Czech Technical University in Prague

Faculty of Electrical Engineering
Department of Economics, Management and Humanities

# HYBRID POWER PLANT FOR POWER SUPPLY OF AUTONOMUS OBJECTS

MASTER THESIS

Study program: Electric Engineering, Power Engineering and Management
Branch of study: Management of Power Engineering and Electrotechnics
Scientific supervisor: Ing. Michaela Makešová

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# MASTER‘S THESIS ASSIGNMENT

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1) Artur Sibgatullin, Vladimir Tolmachev. Justification of the Parameters of RES Based Energy Complexes for Trunk Gas Pipeline Consumers
2) Brealey R., Myers S., Allen F.: Principles of Corporate Finance, McGraw-Hill/Irwin; 11 edition (January 15, 2013)

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## III. Assignment receipt

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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**

The aim of this thesis is economic evaluation of integration result renewable energy sources in autonomous gas-oil objects. Most of such objects in Russia are not connected to the central network system and have expensive power supplied by diesel generators. These objects, as a rule, serve the transportation of oil and gas. These areas, for example, the Nefteyuganskiy rayon, Khanty-Mansiyskiy avtonomnyy okrug have renewable energy potential. So, integration of renewable energy sources with diesel power system may decrease energy cost.

In this thesis, I analyzed the possible variants for combination a hybrid power plant for decentralized power supply of gas-oil objects by economic side. In the introduction I justified the relevance of the problem and in subsequent chapters I proceeded directly to the solution of the question.

This paper contains the following structure: initially, the diploma contains information about the object under study, its technical characteristics, as well as climatic conditions. Initial data for economic analysis: location, configurations of power plant, required number of equipment (wind generators, batteries, diesel generators) is made. According technical part, this analysis includes Economic evaluation of investment decision and comparison combination of structure hybrid power plant, and after that determination of optimal solution for this object.

KEYWORDS

Renewable energy sources, hybrid power plant, wind power plant, diesel power plant, autonomous consumers

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**LIST OF ABBREVIATIONS**

| | |
|---|---|
| AB | Accumulator battery |
| AC | Alternating current |
| ACS | Automatic control system |
| ATS | Automatic transfer switch |
| BP | Battery pack |
| CS | Company standard |
| DC | Direct current |
| DG | Diesel generator |
| ER | Electrical receiver |
| GDP | Gas-distributing plant |
| GTL | Gas trunk line |
| IPS | Independent power supply |
| LVS | Low-voltage switchgear |
| PC | Power consumer |
| PSP | Power supply package |
| PVM | Photovoltaic module |
| RES | Renewable energy source |
| SG | Special group |
| TGPC | Trunk gas pipeline consumers |
| WPP | Wind power plant |
| WG | Wind generator |

## INTRODUCTION

The urgency of the subject of master's work is due to the need to improve the economic efficiency and reliability of power supply systems for long-distance gas pipeline consumers.

Schematic solutions for the power supply of long-distance consumers of the trunk gas pipeline are based on power supply from power lines, which in turn leads to significant losses of electricity during power transmission and multiple conversion of voltage from 6-10 kV to the required voltage of 0.23-0.4 kV.

Introduction of autonomous power supplies on the basis of RES is one of the promising directions of development of power supply systems for the linear part of the main gas pipeline. Their application will allow reducing the total cost of electricity supply to long-distance consumers of the main gas pipeline.

One of the most important tasks in designing the power supply system on the basis of RES is to optimize the composition and determine the parameters of energy sources, on which the realization of the energy potential of renewable energy resources and the reliability of power supply to consumers strongly depends.

Parameters of equipment and composition of such energy complex will depend on the categorization of consumers, requirements to the quality of power supply and specific conditions of operation, so when determining the composition, capacity and operating modes of consumers it is necessary to take into account these factors.

Factors to be taken into account and compared in determining the economic efficiency of power plants [1]:

- Increase in the cost of traditional energy carriers and increase in electricity tariffs;
- The share of possible replacement of energy and fuel from traditional sources by renewable energy sources;
- Traditional energy pricing;
- Cost of construction of stationary facilities and power transmission lines modernization of networks from traditional sources for organization of power supply, including the use of renewable energy sources;
- Fee for technological connection to power grids;
- Cost of additional measures to ensure the required category of reliability of power supply to consumers;

In the first part I will consider the current state of electricity supply to consumers of gas main pipelines and the possibility of using RES for them. In this part features of power supply of similar objects will be considered, technical requirements to them will be analyzed. In the second part the analysis of the consumer, an estimation of power potential of considered area, a choice of structure of the equipment, configurations will be made. In the third part the economic comparison of variants, an estimation of expediency of configuration realization on the basis of RES will be executed.

## 1. The current state of electricity supply trunk gas pipeline consumers of main gas pipelines and the possibility of using renewable energy sources

### 1.1 Properties of power supply trunk gas pipeline consumers and technical requirements for autonomous power supply package based on renewable energy sources for power supply to consumers in the gas industry

The gas transportation system of the Unified Gas Supply System of Russia (Figure 1) has a length of more than 170 thousand km and is characterized by a significant distance from the producers of material and technical resources, undeveloped transport, energy, social and market infrastructure, the length of sections in severe climatic, permafrost, marshy and mountainous areas.


Figure 1- Main planned and operating oil and gas pipelines in Russia [2]

Reliable power supply to long-distance consumers of the main gas pipeline is one of the main factors ensuring stable and uninterrupted operation of gas transportation systems [3, 4].

Typical consumers of the main gas pipeline are: pumping stations (stations of pressure regulation in the main pipeline), units of shut-off valves with automatic drive, with the function of remote control on the pipelines of external gas transport, stations of electrochemical protection against corrosion, leak detection system, stations of linear telemechanics and communication, etc. [1].

Nominal capacity of trunk gas pipeline consumers (TGPC) varies from a few tens to tens and hundreds of kilowatts (high-capacity gas distribution station). Basically, the nominal capacity of the majority of consumers does not exceed 30 kW. The analysis of technical characteristics of typical main gas pipeline consumers shows that the main share of consumers is accounted for by three-phase and single-phase alternating current consumers with frequency of 50 Hz and supply voltage of 380/220 V. There are also consumers with direct current [2].

Electricity supply of TGPC is provided by one of the three main options [1]:

- From a high-voltage 10 (6) kV power line of one-way two-way power supply with subsequent conversion of voltage up to 0.4 kV using 10 (6) / 0.4 (0.23) kV mast transformer substations installed directly at consumers;
- From local autonomous power supplies of different types and their combinations: gas turbine, gas piston units, DGS, power plants based on renewable energy sources, thermoelectric generators, etc.
- Combined method with power supply from external and autonomous power sources.

Each of the power supply options or combinations has its advantages and disadvantages. Therefore, optimization calculations, which justify the selection of a wide variety of options, taking into account local conditions, are quite a challenge.

At present, most of the above-mentioned options of power supply schemes are used. At the same time, the overwhelming majority of power supply schemes for main consumers (more than 70%) are performed according to the centralized scheme from high-voltage overhead power lines of 10 (6) kV, where power supply circuits from external power sources are the most preferable. This approach is explained by the requirements of transition to absolutely autonomous technologies [1].

At the same time, in addition to higher costs, the drawbacks of energy supply schemes from regional power plants are: multiple conversion of electricity to different voltage levels, long-distance transmission of electricity over long distances. All this leads to significant losses of electricity. It should also be noted that there is a need for coordination with the connection points to power plants and protection zones. In addition, local regional networks often have low reliability and, in most cases, experience difficulties in providing the required category of reliability of power supply to backbone consumers. [5]

The statistics of disconnections and failures in power supply systems of main consumers shows that more than 50% of disconnections are accounted for by the power supply system, about 30-35% - by mechanical damage of power lines, about 15% - by scheduled repairs and 2% - by disconnection of relay protection devices [1]

It should be borne in mind that the considerable length of the main gas pipeline and the dispersal of consumers along its route, as well as the difficult geological and climatic conditions of its passage, lead to significant expenditures on the implementation of power supply systems, even in the case of low transmission capacity. The main cost items for traditional power supply methods are the construction of power lines, especially in hard-to-reach and impassable areas, including land acquisition, construction of upstream and downstream transformer substations, connection to local power grids and payment for power consumption. The average cost of sales of 10 (6) kV overhead lines is more than 3.5 million rubles/km, while the average cost of sales of cable lines is more than 10.5 million rubles/km [1].

These problems necessitate, on the one hand, the need to modernize and reconstruct the equipment of the existing power supply systems of main consumers, on the other hand, the need to develop autonomous generation based on low-power sources.

The use of autonomous power supplies is important for power supply in hard-to-reach areas in the absence of external power sources, when it is impossible to provide the required category of reliability of power supply and indicators of power quality.

For local autonomous power plants located in close proximity to consumers, the following technical problems need to be solved:

- Ensuring own needs;
- Selection of the optimal mode of operation of sources;
- Selection of the power supply scheme taking into account the reliability category of consumers;
- Selection of generation sources and their number;
- Selection of automation and control system;
- Ensuring operation and maintenance services;

When feeding consumers from autonomous power supplies, it should be taken into account that:

- It is necessary to constantly monitor the condition of the equipment;
- service life of any autonomous power supply source is approximately 2-3 times less than service life of 10 (6) kV overhead power lines [1].
- There is a dependence on the energy resource, its availability in the necessary amount;

The choice of a variant of the scheme of electric power supply is carried out at a design stage by results of comparison of investment expenses according all factors.

The main problems when choosing a variant of TGPC power supply from a stand-alone power supply, especially on the basis of RES, may be the increased requirements of consumers to the indicators of quality and reliability of power supply, compliance with which will require additional measures and will lead to an increase in capital investments. In order to determine the rational boundaries of the use of autonomous power plants based on renewable energy sources for power supply to consumers via the network, it is necessary to analyze the requirements of consumers to the quality of supply voltage and reliability of power supply.

Among main consumers according to company standard [5] there are consumers of the first, second and third categories in terms of reliability of power supply. The same composition includes special group of electric receivers.

**Characteristics of power consumers (PCs) in terms of power supply reliability [7]:**

- **A special group of PCs of the first category.** A special group of PCs, which uninterrupted operation is necessary for accident-free production in order to prevent the threat to life of people, explosions and fires, was singled out from the group of PC of the 1st category. These include electric motors of gate valves and shut-off valves for compressor drives, fans, pumps, lifting machines at underground mines, as well as emergency lighting at some facilities. In order to supply power to a special group of first PCs, an additional power supply must be provided from a third independent mutually redundant power source (batteries, diesel and gas turbine stations, etc.). An independent power supply for receivers or a group of receivers is defined as a power supply that retains the voltage within the limits specified for post-emergency operation.

- **The first category of PCs** is an PC, the interruption of power supply of which may entail danger to life of people, threat to the security of the state, significant material damage (damage to equipment, mass defect of products), disorder of complex technological process, disruption of functioning of especially important elements of the communal services, objects of communication and television.
- **The second category of PCs** is an PC, the interruption of power supply of which leads to mass undersupply of products, mass downtime of workers, machinery and industrial transport, disruption of normal activities of a significant number of urban and rural residents. It is the most numerous. PCs of the 2nd category should be provided with electricity from two independent mutually redundant power sources. Power supply interruptions are allowed for the time required to switch on the backup power supply by the duty personnel or by the field operational team.
- **The third category of PCs -** all other PCs that do not fall under the definition of 1 and 2 categories. These can include electric receivers in auxiliary shops, in irresponsible warehouses, in shops of non-serial production, etc. One power supply source is sufficient for the power supply of the third category PCs, provided that the power supply interruptions necessary for repair or replacement of the damaged element do not exceed 1 day.

The permissible deviations of the supply voltage frequency from the rated voltage vary within the limits set by GOST [6] and depending on the types of consumers are ± 0.2 Hz, ± 0.4 Hz, ± 1 Hz, ± 5 Hz.

The permissible deviations of the supply voltage (slow voltage changes) from the rated voltage also depend on the types of consumers and are mainly within the limits of GOST [6]: ± (5-10)%. For individual consumers, the permissible deviation of the supply voltage may be ± 15%. Significant voltage deviations (up to -20% from the nominal value) are acceptable for consumers with low sensitivity to voltage fluctuations due to the specifics of their use.

Almost all TGPC are constantly working and should not be subject to changes in operating modes (time shift of consumption, acceptable reduction of energy consumption). In most cases, the operating mode of consumers is long, in some cases repeated and short-term (actuators of shut-off and control valves of pipelines).

Due to the variety of types TGPC, different requirements for reliability of power supply and quality indicators, it is necessary to classify TGPC according to these parameters

Analysis of requirements to the quality of supply voltage and reliability categories of power supply allows to divide main consumers into 4 groups, each of which includes 5 subgroups. At the same time, the groups correspond to the power supply reliability categories, and the subgroups correspond to the requirements for permissible deviations of power supply frequency and voltage from the nominal values. The proposed classification is given in Table 1 [8].

Table 1 - Classification of TGPC by reliability of power supply and quality of supply voltage [8]

| Consumer group | Subgroup of consumers | Reliability category | Type of power supply current | Permissible frequency deviations Hz | | Permissible deviations of power supply voltage, V, max. |
|---|---|---|---|---|---|---|
| | | | | For 159.6 hours | For 168 hours | |
| A | A11 | Special group-1 | AC | ±0,2 | ±0,4 | ± 0.1Unom |
| | A12 | | AC | ±0,2 | ±0,4 | More than ± 0.1Unom |
| | A21 | | AC | ±1 | ± 5 | ± 0.1Unom |
| | A22 | | AC | ±1 | ± 5 | More than ± 0.1Unom |
| | A3 | | DC | - | - | - |
| B | B11 | 1 | AC | ±0,2 | ±0,4 | ± 0.1Unom |
| | B12 | | AC | ±0,2 | ±0,4 | More than ± 0.1Unom |
| | B21 | | AC | ±1 | ± 5 | ± 0.1Unom |
| | B22 | | AC | ±1 | ± 5 | More than ± 0.1Unom |
| | B3 | | DC | - | - | - |
| V | V11 | 2 | AC | ±0,2 | ±0,4 | ± 0.1Unom |
| | V12 | | AC | ±0,2 | ±0,4 | More than ± 0.1Unom |
| | V21 | | AC | ±1 | ± 5 | ± 0.1Unom |
| | V22 | | AC | ±1 | ± 5 | More than ± 0.1Unom |
| | V3 | | DC | - | - | - |
| G | G11 | 3 | AC | ±0,2 | ±0,4 | ± 0.1Unom |
| | G12 | | AC | ±0,2 | ±0,4 | More than ± 0.1Unom |
| | G21 | | AC | ±1 | ± 5 | ± 0.1Unom |
| | G22 | | AC | ±1 | ± 5 | More than ± 0.1Unom |
| | G3 | | DC | - | - | - |

The analysis on the basis of the given classification, admissible deviations of frequency and voltage of a power supply from nominal values of capacities of all long-distance consumers of the main gas pipeline of one of the gas transport enterprises is carried out.

Conclusions from this analysis [9]:

1) The installed power of TGPC is within the limits of: $P_{inst}$ = 0.01...320.0 kW;

Average power of consumers: $P_{av}$ = 5.0 kW, which indicates the predominance of the number of small power consumers (97.7% of consumers with a power of less than 25 kW). Consumers' power by groups are as follows:

- Group A consumers: $P_{inst}$ = 5.3 kW, $P_{av}$ = 5.3 kW;
- Group B consumers: $P_{inst}$ = 0.01...50.0 kW, $P_{av}$ = 1.9 kW;
- Consumers of group V: $P_{inst}$ = 25,0...320,0 kW, $P_{av}$ = 57,3 kW;
- Consumers of group G: $P_{inst}$ = 0.3...58.4 kW, $P_{av}$ = 5.6 kW;

2) 97.1 % of the reviewed TGPC refer to 50 Hz AC power consumers;

3) The considered TGPC is distinguished by a wide range of requirements to power quality indicators: permissible deviations of frequency and voltage of power supply from the nominal value;

4) Among the reviewed TGPC, there are consumers of all categories in terms of power supply reliability, including SG-1 receivers (0.3% of consumers). At the same time, the majority of consumers belong to the 3 (55.3%) and 1 (42.5%) categories of power supply reliability. Among the 1st category consumers there are DC consumers (2.9% of the total number of consumers). A small part of TGPC (1.9%) belongs to the 2nd category of consumers in terms of reliability of power supply, but it should be noted that the installed capacity of these consumers in most cases exceeds the capacity of SG-1, 1 and 3 categories of consumers;

5) For 99,2 % of the reviewed TGPC, it is possible to use AIP as the main or reserve source (in accordance with the requirements of CS [5]), and 54,5 % of consumers allow to use it as the main and the only one. At the same time, it should be noted that according to paragraph 7.7 of CS [5], in the absence of external power supply systems (or their low reliability) as an independent main or backup power supply sources of linear part of the GTL are used IPS, which can be, inter alia, based on RES;

6) From the point of view of expediency of using RES-based AIPs, for example, with IPS, the issue of maintaining the frequency of consumers power supply voltage becomes very important.

The proposed classification of the TGPC allowed to estimate the share of consumers in each category of power supply reliability, for which the allowable frequency deviations are within the limits corresponding to the requirements to the isolated power supply systems with autonomous generator sets according to GOST [6]:

- Group A customers: none;
- Group B customers: 27.9% of the total number of TGPC from $P_{inst}$ = 0.1...50.0 kW and $P_{av}$ = 1.7 kW;
- Group V customers: 1.4 % of the total number of TGPC with $P_{inst}$ = 25.0...320.0 kW and $P_{av}$ = 66.0 kW;
- Group G customers: 16.9 % of the total number of TGPC from $P_{inst}$ = 0.3...58.4 kW and $P_{av}$ = 5.6 kW.

7) As a whole, practically for a half of the considered TGPC (49,1 %) with $P_{inst}$ = 0,01...320,0 kW and Pav = 4,8 kW it is possible to use IPS as the main or reserve power supply source with frequency deviation requirements corresponding to the requirements to the isolated power supply systems with autonomous generator sets according to GOST [6]. 50,1 % of consumers with $P_{inst}$ = 0,1.40,0 kW and $P_{av}$ = 5,3 kW, for which it is also possible to use AIP as the main or reserve power supply source, have requirements to the permissible frequency deviations corresponding to the requirements to the synchronized power supply systems in accordance with GOST [6], therefore, in this case, for IPS on the basis of RES, it is likely that additional measures will be required to maintain the frequency in the power supply system of consumers.

8) 11,6 % of consumers with $P_{inst}$ = 0,3...58,4 kW, Pav = 5,1 kW (group G22) have the lowest requirements to indicators of electric power quality and for them it is possible to use RES-based IPS as a single power supply source.

Thus, the proposed classification of the gas transportation company from the diversity of the reviewed TGPC was highlighted:

a) A group of consumers with frequency deviation requirements corresponding to the requirements for isolated power supply systems with autonomous generator sets in accordance with GOST [6], for which the use of RES-based IPS as the main or reserve power supply source is possible;

b) A group of consumers for whom the use of RES-based IPS as the sole power supply source is the most appropriate;

c) A group of consumers with higher requirements to the indicators of power quality and reliability of power supply, for which the provision of the given indicators of quality of the generated RES-based IPS requires additional measures with appropriate costs.

It should be noted that the application of PSP, having in its composition a power plant based on RES, traditional energy carriers, as well as BP, allows to increase and, if necessary, to ensure a given level of reliability of power supply to consumers and compliance with the requirements of quality indicators of electricity, which is especially important for remote consumers.

In the majority of cases, the main gas pipeline routes are rather remote from small rivers, and therefore, the transmission of energy from small hydro power plants for long distances is a deterrent to the widespread use of small hydro generation for power supply to main consumers, despite many advantages of small hydro power as compared to other types of RES. The use of biomass waste for the production of electric power is expedient in the zones of developed agriculture, in agro-industrial complexes, where there are large stocks of animal waste, in forest processing complexes using wood waste. Otherwise, it is necessary to transport the waste to the places of its processing. This factor is also a deterrent in the use of electric energy sources based on the conversion of biomass waste to supply electricity to main gas pipelines.

Small hydropower and waste biomass have some of the greatest economic potential. However, with regard to power supply to main consumers, the use of these resources is not always feasible.

It makes sense to take into account the variants of wind and solar energy use. Such solutions allow to provide consumers with electricity during a calendar year under almost any weather conditions:

- In cloudy weather or at night, when there is no sun, but there is wind, the main source of electricity are wind turbines.
- In sunny weather, when the wind subsides, the share of electricity generated by photovoltaic panels increases.
- In case of absence of favorable conditions (for example, cloudy, windless weather, night time without wind), consumers are supplied with power from the batteries included in the power plant. With sufficient wind-solar activity, when energy is supplied to consumers by wind turbines and solar panels, the excess of electricity generated at this time is stored in batteries and can be used to cover power shortages in adverse weather conditions.

