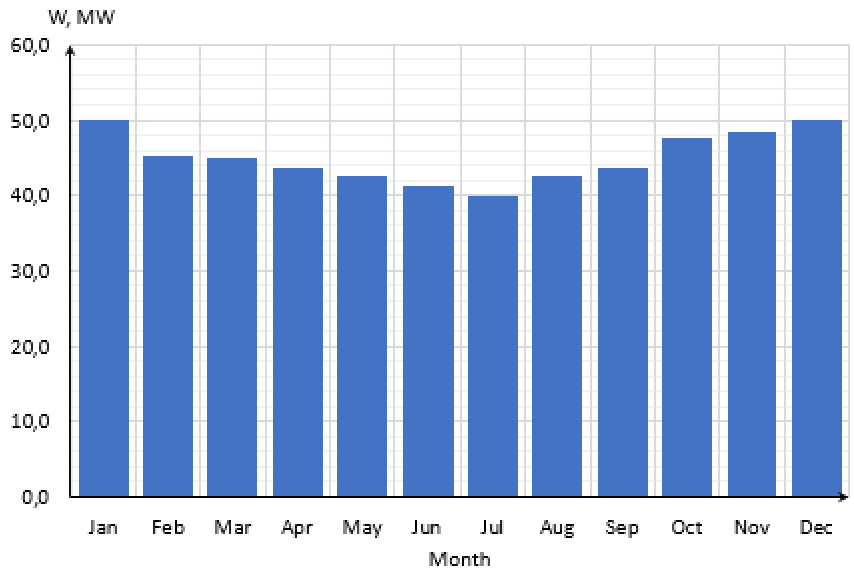


Figure 2.10 – Annual load graph for Soyana village

2.3 Wind energy potential in Soyanskoe rural settlement

The information below was taken from source [2].

Wind energy potential is defined as the total energy of the wind flow of an area at a certain height above the ground surface.

The combination of wind features and energy characteristics is summarized into a wind energy register of the region. The main characteristics of the wind energy register are:

- average annual wind speed, annual and daily wind course;
- velocity repeatability, types and parameters of wind velocity distribution functions;
- vertical profile of the average wind velocity;
- wind energy resources of the region.

Average monthly and annual wind speeds over long periods of time are the basic and initial data for characterizing the overall level of wind intensity. These characteristics provide a preliminary indication of the viability of locating wind power equipment in the desired area. When characterizing, it should be remembered that wind speeds are highly dependent on surface roughness and that data from weather stations may change over time as the surrounding area changes [2].

The gradation distribution of wind speed presented in Table 3.2 makes it possible to calculate the output of a wind power plant for each month. For this purpose, it is necessary to convert the percentage of repeatability of wind speed interval into the corresponding time interval. Then the wind generator capacity corresponding to this wind gradation and the time of wind power plant operation in this mode allows to determine the amount of electricity for the month for the corresponding wind speed. The total energy that can be produced by a wind power plant of a certain type during the time interval under consideration is defined as the sum of energies corresponding to each wind gradation [2].

Table 2.3 – Monthly repeatability in days and percentages of different wind speed gradations, based on data from [23]

Wind speed, m/s	0 – 1		2 – 3		4 – 5		6 – 7		8 – 9		Days in total	Average monthly wind speed, m/s
Number of days in month/percentage of days in month	Days	Percentage	Days	Percentage	Days	Percentage	Days	Percentage	Days	Percentage		
January	0.6	2%	11.8	38%	11.8	38%	3.4	11%	3.4	11%	31	4.46
February	0.3	1%	12.4	40%	11.5	37%	3.4	12%	2.8	10%	28	4.28
March	0.9	3%	12.4	40%	12.4	40%	4.0	13%	1.2	4%	31	4.13
April	1.2	4%	11.8	38%	12.4	40%	3.0	10%	2.4	8%	30	4.19
May	1.9	6%	11.5	37%	13.0	42%	2.8	9%	1.9	6%	31	4.07
June	2.1	7%	10.9	35%	13.6	44%	2.4	8%	1.8	6%	30	4.02
July	3.1	10%	9.6	31%	14.0	45%	2.5	8%	1.9	6%	31	4.01
August	1.9	6%	10.2	33%	14.0	45%	2.8	9%	2.2	7%	31	4.20
September	1.5	5%	10.9	35%	13.0	42%	3.0	10%	2.4	8%	30	4.21
October	0.9	3%	11.2	36%	13.0	42%	3.1	10%	2.8	9%	31	4.36
November	0.6	2%	11.5	37%	12.4	40%	3.3	11%	3.0	10%	30	4.39
December	0.6	2%	10.9	35%	12.4	40%	3.7	12%	3.4	11%	31	4.55
										Year:	**365**	**4.24**

It should be noted that the wind speed increases with distance from the underlying surface and the air flow becomes more stable. The degree of increase of wind velocity with height strongly depends on the roughness of the underlying surface. Approximately the wind speed at height “h” can be estimated by the formula [2]:

$$V_h = V_M \cdot \left(\frac{h}{h_M}\right)^{\alpha}, \tag{2}$$

where V_h − wind speed on the height “h”, [m/s];

V_M − wind speed at mast height, [m/s];

h_M − height of the mast, [m];

α − coefficient related to the average wind speed at the height of the mast.

Table 2.4 – Dependence of coefficient α on wind speed V_M [2]

$V_M, m/s$	0 – 3	3.5 – 4	4.5 – 5	5.5	6 – 11.5	12 – 12.5	13 – 14
α	0.2	0.18	0.16	0.15	0.14	0.35	0.13

It has been accepted that the height of wind speed measurement is equal to 18 meters (h = 18 m). Therefore, according to formula (2), the average wind speed at a height of 18 meters are presented in table 2.5.

Table 2.5 – Wind speeds at the height of 18 m

Month	1	2	3	4	5	6	7	8	9	10	11	12
Average wind speed, m/s	4.46	4.28	4.13	4.19	4.07	4.02	4.01	4.2	4.21	4.36	4.39	4.55
Wind speed at the height of 18 m, m/s	4.96	4.76	4.59	4.66	4.53	4.46	4.46	4.66	4.68	4.85	4.88	5.05

The annual average wind speed is defined as the arithmetic mean value obtained as a result of speed measurements at equal time intervals during a given period: a day, a month, a year, or several years [2]:

$$V_{av} = \frac{1}{n}\sum_{i=1}^{n} V_i, \tag{3}$$

where V_{av} −average wind speed, [m/s];

V_i −wind speed in measurement interval [m/s];

n – number of measurement intervals.

According to data from the Table 2.5 it is possible to determine the average wind speed at an attitude of “h” meters above the earth’s surface:

$$V_{av} = \frac{1}{n}\sum_{i=1}^{n} V_i = \frac{(4.96 + 4.76 + \cdots + 5.05)}{12} = 4.71\ {}^{m}/_{s}. \quad (4)$$

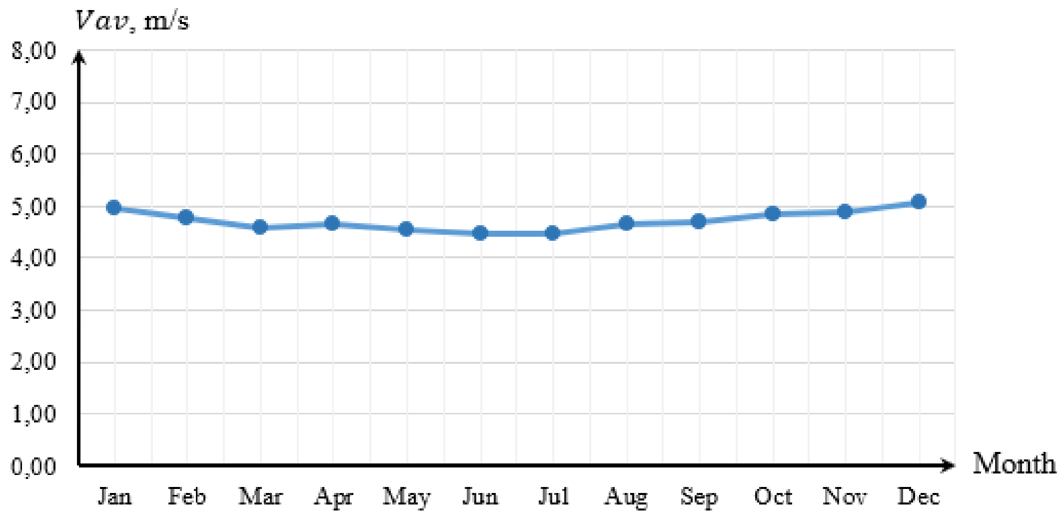


Figure 2.11 – Average month wind velocities, based on table 2.1

According to [2], the wind power plant will be effective if the yearly average wind velocity is more than 4 m/s. The yearly average wind velocity in the Soyanskoye rural settlement is 4.71 m/s.

The efficiency of a wind farm is also related to the terrain. A wind farm must have a clear straight front of the prevailing wind, over open water, flat land or on a smooth hill [12]. The Arkhangelsk region is a vast lowland area. It has a low relief with heights up to 450 meters in the east and a chain of hills with heights up to 350 meters in the west [13]. In the north is the Soyanskoye rural settlement. Therefore, there are no obstacles to the wind, and the construction of a wind farm here is justified.

To assess the prevailing wind direction, a wind rose has been constructed, which is a vector diagram, in which the length of the rays diverging from the center of the diagram in different directions is proportional to the frequency of winds of these directions [2].