Wind-powered solar power plants have a technical perspective of use in companies mainly in those areas where solar and wind potential is high enough to generate electricity. In most regions of Russia, the average annual wind speed does not exceed 5 m/s. Wind zones with the highest energy potential are located mainly on the coast and islands of the Arctic Ocean from the Kola Peninsula to Kamchatka. About 30% of the economic potential of wind energy is concentrated in the Far East, 14% - in the Northern Economic Region, about 16% - in Western and Eastern Siberia. [1]

The potential for the use of solar energy in our country is also uneven. The level of solar radiation varies considerably: from 810 kWh /m$^2$ per year in the remote northern regions to 1400 kWh /m2 per year in the southern regions. Solar radiation levels are also affected by large seasonal variations: at 55° latitude, solar radiation in January is 1.69 kWh /m$^2$, in July it is 11.41 kWh /m$^2$ per day. Conditional zones of wind-solar activity are shown in Fig. 2. [1]

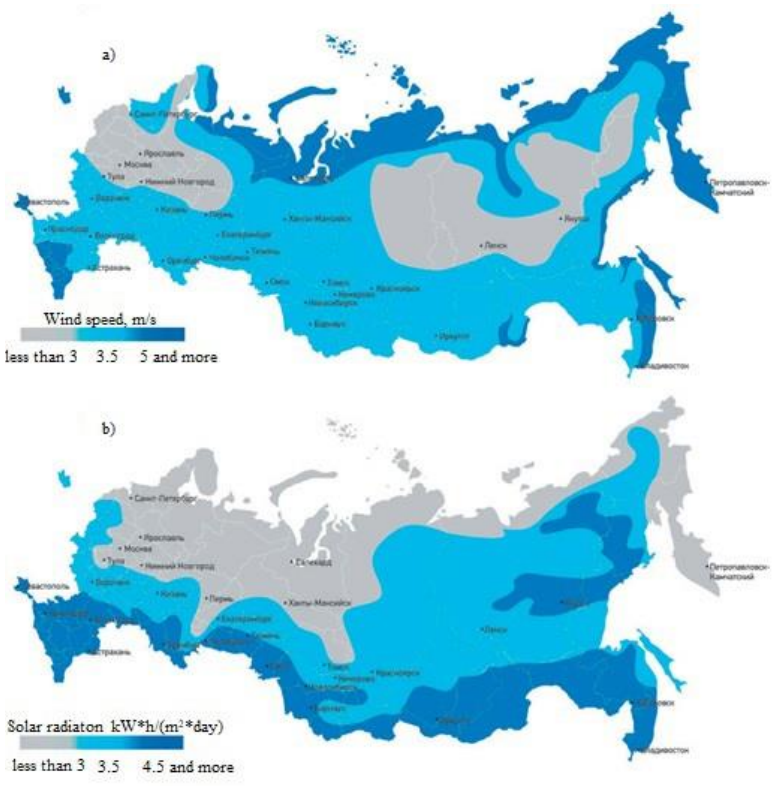


Figure 2 - Zones of average annual wind(a) and solar activity(b) in Russia [1]

RES-based power supplies are already being used at various gas industry facilities, including the TGPC power supply system. These are mainly wind turbines, PVM, and hybrid PSP based on them.

During the operation of the PSP, the following is noted [9]:

Average power generation of one wind turbine of AIR-X type (rated power 400 W at wind speed of 12.5 m/s) in 2012 was 2965 Wh. [10] AIR Breeze's average electricity generation (rated power 200 W at 12.5 m/s wind speed) for 2012 was 4782 Wh. [11]

The average electricity generation of one Whisper 200 type wind turbine (nominal power of 1 kW at wind speed of 11.6 m/s) in 2012 was 11616 Wh. [12]

Such small values of power generation of the wind turbine are explained by the wrong choice of the installation design for these operating conditions (wind speeds), as well as the non-optimal choice of the site for the installation of the wind turbine.

Wind turbine unit "Brise-5000" with the power of 5 kW was put into operation in 2008 as the main source of power supply. Due to low wind load and small amount of electricity generated by the wind power plant, at present the wind power plant is used as a reserve source of power supply, and the main source is the long-distance power transmission line. [13]

Experience of implementation of the project of the wind and DPP with the installed power of 1 MW in the Arctic version for power supply of the village of Amdarma. The northern and far eastern territories of Russia are located in a zone of high wind potential with average wind speeds of more than 5 m/s at a height of 10 m and specific solar density of 400 W/m$^2$. This area is decentralized and had problems with power supply, power supply was provided mainly by DPP. The solution to the problem was the use of a hybrid power plant (WT + DPP). Electricity consumption is 300-400 kW (up to 600 kW peak capacity). The project was implemented in two stages: 1) DPP reconstruction 2) Construction and integration of wind power plants. Input powers: three DGS in the amount of 600 kW and 4x60 kW of WT. Location of the Kara Sea coast. Average annual/maximum wind speed: 8/42 m/s. Minimum temperature -42 C, icing, intense snowstorm. [14]

Essence of the technical solution used:

- Combination of sources on the AC side. Distributed generation based on existing networks.
- Scalability. It is possible to increase the number of power sources connected in parallel
- Modularity
- Adapted technology for hard-to-reach regions. Reducing capital costs
- The main parameter of the system is the level of diesel fuel replacement

Figure 3 shows the scheme of this project.

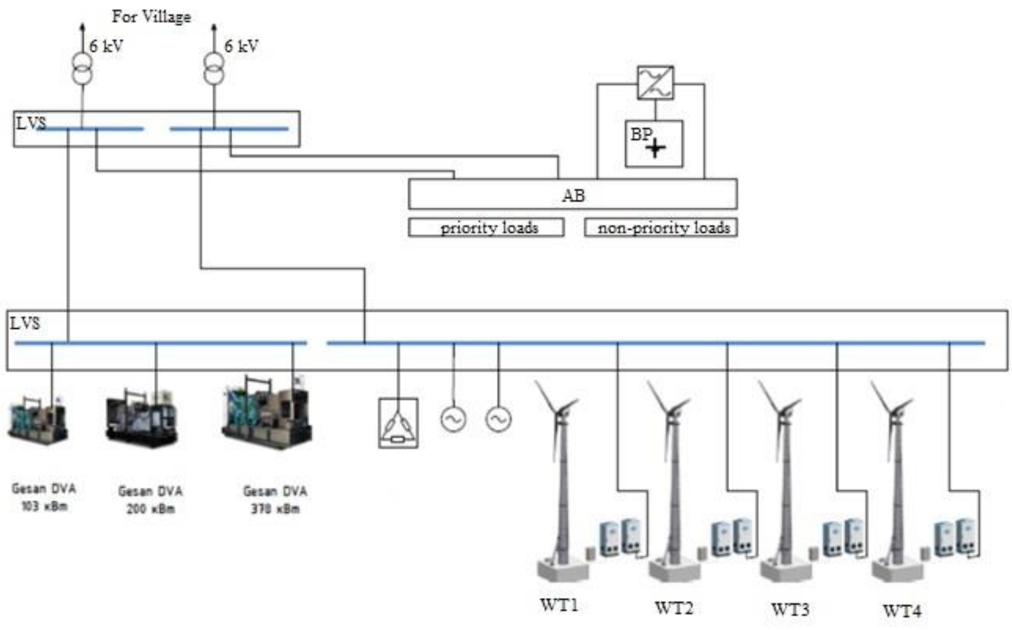


Figure 3 - Project design in Amderma village [14]

We can highlight some of the limitations we faced when implementing this project [14]:

1) Difficulty of integration of DGS with wind-diesel station:

- A completely new ACS was being developed.
- It is not possible to use the means of the DGS controller to control the DPP, as they do not take into account the WPP - the selection of DGS composition and other control solutions do not work.
- The remote control units are controlled in the forced start/stop mode. High demands are made on the rate of change of DGS composition.

2) Complexity of parallel operation of DGS with WPP:

- Problem with power supply from the WT to the grid.
- Problem of DGS phase exit at power surge from WT. The WT is switched off and there is even more power surge at the remote control unit.
- Regulation of the reactive component of the WT current for correct operation of DGS.

Commissioning results:

- At the same time, fuel savings of 36% and less motor-hours were achieved in the first year of operation (as less diesel power plants are used). In the second year, the level of savings increased due to the change in the operation mode of the WPP.
- Due to introduction of a new system of emergency uninterruptible power supply, additional units in the building of the DPP can operate during the complete shutdown of all machines (emergency or service mode of the DPP).

- The WPP has worked out a number of modes with extreme parameters: storm wind more than 30 m/s at negative temperatures, operation in icing conditions.
- Two wind turbines went into uncontrolled acceleration due to some shortcomings in the conditions of the Far North (even though wind turbines were modernized for the Arctic conditions). WT blades have been operated for a long time under overload conditions and have not been destroyed.

Based on the analysis of the experience of using renewable energy sources in the power supply systems of industrial gas consumers, including TGPC, the following conclusions can be drawn. The expediency and scale of RES use are determined primarily by their economic efficiency and competitiveness with alternative energy technologies. The main advantages of RES in comparison with energy sources based on organic fuel are the availability of significant resources, the possibility of their rapid reproduction, the absence of fuel costs and emissions of harmful substances into the environment.

The scale of RES implementation is affected by the restrictions on its implementation:

- RES energy potential;
- Conditions of fuel supply;
- Availability and characteristics of centralized sources;
- Electrical load density;
- Nomenclature of domestic equipment;
- Expenses for power installation with the use of RES.

In each specific case, it is necessary to determine the optimal combination of composition and parameters of the equipment of power supply systems, providing a minimum level of specific costs to cover energy needs with the maximum use of renewable energy.

Optimization of composition and parameters of RES-based PSP equipment is planned to be carried out for specific operation conditions taking into account availability of RES resources and characteristics of electric power consumers.

## 1.2 Technical requirements for autonomous energy complexes based on renewable energy sources for power supply to consumers in the gas industry

Taking into account the requirements of state and industry regulations it is necessary to formulate general technical requirements for autonomous power plants on the basis of renewable energy sources and energy sources based on them for power supply to main consumers, which are taken into account in the future when justifying the composition and parameters of energy sources with the use of today's known algorithms and methods.

Renewable energy sources are usually represented by a block-built version of a complete plant availability, which should include: power supplies, equipment and facilities for control, metering and distribution of electricity. In addition, if mast wind turbines, small hydroelectric power plants, photovoltaic panels with solar tracking systems, and other installations that are technically difficult to place in a block container, it is virtually impossible to achieve energy efficiency.

The energy complex based on renewable energy sources should provide consumers with electricity in accordance with the quality of electricity required by GOST [6].

Schematic solutions used in the energy complex based on renewable energy should ensure the reliability of energy supply to consumers in accordance with their reliability category, according to STO [5].

Nominal voltages of power plants and energy sources on the basis of renewable sources should correspond to the supply voltage of consumers and can be as follows: 24, 48 V DC, 230 V single-phase AC of 50 Hz frequency, 230/400 V three-phase alternating current of 50 Hz frequency.

The power of receivers should not exceed the rated power of the power supply.

The power complex based on renewable energy should be able to operate at low loads (up to 10% of the rated power).

Power receivers must be connected to the bus sections via circuit breakers. Circuit breakers shall be equipped with trip devices to protect the equipment from short-circuit and overload currents. The time of automatic disconnection of the power supply must not exceed the values according to the Rules [15].

The renewable energy system must be able to withstand a three-phase (single-phase) short circuit for the duration of protection in any load mode (up to 100%) without damage. After a short circuit is switched off, the rated voltage shall be achieved with an accuracy of 1% for a maximum period of 7.5 s.

The power plants included in the renewable energy system should be fully automated, without requiring the constant presence of on-duty personnel.

The basic requirements to control, monitoring and protection of the power supply system, imposed on the control system of conventional power plants in accordance with [16], should be complied with when creating the control system of the power plant with the power plants on the basis of renewable energy sources.

Depending on the type of RES used, additional requirements to the automated control system of technological processes are imposed on the power supply system control. The volume of automation is set depending on the applied scheme of power supply and types of power plants taking into account the regulatory documentation for these types of power plants (if any).

For wind turbines the volume of mandatory automation at work as a part of power complex should correspond to the specified in [16].

The automatic control system of the power plant should provide its stable operation in all necessary modes, control parameters, as well as to transfer data and output information about its state to the control system of automatic process control system of PSP.

Depending on the type of power plants based on renewable energy sources used within the framework of the energy complex, the process control system should include a system for collecting (monitoring) information on the relevant parameters of renewable energy sources (wind speed, solar radiation, etc.) existing at the moment, as well as the parameters of the generated electricity from renewable energy sources of power plants and transmit information to the software and hardware complex to generate control effects on other systems. The system of collection (monitoring) of information on parameters of renewable energy sources should also be connected with the system of power generation forecasting by power plants on the basis of renewable energy sources in the short and medium term (one hour, one day in advance), the forecast calculations of which are based on existing mathematical models and methods of forecasting with a high degree of probability (up to 95-98%). Information from both systems (monitoring and forecasting) should be provided to the control room.

The automated process control system of the energy complex based on renewable energy sources should ensure the long-term parallel operation of power plants among themselves and with the external network (in case of commissioning from the external network), the distribution of electricity among power plants and the management of common systems of power plants.

Automatic process control system of the power complex on the basis of renewable energy sources should provide the necessary level of reliability and stability of the power supply system in various disturbances, taking into account the requirements for reliability and continuity of power supply to consumers, depending on their categorization in accordance with STO [5].

The automated system of technological processes control on the basis of renewable energy sources should manage the operation modes of power plants, which are part of the energy complex:

- Control over the charge/discharge of energy accumulators, taking into account the requirements of the technological process and the specifics of operation of power plants based on renewable energy sources to ensure uninterrupted power supply, especially to responsible consumers;
- Automatic start-up of a reserve power plant on a conventional energy carrier and automatic connection of the load to its generator via ATS during periods of insufficient generation of electricity from power plants based on renewable energy sources and when the voltage in the batteries drops below the established limits;
- Automatic return to power supply of the load from power plants operating on renewable energy sources (or from energy storage facilities, depending on the current power supply scheme), when restoring its parameters and when switching off the backup power plant.

Hardware and software of the automated process control system of the power complex on the basis of renewable energy sources should meet the requirements to ensure safe operation in accordance with [16].

Automatic control system of power complex on the basis of renewable energy sources should provide maintenance of parameters of the electric power in the normalized and admissible limits for maintenance of the set quality of the electric power according to [6, 16, 17, 18].

If it is impossible to provide the set parameters of quality of the electric power of the power plants working on renewable energy sources, it is necessary to take additional measures on finishing of indicators of quality to the required values (inclusion of converters, filters, devices of the control and regulation of reactive power etc.) in the scheme with corresponding changes of functions of the automatic control system depending on accepted measures.

In accordance with the requirements [16] automatic control systems of technological processes should be created with the use of SCADA systems designed to control technological processes in the power industry.

To implement the functions of relay protection and local emergency control it is necessary to use multifunctional digital devices of relay protection and automatics of serial production, which are simultaneously devices of the level of control system of automatic control object (terminals) of automatic control system and provide the collection and transfer of all necessary connecting information used for the formation of simulation diagrams of objects, emergency and alarm system, database and archive. Digital relay protection and automation devices should comply with the requirements [19].

In addition to the general requirements to the automated process control system of the PSP, depending on the types of renewable energy sources used in the power plant complex, additional requirements to the automated process control system and additional equipment requiring appropriate automated control can be introduced.

In particular, such requirements can be imposed on wind turbines:

- Setting the wind turbine in protected mode in storm winds exceeding the maximum operating speed of the wind;
- Maintaining the speed and power of the wind turbine at a given level in strong winds;
- control of output voltage, etc.

Additional equipment that requires automated control can include

- Ballast resistances for wind turbines;
- Sun tracking systems for photoelements;
- Maximum power take-off systems for photovoltaic elements, etc;

The renewable energy complex shall be resistant to electromagnetic effects caused by lightning, electrostatic discharges and other electromagnetic influences, as well as to emergency and switching transients in electrical circuits.

In the Energy Complex on the basis of renewable energy sources, technical means should be applied (for example, when installed near a source of pulsed magnetic field), ensuring the stability of electrical equipment to pulsed magnetic fields, which meets the requirements [20].

In the Energy Complex on the basis of renewable energy sources technical means should be applied (for example, when installing near the source of magnetic field of industrial frequency), providing stability of electrical equipment to the magnetic fields of industrial frequency that meet the requirements [21].

General lighting of the equipment located in the units, local lighting of controls and control panels should comply with the requirements [22].

The design of the energy complex on the basis of renewable sources should provide the possibility of local control over the energy complex and power plants.

The design of the energy complex on the basis of renewable sources should ensure fire and explosion safety. General requirements on explosion hazard, explosion protection and explosion protection should correspond to the requirements [23].

Equipment and materials having fire safety certificates in accordance with [29] should be used in the design of renewable energy sources based on renewable sources.

Devices of block-complete execution of a power complex on the basis of renewable energy sources taking into account influence of climatic factors of environment should correspond [30].

Devices of the PSP block-complex design based on RES from the point of view of resistance to external mechanical factors should correspond to [24].

Electrotechnical products based on renewable energy sources in terms of resistance to external climatic factors, indicating the requirements [30], should comply with [25].

The degree of protection of the equipment housings against access to hazardous parts, external solid objects and/or water should be appropriate [26].

The minimum list of signals from an automatic fire alarm and extinguishing system to be transmitted to the control system shall be [27, 28].

## 1.3 Conclusion from chapter one

So, after analyzing the peculiarities of power supply to the main gas pipeline consumers, the experience of application, regulatory documents, the following conclusions can be drawn:

1) Application of renewable energy sources for power supply of the main gas pipeline consumers is reasonable.
2) When designing a hybrid power plant, it is necessary to classify the consumer according to the requirements of supply voltage quality and power supply reliability. This classification allows to determine the types of consumers for which the application of RES is most appropriate, as well as additional measures to improve the indicators of power supply quality.
3) The majority of consumers of gas main pipelines are located in hard-to-reach areas, remote from centralized power supply sources.
4) It is necessary to install additional equipment, control systems to ensure sustainable operation of autonomous hybrid power plant.
5) For efficient operation it is necessary to optimize the composition of hybrid power plant equipment

## 2. Design of hybrid power plant configuration

PAO NK Rosneft has identified a number of potentials for power supply based on RES facilities with typical loads of energy consumers. AO NizhnevartovskNipineft and a number of producers located in the Khanty-Mansiyskiy avtonomnyy okrug, Nefteyuganskiy rayon have been identified. The company is currently considering solutions for the practical application of renewable energy installations at these facilities. [Appendix A, Figure A1]

In this part I will analyze the consumer, assess the wind-solar potential of the area under consideration, choose the composition of equipment, configurations.

### 2.1 Characteristics of power supply object consumers

The calculation will be performed for the facility located in the real location of the gas main pipeline under construction in the Khanty-Mansiyskiy avtonomnyy okrug, Nefteyuganskiy rayon. The objects under consideration are Block Valve Station at the construction sites. From the initial data, the company provides the maximum consumption per day (winter period) and the maximum consumption per month (winter period) (Table 3), the volume of electricity consumption and levels of electrical loads of the Block Valve Station consumers (Table 4) [Appendix A, Figure A1].

The Block Valve Station of gas trunk pipeline is used when laying any pipeline designed for transmission of liquefied or gaseous substances (Figure 4). It is necessary for flow control. It can be installed on a linear section, servicing compressor, pumping, distribution and pumping stations. Crane assemblies in the system are required to shut down specific sections of the route. They are installed every 20 km. Shut-off mechanisms are also installed at the branch lines, in front of various obstacles, on the approaches to the stations. Cranes can be pneumatically hydraulic, pneumatically or manually driven. Blower plugs are installed next to them. They are necessary for emptying the disconnected area during repair work [34]. In our case we consider pneumatic-hydraulic ones with remote control.

Figure 4 - Block valve station [35]

Designed power of consumers of the Block Valve Station according to the project is 10,433 kW. Nominal powers of individual consumers are given in Table 2.

Table 2- Powers and voltages of the consumers of the Block Valve Station [Appendix A, Figure A2]

| Equipments | Nominal power, kW | Voltage, V |
|---|---|---|
| Valve actuator | 5 | 220 |
| Instrumentation and automation | 0,08 | 220 |
| Link | 1,4 | 220 |
| Fire signal system | 0,5 | 220 |
| Security equipment cabinet | 1,0 | 220 |
| Local distribution panel | 1,26 | 220 |
| Lighting of the area | 0,075 | 220 |
| Lighting of the building | 0,018 | 220 |
| Other consumers | 1.1 | 220 |
| Total | 10,433 | |

Table 3 - Maximum power consumption of the Block Valve Station [Appendix A, Figure A2]

| No. | Maximum electricity consumption per day (winter period), kWh/day. | Maximum electricity consumption per month (winter period), kWh/month. |
|---|---|---|
| 1 | 10,1 | 1584 |

Table 4 - Electric power consumption and levels of electric loads of consumers of Block Valve Station during the year [Appendix A, Figure A3]

| Month | Power consumption, kWh | Maximum load values, kW | Maximum load value, in % of total nominal power | Minimum load value, kW | Minimum load value, in % of total nominal power |
|---|---|---|---|---|---|
| January | 1584 | 10,1 | 96,8 | 1,512 | 14,49 |
| February | 1443,3 | 9,64 | 92,4 | 1,432 | 13,73 |
| March | 1248,7 | 9,12 | 87,4 | 0,9 | 8,63 |
| April | 1034,2 | 8,87 | 85 | 0,875 | 8,39 |
| May | 993,4 | 7,64 | 73,2 | 1,231 | 11,8 |
| June | 987,5 | 7,55 | 72,4 | 1,111 | 10,64 |
| July | 1020,3 | 8,55 | 82 | 1,055 | 10,1 |
| August | 1064,1 | 8,67 | 83,1 | 1,132 | 10,9 |
| September | 1150,3 | 8,99 | 86,2 | 0,967 | 9,3 |
| October | 1270,4 | 9,45 | 90,6 | 0,785 | 7,5 |
| November | 1239,0 | 9,33 | 89,4 | 0,654 | 6,3 |
| December | 1384,2 | 9,44 | 90,5 | 1,325 | 12,7 |

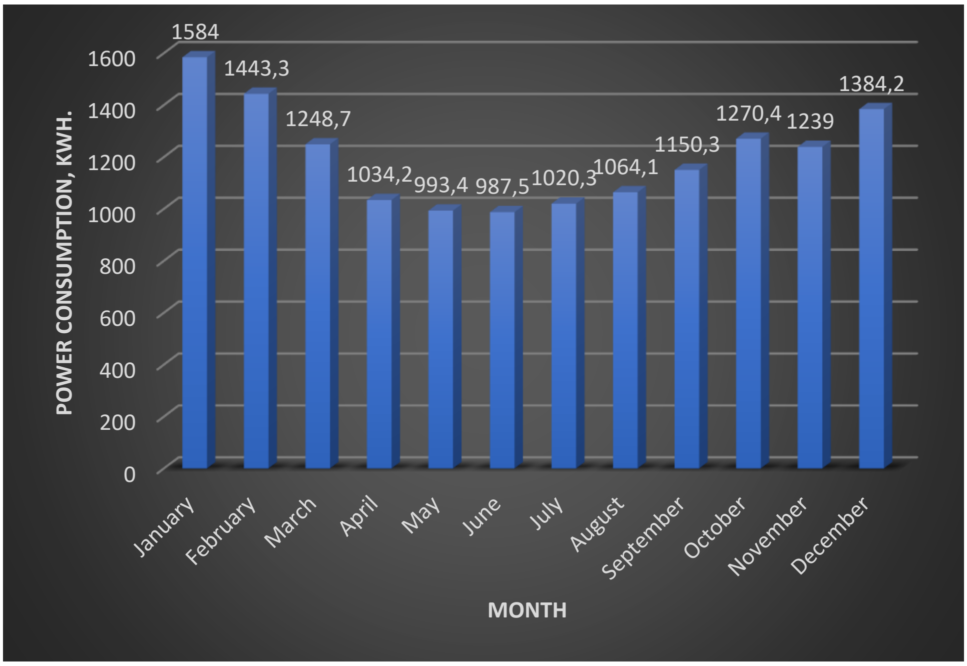


Figure 5- Annual graph of electricity consumption by consumers of Block Valve Station [Appendix A, Figure A3]

It follows from Table 4 that electricity consumption is significantly uneven. This is especially true for the January month, in which both maximum and minimum load values are observed.

Uneven consumption is explained by the fact that a part of consumers of the block valve station work in a repeated short-term mode, for example, a gate valve drive.

Figure 5 shows that electricity consumption in winter months (January, December) is higher than in summer period. The difference in daily load diagrams for January 23 and August 17, shown in Fig. 6, can also be seen.

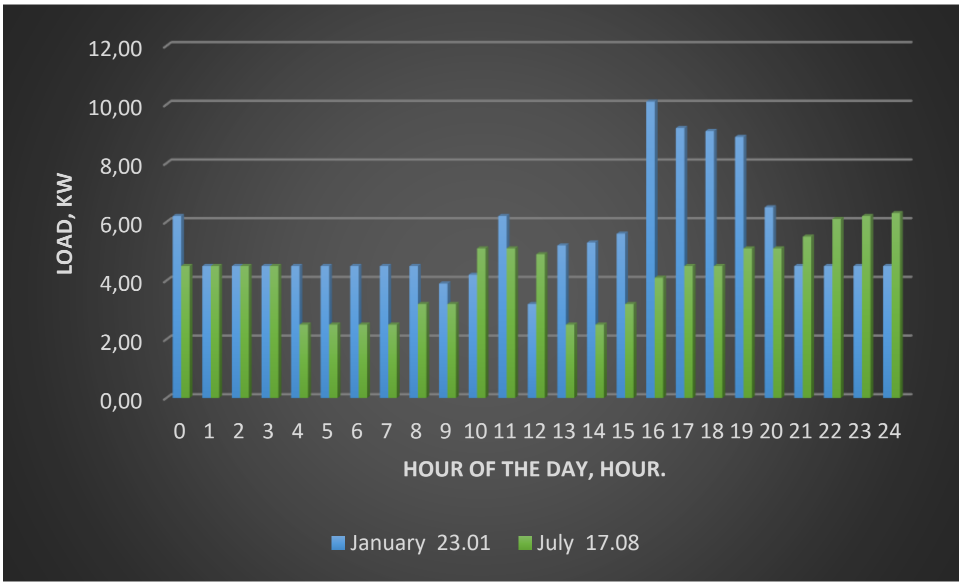


Figure 6 - Winter and summer daily load curve of Block Valve Station [Appendix B, Figure B3]

## 2.2 Evaluation of wind and solar energy potentials in the proposed construction area of the hybrid power plant

The climate of Khanty-Mansiysk is temperate continental taiga and forest-steppe areas with sufficient moisture. It is formed mainly under the influence of continental Arctic air.

Winters are usually severe and prolonged with air temperatures below -30°C during all months from November to April, and below -40°C was not observed only in April. The coldest days were observed in January 1964 and December 1968, when air temperatures dropped to -49.0°C. Strong winds catastrophically lower the comfort temperature. Well, the average temperature in January is only -18.9°C. Thaws in winter are very rare, but possible.

Summers can be hot as opposed to winters, but periods are usually short and often replaced by night frosts. The average temperature in July is +18.4°C, the absolute minimum for this month is +1.2°C and the maximum is +34.5°C.

Spring is short, with frequent returns of cold and sunny weather. Summer comes in Khanty-Mansiysk in June, and in July the average temperature of the thermometer is +18.3°C. The absolute maximum temperature was observed three times: in May 1952, in June 1955 and July 1957. At this time the thermometer column rose to +34.5°C. [36]

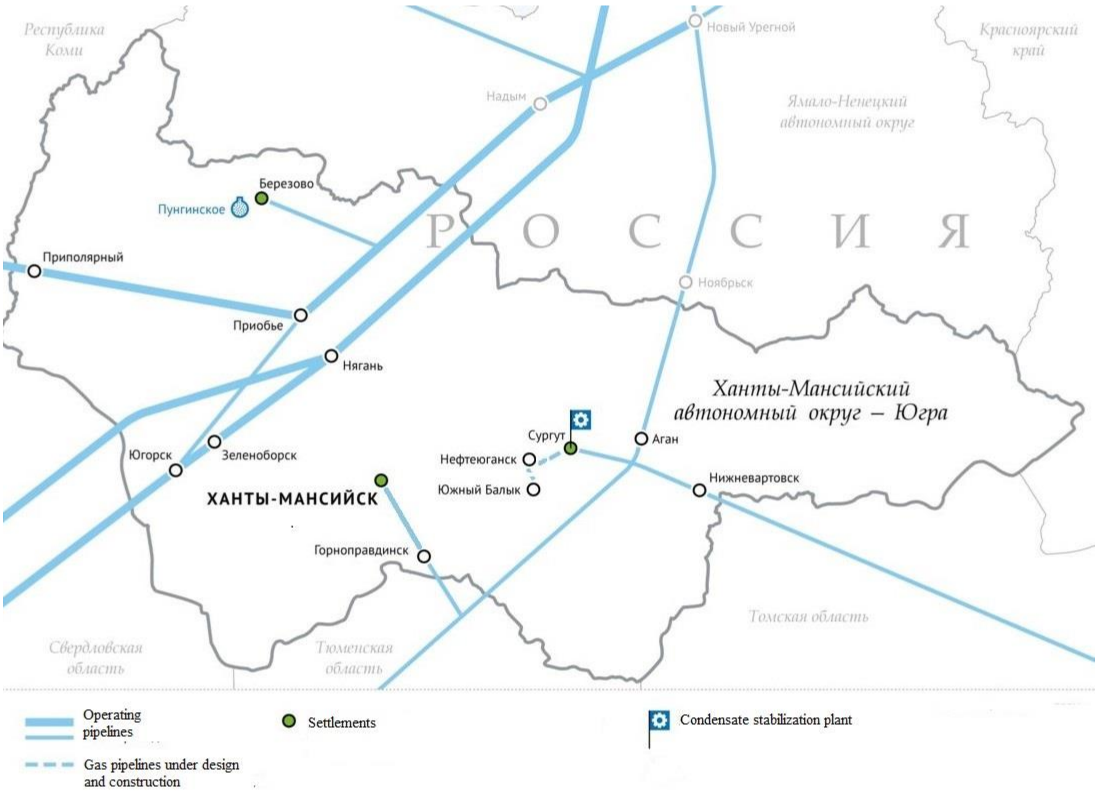


Figure 7 - Pipeline map of Khanty mansiyskiy avtonomnyy okrug for 2019 [37].

The object under consideration is located in the Nefteyuganskiy rayon, the exact location in the technical specification was not given. Therefore, according to the information on gasification of the region presented in [37], I will consider gas pipelines passing through settlements and on the way of their passage, I will choose a point for assessment of climatic potential. In the framework of pre-project calculation and under conditions of limited initial data, this will be sufficient.

Figure 8 - Map of Nefteyuganskiy rayon [38]

In figure 8, the designations KC-5 and KC-6 can be seen. These are compressor stations, therefore, gas pipelines run there. I assumed that to the populated areas. For instance, from KC-5 to the settlement of September, or to Pyat Yakh, etc. Also, the presence of KC-6 indicates that gas pipelines are laid in this area from KC-5 to KC-6. The gas pipeline running between KC-5 and the hard-to-reach Lempino settlement will be considered for calculations.


Figure 9 - Distance between KC-5 and Lempino [38]

The distance between KC-5 and Lempino is 88.11 km (Figure 9), which means that at least three block valve station assemblies are installed on this gas pipeline route. For case, I assume that they are here and for further analysis I will use this geographical zone.

**Evaluation of wind energy potential**

To evaluate the potential of wind energy, I used the Nasa Power Data Access Viewer service.

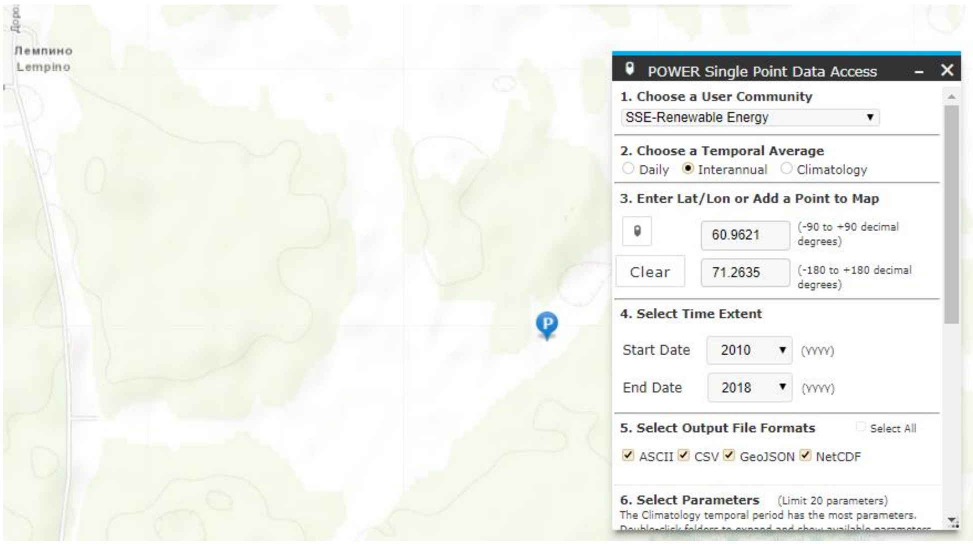


Figure 10- Location of the object on the map of the Nasa Power Data Access Viewer service [39]

This service contains statistical data on wind speeds at a height of 12m. Consequently, the height of the weather vane is 12m. The class of openness of this area can be estimated by the method of Yu.V. Milevsky. The shape of the terrain in this area is concave. Around the bogs and small forests, it can be concluded that the object is among the individual elements of protection, away from the water surface. The class of openness is 6a (7). [40]

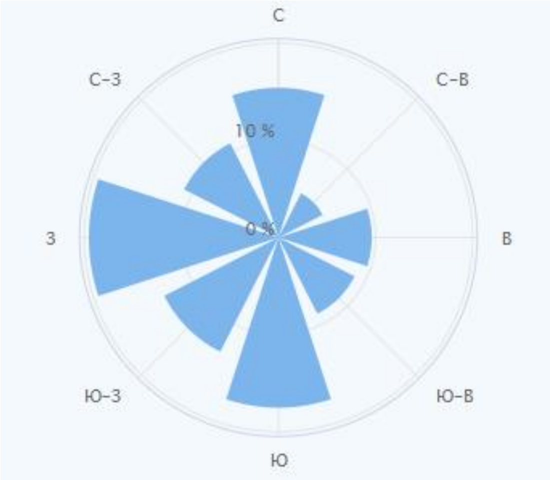


Figure 11- Rose of Wind [41]

As follows from the data on repeatability of wind directions in [41], the West wind prevails in this area. Annex B contains typical statistical data on the processing of long-term wind speed observations of NASA bases. For illustrative purposes, on the basis of data from Annex B, Figure B1, I have drawn the following graphs:

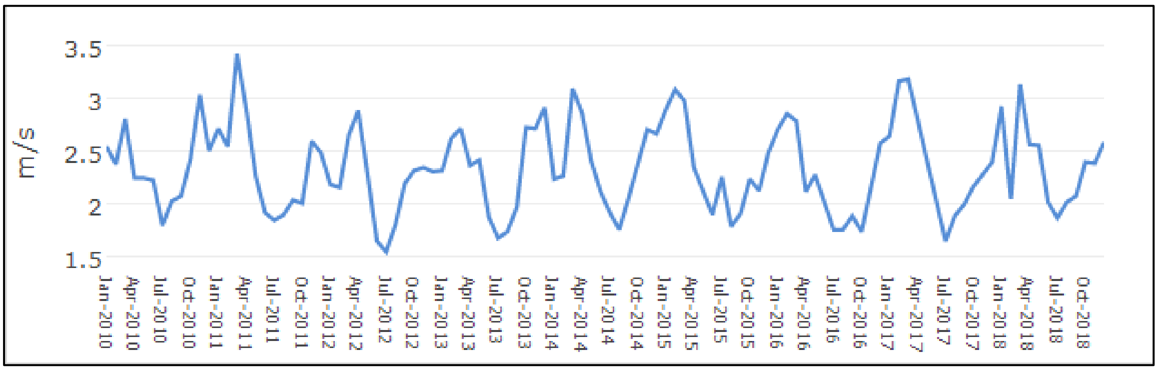


Figure 12 - Monthly average wind speed for 2010 to 2018

From these data, it follows that high wind activity occurs during winter and spring periods. The maximum values of winds for 8 years are observed exactly in this period. And the minimum wind speeds are observed every year in the summer period. For a better understanding it is necessary to assess the dynamics of changes in average daily wind speeds. As the dynamics by years does not change much, the data for 2018 will be enough. Wind speed data for the months January, April, July and October 2018 have also been analysed in Appendix B, Figure B2.  On the basis of these data, I have plotted the change in average daily velocities over the months under review (Figure 13).

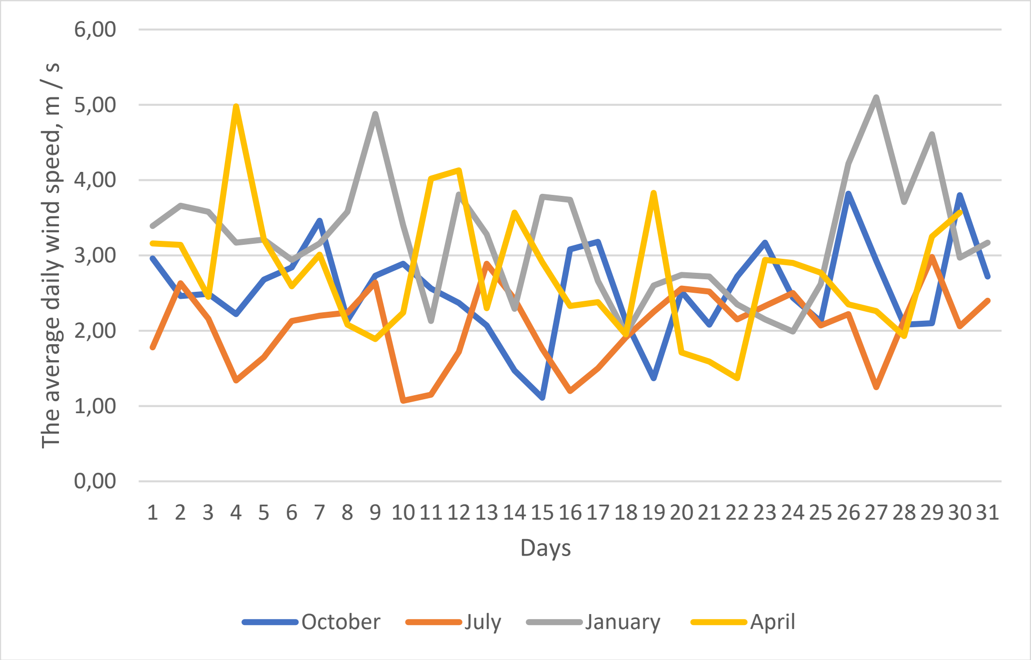


Figure 13 - Dynamics of average daily wind speed change

Figure 13 shows that the minimum values of average daily speeds are observed in July - 1 m/s, and the maximum values in January - 5.1 m/s.

Table 5- Average annual wind speeds from 2010 to 2018 [Appendix B, Figure B1].

| Year | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|---|
| Wind speed m/s | 2,35 | 2,38 | 2,19 | 2,33 | 2,37 | 2,34 | 2,22 | 2,38 |

Table 5 shows average annual wind speeds from 2010 to 2018. The average value for 8 years is 2.618 m/s (Table 5). The following charts (Figure 14) are taken from the Nasa Power Data Access Viewer [39]. They show the number of days at a certain average daily rate per year.

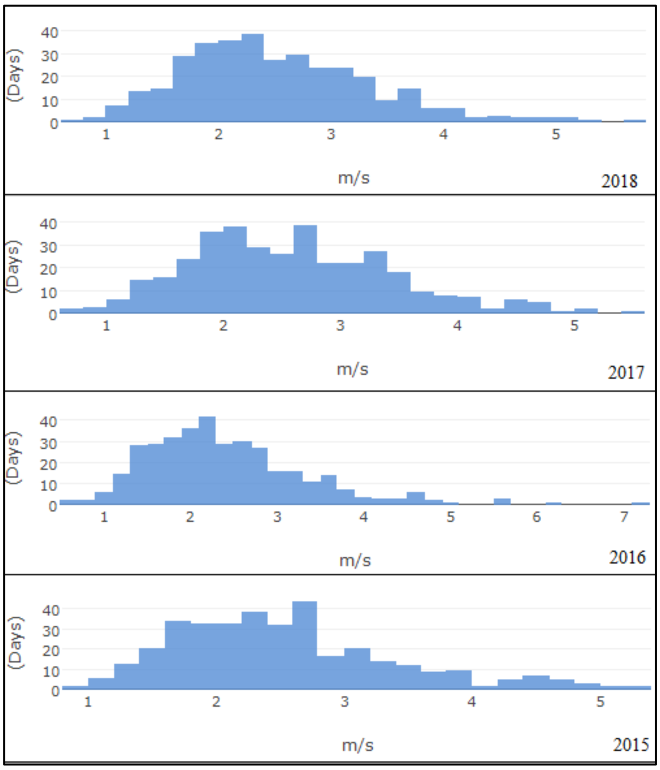


Figure 14- Wind speed repeatability diagrams from 2015 – 2018

Conclusion of evaluation of wind energy potential:

In general, after analysis of the data obtained, it can be concluded that the area has low wind potential. The average annual velocity for 8 years is 2.618 m/s. This may lead to the inexpediency of using wind turbines as part of the energy complex, since this value of wind speed for most wind turbines is close to, equal to or lower than the minimum operating speed of the wind, at which the wind generators begin to produce electricity. But there are wind turbines that are specifically designed to operate at low wind speeds. They can be both horizontal-axial and orthogonal wind generators. Typically, the minimum operating wind speed they have is about 2 m / s. Here it is possible to notice that 261 days in 2018 there was an average daily wind speed more than 2 m/s. In 2017 - 263 days, in 2016 - 252 days, in 2015 - 256 days (Figure 14). These observation data at the vane height of 12 m, if the height of the WPP mast the speed value may be higher, on average 1.2-1.5 times higher, depending on the height. Therefore, WPP is not excluded from consideration as a potential source of energy in a hybrid power plant.

**Evaluation of solar energy potential**

Based on the data presented in Appendix B-Table B1, a graph of the monthly distribution of the annual cumulative solar radiation arrival at the horizontal site over a period of 8 years (from 2010 to 2018) in the vicinity of the site (Figure 15) is constructed.