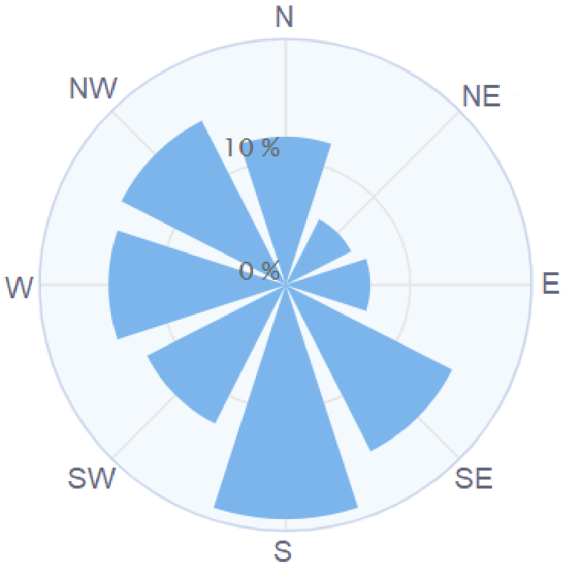


Figure 2.12 – Wind rose for the Soyanskoye rural settlement, based on data from [5]

The prevailing wind direction at the selected site should be taken into account in the construction of the wind turbine, as well as correlate it with the landscape (except for the flat nature of the terrain). Correct accounting of wind directions allows to locate wind turbines on the ground most effectively [2].

CHAPTER 3. Hybrid power supply system, power balance

3.1 Hybrid power supply system

A number of factors affect the specifics of the design of a hybrid system, including the nature of the load, the characteristics of the diesel generators and electrical distribution system, the renewable resource, fuel costs, availability of maintenance staff, and environmental factors [3].

- Electrical load. The magnitude and temporal profile of the local load affect the rated system capacity, energy storage needs, and control system algorithm.
- Diesel generation and electrical distribution system. In existing power systems, the fuel consumption and electrical characteristics of any existing power generation system affect the economics of the hybrid system, equipment selection, and the control system design. Fuel costs are one important factor in determining system operating cost. In new systems, the generation and distribution systems can be designed in conjunction with the design of the hybrid components.
- Renewable resource. The magnitude, variability, and temporal profile of the renewable resource, whether it is wind, solar, hydropower, and/or biomass affect the choice of renewable power system, the control strategy, and storage requirements.
- Maintenance infrastructure. The availability of trained operating and maintenance personnel affects the long-term operability of the system, operating costs, and installation costs.
- Site conditions. Site constraints such as the nature of the terrain, local severe weather conditions, and the remoteness of the site affect the ability to get equipment to the site, equipment design requirements, and operating system requirements.

To ensure an uninterrupted power supply to Soyanskoye rural settlement, it is planned to design a wind farm with storage system and a backup diesel generator. The presence of storage system, allows to reduce the number of switching of the diesel generator and exclude interruptions in power supply during the switching of generating equipment. Usually, the available energy reserve in the batteries can be limited to the time of power supply to the consumer within an hour [2].

The equipment of the wind-diesel power plant with storage system, in addition to the wind generator and diesel generator includes batteries with a device for charging and discharging, inverter, automatic switch over (ASO) system. Inverter in this case is chosen autonomous (battery) [2].

Implementation of the option with the joint operation of the wind generator and diesel generator for a common load requires the choice of a synchronization device [2].

3.2 Wind power generator

In this paper to fully meet the needs of the consumer and taking into account the quite stable price of Russian-made wind turbines and their high energy performance, an option of designing a power supply system based on the wind turbines "Condor Air WES" with different capacities are considered, as the starting and nominal wind speed of generators of this type is 2.5 m/s and 9 m/s, respectively, which corresponds to the wind energy potential of the region [2].

Wind power generator “Condor Air WES” – it is a mechanism that converts the wind energy into electrical energy with a voltage of 220/380 V and a frequency of 50 Hz. Plants are effective when used as the main sources of power for individual houses, farms, businesses, oil and gas facilities, remote from the consumer grid, etc. [6].

Installation starts up at the wind speed of 2,5 m/s, nominal power is produced with the wind speed of about 9 m/s that conditions their using for weak and average winds. Operating temperature in the range from -40 to +50 degrees in the usual version and from -55 to +50 degrees in the northern version [6].

Technical parameters and indicators of this wind turbine are presented in Appendix 1.

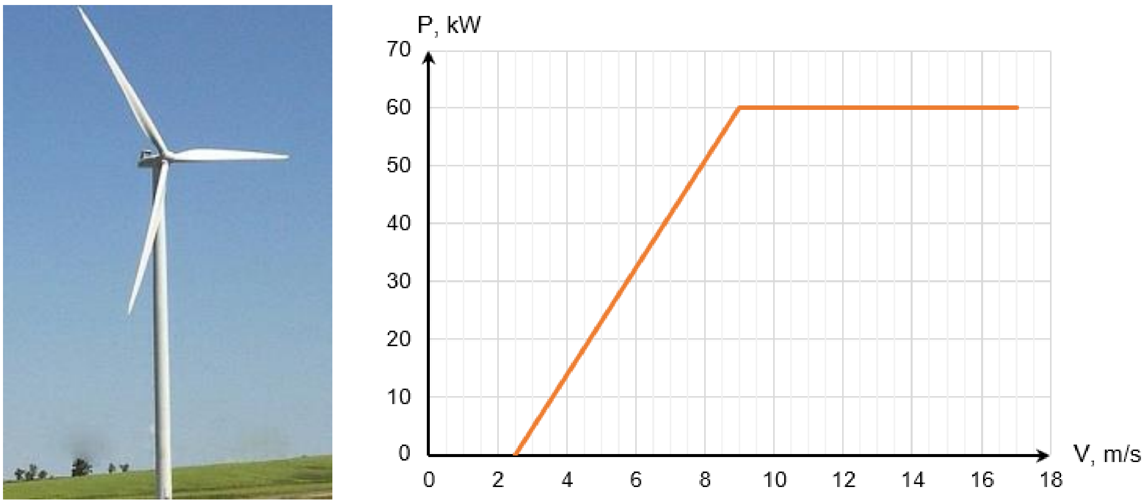


Figure 3.1 – Condor Air 380 wind power generator, 60 kW [6] and its energy characteristic, based on data from [7]

Recommended installation site of the wind park: in close proximity to the power supply facility, on a hill or the others attitudes, without obstructing the wind flow with structures and trees [2].

According to the weather data obtained, the average annual wind speed is 4.68 m / s, respectively, to meet the constant demand for electricity, based on the graph of the dependence of power on wind speed, it is necessary to install a wind farm, consisting of several installations with different capacities, the increase in the number of wind farms in relation to the nominal capacity is associated with the wind potential in the region, since stations deliver 50% power at a wind speed of 4.5 m/s, 100% power at a wind speed of 9 m/s, and the average annual wind speed is in the range between these two values [2].

However, in power supply systems based on such an unreliable energy source, such as wind, it is necessary to have a backup. In the role of the reserve has been chosen diesel power plant. Obviously, the wind potential of the area in this case should be high, and the installed capacity of wind generators should provide the object with wind power in all seasons of the year. In this case, a diesel generator with an installed capacity exceeding the maximum load of the object by 20-25% will be able to provide electricity to consumers during periods of wind slack [2].

Considering the energy characteristics of the wind turbine generator (Figure 3.1), as well as the repeatability of different gradations of wind speed by month (Table 2.3), it is necessary to calculate the amount of electricity generated per month. Table 3.1 shows information about the amount of electricity generated for wind turbines of different capacities.

Table 3.1 clearly demonstrates, that the installation of only one WT “Condor Air WES” will be impractical due to the too large difference between the consumed and generated amount of electricity.

Table 3.1 – Monthly repeatability of different wind speed gradations in days [23]. Generated power of WT Condor Air 20 / 60 kW

Wind speed, m/s	0 – 1 (0)*	2 – 3 (27.78%)	4 – 5 (50%)	6 – 7 (72.22%)	8 – 9 (94.44%)	Days in total	WT 20 kW P_{gen} per month, MW	WT 60 kW P_{gen} per month, MW	2 WT (60+60) P_{gen} per month, MW	3 WT (60+60+20) P_{gen} per month, MW	Consumed power P_{con} per month, MW
January	0.6	11.8	11.8	3.4	3.4	31	7.125	21.378	42.755	46.318	50.013
February	0.3	12.4	11.5	3.4	2.8	28	6.840	20.521	41.042	44.462	45.173
March	0.9	12.4	12.4	4.0	1.2	31	6.588	19.766	39.532	42.826	45.012
April	1.2	11.8	12.4	3.0	2.4	30	6.674	20.024	40.048	43.386	43.560
May	1.9	11.5	13.0	2.8	1.9	31	6.464	19.394	38.788	42.020	42.511
June	2.1	10.9	13.6	2.4	1.8	30	6.368	19.105	38.210	41.394	41.140
July	3.1	9.6	14.0	2.5	1.9	31	6.332	18.997	37.994	41.160	40.010
August	1.9	10.2	14.0	2.8	2.2	31	6.662	19.989	39.978	43.309	42.511
September	1.5	10.9	13.0	3.0	2.4	30	6.699	20.098	40.197	43.547	43.560
October	0.9	11.2	13.0	3.1	2.8	31	6.952	20.857	41.714	45.190	47.512
November	0.6	11.5	12.4	3.3	3.0	30	7.009	21.028	42.056	45.561	48.400
December	0.6	10.9	12.4	3.7	3.4	31	7.258	21.774	43.549	47.178	50.013
Year	**-**	**-**	**-**	**-**	**-**	**365**	**80.976**	**242.931**	**485.862**	**526.350**	**539.415**

* The value next to the wind speed indicates what percentage of the nominal power a wind turbine will produce at the corresponding wind speed. E.g., a wind turbine with a nominal power of 20 / 40 / 60 kW at a wind speed of 2 – 3 m/s will produce 27.78% of the nominal power.

3.3 Diesel generator

Diesel power plants in hybrid power supply systems perform the most important functions of a guaranteed power source. In addition, depending on the structure of the wind-diesel power complex, it can perform buffer functions, compensating for power pulsations of the wind power plant [2].

Diesel fuel is often expensive in remote locations. These diesels often operate at low load and fuel efficiency. Reducing the load or shutting down diesels reduces fuel costs. This can be a goal of integration renewable energy, but it also has negative consequences. Reducing the load on a diesel engine can increase engine maintenance requirements, increase engine wear, and consequently shorten engine life. Frequent starts and stops significantly increase engine wear. In order to improve overall system economics, diesel operation is often set to a minimum load on the diesel, and a minimum run time is set for the diesel. Each of these measures increases fuel consumption compared to operating with frequent starts and stops and no-load operation, but these measures are designed to improve overall system economy by reducing diesel overhauls and increasing replacement intervals [3].