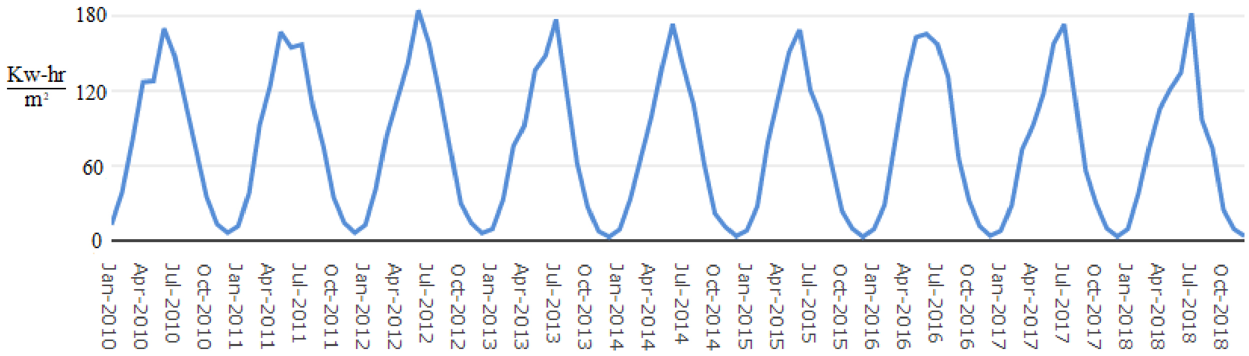


Figure 15 - Monthly distribution of annual solar radiation intake in the period from 2010 to 2018

According to Figure 15, it can be concluded that the greatest solar activity during 8 years is during the summer periods, and the maximums are observed in July.

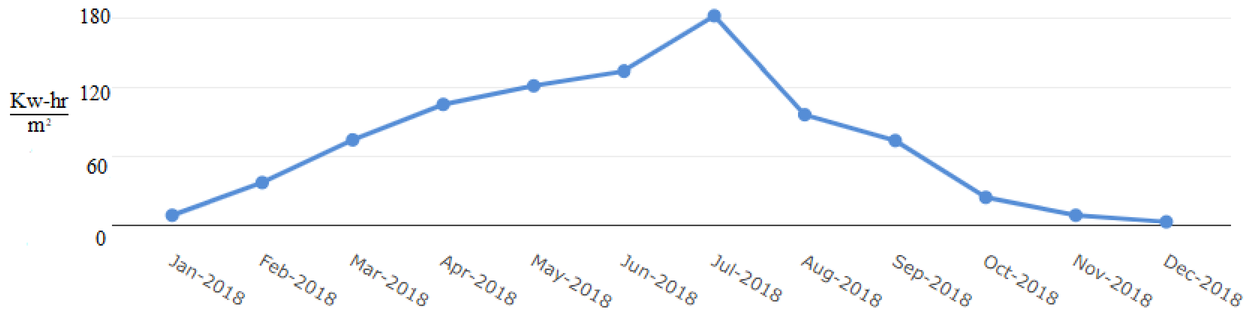


Figure 16- Distribution of annual solar radiation intake for 2018

For the sake of clarity, I have drawn up a monthly distribution schedule for the year 2018. (Figure 16). According to [41], solar electrical installation will be effective if the total annual solar radiation arrival per square meter is more than 1000 kWh.

Table 6 - Aggregate annual solar radiation intake from 2010-2018 [Annex B, Table B1].

| Year | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| Sum | 967,82 | 944,77 | 856,34 | 918,22 | 892,49 | 899,31 | 904,21 | 885,98 | 892,8 |
| Average | 906,88 | | | | | | | | |

Conclusion of evaluation of solar energy potential:

I calculated the total value for each year, then I calculated the average value for 8 years (Table 6). It is 906.88 kWh per square meter. That's less than 1,000 kWh. There is also a significant irregularity of solar energy arrival during the year (Figure 15,16) According to [41], under these conditions, solar energy use is not reasonable. According to my assessment, the use of solar energy is excluded from consideration.

### 2.3 Justification of choice of composition of main equipment

At the stage of pre-project studies under conditions of insufficient or limited initial information for the enlarged (estimated) calculations it is possible to use the average indicators of renewable energy resources arrival intensity (average annual wind speed, (average hour, average monthly and annual data), etc.), for which the average annual values of the generated electricity by each type of power plants are calculated for each type of power plant, and for each type of plant it is possible to use the average annual values of the generated electricity. [8]

In this section, I will make an option to optimize the energy complex on the basis of averages values. It is necessary to estimate variants of wind generators, solar panels and their possible effective use in the considered geographical area, number of power installations for each type of source and level of their capacity. The basic composition of the equipment means the installation of energy sources such as wind turbines, solar panels, storage batteries and diesel units.

Input data: annual average wind speed according to Nasa database $V_{AV}$=2.618 m/s, annual consumption $E^{c}_{year}$=12835.4 kWh/year and maximum load value in the year $P_n$=10.1 kWh/day. To consider possible deviations of calculated load values from their actual values, I accept correction factor $k_n$=1.1.

#### Selection of wind generator

I will choose WT from 11 options, on my assumption, more suitable for work in these conditions. Their technical and economic characteristics are presented in Table C1 of Annex C. These options were selected according to the minimum wind speed, tower height (more than 12m) and wind generator price.

I will use the following formula [42] to calculate the average annual wind speed ($V_{avi}$) reduced to the height of the WT tower:

$$V_{avi}(H_t) = K_{ws} \cdot V_{avi}^{\min} \cdot \frac{K_O}{K_{AO}} \cdot [(\frac{H_t}{h_m})^{0,6\cdot(V_{avi}^{\min})^{-0,77}}] \quad (1)$$

Where $K_{ws}$ - the coefficient of wind speed change, which takes into account the specific terrain; $V_{avi}^{min}$- the lower boundary of the wind speed range at the height of the weather vane of the weather station; $K_O$- class of openness of the terrain by Milevsky; $K_{AO}$- the actual class of openness of the weather station, $H_t$- the height of the tower of the wind generator, $h_m$- the height at which measurements of wind speed were made.

The actual openness class is determined by the formula [43]:

$$K_O = \sum_{j=1}^{8} K_{Oj} \cdot \tau_j \quad (2)$$

Where $K_{Oj}$ - the openness class of the j-th rumba, $\tau_j$ - repeatability of the wind direction of the j-th rumba

Let's start with the $K_O$ definition. As can be seen from formula (2) it is defined as weighted average, considering the local rose of winds, which is shown in Figure 11. Under rumba we mean directions of parts of the world, there are eight of them (from North to Northwest), the order is calculated in a clockwise direction, starting from the North.

$$K_O = \sum_{j=1}^{8} K_{Oj} \cdot \tau_j = 7\cdot 0{,}15 + 7\cdot 0{,}11 + 7\cdot 0{,}2 + 7\cdot 0{,}12 + 7\cdot 0{,}18 + 6\cdot 0{,}08 + 6\cdot 0{,}1 + 6\cdot 0{,}05 = 6{,}7 \quad (3)$$

The coefficient of wind speed change, considering the terrain specificity, is adopted equal to $K_{ws}$=1. Example of calculation for BCC Excel 10. The height of the tower of this model will be 49 meters. Wind speed according to formula (1):

$$V_{avi}(H_t) = K_{ws} \cdot V_{avi}^{\min} \cdot \frac{K_O}{K_{AO}} \cdot [(\frac{H_t}{h_m})^{0,6\cdot(V_{avi}^{\min})^{-0,77}}] = 1\cdot 2{,}618 \cdot \frac{7}{6{,}7} \cdot [(\frac{49}{10})^{0,6\cdot(2,618)^{-0,77}}] = 4{,}3(m/s) \quad (4)$$

Power of the wind generator at the average annual speed reduced to the height of the tower is determined by the passport dependence of power on wind speed. Figure 17 shows a similar dependence for Wind generator BVC Excel 10.

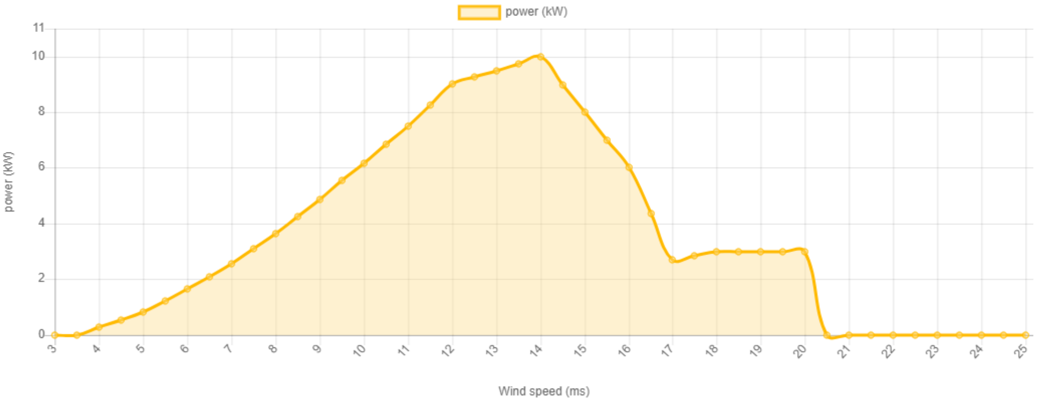


Figure 17 - Power dependence of wind power plant BVC Excel 10 [44]

Figure 17 shows that at wind speed $V_{пр}(H_{вк}) = 4{,}3\ m/s$ corresponds to the WG power is $P_{WG} = 410\ W$. Then, using the formula (5), you need to determine the amount of WT needed to cover the average annual load:

$$n_i^{max} = \left[ к_n \cdot \frac{E_{year}^{c}}{E_{iyear}} \right] \quad (5)$$

Where $к_n = 1{,}05 \ldots 1{,}15$ is a constant coefficient that considers possible deviations of calculated values from their actual values, because electricity consumption during the year may be significantly uneven, $E_{year}^{c}$ - annual consumption of electricity by consumers of the object, $E_{iyear}$ - annual production of electricity by the source converting renewable resource.

Calculation of WG type BWC Excel 10:

$$\mathrm{n}_{\mathrm{WG}}^{\max} = \left[\kappa_{\mathrm{n}} \cdot \frac{\mathrm{E}_{\mathrm{year}}^{\mathrm{c}}}{\mathrm{E}_{\mathrm{WGyear}}}\right] = \left[1{,}11 \cdot \frac{14419400}{410 \cdot 8760}\right] = 4 \text{ (6)}$$

For the resulting number of wind generators as part of a wind power plant, the capacity and electricity production of the wind power plant during the year at an average annual wind speed reduced to the height of the tower is determined:

$$P_{WPP} = P_{WG} \cdot n_{WG}^{MAX} = 410 \cdot 4 = 1640\ W \text{ (7)}$$

$$E_{WPPyear} = P_{WPP} \cdot T_{year} = 1640 \cdot 8760 = 14366{,}4\ kWh/year \text{ (8)}$$

WPP output at nominal power (at nominal wind speed) is equal, respectively:

$$E_{WPPyear}^{nom} = P_{WPP}^{nom} \cdot T_{year} = P_{WG}^{nom} \cdot T_{year} \cdot n_{WG}^{max} = 10 \cdot 8760 \cdot 4 = 350400\ kWh/year \text{ (9)}$$

The utilization factor of the installed power of the wind turbine generator is calculated by the formula:

$$ICUF_{WG} = \frac{E_{WPPyear}}{E_{WPPyear}^{nom}} = \frac{14366{,}4}{350400} = 0{,}041 = 4{,}1\% \text{ (10)}$$

Similar calculations are performed for all other wind turbine models. All 11 options are calculated. The results of the ICUF calculation are given in Table C2 of Appendix C.

As follows from the calculation results, the maximum ICUF was obtained from the SW-2.5 KW wind generator, which is 11.2%.

**Selection traditional source and batteries**

As a traditional source, I consider diesel generator. In the calculations based on averaged indicators, the power of a traditional source is selected from the maximum load, given the normal load on a diesel generator of 70%:

$$P_{DG} = \frac{[P_n^{max}]}{70} \cdot 100 = \frac{10{,}1}{70} \cdot 100 = 14{,}43 \text{ kW (11)}$$

I choose a DG for the minimum specific annual fuel consumption. The choice is to compare the passport data, namely the comparison of the specific fuel consumption of the DG in question, which have the same power, the main selection criterion is the minimum fuel consumption. At the same time, the mode of operation of the DG is assumed — inclusion when the power of renewable sources is not enough to cover the load and the batteries are discharged, at this moment the diesel engine starts to operate in nominal mode, part of the power will go to cover the load, and the other part will go to charge battery pack. In other cases, the diesel generator runs. It must be considered that the charge current of the battery coming from the diesel engine must correspond to the permissible charge current of the battery. As a result, it is assumed that the DG always runs at rated power, the specific annual effective fuel consumption will be equal to the passport.

I have chosen for consideration DG GENBOX KBT15M-3000. Technical specifications are given in Appendix D, Table D1.

As part of the traditional power supply system (without the use of power plants based on RES) BP have the function of an emergency power supply for the power supply of critical consumers - SG-1, in case of voltage loss from the main and backup power supplies. At the same time, the BP capacity should provide power supply to the load of SG-1 consumers after power failure from the main and backup power sources for the necessary recovery time of the main power source, taking into account the remoteness of the object, transport accessibility, temperature drop and the associated decline in the BP capacity [5].

In case of using BP as part of a standalone PSP with RES, BP functions change. Here BP acts as a buffer store of energy, unevenly supplied by RES, due to which it is possible to more effectively redistribute the energy received from RES in time and smooth out load peaks. The capacity of BP in this case should be optimized so that the energy from RES is used as efficiently as possible, that is, the dissipation of excess energy from RES is minimal, and the traditional power supply is switched on as rarely as possible. At the same time, the cost of BP must also be optimized. Therefore, energy storage is one of the key issues when using RES.

The basis for the selection is the average annual load, the backup time, according to the statement of work 32 hours. Allowed to consider batteries of the brand VOLTA GEL 12-200.

$$Q_{BP}^{nom} = \frac{\frac{k_n \cdot E_{year}^{c}}{T_{year}} \cdot t_{backup}}{U_{BP}^{nom} \cdot k_{AB}} = \frac{\frac{1,1 \cdot 12835,4 \cdot 1000}{8760} \cdot 32}{12 \cdot 0,8} = 5372,5\ A \cdot h \quad (20)$$

Losses in inverters are not included in the calculation based on the average values. For the calculated capacitance, the nominal capacitance and the number of parallel connected elements are selected. Gel battery manufactured by VOLTA with nominal capacity of 200 Ah, voltage 12 V.

The maximum number of batteries in BP is determined by the formula:

$$n_{AB} = \frac{Q_{BB}^{nom}}{Q_{AB}^{nom}} = \frac{5372,5}{200} = 28 \quad (23)$$

I have chosen for consideration VOLTA GEL 12-200. Technical specifications are given in Appendix D, Table D2.

## 2.4 Hybrid Power Plant Configuration Options

So, after the above calculations and analyses, the main equipment of a hybrid power plant may include: wind generators, a diesel power plant and storage batteries. The object under consideration is characterized as a consumer of the special first group, it needs three independent power sources. If not used as part of a WG, a second diesel power plant can be used as an additional power source. The option without a battery is not possible due to the fact that the power supply should not be interrupted for a single second. In the event of an emergency power switch to the battery, time is displayed for switching to a third emergency power source, e.g. a second diesel power station.

Table 7 - Hybrid power plant main equipment configuration options

| | WG, unit | DG, unit | BP, unit |
|---|---|---|---|
| Configuration A | n | 1 or 2 | 1 |
| Configuration B | 0 | 2 | 1 |

Where n is a variable of the number of wind turbines. They can take values n= [0...6], where 6 is a value for complete coverage of average annual load by wind turbines [Appendix C, Table C2]. It is necessary to determine their optimal values to minimize the diesel power plant operation. In other words, it is necessary to draw up and solve the optimization task, for this purpose it is necessary to determine the selection criteria. In this problem, there are nonlinear dependencies of mathematical models of plants based on renewable energy sources, as well as random values in the initial information (energy supply from renewable sources in time).

### Calculation of values of electric power generation by wind generators on the basis of the detailed information on receipt of resources in the considered area

Wind energy potential was estimated on the basis of annual average figures. For calculations of electricity generation by wind generators it will be necessary to plot the distribution of wind speeds during the year, for this I will use the data taken from [49]. Values of average daily wind speed are not enough, because wind energy is characterized by speed, which is a random variable in space and time. To calculate electricity generation from wind turbines, it is necessary to know how many hours per month and a specific speed value was observed per year. For this purpose, the data set, which can be taken from [49], contains measurements of speeds during several years, measurements are made every 30 minutes at a weather station of the area under consideration [Appendix E, Figure E1]. For data analysis I will use the excel software package. Because the data volume is very large, I will only show a small part of it in Figures E1-E2 to show the logic of my actions.

Figure E2 shows thirty-minute average wind speeds averaged over 5 years. Actually, I analyzed this data set according to the method presented in [50]. With the help of Excel program complex the number of repetitions of certain wind velocity gradations in each month starting from 2,5 m/s was calculated, because this is the minimum value for the considered wind generator, the maximum fixed value for all months is 5,5 m/s. The results are presented in Table E1.

Then, on the basis of these results, the probabilities of wind velocity gradation during the considered period of time according to the formula 24 were calculated:

$$F_{vi} = \frac{n_i}{N} \cdot 100\% \quad (24)$$

Where $F_{vi}$ - the probability of gradation of wind speed $Vi$ during the considered period of time (month); $n_i$ - the fixed number of measurements of i-th wind gradation; $N$ - the total number of measurements. The results are presented in Table E2.

These data were then recalculated into the number of hours per month, year (Table E3) and plots of the distribution of wind speeds during the month and year were drawn.

For illustrative purposes, I will present the graph of distribution during the year (Figure 18).

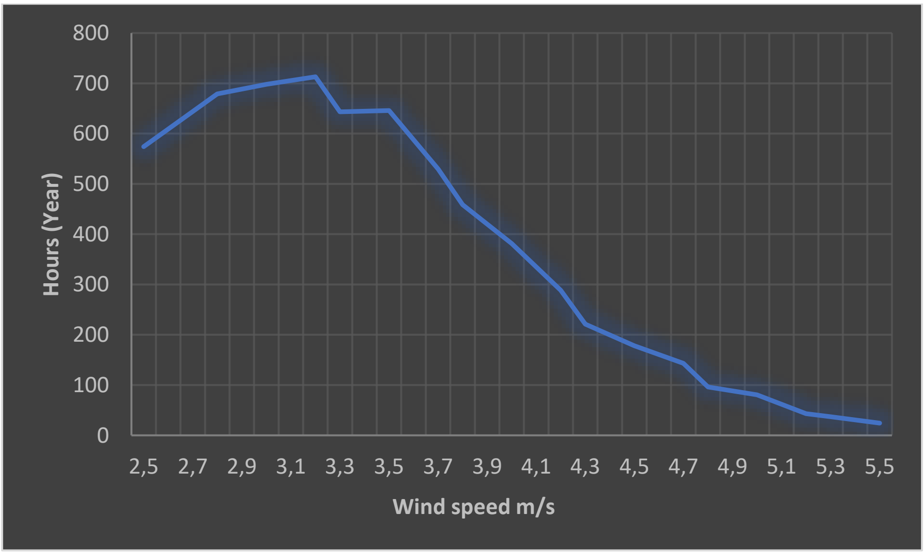


Figure 18 - Repeatability graph of different wind speeds in hours for an average year

So, further, on the basis of these data it is necessary to calculate how much one wind turbine generator SW-2.5 KW, which was selected in the previous paragraph 2.3, will produce per month for detailed calculation of consumption coverage. For this purpose, its capacity characteristic is necessary. It is shown in Figure 19.

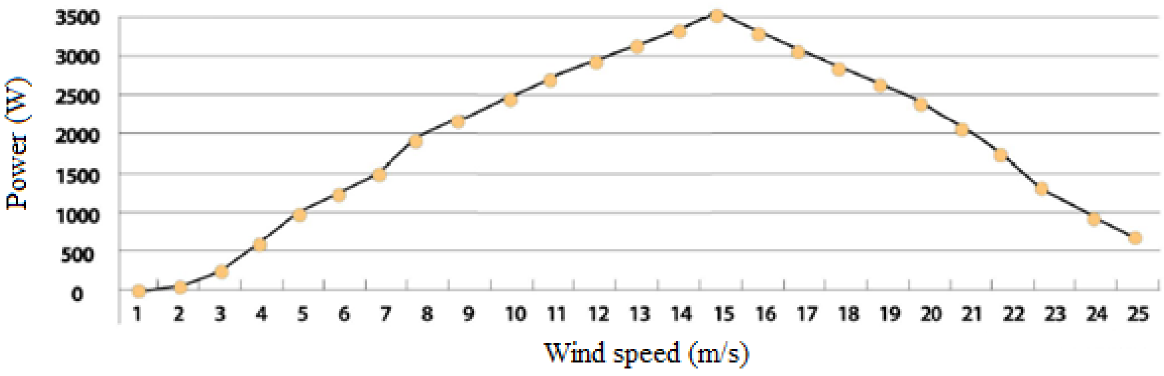


Figure 19 - Power characteristic of the SW-2,5 KW wind generator depending on the wind speed [51]

Based on the dependence (Figure 19) and the duration of the wind gradations per in hours per month, corresponding to the wind gradations (Table E3), I will calculate the monthly electricity generation, I will use the following formula (25):

$$W_{WG} = \sum_{i=2,5}^{5,5} (T_i \cdot P_i) \quad (25)$$

The calculation results are shown in table 8.

Table 8 - Values of monthly electricity production by one wind generator

| Month | Electric power, kWh |
|---|---|
| January | 294,15 |
| February | 242,74 |
| March | 538,86 |
| April | 445,08 |
| May | 378,38 |
| June | 296,07 |
| July | 195,04 |
| August | 193,30 |
| September | 211,49 |
| October | 339,35 |
| November | 276,44 |
| December | 306,96 |

Now, I have data on the generation of electricity by wind generators, and I can calculate the load coverage.