The integration of the ASO system will enable the system to switch the facility power supply to the standby diesel generator in the absence or lack of wind [2].

Based on the necessity to provide consumers with electricity in all situations, the number and capacity of diesel generators should be selected taking into account the following requirements [2]:

- The total capacity of the units should be 25% more than the daily maximum load: 1.25
- For convenience of service, it is desirable to choose the same type and size diesel generator sets.
- Load of diesel generators should be within 20-80% of the rated capacity.
- The number of diesel generator sets should be redundant to make it possible to take the units out of operation for maintenance, current and general repairs.
- The operating conditions of diesel generator sets must comply with the climatic characteristics of the area.

To analyze the technical and economic performance of diesel generator sets it is necessary to evaluate the dependence of fuel consumption of a diesel generator on the level of its load [2]. In the Mezensky municipal district, a diesel generator with a capacity of 400 kW is already installed, but there is no information about its model. This diesel generator generates electrical energy for several rural settlements, including the village of Soyana [11].

“The Diesel Company” is the most widespread manufacturer and seller of diesel engines in Russia. This ensures the widest availability of spare parts in any region of Russia. In this case, it is possible to take into consideration the expected model – the diesel generator YMZ AD-400 with the capacity of 400 kW. Its nominal fuel consumption is 208 grams per kWh or 0.247 liters per kWh [14]. Technical parameters and indicators of diesel generator YMZ AD-400 are presented in Appendix 2. Diesel generator YMZ AD-400 is presented on the figure 3.2.

Figure 3.2 – Diesel generator YMZ AD-400 [14]

Fuel supply to the settlements of Mezensky municipal district is carried out according to the government schedule. Since the operation of delivering diesel fuel by road in harsh winter conditions is extremely difficult, fuel reserves are formed in advance for the entire winter period. The entire process of electricity supply, purchase and delivery of fuel to Mezensky district is carried out by the local authorities, namely the Arkhangelsk department of internal policy and local self-government [15].

To analyze the technical and economic performance of the diesel generator it is necessary to evaluate the dependence of fuel consumption of diesel generator on the degree of its load [2].

Based on the linearization of the consumption characteristics of the diesel engine, it is possible to use an approximate formula [2] to determine the specific fuel consumption for the generation of 1 kWh of electricity:

$$G_1 = K_{nl} \cdot G_{nom} + (1 - K_{nl}) \cdot G_{nom} \cdot \frac{P_1}{P_{nom}}, \qquad [g/kWh] \qquad (5)$$

where G_1 − actual fuel consumption;

$G_{nom} = 208\, g/kWh$ − nominal fuel consumption;

$P_1 = 67.22\, kW$ − power consumption of Soyana village;

$P_{nom} = 400\, kW$ − nominal power of diesel generator;

K_{nl} − coefficient characterizing the fuel consumption at no-load conditions, ($K_{nl} = 0.3$).

With the knowledge of the specific consumption of diesel generator for the corresponding load mode and the amount of electricity produced, it is possible to determine the amount of fuel consumed for the certain period of time [2]:

$$m = \frac{G_1 \cdot W_{consumed}}{1000}, \qquad [kg] \tag{6}$$

where $W_{consumed} = 539.415\ MW -$ annual amount of consumed electrical energy.

According to the load graphs (Figure 2.9 and Figure 2.10) and taking into account a capacity of diesel generator, which is installed in the Mezensky municipal district, as well as using formulas (5) and (6) the amount of fuel consumed per year to fully meet requirements of the consumer has been determined.

$$m_1 = 46\ 858\ kg.$$

There are a number of factors that affect fuel consumption [16]. Under optimum conditions - temperature 20 °C, humidity 50% and pressure 750 mm Hg, in besides deterioration and load, consumption is influenced by:

- Climatic conditions - low temperature increases the viscosity of the fuel, which gives it incomplete combustion in the engine and increases consumption;
- Humidity - the presence of water vapors deteriorates fuel quality, which negatively affects engine operation;
- Air pressure - in high altitude conditions engine power is reduced due to lack of oxygen in the air-fuel mixture, while its consumption increases;
- Fuel quality - presence of external impurities leads to contamination of filters.

Thus, it was obtained that the average annual fuel consumption with installation of two WT (60 kW) and one WT (20 kW) fuel consumption will be equal to $m_2 = 1\ 135\ kg$.

3.4 Power balance

Power balances include energy generated by a wind farm and consumed by a rural settlement. The ratio of generated and consumed electricity varies significantly by month; therefore, a monthly analysis of power balances is required [2].

Table 3.2 – Power balance of installed wind turbines in Soyanskoye rural settlement

Month	P_{con}, MW	P_{gen}, MW $(2\ WT: 60 + 60)$	ΔP, MW	P_{gen}, MW $(3\ WT: 60 + 60 + 20)$	ΔP, MW
January	50.013	42.755	-7.258	46.318	-3.695
February	45.173	41.042	-4.131	44.462	-0.711
March	45.012	39.532	-5.480	42.826	-2.186
April	43.560	40.048	-3.512	43.386	-0.174
May	42.511	38.788	-3.723	42.020	-0.491
June	41.140	38.210	-2.930	41.394	0.254
July	40.010	37.994	-2.016	41.160	1.150
August	42.511	39.978	-2.533	43.309	0.798
September	43.560	40.197	-3.363	43.547	-0.013
October	47.512	41.714	-5.798	45.190	-2.322
November	48.400	42.056	-6.344	45.561	-2.839
December	50.013	43.549	-6.464	47.178	-2.835
Total:	**539.415**	**485.862**	**-53.553**	**526.350**	**-13.065**

The shortage of electricity from 2 WT of 60 kW each for the year is 53.553 MW. This electricity must be obtained from a diesel generator. And also, shortage of electricity from 3 WT (2 wind turbines with a rated capacity of 60 kW and one wind turbine with a rated capacity of 20 kW) for the year is 13.065 MW. Hybrid power plant provides fuel and fuel and lubricants (POL) savings [2].

The principle of constructing a wind-diesel power plant consists in the possibility of obtaining additional energy from wind turbines to reduce the cost of diesel fuel. The diesel generator compensates for the lack of energy received from wind turbines. For this purpose, the diesel generator must have an automatic start system that reacts to changes in power consumption [2].

a) 2 WT: 60 kW each   b) 3 WT: 2x60+20

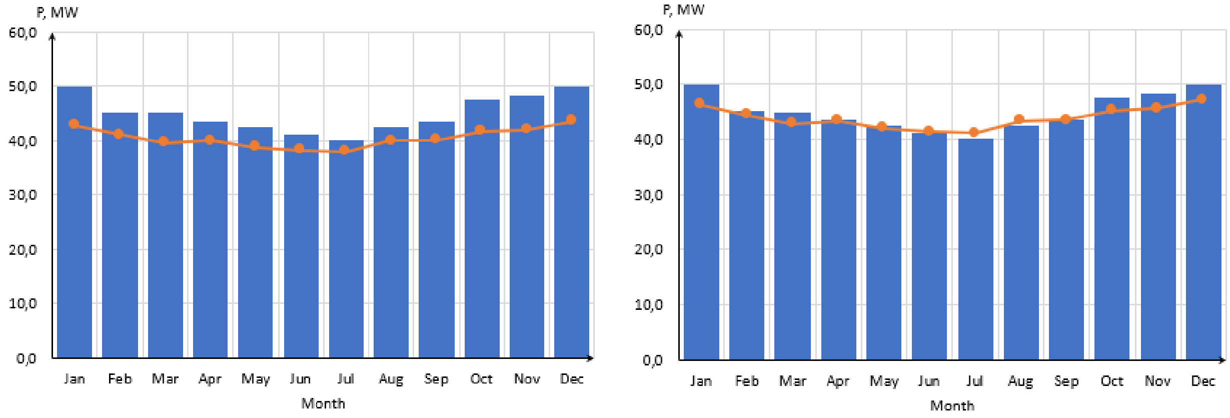


Figure 3.3 – Load coverage by wind turbines of Soyanskoye rural settlement, based on the Figure 2.10 and Table 3.2

An increase in the installed capacity of the wind section of a hybrid power plant makes it possible to increase power generation, achieve greater savings in diesel fuel, but, at the same time, increase the cost of plant equipment.

3.5 Structure and equipment of a wind-diesel power plant

The principle of construction of a wind-diesel power plant is the possibility of obtaining additional energy from wind turbines to reduce the cost of diesel fuel. The diesel generator compensates for the lack of energy received from wind turbines. To realize this, diesel generator must have ASO system that responds to changes in power consumption. In transient modes of generation, as well as covering peak power is due to the work of the power module “Delta” NH PLUS-series 20 kVA (3ph-3ph). “Delta” power module is an uninterruptible power supply with different functionalities. Delta modules are installed in a special power control box [2]. Technical parameters are presented in Appendix 3. Selected uninterruptible power supply source is presented on the Figure 3.4.

Uninterruptible power supply "Delta" provides power to loads from wind farms through the inverter with the accumulation of surplus electricity in batteries. During periods of no wind power loads are transferred to the batteries, as the discharge of which is turned on by the diesel generator and the transfer of consumers of electricity to it. The diesel generator also provides battery charging through the "EDS60" controllers [2].

Figure 3.4 – Automatic switch over (ASO) system “Delta” NH PLUS [17]

The operation of wind, hybrid or other power plants based on renewable energy must be supplemented with one of the main elements - the electrical energy storage device, the battery. Lead-Acid storage batteries “Delta” DTM-12200 L performs a buffer function. During storage, it is recommended to check the battery voltage once every six months and prevent the voltage from dropping below 12.6 Volts, and when the voltage reaches 12.6 Volts, recharge the battery. Following this recommendation will significantly extend the life of battery [18]. Technical parameters are presented in Appendix 4. According to the technical specifications of wind turbines: for a WT with a nominal power 60 kw at least 40 storage batteries are required, for a WT 20 kw 20 batteries are required. Selected battery is presented on the Figure 3.5.

Figure 3.5 – Lead-Acid storage battery “Delta” DTM-12200L [18]

If there is a shortage of generating capacity of wind turbines, the power module starts the diesel generator, if the generating capacity of wind turbines increases, the diesel generator is switched off. ASO switches the network of wind turbines and diesel generator. When the diesel generator is running, the batteries are recharged [2]. The schematic diagram of the wind-diesel power plant is presented on Figure 3.6.

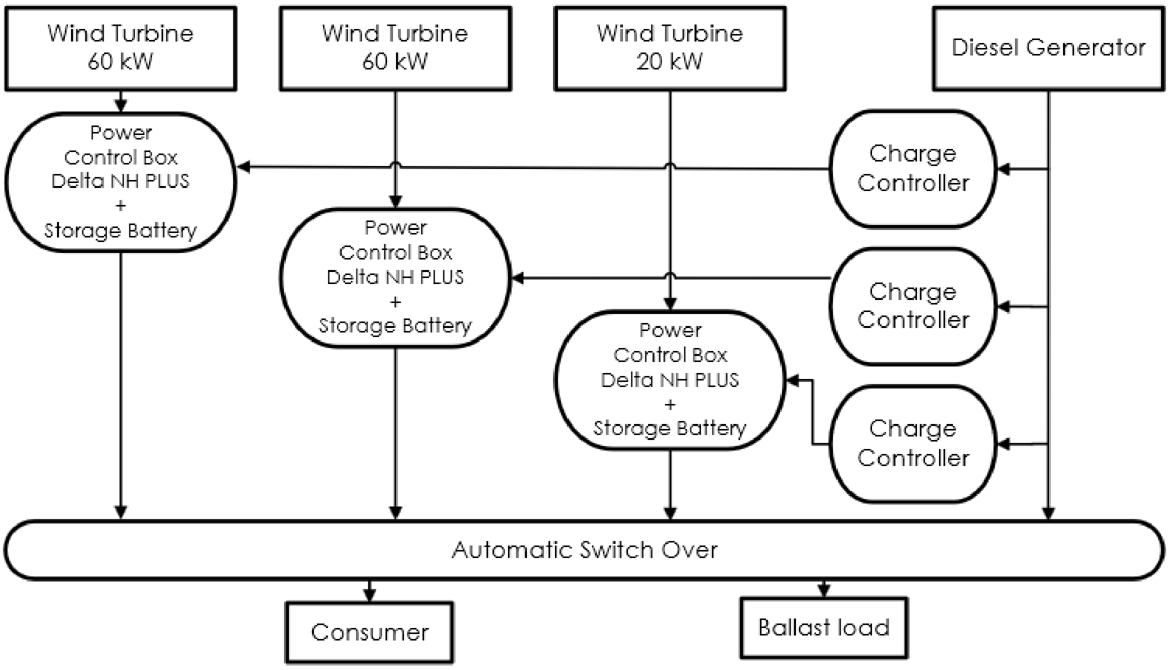


Figure 3.6 - The block diagram of a wind-diesel power plant, based on data from [2]

Table 3.3 – Wind-diesel power plant equipment [6, 17, 18]

Equipment	Amount	Lifetime, years	Price, RUB	Total price, RUB	Total price*, EUR
WT “Condor Air 380/50-60” [6]	2	20	3 289 000	6 578 000	79 319.91
WT “Condor Air 380/50-20” [6]	1	20	1 320 000	1 320 000	15 917.04
Power module “Delta” NH PLUS [17]	3	20	235 500	706 500	8 519.23
Power control box for power module “Delta” up to 80 kVA [17]	3	20	462 000	1 386 000	16 712.89
Lead-Acid storage batteries “Delta” DTM-12200L, 12V, 200Ah [18]	100	12	35 150	3 515 000	42 385.14
Charge controller “EDS60” [17]	3	20	210 180	630 540	7 603.28
Automatic Switch Over [17]	1	20	477 800	477 800	5 761.49
Total cost	-			14 613 840	176 218.98

*Currency conversion (1 Euro to ruble exchange rate is equal to 82.93 ₽) was performed according to exchange rate of the Central bank of the Russian Federation for 27 December 2021 [19].

3.6 Calculation of greenhouse gas emissions

The information below was taken from source [20].

Carbon dioxide emissions from stationary combustion result from the release of carbon from the fuel during combustion and depend on the carbon content of the fuel. The carbon content of fuels is a physicochemical characteristic specific to each fuel and does not depend on the combustion process or conditions.

All released carbon is considered as CO2 emissions. Unoxidized carbon remaining in the form of particulate matter, soot, or ash is excluded from total greenhouse gas emissions by multiplying by the carbon oxidation factor in the fuel (which shows the fraction of carbon burned).

Calculation of CO2 emissions for each type of fuel for individual sources (combustion plants) is made according to the formula:

$$E = M \cdot K_1 \cdot TNV \cdot K_2 \cdot \frac{44}{12}, \tag{7}$$

where E – annual emission of CO2 in weight units (tons/year);

M – actual fuel consumption for the year (tons/year);

$K_1 = 0.99$ – carbon oxidation factor in the fuel (shows the fraction of carbon burned);

TNV =43.02 – net calorific value (J/tons);

$K_2 = 0.019$ – carbon emission factor (tons/J);

$^{44}/_{12}$ – carbon to CO2 conversion factor.

Based on the above calculations (section 3.3) it is possible to summarize that the diesel power plant consumes 98 394 kilograms of diesel fuel per year. However, the wind-diesel power plant with the installation of two wind turbines consumes 37 325 kilograms of diesel fuel per year. In this way the amount of carbon dioxide emissions into the atmosphere can be compared.

$$Q_1 = 46\ 858\ kg.$$

$$Q_2 = 35\ 575\ kg.$$

$$Q_3 = 30\ 634\ kg.$$

Greenhouse gas emissions for diesel power plant:

$$E = 46.858 \cdot 0.99 \cdot 43.02 \cdot 0.019 \cdot \frac{44}{12} = 139.032\ tons\ per\ year.$$

Greenhouse gas emissions for wind-diesel power plant (two WT 60 kW):

$$E = 35.575 \cdot 0.99 \cdot 43.02 \cdot 0.019 \cdot \frac{44}{12} = 105.554\ tons\ per\ year.$$

Greenhouse gas emissions for wind-diesel power plant (two WT 60 kW + one WT 20 kW):

$$E = 30.634 \cdot 0.99 \cdot 43.02 \cdot 0.019 \cdot \frac{44}{12} = 90.894\ tons\ per\ year.$$

It can be clearly seen, that hybrid power plant with installation of two WT Condor Air 60 kW decreases greenhouse gas emissions in the atmosphere by almost 30 tons. On the other hand, hybrid power plant with installation of two WT (60 kW) and one WT (20 kW) decreases greenhouse gas emissions in the atmosphere by almost 50 tones.

CHAPTER 4. Evaluation and optimization the project from economic and financial point of view

This section is devoted to the economic analysis of the developed power supply system in order to determine whether the project is feasible or not. For this purpose, along with determining costs, investments, and possible revenue, a sensitivity analysis will be conducted using parameters such as the discount rate, electricity price, inflation rate and investment costs for hybrid station equipment.

4.1 Economic evaluation methodology

To implement the project, it is necessary to estimate the volume of investments and expected expenditures, as well as analyze the options with Net Present Value and Annual Payments.

Net Present Value

The Net Present Value (NPV) is the criterion that allows you to decide whether it is reasonable to invest in a project. NPV estimate the difference between the present value of cash inflows and the present value of cash outflows. However, there are no cash flows in the current project, so the net present value for each measure will be estimated on the basis of electricity bills, taking into account annual inflation and the expected life of the project. Because the NPV calculation is purely cost-based, the NPV for all measures will be negative, and a higher NPV would be more desirable [1].

The NPV is calculated according to following formula [1]:

$$NPV = C_0 + \sum_{t=1}^{T} \frac{C_t}{(1+r)^t}; \quad (8)$$

where: C_0 – Initial investment in the project (usually a negative number);

T – Service lifespan of the equipment [years];

t – Number of time periods;

C_t – Summary cash flow in the period t;

r – Discount rate [%].

The NPV approach properly considers the time value of money and adjusts for project's risk using the opportunity cost of capital as the discount rate. Thus, it clearly measures the increase in market value or wealth created by the project. NPV is the only metric that provides a theoretically correct measure of project cost [1].

Internal rate of return

Internal rate of return (IRR) is next criterion with which the project can be estimated in the economic point of view. In fact, IRR is a discount rate, when NPV of the project is zero. IRR can be calculated using the following formula [1]:

$$NPV = C_0 + \sum_{t=1}^{T} \frac{C_t}{(1 + IRR)^t} = 0\,; \tag{9}$$

where: C_0 – Initial investment in the project (usually a negative number);

T – Service lifespan of the equipment;

t – Number of time periods;

C_t – Summary cash flow in the period t;

IRR – Internal rate of return.

Equivalent annual annuity

After this it is necessary to calculate the annual cost of the equipment. The amount of annuity payment with a given present or future value is calculated using the following formula [1]:

$$EAA = \frac{-NPV}{T\ annuity\ factor}; \tag{10}$$

$$PVAF = \frac{1}{(1+r)^T} \cdot \frac{(1+r)^T - 1}{r};$$

where: EAA – equivalent annual annuity;

$r -$ discount rate.

4.2 General economic parameters

In order to implement a project, it is necessary to know the basic economic parameters for the country where the project will be implemented. This subchapter estimates parameters such as inflation rate, corporate tax and discount rate.

Inflation

Inflation is an increase in the general price level of goods and services. In inflation, the price of identical goods increases over time. In effect, the purchasing power of money is reduced and money becomes worthless. It is only possible to estimate the future rate of inflation by analyzing inflation in previous years. Therefore, for this project I have taken the average geometric inflation rate for the last 10 years. The data is presented in table 4.1.

Table 4.1 – Historic inflation in Russia for 10 years [24]

Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Inflation, %	6.58	6.45	11.36	12.91	5.38	2.52	4.27	3.05	4.91	8.39
Average inflation, %	6.582									

The real cash flow value depends on the average value of the inflation rate thus it is calculated as:

$$CF_{real} = \frac{CF_{nom}}{(1 + inflation\ rate)^t}; \quad (11)$$

where: CF_{nom} – nominal cash flow for a year "t".