## Calculation energy balances

Choices of the structure of construction and equipment of a hybrid wind-diesel power station can be worked out on the basis of the energy balance of an autonomous power supply system. The ratio of wind and diesel generation to cover the electrical loads of the power supply object is determined by the installed capacity of the wind generators, wind energy potential and average power consumption in the considered time interval. It is obvious that with an increase in the installed capacity of a wind power plant, the share of wind generation increases and the fuel and engine life of diesel generators are saved. However, at the same time, capital costs for wind power equipment increase, which is not always economically feasible in comparison with a diesel power station. Thus, the economic criterion for a rational ratio of costs for wind and diesel generation implies at least limiting the cost of the wind part of a hybrid power plant to the level of achieved savings on the operation of the diesel part.

So, after the optimization stage in comparison with the ICUF of different wind generators, for configuration A, it is possible to install from 1 to 6 SW wind generators - 2.5 kW, at this stage it is difficult to say what amount will be optimal, it is necessary to take into account economic factors, therefore, all further analysis is allowed 6 configuration options A.

To begin with, I will calculate how much of the consumption will be covered by electricity generated from a different number of wind generators.

Table 9 – Electriciy, produced by wind generators SW-2,5 KW

| Month | January | February | March | April | May | June | July | August | September | October | November | December |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Consumption kWh | 1584,00 | 1443,30 | 1248,70 | 1034,20 | 993,40 | 987,50 | 1020,30 | 1064,10 | 1150,30 | 1270,40 | 1239,00 | 1384,20 |
| 1 generator produces per 1 month, kWh | 294,15 | 242,74 | 538,86 | 445,08 | 378,38 | 296,07 | 195,04 | 193,30 | 211,49 | 339,35 | 276,44 | 306,96 |
| Load graph coverage (1 generator), % | 18,57 | 16,82 | 43,15 | 43,04 | 38,09 | 29,98 | 19,12 | 18,17 | 18,39 | 26,71 | 22,31 | 22,18 |
| Load graph coverage (2 generators), % | 37,14 | 33,64 | 86,31 | 86,07 | 76,18 | 59,96 | 38,23 | 36,33 | 36,77 | 53,42 | 44,62 | 44,35 |
| Load graph coverage (3 generators), % | 55,71 | 50,45 | 129,46 | 129,11 | 114,27 | 89,95 | 57,35 | 54,50 | 55,16 | 80,14 | 66,94 | 66,53 |
| Load graph coverage (4 generators), % | 74,28 | 67,27 | 172,62 | 172,15 | 152,36 | 119,93 | 76,46 | 72,66 | 73,54 | 106,85 | 89,25 | 88,71 |
| Load graph coverage (5 generators), % | 92,85 | 84,09 | 215,77 | 215,18 | 190,45 | 149,91 | 95,58 | 90,83 | 91,93 | 133,56 | 111,56 | 110,88 |
| Load graph coverage (6 generators), % | 111,42 | 100,91 | 258,92 | 258,22 | 228,54 | 179,89 | 114,70 | 108,99 | 110,31 | 160,27 | 133,87 | 133,06 |

As can be seen from table 9, some options require the installation of higher capacities, for example, for 6 variants of wind generators, however, in this option, the complete replacement of the diesel power plant.

## Calculatuin of diesel fuel consumption

In both configurations, whether or not wind generators are installed independently, two independent diesel generators will be used, both are designed to cover the load on their own, this decision was made according to the consumer category, which requires one - a constant power source and two backup ones. In my case, the third battery pack is 36 hours of battery life, which allows you to switch diesel generators between each other or reserve power while the repair team arrives, and in configuration A, the batteries allow you to more efficiently distribute energy from wind generators.

For the installation, from the above calculations, two diesel generator sets of the GENBOX KBT15M-3000 model with nominal fuel consumption of 0.31 l / kWh were taken for further economic analysis, it is necessary to calculate how much diesel fuel is needed for each configuration per year. For further economic analysis, it is necessary to calculate how much diesel fuel is needed for each configuration per year. Except for rated fuel consumption there is real fuel consumption which depends on load and can be calculated with the following formula [41]:

$$G_{real} = k_{nl}G_n + (1-k_{nl})G_n \frac{P_1}{P_n} \quad (26)$$

Where $G_{real}$ – real fuel consumption; $G_n$ – nominal fuel consumption; $k_{nl}$ – no load fuel consumption coefficient ($k_{nl}$=0,3); $P_1$ – load on the generator; $P_n$ – nominal power of the generator ($P_n$=14,9 kW)

Results for real fuel consumption (50%, 75%, 100% load) in table D1. We know rated fuel consumption for respective load mode and volume of generated energy, we can calculate volume of consumed fuel for the period of time with following formula [41]:

$$Q_f = G_1 W \quad (27)$$

Where W- generated in day, month or year

Table 10 – Fuel consumption

| Variant of wind intallation composition | Configuration A | | | | | | Configuration B |
|---|---|---|---|---|---|---|---|
| | 1 WG | 2 WG | 3 WG | 4 WG | 5 WG | 6 WG | |
| Fuel consumption, t/year | 3,32 | 2,16 | 1,26 | 0,62 | 0,18 | 0 | 4,47 |

## Composition of configurations

Choices of the structure of construction and equipment of a hybrid wind-diesel power station can be worked out on the basis of the energy balance of an autonomous power supply system. The ratio of wind and diesel generation to cover the electrical loads of an object is determined by the installed capacity of wind generators, wind energy potential and average power consumption in the considered time interval, the category of consumer electricity supply.

Table 11 – Production electricity by wind generatorors

| Number of generators | Production by Wind generators (kWh) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | January | February | March | April | May | June | July | August | September | October | November | December | Year | % |
| 1 | 294,15 | 242,74 | 538,86 | 445,08 | 378,38 | 296,07 | 195,04 | 193,30 | 211,49 | 339,35 | 276,44 | 306,96 | 3717,88 | 25,78 |
| 2 | 588,31 | 485,47 | 1077,72 | 890,17 | 756,77 | 592,15 | 390,08 | 386,60 | 422,97 | 678,71 | 552,88 | 613,93 | 7435,76 | 51,57 |
| 3 | 882,46 | 728,21 | 1616,59 | 1335,25 | 1135,15 | 888,22 | 585,12 | 579,90 | 634,46 | 1018,06 | 829,33 | 920,89 | 11153,64 | 77,35 |
| 4 | 1176,61 | 970,94 | 2155,45 | 1780,33 | 1513,54 | 1184,30 | 780,16 | 773,20 | 845,94 | 1357,41 | 1105,77 | 1227,86 | 14871,51 | 103,14 |
| 5 | 1470,77 | 1213,68 | 2694,31 | 2225,42 | 1891,92 | 1480,37 | 975,21 | 966,50 | 1057,43 | 1696,76 | 1382,21 | 1534,82 | 18589,39 | 128,92 |
| 6 | 1764,92 | 1456,42 | 3233,17 | 2670,50 | 2270,31 | 1776,45 | 1170,25 | 1159,79 | 1268,91 | 2036,12 | 1658,65 | 1841,79 | 22307,27 | 154,70 |
| Consumption | 1584,00 | 1443,30 | 1248,70 | 1034,20 | 993,40 | 987,50 | 1020,30 | 1064,10 | 1150,30 | 1270,40 | 1239,00 | 1384,20 | 14419,40 | |

Table 11 presents the production of electricity by wind generators by month, year and percentage of production from annual consumption. This data is enough to determine what type of structure will be for a particular configuration.Variants of the structure for constructing a wind-diesel energy complex of autonomous power supply of the object in question will be carried out according to two structures.

### Structure 1

When using from 1 to 3 wind generators, the annual load coverage is less than 80% (table 11). In these cases, most of the electricity needs to be received from a diesel generator. The principle of constructing this structure is the possibility of obtaining additional electricity from wind turbines to reduce diesel costs and save resources, the main source is a diesel generator. To do this, the diesel generator must have an automatic start-up system that responds to changes in power consumption. In transient conditions, the generation, as well as coverage of peak power, occurs due to the operation of Multi-Brand 5 kW (48V) power modules and a battery. The Multi-Brand Power Module is an uninterruptible power supply with various functionalities. The battery performs buffer functions. Multi-Brand modules are installed in a special power cabinet. With a lack of generating capacity of wind turbines, the power module starts the diesel generator, with an increase in generating power of wind turbines, the diesel generator is turned off. ATS switches the network of wind turbines and diesel generator. During the operation of the diesel generator, the batteries are recharged. Also, according to the category of power supply, it is necessary to install an additional standby diesel generator set and ATS units.

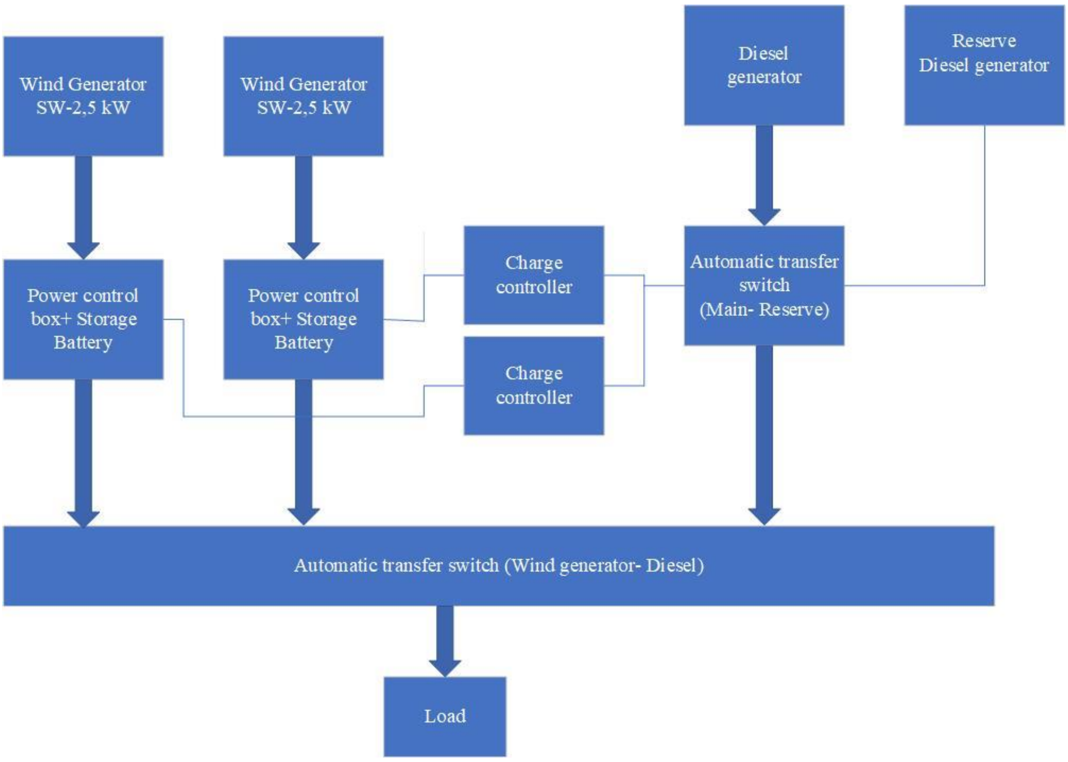


Figure 20 – Structure 1

It should be noted that the type SW wind generator uses an asynchronous generator with a phase rotor with adjustable excitation, which ensures stabilization of the output stator voltage. Power control box with uninterruptible power supply provides power to loads from wind generators through a rectifier-inverter converter with the accumulation of excess electricity in batteries. During periods of calm, the power supply of the loads is transferred to the rechargeable batteries, during the discharge of which the diesel generator is turned on and consumers of electricity are transferred to it. A diesel generator provides rechargeable batteries through charge controllers. Installation of additional ballast loads is not required.

This type of structure will be used for configuration A with one, two and three wind generators.

**Structure 2**

When using from 4 to 6 wind generators, the annual load coverage is more than 100% (table 11). A rational solution for this option is with a system with energy storage and minimal participation of diesel generators in operation. Batteries operate in a buffer mode, smoothing out fluctuations in wind and loads and ensuring continuity of power supply when switching loads to diesel generators. In this structure, a second diesel generator is not required, since wind generators almost completely replace the work of the main one.

In fact, the inverter performs the control functions with the following features::

- Conversion of direct voltage to alternating 220V, 50 Hz
- Charge gel batteries
- The ability to synchronize with the electric generator, which allows you to summarize the energy from the diesel generator and wind generators through batteries with priority from renewable

energy sources

- Automatic instant switching from batteries to wind generators and vice versa
- Automatic shutdown during overloading, overheating, battery protection from unacceptable discharge and other protections
- Switching to additional ballast load

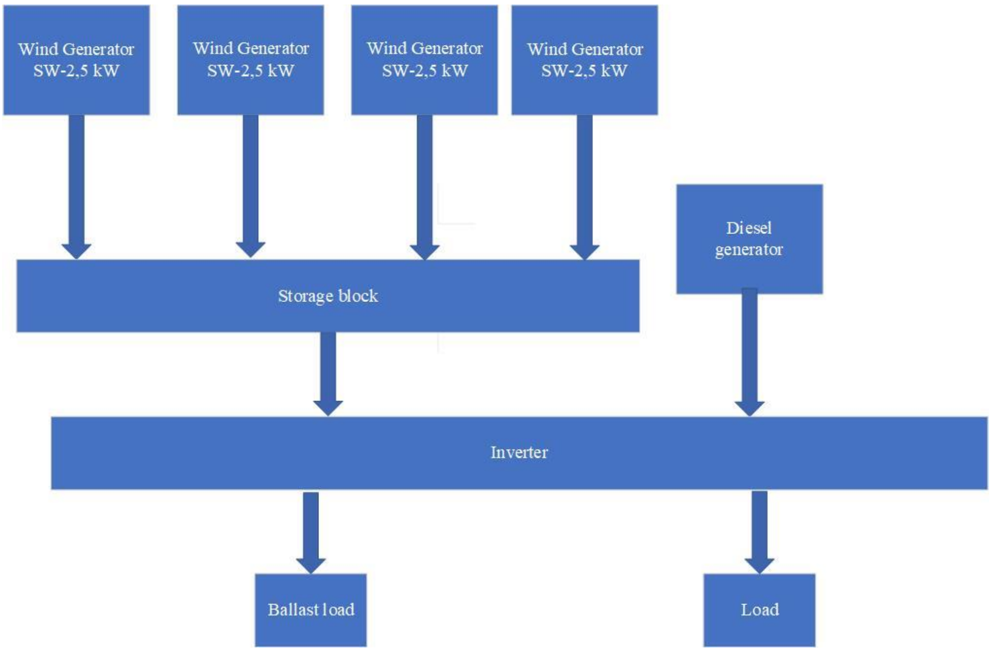


Figure 21 – Structure 2

**Structure 3**

Structure 3 is intended for configuration B, in which wind generators are not used, and the power supply is provided only from the diesel generator and reserve sources, according to the category of power supply of the facility. In this case, the diesel generator runs all the time, the batteries act as a backup power source in the event of a breakdown of the first diesel generator and the backup one, provide a backup time of 36 hours, according to the power supply category of the facility, for the arrival time of the revision staff.

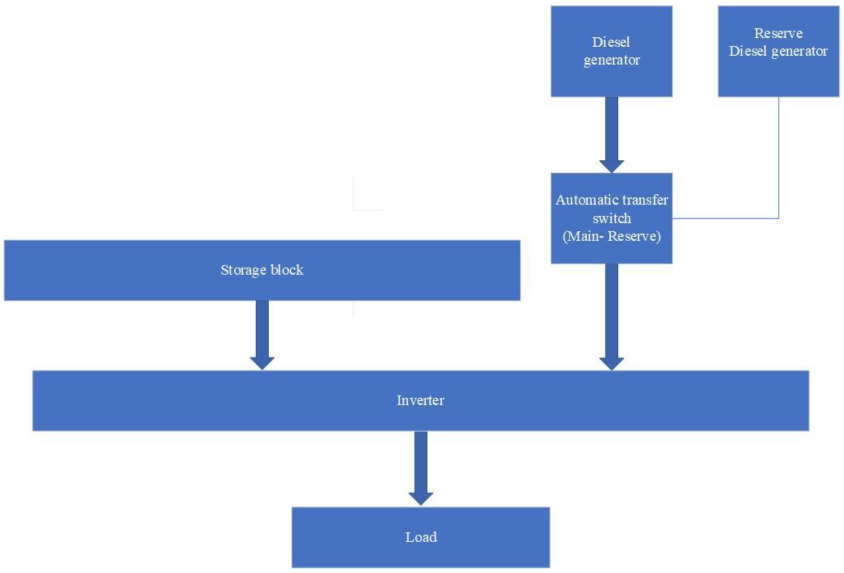

Figure 22 – Structure 3

The list of equipment for all configurations is presented in Appendix F.

## 2.5 Conclusion from chapter two

The technical part of the project is completed. Table 12 shows the total investment for each configuration.

Table 12 – Total configurations

| Configuration | Total investment, with VAT (RUB) |
|---|---|
| Configuration A, 1 wind generator, structure 1 | 1 811 800 |
| Configuration A, 2 wind generators, structure 1 | 2 140 400 |
| Configuration A, 3 wind generators, structure 1 | 2 496 000 |
| Configuration A, 4 wind generators, structure 2 | 2 328 400 |
| Configuration A, 5 wind generators, structure 2 | 2 612 000 |
| Configuration A, 6 wind generators, structure 2 | 2 905 600 |
| Configuration B, without wind generators, structure 3 | 1 454 000 |

As a result, for further economic analysis, I will consider 7 options for configuration A and Configuration B with different structures of electrical circuits and equipment.

## 3. Economic analysis

The step after designing a hybrid power plant is its economic assessment. In this chapter I will evaluate the volume of investments in the construction of configurations, costs and revenues. Then, based on this data, I will calculate the net present value and evaluate whether the projects is profitable or not.

Well-known fact, solving problems in the construction, power supply and maintenance of facilities, large companies trust contractors, Rosneft is no exception.

In this case of study, I am faced with the task of economic comparison of five options for power supply of autonomous object. Each of the options considered has its advantages and disadvantages from a technical point of view. Therefore, I am going to carry out the calculations of the necessary economic indicators of each option, and also see how various input parameters and secondary indicators can affect the final result. Another feature of this case is that I am going to consider these options from investor of view. In this case, from investor point of view, this means that investor takes all the costs for this project and, taking into account all tax fees, should ultimately get as minimum NPV = 0.

It is necessary to discuss economical assumption:

- The contractor acts as an investor
- The contractor provides a ready-made solution to the company. Also, the contractor takes care of maintenance, repair, fuel delivery, etc. The customer will need to make only an annual payment, which will be put out by the investor
- Initial investment - own funds of contractor
- The minimum price is the price set by the investor to the company at which the project NPV=0
- The contract is for 20 years
- No fixed unit price for electricity. It is not known at what price the company will agree. Comparison of projects I will produce at a price for a typical diesel configuration for such autonomous objects (Configuration B)

### 3.1 Methodology of economic evaluation

To implement the project, it is necessary to evaluate the volume of investments, estimated costs and revenues, as well as analyze the project with the main economic criteria. Here is a list of key economic criteria:

- Net Present Value;
- Profitability Index;
- Internal Rate of Return;
- EAA

Below I will describe what the criteria mean and methodology of calulation.

**Net Present Value**

$$NPV = \sum_{t=1}^{T} \frac{CF_t}{(1+r)^t} - INV \quad (28)$$

Where

$CF_t$ – cash flow in the period t;

$r$ - discount rate;

INV – initial investment in the project;

t – number of time periods;

T – lifetime of the project;

NPV shows the difference between the present value of cash inflows and the present value of cash outflows. However, there is no cash flow in the current project, so the NPV for each possible measure will be calculated on the basis of electricity charges, taking into account the annual increase in tariffs, inflation and project life expectancy. Since NPV calculation is based solely on costs, then NPV for all measures considered will be negative, and a higher NPV would be a more desirable option. [49]

**Profitability Index**

Profitability index shows relation between Net Present Value and investment. Formula for profitability index is presented below [49]:

$$Profitability\ index = \frac{NPV}{INV} + 1 \quad (29)$$

Where

NPV – Net Present Value;

INV – initital investment in the project

Project is considered as successful if the profitability index is greater than one. This follows from:

$$\frac{NPV}{INV} + 1 = \frac{1}{INV} \sum_{1}^{t} \left(\frac{CF_t}{(1+r)^t}\right) - \frac{INV}{INV} + 1 = \frac{1}{INV} \sum_{1}^{t} \left(\frac{CF_t}{(1+r)^t}\right) \quad (30)$$

### 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. Actually, IRR is a discount rate, when NPV of the project is equal to zero. IRR may be calculated with following formula [49]:

$$\sum_{1}^{T}\frac{CF_t}{(1+r)^t}-INV=0 \quad (31)$$

Where

$CF_t$ – cash flow in the period t;

INV – initial investemnt in th project;

T – lifetime of the project;

r – Internal Rate of Return (discount)

The greater IRR the better.

## 3.2 Economic parameters

For a projects, it is necessary to know the various economic parameters for the country in which the project is to be realized. In my case, this is Russia. Therefore, the task for the next chapter will be to find the level of inflation and the tax rate in Russia, as well as to calculate the discount rate.

### Inflation

Inflation shows average increasing of prices on products in the country during the year. To estimate inflation of the next years it is necessary to analyze inflation for last  years. The data is presented in Table 13.