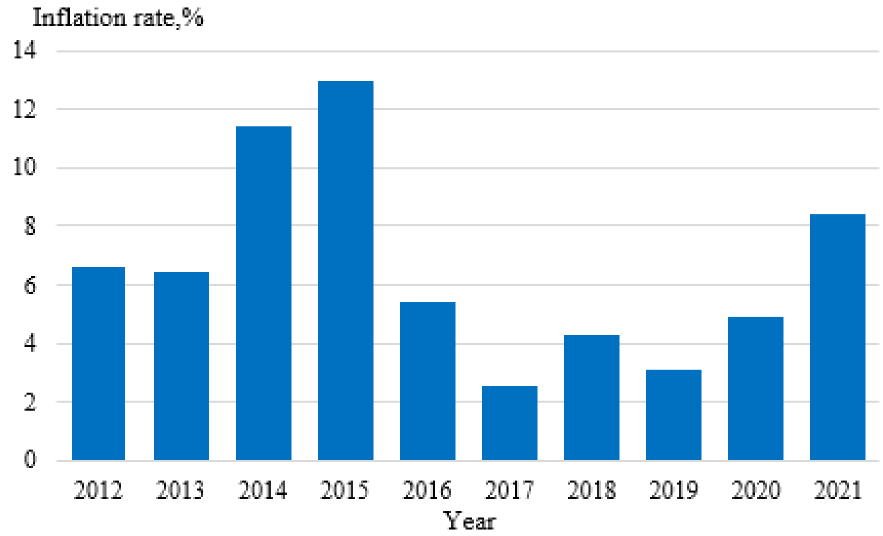


Figure 4.1 – Historic inflation in Russia based on data from [24]

Corporate tax

Corporate tax is a direct tax levied on the profits of an organization. Profit for the purposes of this tax is generally defined as income from a company's activities reduced by the amount of statutory deductions and exemptions. According to the tax law of Russia, corporate tax rate is equal to 20% [25].

Discount rate

The discount rate is the ratio of return used to discount future cash flows to their present value. According to Capital Asset Pricing Model (CAPM), the discount rate can be calculated using followed formula [1]:

$$r = r_f + \beta \cdot (r_m - r_f) = 7.42 + 0.84 \cdot 8.1 = 14.224\%; \quad (12)$$

where: $r_f = 7.42\%$ – Risk free rate equals to 10 years federal bond ratio in Russia [26];

$\beta = 0.84$ – The average volatility of stocks in sector of power generation in Russia's market [27];

$r_m - r_f = 8.1\%$ – Average risk premium rate on market for 10 years [28].

Depreciation

Depreciation is a noncash expense; it is important only because it reduces taxable income. It provides an annual *tax shield* equal to the product of depreciation and the marginal tax rate [1]. For these purposes, it was decided to apply the linear method of depreciation

In Russia the method of depreciation calculation is established by the taxpayer independently for all objects of depreciable property and is reflected in the accounting policy for tax purposes. Taxpayers have the right to choose one of the following methods of depreciation [34]:

- the linear method;
- nonlinear method.

The annual amount of depreciation in relation to the object of depreciable property is determined as the product of its original cost and the rate of depreciation determined for this object. The depreciation rate for each object of depreciable property is determined by the formula [34]:

$$Depreciation = \frac{1}{T}; \tag{13}$$

where: T – Lifetime of equipment [years].

Escalation

The escalation rate shows how much the price of a product has changed over time. Prices for electricity and diesel fuel in Russia change every year. Accordingly, it was customary to independently calculate the escalation rate for electricity and diesel prices in the Arkhangelsk region.

According to the regulation on setting electricity tariffs for decentralized consumers not technologically connected to the UES (Unified Energy System) of Russia, the weighted average cost per unit of electricity (power) for the last 10 years is presented in the Table 4.2 [36].

Table 4.2 – Energy price change in Arkhangelsk region [36]

Year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Energy price, RUB/kWh	17.37	17.82	18.46	19.10	19.96	20.21	20.79	21.57	22.10	22.69
Energy price, EUR/kWh	0.21	0.21	0.22	0.23	0.24	0.24	0.25	0.26	0.26	0.27
Average escalation, %	3.012									

Table 4.3 – Diesel fuel price change in Arkhangelsk region [30]

Year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Fuel price, RUB/liter	33	33.95	34.84	36.4	39.9	46.29	47.29	47.9	53	54.01
Fuel price, EUR/liter	0.398	0.409	0.42	0.439	0.481	0.558	0.57	0.577	0.639	0.651
Average escalation, %	5.63									

4.3 Inputs for economic model

During the creation of the economic model, it is important to consider the main input parameters. On this step of economic evaluation, it is necessary to compare options of power supply:

1. Power supply system without Renewable energy sources (Electricity tariff Arkhangelsk region is 22.695 = RUB/kWh) [36].

2. Hybrid power supply system from the point of view of the rural settlement association.

In addition, the option of power supply from the point of view of an outside investor will be considered.

Initial project investments

According to the Table 3.3 the total cost of wind-diesel power plant equipment is 14 613 840 RUB. But it is also necessary to take into account the cost of equipment installation which is equal to 20% from the initial investment [2].

$$C_0 = C + 20\% = 14\ 613\ 840 + 20\% = 17\ 536\ 608\ RUB; \quad (14)$$

where C_0 –initial investment [RUB];

C – equipment cost [RUB];

20% - equipment installation cost.

Lifetime of the whole project is 20 years, since the chosen units of equipment have service life for 20 years. However, useful lifespan of diesel generator is approximately 11 years, and lifespan of the lead-acid storage batteries is only 12 years, which means that a new diesel generator and a new storage system of the same type will have to be purchased in the 11th and 12th year of the project respectively.

$$C_{DG} = C + 20\% \cdot (1 + inf)^T = 3\ 926\ 558 \cdot (1 + 0.2) \cdot (1 + 0.06582)^{11} = 9\ 499\ 828.89\ RUB; \quad (15)$$

where C_{DG} – price of the diesel generator after 11 years [RUB];

C –initial price for 1 unit of diesel generator [RUB] [14];

20% - equipment installation cost;

$inf = 6.582\%$ – average inflation rate in Russia;

T – lifetime of the batteries [years].

$$C_{bat} = C \cdot (1 + inf)^T = 4\ 218\ 000 \cdot (1 + 0.06582)^{12} = 9\ 063\ 855.25\ RUB; \quad (16)$$

where C_{bat} – price of the lead-acid storage batteries after 12 years [RUB];

C –initial price for 100 units of lead-acid storage batteries including installation cost [RUB];

$inf = 6.53\%$ – average inflation rate in Russia;

T – lifetime of the batteries [years].

Hence, the values of initial investments in the first year are equal to 17 536 608 RUB; investments in the 11^{th} year are equal to 9 499 828.89 RUB; and investments in the 12^{th} year of operation are equal to 9 063 855.25 RUB.

In the end of 20^{th} year of project operation diesel generator and batteries will have residual value (salvage value) for the left period of their lifetime (2 years and 4 years respectively). If a salvage value can be determined for a certain asset, its depreciable amount is equal to the original cost of the asset after subtracting the salvage value [35].

Depreciable amount is the cost (or part of the cost) of a tangible or intangible asset that will be depreciated/amortized over its useful life [35].

$$Salvage\ value_{DG} = C_{DG} \cdot \frac{t}{T} = 9\,499\,828.89 \cdot \frac{2}{11} = 1\,727\,241.62\ RUB; \qquad (17)$$

where $t -$ remaining lifetime of diesel generator in the 20^{th} year of project operation [years];
$T -$ lifespan of diesel generator [years].

$$Salvage\ value_{bat} = C_{bat} \cdot \frac{t}{T} = 9\,063\,855.25 \cdot \frac{4}{12} = 3\,021\,285.083\ RUB; \qquad (18)$$

where $t -$ remaining batteries lifetime in the 20^{th} year of project operation [years];
$T -$ lifespan of batteries [years].

Revenue from selling energy (investor point of view)

According to [36] electricity tariff for consumers not technologically connected to the UES in Archangelsk region is 22.695 RUB/kWh. Also, this price is annually changing by 4.22%. The practice shows that the price of electricity in the decentralized power supply system can be 10-20 times higher than the tariff [2]. The base for sold energy earnings is calculated as:

$$E = P_{annual} \cdot C_{kW/h} = 539.415 \cdot 10^3 \cdot 22.695 = 12\,242\,023.43\ RUB; \qquad (19)$$

where $P_{annual} -$ annual amount of electricity consumption [MWh];
$C_{kW/h} = 22.695 -$ electricity tariff [RUB/kWh].

Earnings in the year “t” taking into account the escalation rate for energy prices:

$$Earnings = 12\,242\,023.43 \cdot \left(1 + Esc_{energy}\right)^t. \qquad (20)$$

Loan (rural settlement association point of view)

The necessary funds for the initial investment can be taken on loan. The key interest rate of the Central Bank of Russia is 14% [37].

Maintenance costs

The annual maintenance cost for wind turbines "Condor Air WES" was taken as 2% from wind turbines investments [2]. The maintenance of batteries and power modules "Delta" throughout their lifetime is not required, according to the producer [17, 18].

$$C_{maint} = (6\,578\,000 + 1\,320\,000) \cdot 2\% = 157\,960\ RUB. \quad (21)$$

Salary expenditures

Designed hybrid power supply system including all equipment require three specialists (electricians) to service it [2]. Average monthly salary for electrician in Archangelsk region is 35 000 RUB [31]. However, in this case it is also necessary to take into account the deductions to the Federal Tax Service (FTS) of Russia that the employer makes for each of his employees [33]:

- Personal income tax – 13% (4 550 RUB);
- Pension deductions to the FTS – 22% (7 700 RUB);
- Medical deductions to the FTS – 5.1% (1 785 RUB);
- Social deductions to the FTS – 2.9% (1 015 RUB).

Further salary expenditures were made taking into account the inflation rate. Thus, the base for salary expenditures is calculated as:

$$C = 35\,000 \cdot (1 + 0.13 + 0.22 + 0.051 + 0.029) \cdot 3 \cdot 12 = 1\,801\,800\ RUB. \quad (22)$$

Salary expenses in the year "t":

$$C_{sal} = 1\,801\,800\ \cdot (1 + inffaltion)^t. \quad (23)$$

Diesel fuel expenditures

The selected wind turbines "Condor Air WES" of the hybrid power plant will generate **526.35 MW** annually, the rest load **13.065 MW** (See section 3.4) will be covered by diesel generator "YMZ AD-400". Calculation of diesel fuel consumption in section 3.3 shows that the installation of two 60 kW wind turbines and one 20 kW wind turbine will reduce the consumption of diesel fuel to **1 135 kg** per year. Taking into account that the density of diesel fuel is 840 kg/m^3 [32], the required amount of purchased diesel fuel annual reserve will be **1 351.2 liters**.

The price of a liter of diesel fuel in Arkhangelsk is 54.01 rubles [30]. Thus, it is possible to calculate fuel cost for 2022 (first year of project operation). Further expenses for the purchase of diesel fuel were made taking into account the escalation rate.

$$C_{fuel} = 1\,351.2 \cdot 54.01 = 72\,978.312\ RUB. \quad (24)$$

4.4 Calculation of economic model

In accordance with all previously mentioned economic factors and initial data, an economic model for each option of power supply system have been created. The next step of the economic evaluation is to calculate the NPV for each option. Since there is no inflow of cash flow, the NPV of each project will be less than zero, consequently the most economically advantageous project will be the one with the highest NPV.

Table 4.4 – Economic criteria of scenarios 0 and 1 (Appendices 5 and 6 respectively)

No	Scenario	NPV, RUB	NPV, EUR	EAA, RUB	EAA, EUR
0	Base variant (nowadays situation)	-98 233 098.36	-1 184 530.3	-15 023 744.08	-181 161.75
1	From a point of view of a rural settlement association	-39 082 465.77	-471 270.54	-5 977 261.98	-72 075.99

Table 4.5 – Economic criteria of scenario 2 (Appendix 7)

No	Scenario	NPV, RUB/EUR	EAA, RUB/EUR	IRR	Electricity price when NPV is zero, RUB/EUR
2	From a point of view of an outside investor	42 467 761.1 / 512 091.65	6 709 167.23 / 80 901.57	50.96%	10.43 / 0.125

Comparative analysis shows that the most economically advantageous scenario is No 1 with the highest NPV which is equal to -39 082 465.77 RUB (-471 270.54 EUR). Economic calculations were performed in the Excel. Detailed calculations are presented in the Appendices 5-7.

4.5 Sensitivity analysis

A sensitivity analysis determines how different values of an independent variable affect a particular dependent variable under a given set of assumptions. In other words, sensitivity analyses study how various sources of uncertainty in a mathematical model contribute to the model's overall uncertainty [38].

For scenarios 0 and 1 the sensitivity analysis will be performed for the following parameters:

- Discount rate;
- Inflation rate;
- Loan;
- Electricity escalation rate.

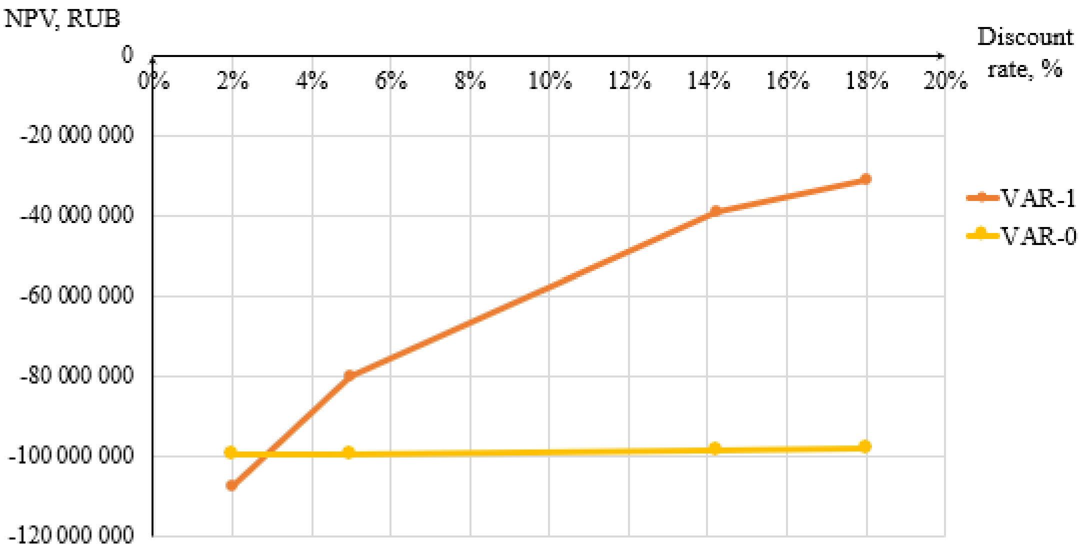


Figure 4.2 – Dependence of NPV on discount rate

As can be seen from the Figure 4.2 the NPV first variant increases with the growth of discount rate. This can be explained by negative cash flows throughout the whole life time of the project. The NPV of zero variant remains approximately the same.

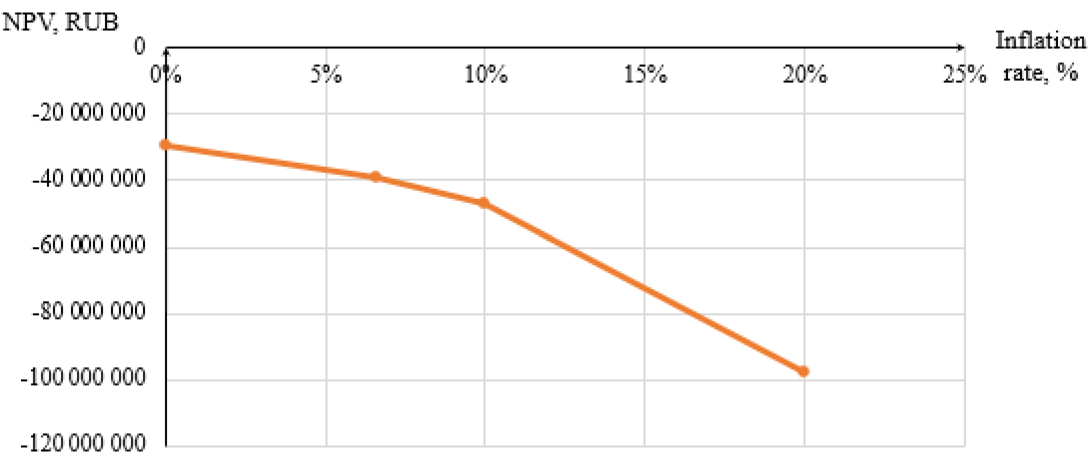
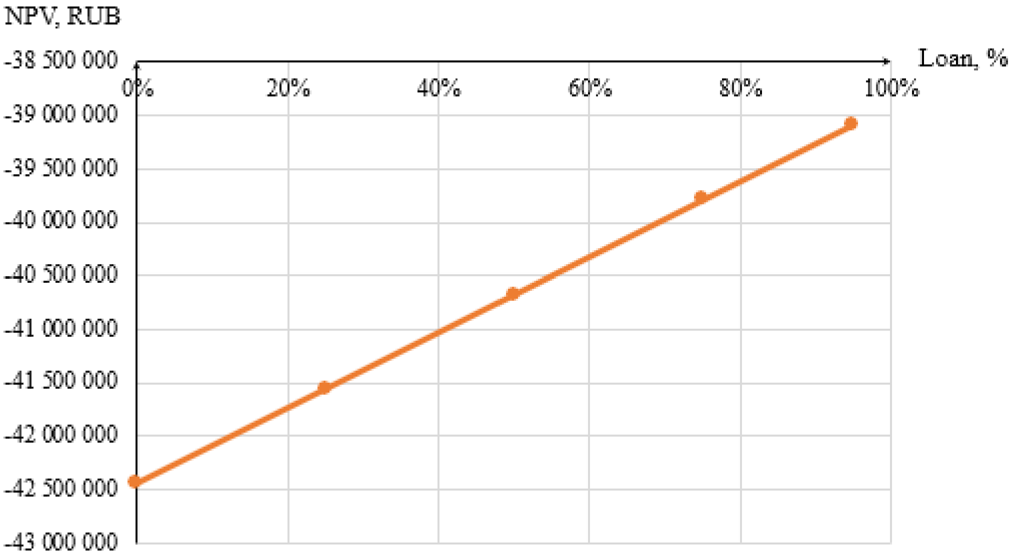


Figure 4.3 – Dependence of NPV on inflation rate

The drop of NPV with the growth of inflation rate is presented on the Figure 4.3.



`Figure 4.4 – Dependence of NPV on loan

Figure 4.4 demonstrates that NPV increases with the growth of the value of loan. Taking a loan allows to spread the costs over the duration of the project, compared with the high costs of investment in the first year.

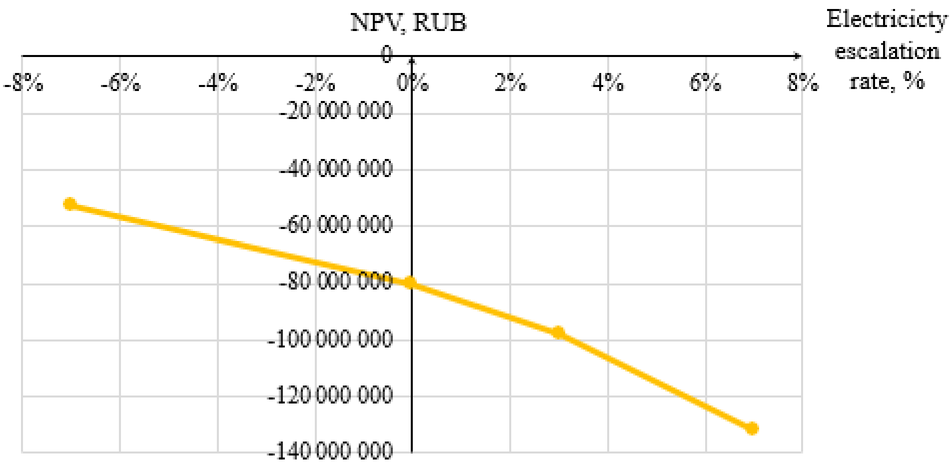


Figure 4.5 – Dependence of NPV on electricity escalation rate

Figure 4.5 shows proportional decrease of NPV with the growth of electricity price.