Table 13 – Inflation in Russia [50]

| Year | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|
| Inflation, % | 7,78 | 5,1 | 5,53 | 5,45 | 10,1 | 11,1 | 4,38 | 2,42 | 4,27 | 3,05 |
| Average inflation, % | 5,98 | | | | | | | | | |

Accoring table 13, I ploted the graph:

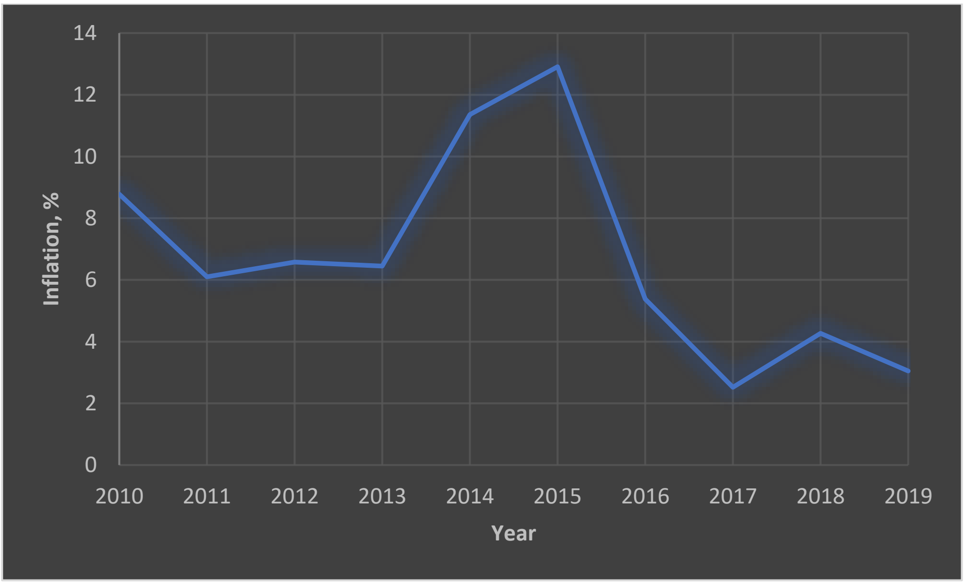


Figure 23 – Infaltion in Russian Federation

**Discount rate**

It is necessary to calculate discount rate to evaluate risk of the project. To calculate discount rate I used Capital Assets Pricing Model:

$$ER_i = R_f + \beta \cdot (MRP - R_f) \quad (32)$$

Where [51]: $R_f$ – risk-free rate, equal to federal bonds rate in Russia (5,5%); $\beta$ - stock volatility of the company (0,63), in Russian sector of power generation it is; MRP – market risk premium in Russia (7,5%)

$$ER_i = 5,5\% + 0,63 \cdot (7,5 - 5,5) = 8,65\% \quad (33)$$

**Escalation rate**

Costs of goods every year increase or escalate. Average escalation can be taken according to inflation. In this case escalation is equal to 5.98%.

**Taxes**

According to the tax law of Russia, corporate tax rate is equal to 20% [51]

**Depreciation**

In Russia depreciation may be calculated in accumulated depressiasion method. According to Russian laws, the firm has a right to select the method for calculation of depreciation [51].

Accelerated depressiasion. This type of depreciation can be calculated according to the following formulas [49]:

For first year:

$$Depreciation = \frac{INV}{T} \quad (34)$$

For other years:

$$Depreciation = INV \cdot \frac{2 \cdot (T - t + 1)}{T^2} \quad (35)$$

## 3.3 Inputs for economical model

**Investment**

According to Table 12 the projects need to several value to invest. I need to install the equipment in which I invest. Cost of installation is equal to 20% of the equipment price [41]. So, it will be in table 14.

Lifetime of the project is 20 years but lifetime of the batteries is 10 years. Therefore, in the end of 10th year it is necessary to buy new batteries. And the same situation with diesel generators with lifetime of 40 000 working hours, it must be borne in mind that in each configuration a different number of hours of operation of a diesel generator. I need to take into account in economic calculations. This values should be discounted according periods.

After 20 years, some equipment will have a residual value for the remaining time until the end of the project. Therefore, at the end of the project, I can sell this equipment at the price of their residual value. This revenue will be accounted in the cash flow of 20th year.

**Costs**

**Fuel cost**

Hybrid power plant with wind turbines produces different amounts of electricity from wind turbines depending on the configuration, and the rest of the load is covered by a diesel generator.

These volumes will be covered by a diesel generator, and this will require a different amount of fuel per year. (Table 10).

The nearest fuel base to the facility is Antipinsky Oil Refinery. They carry out bulk delivery by tanks. At least one ton. The distance from the fuel base to the facility is approximately 500 km. Price for one ton of diesel fuel is 45500 RUB. Also it is necessary to pay for shipping. We can use service of Trader-Oil company and its price is 20 000 RUB for shipping of one ton of fuel. This fuel delivery option is suitable for configurations A (1,2,3 WG) and B [52]. For example, annual cost of configuration B for fuel is:

$$Fuel\cos t = 4,47 \cdot (45500 + 20000) = 270435\, RUB \quad (36)$$

For other options, small wholesale will be purchased at a price of 53000 rubles per ton and delivery of 25000 rubles [52]. For example, annual cost of configuration A (4,5,6 WG) for fuel is:

$$Fuel\cos t = (0,62 + 0,1) \cdot (53000 + 25000) = 56160 \quad (37)$$

It is also necessary to take into account for configuration with wind generators an additional 100 liters of diesel fuel for emergency situations, which will be consumed in cases of breakdown of wind generators.

**Maintenance cost**

The equipment should be serviced. Maintenance prices for wind and diesel generators have already been calculated. (Appendix E). Gel batteries do not require maintenance and work throughout their entire service life. The rest of the equipment does not require significant maintenance, I do not take it into account.

Table 14 – Total configurations with investment and costs.

| Configuration | Initial investment, with VAT (RUB) | Costs, with VAT (RUB) |
|---|---|---|
| Configuration A, 1 wind generator, structure 1 | 1 811 800 | 242 460 |
| Configuration A, 2 wind generator, structure 1 | 2 140 400 | 176 480 |
| Configuration A, 3 wind generator, structure 1 | 2 496 000 | 126 900 |
| Configuration A, 4 wind generators, structure 2 | 2 328 400 | 111 160 |
| Configuration A, 5 wind generators, structure 2 | 2 612 000 | 86 840 |
| Configuration A, 6 wind generators, structure 2 | 2 905 600 | 82 800 |
| Configuration B, without wind generators, structure 3 | 1 454 000 | 285 435 |

## 3.4 Economic model

At this stage, I create an economic model using the input parameters that were described above. Appendix G presents economic models of all configurations with for 28 RUB/kWh unit price. This is the market price for isolated power supply facilities that are not connected to the central power supply system.

[53] But the real price always depends on the location of such objects, the cost of fuel, delivery, etc. It is not known at what price the company will agree to conclude a contract. The calculation results are shown in the table below.

Table 15 – Calculation results with 28 RUB/kWh

| Configuration | NPV | PI | IRR | EAA |
|---|---|---|---|---|
| Configuration A, 1 WG, structure 1 | -520 839,89 ₽ | 0,71 | 4,65% | -55 640,16 ₽ |
| Configuration A, 2 WG, structure 1 | 68 724,53 ₽ | 1,03 | 9,06% | 7 341,69 ₽ |
| Configuration A, 3 WG, structure 1 | 453 263,8 ₽ | 1,18 | 10,96% | 48 421,16 ₽ |
| Configuration A, 4 WG, structure 2 | 852 457,87 ₽ | 1,37 | 12,9% | 94 442,36 ₽ |
| Configuration A, 5 WG, structure 2 | 884 061,94 ₽ | 1,34 | 12,6% | 91 066,16 ₽ |
| Configuration A, 6 WG, structure 2 | 627 580,25 ₽ | 1,22 | 11,26% | 67 042,99 ₽ |
| Configuration B, 0 WG, structure 3 | -997 250, 45 ₽ | 0,31 | - | -106 534,03 ₽ |

As can be seen from table 15, the best option is configuration A with 3 wind generators of structure 1. It is necessary to find the minimum unit prices for each configuration at which the NPV of the project will be zero. The results are shown in the table 16

Table 16 – Unit electricity prices of all configurations

| Configuration | Minimun unit electricity price (RUB/kWh) |
|---|---|
| Configuration A, 1 wind generator, structure 1 | 31,34 |
| Configuration A, 2 wind generator, structure 1 | 27,56 |
| Configuration A, 3 wind generator, structure 1 | 25,19 |
| Configuration A, 4 wind generators, structure 2 | 22,33 |
| Configuration A, 5 wind generators, structure 2 | 22,53 |
| Configuration A, 6 wind generators, structure 2 | 23,9 |
| Configuration B, without wind generators, structure 3 | 34,4 |

As can be seen from table 16, the lowest price is Configuration A (4 WG). For a better understanding, it is necessary to analyze the sensitivity of the dependence of the NPV and unit price for customer. This is shown in the Figure 24.

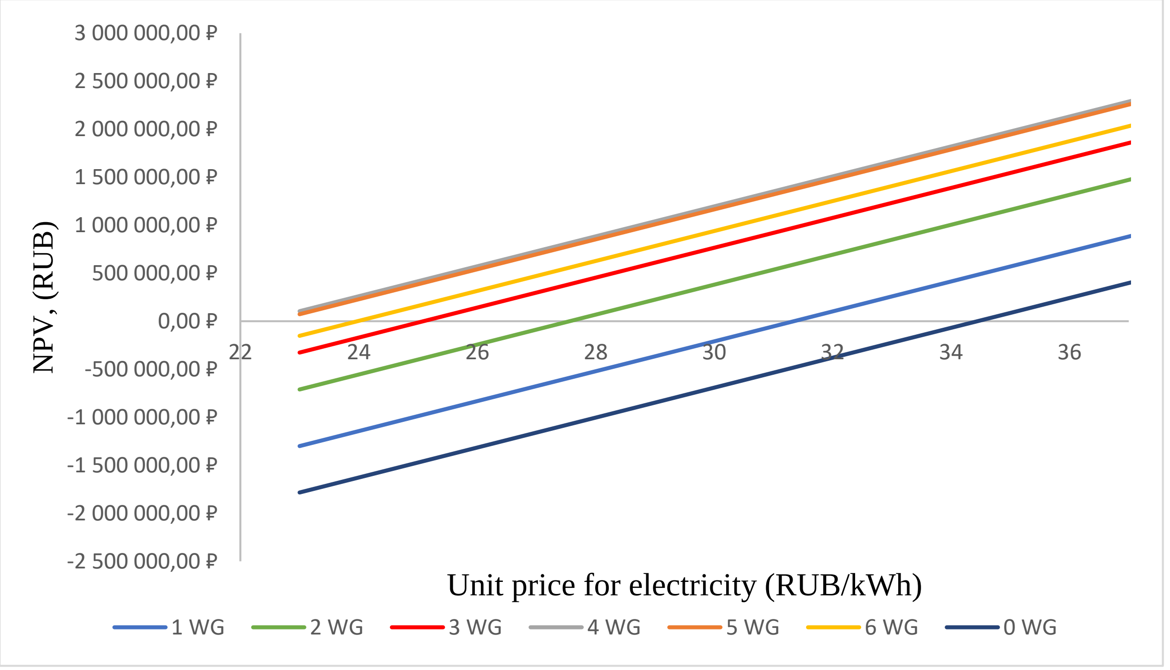


Figure 24 – Dependence of NPV on unit electricity price for customer

### 3.5 Sensitivity analysis

Sensitivity analysis of the project can show how different parameters influence on NPV. After sensitivity analysis it is possible to make conclusions which factors have more or less influence on NPV. In sensitivity analysis I use the real price equal to 28 RUB/kWh.

Here is a list of parameters which will be used in sensitivity analysis of NPV:

- Discount rate
- Escalation
- Diesel generator price
- Wind generator price
- Fuel price

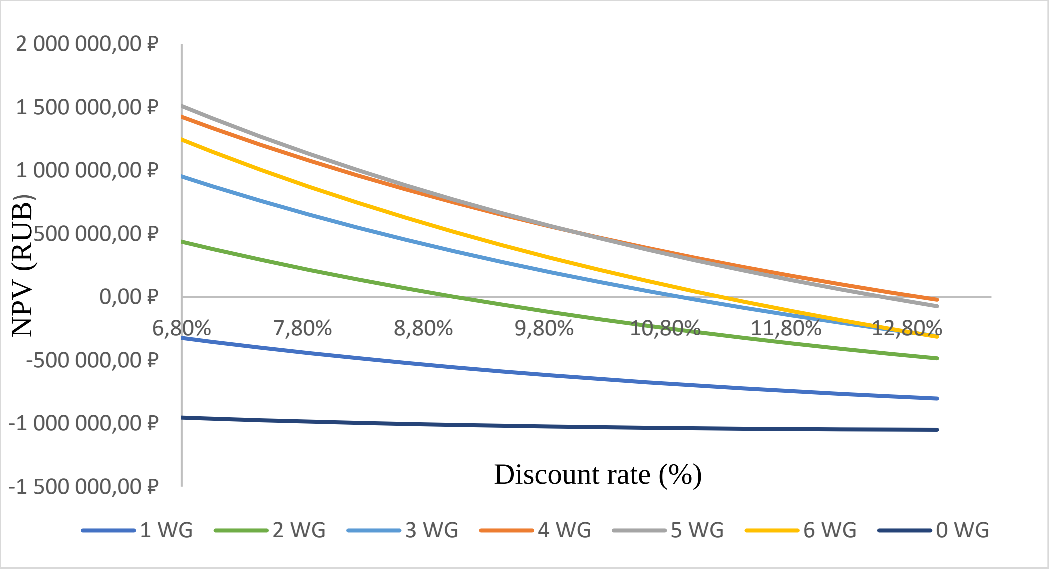


Figure 25 – Dependence of Discount rate on NPV

The graph in Figure 25 has exponential characteristic for each configuration. The greater the discount rate the less NPV. It should be noted that for the unit electricity price of 28 RUB/ kWh there are no positive values of the discount rate.

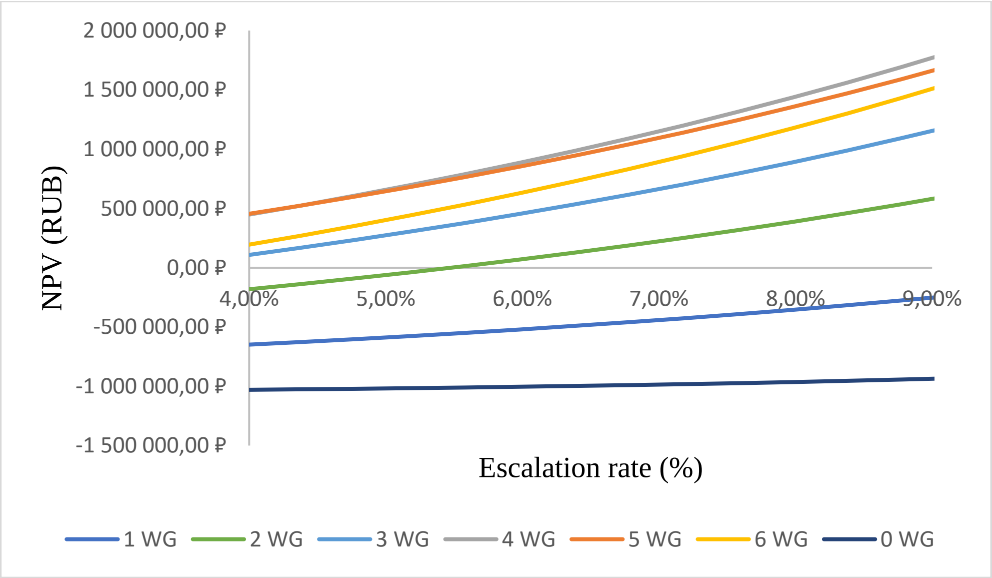


Figure 26 – Dependence of Escalation rate on NPV

The graph in Figure 26 has exponential characteristic.

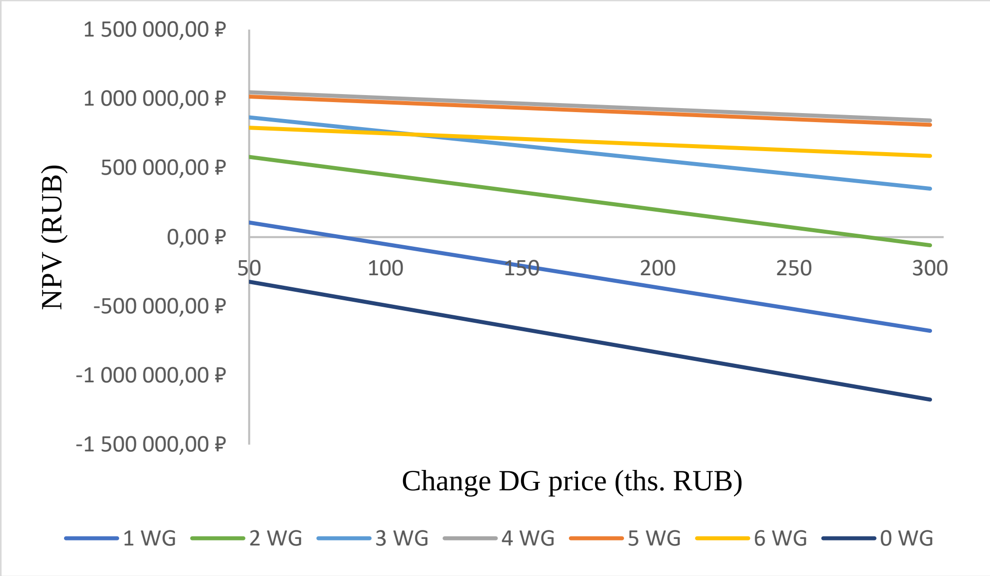


Figure 27 – Dependence of Changing DG price on NPV

As can be seen from Figure 27, the change in the price of a diesel generator has a linear dependence with the NPV of all configurations. The higher the price of diesel generators, the lower the NPV of each configuration. This dependence exists because one reserve diesel generator is installed in each configuration and its price is taken into account in investments. And at a unit electricity price of 28 RUB/ kWh, the influence of the price of a diesel generator has a weak dependence on the NPV configuration B, which I use only diesel generators for power supply.

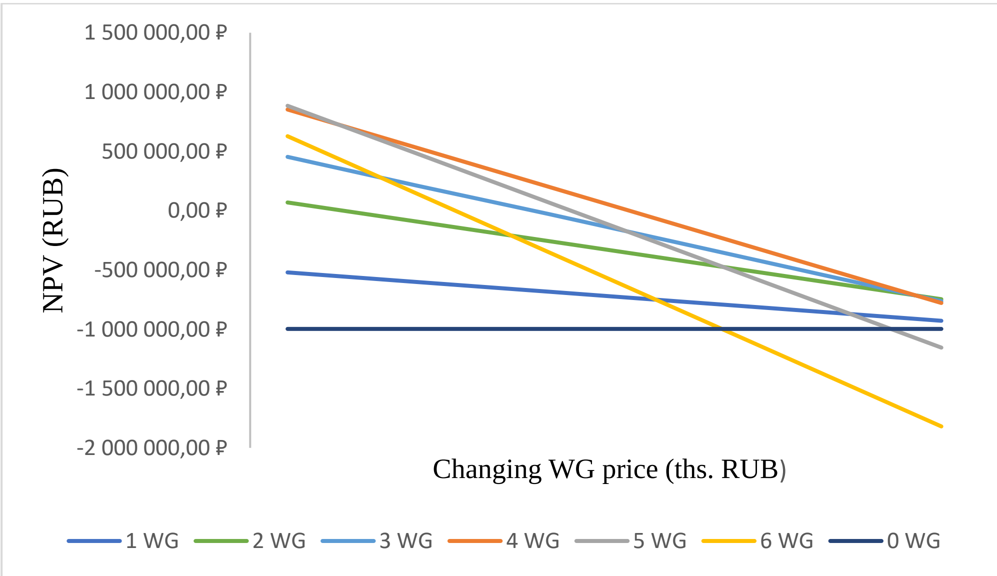


Figure 28 – Dependence of Changing WG price on NPV

As can be seen from Figure 28, the change in the price of a wind generator has a linear dependence with the NPV of all configurations. The higher the price of diesel generators, the lower the NPV of configurations with wind generators.