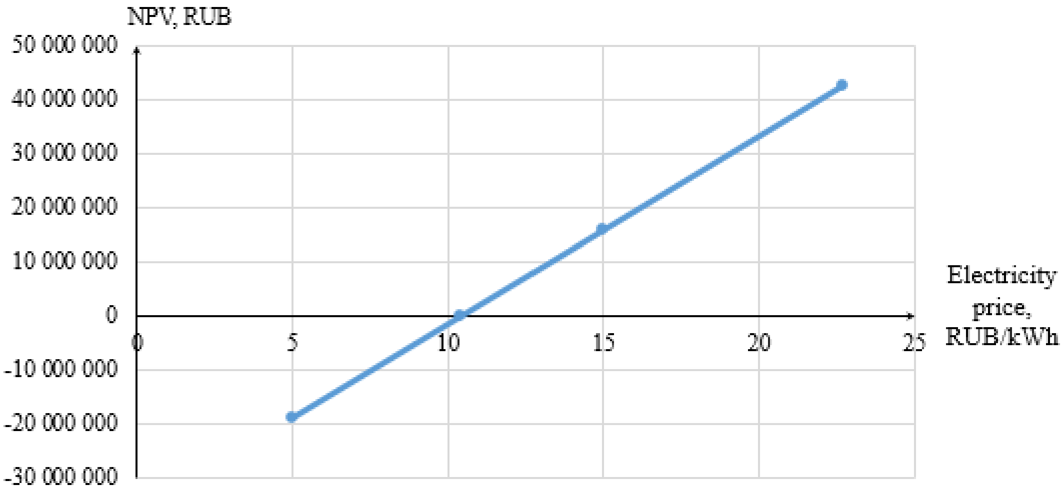


Figure 4.6 – Dependence of NPV on the price of electricity sold

The Figure 4.6 illustrates a direct correlation between the NPV and price at which an outside investor will sell electricity to the residents of Soyanskoe rural settlement.

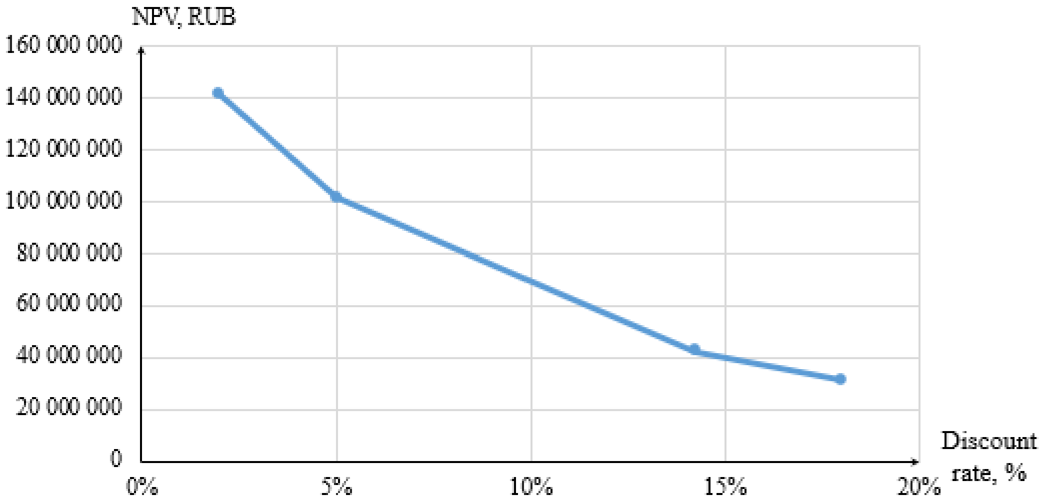


Figure 4.7 – Dependence of NPV on discount rate

As can be seen from the Figure 4.7 the NPV has an exponential inverse dependence on discount rate, the greater discount rate, the less NPV.

CONCLUSION

This work presents how the integration of renewable energy sources into a diesel power plant can assist in reducing fuel costs and carbon emissions.

In this paper, I designed a hybrid power plant based on a diesel power plant located in Soyanskoe rural settlement. In the beginning of the work, I analyzed the geography and weather conditions of the area. According to my analysis, the average wind speed in the region is 4.71 m/s, and this is a suitable value for the effective use of wind turbines. Moreover, the given analysis of the repeatability of different wind speed gradations allowed me to choose the number of wind turbines required to make the energy balance.

The designed wind-diesel power station consists of three wind turbines "CONDOR AIR WES", two of them with capacity 60 kW, and one with capacity 20 kW; 100 storage batteries; three power control units; automatic reserve switching unit; charge controllers and a 400-kW diesel generator, which was already installed at the power station earlier. The wind turbines cover 97.57% of the customers' energy needs. The missing energy is supplied by a diesel generator. Fuel consumption has been reduced from 46.86 to 1.14 tons per year. Before the wind turbines were installed, carbon emissions were 140 tons per year. After the recommended use of the wind-diesel power plant, carbon emissions dropped to 90 tons per year.

Economic comparative analysis was performed for two options of power supply system: diesel power plant without integration of renewable energy sources and wind-diesel power plant from the point of view of the residents of the rural settlement. The results of the analysis show that despite the negative NPV of both scenarios (NPV of 0 scenario = -98 230 350,96 RUB; NPV of 1 scenario = -39 082 465,77 RUB), option 1 is more effective than a diesel power plant without integration of wind turbines. Presented calculations shows that if the power plant is upgraded with wind turbines, it is possible to save about 60 million rubles.

Furthermore, the NPV sensitivity analysis was performed for both options. The graphs presented in the Figures 4.2 – 4.5 show how the NPV depends on the discount rate, inflation, escalation and loan amount.

In addition to this, an economic evaluation of the wind-diesel power plant development project was conducted from the perspective of an outside investor. The investor decides to assume all costs, but at the same time sell the generated electricity to the residents of the settlement at its set price.

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APPENDICES

Appendix 1 – Technical parameters of wind generator Condor Air WES 380/50-60 [7]

Parameter	Condor Air 20 kW	Condor Air 40 kW	Condor Air 60 kW
Diameter of wind wheel, m	11.5	14	17.5
Height of blade, m	5.5	6.5	8.5
Nominal number of rotations, rot/min	25-30	25-30	25-30
Nominal power, kW	20	40	60
Maximal power, kW	22	42	62.5
Start wind velocity, m/s	2.5	2.5	2.5
Nominal wind velocity, m/s	9	9	9
Operating wind velocity, m/s	3-20	3-20	3-20
Hurricane wind protection	Automatic	Automatic	Automatic
Automatic wind orientation	Yes	Yes	Yes
Tower height, m	12	18	18
Wind installation weight (without tower), kg	1300	1850	2400
Number of blades	3	3	3
Wind usage efficiency factor	>0.42	>0.42	>0.42
Generator frequency, Hz	0-50	0-50	0-50
Nominal current, A	70	100	100
Recommended number of batteries	20	40	40
Recommended capacity of batteries, A·h	200	200	200
Converting system efficiency	>0.85	>0.85	>0.85
Noise level not more, Db	55	65	65
Limit of wind velocity, m/s	35	35	35

Appendix 2 – Technical parameters of diesel generator YMZ AD-400 [14]

Cost, RUB	3 926 558
Nominal power, kW	400
Reserve power, kW	440
Current	AC, three phase
Nominal frequency, Hz	50
Nominal voltage, V	380
Nominal current, A	720
Power factor, $cos\varphi$	0.8
Dimensions, L x W x H, mm	3 350 x 1 300 x 2 150
Weight, kg	4 470
Specific fuel consumption at 100% of nominal power, g/kWh	208
Fuel tank capacity, liter	950
Cooling system capacity, liter	90
Lubrication system, liter	47

Appendix 3 – Technical parameters of the power module "Delta" NH PLUS-series 20 kVA (3ph-3ph) [17]

Input voltage, V	380/220 (3 phase, 4 conductors + PE)
Input power factor	> 0.99
Output voltage, V	380/220 (3 phase, 4 conductors + PE)
Efficiency, %	94
Dimensions, L x W x H, mm	850 x 520 x 1165

Appendix 4 – Technical parameters of the Lead-Acid storage batteries “Delta” [18]

Parameter	Battery “Delta” DTM-12150 L	Battery “Delta” DTM-12200 L
Nominal voltage, V	12	12
Nominal capacity, A*h	150	200
Lifetime, years	12	12
Internal resistance, mOhm	3.1	3.5
Minimal charging current, A	15	20
Maximum charging current, A	40	60
Maximum discharge current, A	970	1000
Dimensions, L x W x H, mm	482 x 170 x 240	522 x 238 x 218
Weight, kg	47.0	65.5

Appendix 5 – Zero (base) variant calculation

VAR-0 nowadays situation	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Energy consumption expenses		12 610 753,17	12 990 589,06	13 381 865,60	13 784 927,39	14 200 129,40	14 627 837,30	15 068 427,76	15 522 288,80	15 989 820,14	16 471 433,53	16 967 553,10	17 478 615,80	18 005 071,71	18 547 384,47	19 106 031,69	19 681 505,37	20 274 312,31	20 884 974,59	21 514 030,03	22 162 032,61
CF		- 12 610 753,17	- 12 990 589,06	- 13 381 865,60	- 13 784 927,39	- 14 200 129,40	- 14 627 837,30	- 15 068 427,76	- 15 522 288,80	- 15 989 820,14	- 16 471 433,53	- 16 967 553,10	- 17 478 615,80	- 18 005 071,71	- 18 547 384,47	- 19 106 031,69	- 19 681 505,37	- 20 274 312,31	- 20 884 974,59	- 21 514 030,03	- 22 162 032,61
DCF		- 11 040 370,82	- 9 956 670,05	- 8 979 343,17	- 8 097 948,76	- 7 303 070,26	- 6 586 215,45	- 5 939 725,68	- 5 356 694,06	- 4 830 891,65	- 4 356 700,96	- 3 929 055,89	- 3 543 387,60	- 3 195 575,74	- 2 881 904,40	- 2 599 022,41	- 2 343 907,56	- 2 113 834,27	- 1 906 344,51	- 1 719 221,54	- 1 550 466,18
NPV	- 98 230 350,96																				
EAA	- 15 023 323,90																				

Appendix 6 – First variant (rural settlement association point of view)

VAR-1 RURAL ASSOCIATION	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Investment Equipment	665 930,40																				
Investment Batteries	210 900,00												9 063 855,25								
Investment Diesel Generator												9 499 828,90									
Batteries Salvage Value (Selling)																					3 021 285,08
Diesel Generator Salvage value (Selling)																					1 727 241,62
Maintenance		168 356,93	179 438,18	191 248,80	203 836,80	217 253,34	231 552,95	246 793,76	263 037,73	280 350,87	298 803,57	318 470,82	339 432,57	361 774,02	385 585,99	410 965,26	438 014,99	466 845,14	497 572,88	530 323,13	565 229,00
Fuel costs		77 084,52	81 421,77	86 003,06	90 842,12	95 953,45	101 352,38	107 055,09	113 078,67	119 441,17	126 161,66	133 260,30	140 758,34	148 678,27	157 043,82	165 880,07	175 213,50	185 072,09	195 485,38	206 484,59	218 102,68
Salary		1 920 394,48	2 046 794,84	2 181 514,88	2 325 102,19	2 478 140,41	2 641 251,61	2 815 098,80	3 000 388,60	3 197 874,18	3 408 358,25	3 632 696,39	3 871 800,47	4 126 642,38	4 398 257,98	4 687 751,32	4 996 299,11	5 325 155,52	5 675 657,25	6 049 229,01	6 447 389,27
Loan repayment		2 515 393,21	2 515 393,21	2 515 393,21	2 515 393,21	2 515 393,21	2 515 393,21	2 515 393,21	2 515 393,21	2 515 393,21	2 515 393,21	2 515 393,21	2 515 393,21	2 515 393,21	2 515 393,21	2 515 393,21	2 515 393,21	2 515 393,21	2 515 393,21	2 515 393,21	2 515 393,21
Interest		2 332 368,86	2 306 745,46	2 277 534,77	2 244 234,59	2 206 272,38	2 162 995,47	2 113 659,78	2 057 417,11	1 993 300,45	1 920 207,46	1 836 881,46	1 741 889,82	1 633 599,34	1 510 148,20	1 369 413,90	1 208 976,80	1 026 078,50	817 574,44	579 879,81	308 907,94
Redemption		183 024,34	208 647,75	237 858,44	271 158,62	309 120,82	352 397,74	401 733,42	457 976,10	522 092,76	595 185,74	678 511,75	773 503,39	881 793,87	1 005 245,01	1 145 979,31	1 306 416,41	1 489 314,71	1 697 818,77	1 935 513,39	2 206 485,27
Debt value	16 659 777,60	16 476 753,26	16 268 105,51	16 030 247,07	15 759 088,45	15 449 967,63	15 097 569,89	14 695 836,47	14 237 860,36	13 715 767,61	13 120 581,86	12 442 070,12	11 668 566,73	10 786 772,86	9 781 527,86	8 635 548,55	7 329 132,14	5 839 817,43	4 141 998,66	2 206 485,27	0,00
Total Expenses		4 498 204,79	4 614 400,25	4 736 301,51	4 864 015,69	4 997 619,58	5 137 152,42	5 282 607,44	5 433 922,10	5 590 966,67	5 753 530,95	5 921 308,97	6 093 881,19	6 270 694,01	6 451 035,99	6 634 010,54	6 818 504,40	7 003 151,24	7 186 289,96	7 365 916,55	7 539 628,89
CF	- 876 830,40	- 4 498 204,79	- 4 614 400,25	- 4 736 301,51	- 4 864 015,69	- 4 997 619,58	- 5 137 152,42	- 5 282 607,44	- 5 433 922,10	- 5 590 966,67	- 5 753 530,95	- 15 421 137,86	- 15 157 736,44	- 6 270 694,01	- 6 451 035,99	- 6 634 010,54	- 6 818 504,40	- 7 003 151,24	- 7 186 289,96	- 7 365 916,55	- 2 791 102,19
DCF	- 876 830,40	- 3 938 055,74	- 3 536 718,81	- 3 178 097,72	- 2 857 363,61	- 2 570 255,94	- 2 313 014,01	- 2 082 316,72	- 1 875 229,78	- 1 689 159,35	- 1 521 811,31	- 3 570 963,48	- 3 072 882,65	- 1 112 935,18	- 1 002 366,08	- 902 434,50	- 812 028,54	- 730 160,45	- 655 952,17	- 588 622,51	- 195 266,82
NPV	- 39 082 465,77																				
EAA	- 5 977 261,98																				

Appendix 7 – Second variant (an outside investor point of view)

VAR-2 INVESTOR POINT OF VIEW	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Investment Equipment	13 318 608,00																				
Investment Batteries	4 218 000,00												9 063 855,25								
Investment Diesel Generator												9 499 828,90									
Depreciation Batteries		351 500,00	351 500,00	351 500,00	351 500,00	351 500,00	351 500,00	351 500,00	351 500,00	351 500,00	351 500,00	351 500,00	351 500,00	755 321,27	755 321,27	755 321,27	755 321,27	755 321,27	755 321,27	755 321,27	755 321,27
Depreciation Equip		665 930,40	665 930,40	665 930,40	665 930,40	665 930,40	665 930,40	665 930,40	665 930,40	665 930,40	665 930,40	665 930,40	665 930,40	665 930,40	665 930,40	665 930,40	665 930,40	665 930,40	665 930,40	665 930,40	665 930,40
Depreciation Diesel Generator		428 351,78	428 351,78	428 351,78	428 351,78	428 351,78	428 351,78	428 351,78	428 351,78	428 351,78	428 351,78	428 351,78	949 982,89	949 982,89	949 982,89	949 982,89	949 982,89	949 982,89	949 982,89	949 982,89	949 982,89
Batteries Salvage Value (Selling)																					3 021 285,08
Diesel Generator Salvage value (Selling)																					1 727 241,62
Maintenance		168 356,93	179 438,18	191 248,80	203 836,80	217 253,34	231 552,95	246 793,76	263 037,73	280 350,87	298 803,57	318 470,82	339 432,57	361 774,02	385 585,99	410 965,26	438 014,99	466 845,14	497 572,88	530 323,13	565 229,00
Fuel costs		77 084,52	81 421,77	86 003,06	90 842,12	95 953,45	101 352,38	107 055,09	113 078,67	119 441,17	126 161,66	133 260,30	140 758,34	148 678,27	157 043,82	165 880,07	175 213,50	185 072,09	195 485,38	206 484,59	218 102,68
Salary		1 920 394,48	2 046 794,84	2 181 514,88	2 325 102,19	2 478 140,41	2 641 251,61	2 815 098,80	3 000 388,60	3 197 874,18	3 408 358,25	3 632 696,39	3 871 800,47	4 126 642,38	4 398 257,98	4 687 751,32	4 996 299,11	5 325 155,52	5 675 657,25	6 049 229,01	6 447 389,27
Total Expenses		3 611 618,11	3 753 436,97	3 904 548,92	4 065 563,28	4 237 129,38	4 419 939,13	4 614 729,83	4 822 287,18	5 043 448,40	5 279 105,67	15 030 038,59	15 383 259,91	7 008 329,22	7 312 122,34	7 635 831,20	7 980 762,16	8 348 307,30	8 739 950,08	9 157 271,30	9 601 955,51
Revenue energy sold		12 610 753,17	12 990 589,06	13 381 865,60	13 784 927,39	14 200 129,40	14 627 837,30	15 068 427,76	15 522 288,80	15 989 820,14	16 471 433,53	16 967 553,10	17 478 615,80	18 005 071,71	18 547 384,47	19 106 031,69	19 681 505,37	20 274 312,31	20 884 974,59	21 514 030,03	22 162 032,61
Tax Base		8 999 135,07	9 237 152,08	9 477 316,68	9 719 364,11	9 963 000,02	10 207 898,17	10 453 697,93	10 700 001,62	10 946 371,74	11 192 327,86	11 437 343,41	11 159 211,14	10 996 742,49	11 235 262,13	11 470 200,49	11 700 743,20	11 926 005,00	12 145 024,52	12 356 758,73	12 560 077,10
Tax		1 799 827,01	1 847 430,42	1 895 463,34	1 943 872,82	1 992 600,00	2 041 579,63	2 090 739,59	2 140 000,32	2 189 274,35	2 238 465,57	2 287 468,68	2 231 842,23	2 199 348,50	2 247 052,43	2 294 040,10	2 340 148,64	2 385 201,00	2 429 004,90	2 471 351,75	2 512 015,42
EAT		7 199 308,05	7 389 721,67	7 581 853,34	7 775 491,29	7 970 400,02	8 166 318,54	8 362 958,34	8 560 001,30	8 757 097,39	8 953 862,29	9 149 874,73	8 927 368,91	8 797 393,99	8 988 209,70	9 176 160,39	9 360 594,56	9 540 804,00	9 716 019,61	9 885 406,99	10 048 061,68
CF	- 17 536 608,00	8 645 090,23	8 835 503,85	9 027 635,53	9 221 273,47	9 416 182,20	9 612 100,72	9 808 740,52	10 005 783,48	10 202 879,58	10 399 644,47	1 095 828,02	1 830 926,95	11 168 628,55	11 359 444,26	11 547 394,95	11 731 829,12	11 912 038,56	12 087 254,17	12 256 641,55	17 167 822,94
DCF	- 17 536 608,00	7 568 540,97	6 771 994,41	6 057 618,56	5 417 032,53	4 842 705,18	4 327 869,18	3 866 443,73	3 452 965,06	3 082 524,09	2 750 710,25	253 753,12	371 178,35	1 982 230,29	1 765 037,68	1 570 809,61	1 397 165,63	1 241 969,39	1 103 303,74	979 448,39	1 201 068,93
NPV	42 467 761,10																				
EAA	6 709 167,23																				
IRR	50,96%																				
Price when NPV=0	10,43																				