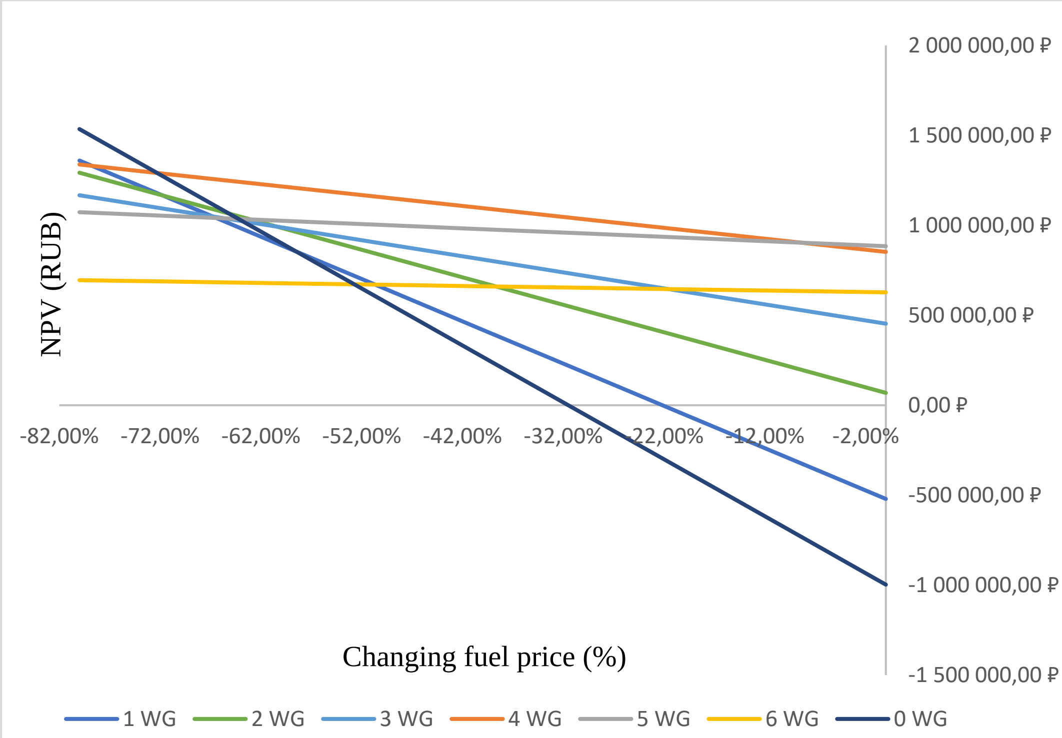


Figure 29 – Dependence of Changing fuel price on NPV

The graph in Figure 29 has linear characteristic. At a unit electricity price of 28 RUB/ kWh, the NPV of configuration B will be higher than the rest only with a decrease in fuel prices by about 70%. This is due to the strong remoteness of the facility from central infrastructures and fuel costs are very high when operating such autonomus objects.

### 3.6 Conclusion from chapter three

Six configurations with wind-diesel power supply and one diesel configuration were analyzed. They differ in the number of generator sets, equipment and type of circuits. The best option is Configuration A (4WG) structure 2. Minimum unit electricity price is 22 RUB/kWh. The NPV of this project will be (when selling electricity to the company at a price of 28 RUB/ kWh) 852457.87 RUB.

## CONCLUSION

I studied the experience of using renewable energy sources for power supply of oil and gas industry facilities, which are remote from the central power supply. Usually, in Russia in such regions consumers are supplied by diesel power plants. However it is expensive, there is harmful for the environment carbon emission and there might be interruptions in diesel fuel shipping. This paper presents how integration of renewable source of energy in diesel power plant can help to decrease fuel costs and carbon emission. Also there are more power sources in the hybrid power plant, therefore the reliability is higher.

In this paper I designed a hybrid power plant based on the diesel power plant. When designing a hybrid power plant for such facilities, it is necessary to classify the consumer in accordance with the requirements for the quality of the supply voltage and the reliability of the power source. This classification allows you to determine the types of consumers for which the use of renewable energy is most appropriate, as well as additional measures to improve the quality of electricity supply. Most consumers of main gas pipelines are located in remote places, away from centralized power supplies. It is necessary to install additional equipment, control systems to ensure the stable operation of an autonomous hybrid power plant. For efficient operation, it is necessary to optimize the composition of the hybrid power plant equipment.

I took the initial data of power consumption from the technical data of the company. I studied the terrain of the location of the considering object and evaluated the potential of wind and solar energy. It was decided to use wind generators, as Solar potential in this region is low. After selecting models of wind turbines according to the ICUF criterion, I decided to install wind turbines model SW-2,5 kW. Considering all the factors, I designed configurations of the hybrid power plant for the real Rosneft facility under construction.

Six configurations with wind-diesel power supply and one diesel configuration were analyzed. They differ in the number of generator sets, equipment and type of circuits. I made an economic evaluation of the configurations. I estimated costs and investments in the configurations and based on this data I calculated minimal unit electricity prices for each configuration. The best option is Configuration A (4WG) structure 2. Minimum unit electricity price is 22 RUB/kWh. The NPV of this project will be (when selling electricity to the company at a price of 28 RUB/ kWh) 852457.87 RUB. I also rated the minimum price and NPV of a power station that only works with diesel generators. Its minimum price is 34.4 RUB/ kWh, and its NPV is -997 250.45 RUB at a selling price of 28 RUB/kWh. I also did an NPV sensitivity analysis. The graphs in Figures 25-29 show how the NPV depends on the discount rate, escalation rate, changing DG price, changing WG price, changing fuel price.

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APPENDICES

Appendix A - Letter from the company representative with the technical case

Figure A1- Part 1

**АКЦИОНЕРНОЕ ОБЩЕСТВО "НИЖНЕВАРТОВСКИЙ НАУЧНО-ИССЛЕДОВАТЕЛЬСКИЙ И ПРОЕКТНЫЙ ИНСТИТУТ НЕФТЕДОБЫЧИ"**
(АО Нижневартовск НИПИнефть)

Почтовый / юридический адрес: г. Нижневартовск, ул. Ленина, д. 5
Телефакс (846) 205 86 00, факс: (846) 205 86 01, e-mail: snipoil@samnipineft.ru
ОКПО 51887016, ОГРН 1026301159939, ИНН/КПП 6316058992/631050001

от 09.09.2019 № исх-си по9-02960

на № ______ от ______

Уважаемые коллеги!

АО «НижневартовскНИПИнефть» в интересах ПАО «НК «Роснефть» разработаны технические решения по применению возобновляемых источников энергии (далее ВИЭ) для электроснабжения нефтегазодобывающих предприятий, определен перечень потенциальных для электроснабжения на основе ВИЭ объектов с характерными нагрузками энергопотребителей.

В настоящий момент определены объекты ряда добывающих Обществ, расположенных на территории Ханты-Мансийского автономного округа, Нефтеюганского района. Прорабатывается вопрос практического применения установок ВИЭ на указанных объектах.

На основании изложенного прошу Вас направить в наш адрес, в том числе на адрес электронной почты: snipoil@samnipineft.ru технико-коммерческие предложения в соответствии с приложениями 1 к данному письму. В Приложении 2 представлены типовые мощности потребителей, максимальные потребления электроэнергии, сезонные потребления электроэнергии.

Приложение: формат предоставления ТКП на 2 л.

С уважением,

Начальник управления планирования
Объектов энергетики

И.С. Ефремов

Исп. Гаврилов А.К.,
Тел. (846) 314-86-34

Figure A2- Part 2

Приложение 2

**Опросный лист на гибридную ветро-солнечную энергоустановку, с учетом следующих основных параметров:**

1. Время автономной работы энергоустановки – 32 часа (при полностью заряженных аккумуляторных батареях, ветрогенератор и солнечные модули не работают).
2. Номинальное выходное напряжение – 220/380 В.
3. Установка должна обеспечивать возможность легкого монтажа и демонтажа на объекте Заказчика.
4. Напряжение аккумуляторного блока энергоустановки – 48 В.
5. Глубина разряда аккумуляторного блока – 80%.
6. Подключение резервного источника питания через АВР.
7. Максимальное потребление электроэнергии по объектам:

**Потребление электроэнергии и среднесуточная мощность**

| № п/п | Максимальное потребление электроэнергии в сутки (зимний период), кВт*ч/сут. | Максимальное потребление электроэнергии месяц (зимний период), кВт*ч/мес. |
|---|---|---|
| 1 | 10.1 | 1584 |

8. Местоположение объекта – Ханты-Мансийский автономный округ, Нефтеюганский район.
9. Тип объекта- Крановый узел насосной станции с сопутствующем оборудованием

**Мощности потребителей крановых узлов магистрального газопровода**

| Оборудование | Установленная мощность, кВт | Напряжение, В |
|---|---|---|
| Привод задвижки | 5 | 220 |
| Контрольно-измерительные приборы и автоматика | 0,08 | 220 |
| Связь | 1,4 | 220 |
| Пожарная сигнализация | 0,5 | 220 |
| Шкаф технических средств охраны | 1,0 | 220 |
| Щит собственных нужд | 1,26 | 220 |
| Освещение площадки | 0,075 | 220 |
| Освещение укрытия | 0,018 | 220 |
| Прочие потребители | 1.1 | 220 |
| Итого | 10,433 | |

1

Figure A3 – Part 3

**Объемы потребления электроэнергии и уровни электрических нагрузок потребителей крановых узлов за 2018**

| Месяц | Объем потребления электроэнергии, кВт*ч | Максимальные значения нагрузки, кВт | Максимальное значение нагрузки, в % от суммарной номинальной мощности | Минимальное значение нагрузки, кВт | Минимальное значение нагрузки, в % от суммарной номинальной мощности |
|---|---|---|---|---|---|
| Янв. | 1584 | 10,1 | 96,8 | 1,512 | 14,49 |
| Фев. | 1443,3 | 9,64 | 92,4 | 1,432 | 13,73 |
| Март | 1248,7 | 9,12 | 87,4 | 0,9 | 8,63 |
| Апр. | 1034,2 | 8,87 | 85 | 0,875 | 8,39 |
| Май | 993,4 | 7,64 | 73,2 | 1,231 | 11,8 |
| Июнь | 987,5 | 7,55 | 72,4 | 1,111 | 10,64 |
| Июль | 1020,3 | 8,55 | 82 | 1,055 | 10,1 |
| Авг. | 1064,1 | 8,67 | 83,1 | 1,132 | 10,9 |
| Сент. | 1150,3 | 8,99 | 86,2 | 0,967 | 9,3 |
| Окт. | 1270,4 | 9,45 | 90,6 | 0,785 | 7,5 |
| Нояб. | 1239,0 | 9,33 | 89,4 | 0,654 | 6,3 |
| Дек. | 1384,2 | 9,44 | 90,5 | 1,325 | 12,7 |

**Зимние и летние суточные графики нагрузки крановых узлов за 23 января и 17 августа 2018**

| Зимний период (кВт) | | Летний период (кВт) | |
|---|---|---|---|
| 0 | 6,20 | 0 | 4,5 |
| 1 | 4,50 | 1 | 4,5 |
| 2 | 4,50 | 2 | 4,5 |
| 3 | 4,50 | 3 | 4,5 |
| 4 | 4,50 | 4 | 2,5 |
| 5 | 4,50 | 5 | 2,5 |
| 6 | 4,50 | 6 | 2,5 |
| 7 | 4,50 | 7 | 2,5 |
| 8 | 4,50 | 8 | 3,2 |
| 9 | 3,90 | 9 | 3,2 |
| 10 | 4,20 | 10 | 5,1 |
| 11 | 6,20 | 11 | 5,1 |
| 12 | 3,20 | 12 | 4,9 |
| 13 | 5,20 | 13 | 2,5 |
| 14 | 5,30 | 14 | 2,5 |
| 15 | 5,60 | 15 | 3,2 |
| 16 | 10,10 | 16 | 4,1 |
| 17 | 9,20 | 17 | 4,5 |
| 18 | 9,10 | 18 | 4,5 |
| 19 | 8,90 | 19 | 5,1 |
| 20 | 6,50 | 20 | 5,1 |
| 21 | 4,50 | 21 | 5,5 |
| 22 | 4,50 | 22 | 6,1 |
| 23 | 4,50 | 23 | 6,2 |
| 24 | 4,50 | 24 | 6,3 |

2

Appendix B - Wind speed and solar radiation statistics data [39]

Figure B1 - Wind speed data for 2010-2018

Parameter(s):

WS10M_MIN MERRA2 1/2x1/2 Minimum Wind Speed at 10 Meters (m/s)

WS10M MERRA2 1/2x1/2 Wind Speed at 10 Meters (m/s)

WS10M_MAX MERRA2 1/2x1/2 Maximum Wind Speed at 10 Meters (m/s)

WS10M_RANGE MERRA2 1/2x1/2 Wind Speed Range at 10 Meters (m/s)

| PARAMETER | YEAR | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| -END HEADER- | | | | | | | | | | | | | | |
| WS10M_MIN | 2010 | 1.93 | 1.54 | 1.71 | 1.37 | 1.28 | 1.33 | 1.13 | 1.28 | 1.34 | 1.85 | 2.12 | 1.70 | 1.55 |
| WS10M_MIN | 2011 | 2.12 | 1.80 | 2.40 | 1.79 | 1.23 | 1.17 | 0.96 | 1.24 | 1.39 | 1.35 | 1.85 | 1.96 | 1.60 |
| WS10M_MIN | 2012 | 1.69 | 1.53 | 1.80 | 1.66 | 1.37 | 0.94 | 0.84 | 1.08 | 1.41 | 1.59 | 1.49 | 1.72 | 1.43 |
| WS10M_MIN | 2013 | 1.73 | 1.68 | 1.62 | 1.43 | 1.33 | 1.14 | 1.05 | 1.12 | 1.34 | 1.80 | 1.86 | 2.24 | 1.53 |
| WS10M_MIN | 2014 | 1.52 | 1.72 | 2.07 | 1.83 | 1.25 | 1.28 | 1.01 | 0.93 | 1.29 | 1.61 | 1.94 | 2.03 | 1.54 |
| WS10M_MIN | 2015 | 2.04 | 2.21 | 1.98 | 1.45 | 1.27 | 1.15 | 1.36 | 1.00 | 1.21 | 1.41 | 1.61 | 1.79 | 1.54 |
| WS10M_MIN | 2016 | 2.14 | 2.03 | 1.66 | 1.37 | 1.27 | 1.22 | 1.11 | 1.07 | 1.15 | 1.22 | 1.37 | 1.81 | 1.45 |
| WS10M_MIN | 2017 | 1.92 | 2.34 | 2.43 | 1.73 | 1.26 | 1.24 | 0.93 | 1.17 | 1.27 | 1.52 | 1.65 | 1.79 | 1.60 |
| WS10M_MIN | 2018 | 2.21 | 1.34 | 1.97 | 1.53 | 1.42 | 1.20 | 1.21 | 1.20 | 1.35 | 1.64 | 1.46 | 1.97 | 1.54 |
| WS10M_MAX | 2010 | 3.13 | 3.14 | 3.70 | 3.03 | 3.05 | 3.08 | 2.41 | 2.78 | 2.86 | 2.98 | 3.92 | 3.23 | 3.11 |
| WS10M_MAX | 2011 | 3.24 | 3.19 | 4.37 | 3.99 | 3.25 | 2.63 | 2.59 | 2.54 | 2.68 | 2.62 | 3.32 | 3.00 | 3.12 |
| WS10M_MAX | 2012 | 2.61 | 2.78 | 3.49 | 3.85 | 3.12 | 2.29 | 2.19 | 2.54 | 2.86 | 2.94 | 3.06 | 2.84 | 2.88 |
| WS10M_MAX | 2013 | 2.81 | 3.37 | 3.66 | 3.33 | 3.33 | 2.50 | 2.29 | 2.25 | 2.55 | 3.51 | 3.40 | 3.54 | 3.04 |
| WS10M_MAX | 2014 | 2.85 | 2.74 | 4.10 | 3.73 | 3.41 | 2.96 | 2.71 | 2.44 | 2.81 | 3.07 | 3.47 | 3.24 | 3.13 |
| WS10M_MAX | 2015 | 3.65 | 3.85 | 3.77 | 3.19 | 2.96 | 2.57 | 3.07 | 2.47 | 2.61 | 2.95 | 2.63 | 3.11 | 3.07 |
| WS10M_MAX | 2016 | 3.27 | 3.58 | 3.74 | 2.86 | 3.12 | 2.75 | 2.34 | 2.42 | 2.55 | 2.18 | 2.92 | 3.29 | 2.92 |
| WS10M_MAX | 2017 | 3.26 | 3.86 | 3.83 | 3.77 | 3.60 | 2.74 | 2.29 | 2.57 | 2.71 | 2.75 | 2.87 | 2.99 | 3.10 |
| WS10M_MAX | 2018 | 3.53 | 2.67 | 4.11 | 3.42 | 3.50 | 2.73 | 2.59 | 2.77 | 2.80 | 3.19 | 3.18 | 3.12 | 3.14 |
| WS10M_RANGE | 2010 | 1.20 | 1.60 | 1.99 | 1.66 | 1.77 | 1.75 | 1.28 | 1.50 | 1.53 | 1.13 | 1.80 | 1.53 | 1.56 |
| WS10M_RANGE | 2011 | 1.12 | 1.39 | 1.97 | 2.20 | 2.03 | 1.46 | 1.63 | 1.30 | 1.29 | 1.27 | 1.47 | 1.05 | 1.51 |
| WS10M_RANGE | 2012 | 0.92 | 1.26 | 1.69 | 2.19 | 1.75 | 1.36 | 1.35 | 1.47 | 1.45 | 1.36 | 1.57 | 1.12 | 1.45 |
| WS10M_RANGE | 2013 | 1.08 | 1.70 | 2.04 | 1.90 | 2.01 | 1.36 | 1.24 | 1.13 | 1.21 | 1.70 | 1.54 | 1.29 | 1.51 |
| WS10M_RANGE | 2014 | 1.33 | 1.02 | 2.03 | 1.90 | 2.15 | 1.69 | 1.70 | 1.51 | 1.51 | 1.47 | 1.53 | 1.21 | 1.59 |
| WS10M_RANGE | 2015 | 1.61 | 1.63 | 1.79 | 1.74 | 1.69 | 1.42 | 1.71 | 1.47 | 1.40 | 1.54 | 1.02 | 1.31 | 1.53 |
| WS10M_RANGE | 2016 | 1.13 | 1.54 | 2.08 | 1.49 | 1.85 | 1.53 | 1.22 | 1.35 | 1.41 | 0.96 | 1.55 | 1.48 | 1.47 |
| WS10M_RANGE | 2017 | 1.34 | 1.52 | 1.39 | 2.04 | 2.34 | 1.50 | 1.36 | 1.39 | 1.43 | 1.23 | 1.22 | 1.19 | 1.50 |
| WS10M_RANGE | 2018 | 1.32 | 1.34 | 2.15 | 1.89 | 2.08 | 1.53 | 1.38 | 1.56 | 1.45 | 1.55 | 1.72 | 1.15 | 1.59 |
| WS10M | 2010 | 2.54 | 2.37 | 2.80 | 2.24 | 2.24 | 2.22 | 1.79 | 2.02 | 2.07 | 2.42 | 3.03 | 2.50 | 2.35 |
| WS10M | 2011 | 2.71 | 2.54 | 3.42 | 2.89 | 2.26 | 1.91 | 1.84 | 1.89 | 2.03 | 2.00 | 2.59 | 2.48 | 2.38 |
| WS10M | 2012 | 2.18 | 2.15 | 2.65 | 2.88 | 2.28 | 1.64 | 1.54 | 1.80 | 2.19 | 2.31 | 2.34 | 2.30 | 2.19 |
| WS10M | 2013 | 2.31 | 2.62 | 2.71 | 2.36 | 2.41 | 1.87 | 1.67 | 1.73 | 1.96 | 2.72 | 2.71 | 2.91 | 2.33 |
| WS10M | 2014 | 2.23 | 2.26 | 3.09 | 2.86 | 2.40 | 2.11 | 1.91 | 1.75 | 2.05 | 2.38 | 2.70 | 2.66 | 2.37 |
| WS10M | 2015 | 2.89 | 3.08 | 2.97 | 2.34 | 2.13 | 1.89 | 2.25 | 1.78 | 1.90 | 2.23 | 2.12 | 2.48 | 2.34 |
| WS10M | 2016 | 2.70 | 2.85 | 2.78 | 2.11 | 2.27 | 2.03 | 1.75 | 1.75 | 1.88 | 1.73 | 2.18 | 2.57 | 2.22 |
| WS10M | 2017 | 2.64 | 3.16 | 3.18 | 2.79 | 2.44 | 2.02 | 1.64 | 1.88 | 1.99 | 2.16 | 2.28 | 2.39 | 2.38 |
| WS10M | 2018 | 2.92 | 2.04 | 3.13 | 2.56 | 2.55 | 2.01 | 1.86 | 2.01 | 2.07 | 2.39 | 2.38 | 2.58 | 2.38 |

Figure B2 - Average daily wind speed data for the months of 2018: April, January, July, October

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2018 04 01 | 3.16 | 2018 01 01 | 3.39 | 2018 07 01 | 1.78 | 2018 10 01 | 2.96 |
| 2018 04 02 | 3.14 | 2018 01 02 | 3.66 | 2018 07 02 | 2.63 | 2018 10 02 | 2.46 |
| 2018 04 03 | 2.45 | 2018 01 03 | 3.58 | 2018 07 03 | 2.16 | 2018 10 03 | 2.49 |
| 2018 04 04 | 4.98 | 2018 01 04 | 3.17 | 2018 07 04 | 1.34 | 2018 10 04 | 2.22 |
| 2018 04 05 | 3.21 | 2018 01 05 | 3.21 | 2018 07 05 | 1.65 | 2018 10 05 | 2.68 |
| 2018 04 06 | 2.59 | 2018 01 06 | 2.94 | 2018 07 06 | 2.13 | 2018 10 06 | 2.84 |
| 2018 04 07 | 3.01 | 2018 01 07 | 3.16 | 2018 07 07 | 2.20 | 2018 10 07 | 3.46 |
| 2018 04 08 | 2.08 | 2018 01 08 | 3.58 | 2018 07 08 | 2.24 | 2018 10 08 | 2.14 |
| 2018 04 09 | 1.89 | 2018 01 09 | 4.88 | 2018 07 09 | 2.64 | 2018 10 09 | 2.73 |
| 2018 04 10 | 2.24 | 2018 01 10 | 3.40 | 2018 07 10 | 1.07 | 2018 10 10 | 2.89 |
| 2018 04 11 | 4.02 | 2018 01 11 | 2.13 | 2018 07 11 | 1.15 | 2018 10 11 | 2.56 |
| 2018 04 12 | 4.13 | 2018 01 12 | 3.81 | 2018 07 12 | 1.72 | 2018 10 12 | 2.37 |
| 2018 04 13 | 2.30 | 2018 01 13 | 3.28 | 2018 07 13 | 2.89 | 2018 10 13 | 2.07 |
| 2018 04 14 | 3.57 | 2018 01 14 | 2.29 | 2018 07 14 | 2.42 | 2018 10 14 | 1.47 |
| 2018 04 15 | 2.91 | 2018 01 15 | 3.78 | 2018 07 15 | 1.76 | 2018 10 15 | 1.11 |
| 2018 04 16 | 2.33 | 2018 01 16 | 3.74 | 2018 07 16 | 1.20 | 2018 10 16 | 3.08 |
| 2018 04 17 | 2.38 | 2018 01 17 | 2.66 | 2018 07 17 | 1.50 | 2018 10 17 | 3.18 |
| 2018 04 18 | 1.95 | 2018 01 18 | 1.96 | 2018 07 18 | 1.91 | 2018 10 18 | 2.13 |
| 2018 04 19 | 3.83 | 2018 01 19 | 2.60 | 2018 07 19 | 2.25 | 2018 10 19 | 1.37 |
| 2018 04 20 | 1.71 | 2018 01 20 | 2.74 | 2018 07 20 | 2.56 | 2018 10 20 | 2.52 |
| 2018 04 21 | 1.59 | 2018 01 21 | 2.72 | 2018 07 21 | 2.52 | 2018 10 21 | 2.08 |
| 2018 04 22 | 1.37 | 2018 01 22 | 2.35 | 2018 07 22 | 2.15 | 2018 10 22 | 2.72 |
| 2018 04 23 | 2.94 | 2018 01 23 | 2.15 | 2018 07 23 | 2.33 | 2018 10 23 | 3.17 |
| 2018 04 24 | 2.90 | 2018 01 24 | 1.99 | 2018 07 24 | 2.50 | 2018 10 24 | 2.44 |
| 2018 04 25 | 2.77 | 2018 01 25 | 2.62 | 2018 07 25 | 2.07 | 2018 10 25 | 2.12 |
| 2018 04 26 | 2.35 | 2018 01 26 | 4.22 | 2018 07 26 | 2.22 | 2018 10 26 | 3.82 |
| 2018 04 27 | 2.26 | 2018 01 27 | 5.10 | 2018 07 27 | 1.25 | 2018 10 27 | 2.93 |
| 2018 04 28 | 1.93 | 2018 01 28 | 3.71 | 2018 07 28 | 2.14 | 2018 10 28 | 2.08 |
| 2018 04 29 | 3.25 | 2018 01 29 | 4.61 | 2018 07 29 | 2.98 | 2018 10 29 | 2.10 |
| 2018 04 30 | 3.57 | 2018 01 30 | 2.97 | 2018 07 30 | 2.06 | 2018 10 30 | 3.80 |
| | | 2018 01 31 | 3.17 | 2018 07 31 | 2.40 | 2018 10 31 | 2.72 |

Table B1 - Data on total monthly values of solar radiation intake from 2010 to 2018 [39].

| Year | January | February | March | April | May | June | July | August | September | October | November | December |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2010 | 11,78 | 39,68 | 83,08 | 131,44 | 132,37 | 176,08 | 152,83 | 114,7 | 70,37 | 35,96 | 13,33 | 6,2 |
| 2011 | 12,71 | 39,37 | 95,79 | 128,34 | 172,98 | 159,96 | 162,44 | 112,84 | 78,43 | 35,34 | 14,57 | 6,2 |
| 2012 | 9,3 | 43,09 | 87,11 | 117,8 | 146,94 | 190,96 | 163,68 | 122,45 | 72,85 | 30,38 | 14,26 | 5,89 |
| 2013 | 8,99 | 33,48 | 78,43 | 94,86 | 141,05 | 153,45 | 183,21 | 122,76 | 64,17 | 27,59 | 7,44 | 2,79 |
| 2014 | 8,06 | 33,79 | 68,82 | 101,99 | 143,53 | 179,49 | 144,15 | 112,22 | 63,24 | 22,63 | 11,16 | 3,41 |
| 2015 | 9,3 | 28,21 | 81,53 | 121,21 | 155,62 | 174,84 | 124,62 | 102,92 | 64,17 | 24,49 | 9,61 | 2,79 |
| 2016 | 7,75 | 29,14 | 81,22 | 132,37 | 168,64 | 171,43 | 162,75 | 135,78 | 68,51 | 32,86 | 11,78 | 3,72 |
| 2017 | 9,3 | 28,83 | 75,64 | 94,55 | 120,9 | 163,37 | 179,18 | 113,46 | 57,66 | 30,07 | 9,92 | 3,1 |
| 2018 | 0 | 38,75 | 77,19 | 109,12 | 125,86 | 138,88 | 188,48 | 99,82 | 76,57 | 25,42 | 9,3 | 3,41 |

Appendix C – Calculation results for wind generators

Table C1- Technical and economic characteristics of wind generators

| Type | Nominal power, kW | Wind speed, m/s | | | | Tower, m | Wind generator price, th. rub. (with VAT) | Tower price, th. rub. (with VAT) | Lifetime, year |
|---|---|---|---|---|---|---|---|---|---|
| | | min | nominal | max | Maximum storm wind speed | | | | |
| BWC Exce1 10 | 10,0 | 2,5 | 12,0 | 20 | 60 | 49 | 1859,18 | 1404,19 | 30 |
| LOW WIND 1 kW-48V | 1,0 | 2,5 | 9,0 | 25 | 40 | 12 | 85,68 | 78,6 | 15 |
| LOW WIND 2,5 kW-48V | 2,5 | 2,5 | 10,0 | 25 | 50 | 12 | 131,88 | 78,6 | 15 |
| VAWT2 | 2,0 | 1,8 | 10,0 | 45 | 45 | 12 | 320,76 | 78,6 | 20 |
| VAWT3 | 3,0 | 1,8 | 12,0 | 45 | 45 | 12 | 510,84 | 78,6 | 20 |
| SW-2,5 KW | 2,5 | 2,5 | 11,5 | - | 40 | 12 | 200,00 | 78,6 | 20 |
| ANTARIS 2,5 kW | 2,5 | 2,2 | 11,0 | - | 58 | 12 | 200,00 | - | - |
| ANTARIS 3,5 kW | 3,5 | 2,2 | 11,0 | - | 58 | 12 | 300,00 | - | - |
| ANTARIS 4,5 kW | 4,5 | 2,2 | 10,5 | | 58 | 12 | 400,00 | - | - |
| ANTARIS 6,5 kW | 6,5 | 1,8 | 10,0 | - | 58 | 12 | 600,00 | - | - |
| ANTARIS 9,5 kW | 9,5 | 1,8 | 11,0 | - | 58 | 12 | 800,00 | - | - |

Table C2 - Results of calculation of installed capacity utilization factors for WG

| Type | Nominal power, kW | Tower, m | Nominal Wind speed, m/s | Average annual wind speed recalculated to tower height, m/s | WG power at average annual wind speed at tower height, W | Number of WG to cover the average annual load | Power of WPP at average annual wind speed, kW | Electricity generation of WPP during the year at average annual wind speed, kWh/year | WPP generation during the year at nominal wind speed, kWh/year | ICUF, % |
|---|---|---|---|---|---|---|---|---|---|---|
| BWC Exce1 10 | 10,00 | 49,00 | 12,00 | 4,31 | 410 | 4 | 1,64 | 14366,4 | 350400 | 4,10 |
| LOW WIND 1 kW-48V | 1,00 | 12,00 | 9,00 | 2,88 | 90 | 18 | 1,62 | 14191,2 | 157680 | 9,00 |
| LOW WIND 2,5 kW-48V | 2,50 | 12,00 | 10,00 | 2,88 | 210 | 8 | 1,68 | 14716,8 | 175200 | 8,40 |
| VAWT2 | 2,00 | 12,00 | 10,00 | 2,88 | 150 | 11 | 1,65 | 14454 | 192720 | 7,50 |
| VAWT3 | 3,00 | 12,00 | 12,00 | 2,88 | 190 | 9 | 1,71 | 14979,6 | 236520 | 6,33 |
| SW-2,5 KW | 2,50 | 12,00 | 11,50 | 2,88 | 280 | 6 | 1,68 | 14716,8 | 131400 | 11,20 |
| ANTARIS 2,5 kW | 2,50 | 12,00 | 11,00 | 2,88 | 50 | 33 | 1,65 | 14454 | 722700 | 2,00 |
| ANTARIS 3,5 kW | 3,50 | 12,00 | 11,00 | 2,88 | 50 | 33 | 1,65 | 14454 | 1011780 | 1,43 |
| ANTARIS 4,5 kW | 4,50 | 12,00 | 10,50 | 2,88 | 110 | 15 | 1,65 | 14454 | 591300 | 2,44 |
| ANTARIS 6,5 kW | 6,50 | 12,00 | 10,00 | 2,88 | 210 | 8 | 1,68 | 14716,8 | 455520 | 3,23 |
| ANTARIS 9,5 kW | 9,50 | 12,00 | 11,00 | 2,88 | 250 | 7 | 1,75 | 15330 | 582540 | 2,63 |

Appendix D - Technical and economic characteristics of DG and AB

Table D1 - Technical characteristics of DG with capacity of 11,5 kW. [46]

| Parameter | Value |
|---|---|
| Type | GENBOX KBT15M-3000 |
| Nominal power, kW | 14,9 |
| Maximum power, kW | 16,5 |
| Nominal fuel consumption, l/kWh | 0,31 |
| Fuel consumption at 100% load, l/h | 5,03 |
| Fuel consumption at 75% load, l/h | 3,78 |
| Fuel consumption at 50% load, l/h | 2,49 |
| Resource, h | 40 000 |
| Price, RUB (with VAT) | 250 000 |
| Average cost of maintenance, RUB. (with VAT) | 15 000 |
| Maintenance interval, once a year | 1 |
| Cost of diesel fuel in Nefteyugansk region, rub/l (with VAT) [47]. | 53,58 |

Table D2 - Technical and economic characteristics of the AB [48]

| Parameter | Value |
|---|---|
| Model | VOLTA GEL 12-200 |
| Battery rated capacity, A·h. | 200 |
| Nominal battery voltage, V | 12 |
| Battery discharge depth, % | 80 |
| Lifetime, years | 15 |
| Price of the battery, thousand rubles. (with VAT) | 26,5 |
| Type | Gel |
| Operating temperature range, °C | -20°C... +60°C |

Appendix E - Calculation results of values of electric power generation by wind generators on the basis of the detailed information on receipt of resources in the considered area

Figure E1 - Wind speed data at a height of 12 meters of the considered area for the period 2014-2019. Screenshot from Excel [49]

| Decembe | Day | Time | Wind speed (m/s) 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | Average |
|---|---|---|---|---|---|---|---|---|---|
| | 31.12. | 23:30 | 2 | 2 | 4 | 4 | 6 | 4 | 3,67 |
| | 31.12. | 23:00 | 2 | 3 | 5 | 4 | 6 | 5 | 4,17 |
| | 31.12. | 22:30 | 2 | 4 | 4 | 5 | 6 | 4 | 4,17 |
| | 31.12. | 22:00 | 2 | 3 | 4 | 5 | 6 | 5 | 4,17 |
| | 31.12. | 21:30 | 2 | 3 | 4 | 5 | 6 | 4 | 4,00 |
| | 31.12. | 21:00 | 3 | 2 | 4 | 4 | 6 | 5 | 4,00 |
| | 31.12. | 20:30 | 3 | 3 | 4 | 4 | 6 | 5 | 4,17 |
| | 31.12. | 20:00 | 3 | 2 | 4 | 3 | 6 | 6 | 4,00 |
| | 31.12. | 19:30 | 3 | 2 | 4 | 4 | 6 | 6 | 4,17 |
| | 31.12. | 19:00 | 3 | 2 | 4 | 4 | 5 | 6 | 4,00 |
| | 31.12. | 18:30 | 3 | 2 | 3 | 3 | 4 | 7 | 3,67 |
| | 31.12. | 18:00 | 3 | 2 | 3 | 4 | 4 | 7 | 3,83 |
| | 31.12. | 17:30 | 3 | 1 | 3 | 4 | 4 | 6 | 3,50 |
| | 31.12. | 17:00 | 3 | 1 | 3 | 5 | 4 | 7 | 3,83 |
| | 31.12. | 16:30 | 3 | 1 | 3 | 5 | 4 | 7 | 3,83 |
| | 31.12. | 16:00 | 3 | 2 | 3 | 4 | 5 | 6 | 3,83 |
| | 31.12. | 15:30 | 3 | 2 | 2 | 5 | 5 | 5 | 3,67 |
| | 31.12. | 15:00 | 3 | 1 | 2 | 5 | 4 | 6 | 3,50 |
| | 31.12. | 14:30 | 3 | 1 | 2 | 5 | 4 | 6 | 3,50 |

| Novembe | Day | Time | Wind spee | 2015 | 2016 | 2017 | 2018 | 2019 | Average |
|---|---|---|---|---|---|---|---|---|---|
| | 30.11. | 23:30 | 2 | 3 | 0 | 2 | 2 | 3 | 2,00 |
| | 30.11. | 23:00 | 4 | 3 | 0 | 2 | 2 | 3 | 2,33 |
| | 30.11. | 22:30 | 3 | 3 | 0 | 2 | 2 | 3 | 2,17 |
| | 30.11. | 22:00 | 4 | 3 | 0 | 2 | 2 | 4 | 2,50 |
| | 30.11. | 21:30 | 5 | 3 | 0 | 2 | 1 | 6 | 2,83 |
| | 30.11. | 21:00 | 5 | 2 | 0 | 3 | 2 | 6 | 3,00 |
| | 30.11. | 20:30 | 6 | 2 | 0 | 2 | 2 | 6 | 3,00 |
| | 30.11. | 20:00 | 4 | 2 | 0 | 2 | 1 | 6 | 2,50 |
| | 30.11. | 19:30 | 5 | 2 | 1 | 2 | 1 | 6 | 2,83 |
| | 30.11. | 19:00 | 5 | 3 | 1 | 2 | 0 | 5 | 2,67 |
| | 30.11. | 18:30 | 5 | 3 | 2 | 2 | 0 | 7 | 3,17 |
| | 30.11. | 18:00 | 6 | 4 | 1 | 1 | 0 | 6 | 3,00 |
| | 30.11. | 17:30 | 6 | 3 | 1 | 1 | 2 | 6 | 3,17 |
| | 30.11. | 17:00 | 5 | 3 | 2 | 1 | 2 | 6 | 3,17 |
| | 30.11. | 16:30 | 5 | 3 | 2 | 1 | 3 | 6 | 3,33 |
| | 30.11. | 16:00 | 5 | 3 | 2 | 1 | 2 | 5 | 3,00 |
| | 30.11. | 15:30 | 6 | 3 | 3 | 2 | 2 | 5 | 3,50 |
| | 30.11. | 15:00 | 6 | 3 | 3 | 1 | 2 | 7 | 3,67 |
| | 30.11. | 14:30 | 6 | 3 | 3 | 1 | 2 | 6 | 3,50 |

Figure E2 - The value of wind speeds averaged for 2014-2019. Screenshot from Excel

| | January | February | March | April | May | June | July | August | Septembe | October | November | December |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0:00 | 3,2 | 2,3 | 2,7 | 3,5 | 3,5 | 2,3 | 4,0 | 2,3 | 1,7 | 3,7 | 2,0 | 3,7 |
| 0:30 | 2,7 | 2,3 | 2,5 | 3,7 | 3,7 | 2,8 | 3,5 | 2,3 | 1,8 | 3,7 | 2,3 | 4,2 |
| 1:00 | 2,8 | 2,5 | 2,8 | 3,5 | 3,2 | 2,5 | 3,2 | 2,2 | 2,0 | 3,5 | 2,2 | 4,2 |
| 1:30 | 3,0 | 3,0 | 2,8 | 4,0 | 3,2 | 2,7 | 3,3 | 2,0 | 2,3 | 3,7 | 2,5 | 4,2 |
| 2:00 | 2,8 | 3,3 | 2,8 | 3,2 | 2,8 | 2,7 | 3,3 | 2,3 | 2,5 | 3,5 | 2,8 | 4,0 |
| 2:30 | 3,0 | 3,8 | 3,0 | 3,2 | 3,0 | 2,3 | 3,7 | 2,3 | 2,5 | 3,8 | 3,0 | 4,0 |
| 3:00 | 2,7 | 3,5 | 3,2 | 3,0 | 2,8 | 2,5 | 3,7 | 2,3 | 2,2 | 3,5 | 3,0 | 4,2 |
| 3:30 | 2,7 | 3,3 | 3,3 | 2,8 | 2,5 | 3,2 | 3,3 | 2,5 | 2,3 | 3,7 | 2,5 | 4,0 |
| 4:00 | 3,3 | 2,8 | 3,0 | 3,0 | 3,0 | 3,0 | 3,0 | 2,2 | 2,0 | 3,3 | 2,8 | 4,2 |
| 4:30 | 3,2 | 3,5 | 3,3 | 2,7 | 3,2 | 3,2 | 3,2 | 2,3 | 2,2 | 3,5 | 2,7 | 4,0 |
| 5:00 | 3,3 | 3,2 | 3,7 | 4,0 | 3,0 | 3,7 | 3,3 | 2,7 | 2,5 | 3,5 | 3,2 | 3,7 |
| 5:30 | 3,3 | 3,5 | 3,8 | 3,2 | 3,0 | 3,5 | 3,5 | 2,7 | 2,8 | 3,7 | 3,0 | 3,8 |
| 6:00 | 2,8 | 3,7 | 4,2 | 4,0 | 3,3 | 4,0 | 3,0 | 2,5 | 2,8 | 3,7 | 3,2 | 3,5 |
| 6:30 | 2,7 | 3,8 | 4,7 | 4,0 | 4,0 | 4,5 | 3,2 | 3,2 | 3,0 | 3,5 | 3,2 | 3,8 |
| 7:00 | 2,7 | 4,2 | 4,3 | 4,2 | 4,0 | 3,7 | 2,8 | 3,2 | 3,3 | 3,7 | 3,3 | 3,8 |

Table E1 - Repeatability of gradations of wind speeds for each month of an average year

| Graduation m/s | January | February | March | April | May | June | July | August | Septembe | October | Novembe | December |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2,5 | 95 | 103 | 23 | 57 | 73 | 120 | 131 | 140 | 142 | 77 | 76 | 99 |
| 2,6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2,7 | 98 | 143 | 34 | 85 | 77 | 102 | 137 | 114 | 146 | 80 | 96 | 162 |
| 2,8 | 100 | 146 | 48 | 84 | 104 | 131 | 132 | 128 | 129 | 105 | 103 | 133 |
| 2,9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 128 | 122 | 50 | 76 | 132 | 123 | 141 | 103 | 121 | 121 | 133 | 130 |
| 3,1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3,2 | 135 | 141 | 79 | 96 | 132 | 123 | 93 | 95 | 113 | 129 | 106 | 168 |
| 3,3 | 122 | 126 | 84 | 89 | 137 | 113 | 90 | 72 | 81 | 131 | 102 | 125 |
| 3,4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3,5 | 133 | 137 | 93 | 111 | 118 | 129 | 66 | 69 | 75 | 130 | 99 | 117 |
| 3,6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3,7 | 93 | 70 | 116 | 90 | 111 | 121 | 56 | 35 | 54 | 109 | 81 | 111 |
| 3,8 | 81 | 56 | 117 | 106 | 112 | 84 | 28 | 31 | 49 | 96 | 64 | 83 |
| 3,9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 65 | 25 | 136 | 107 | 79 | 40 | 19 | 26 | 27 | 90 | 70 | 69 |
| 4,1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4,2 | 36 | 21 | 111 | 79 | 83 | 47 | 13 | 16 | 20 | 52 | 47 | 45 |
| 4,3 | 19 | 12 | 110 | 69 | 65 | 26 | 10 | 16 | 11 | 44 | 26 | 29 |
| 4,4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4,5 | 29 | 7 | 94 | 63 | 40 | 20 | 9 | 17 | 4 | 36 | 18 | 15 |
| 4,6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4,7 | 16 | 2 | 81 | 72 | 35 | 11 | 5 | 9 | 5 | 30 | 11 | 6 |
| 4,8 | 7 | 1 | 66 | 56 | 18 | 11 | 2 | 7 | 1 | 11 | 7 | 3 |
| 4,9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 7 | 3 | 62 | 41 | 11 | 7 | 2 | 3 | 3 | 11 | 7 | 2 |
| 5,1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5,2 | 1 | 0 | 37 | 20 | 11 | 3 | 2 | 3 | 2 | 2 | 4 | 0 |
| 5,3 | 0 | 0 | 38 | 23 | 1 | 0 | 0 | 0 | 4 | 1 | 6 | 0 |
| 5,4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5,5 | 0 | 0 | 26 | 11 | 4 | 1 | 0 | 0 | 2 | 0 | 4 | 0 |

Table E2 - Probabilities of gradation of wind speeds by months as a percentage

| Graduation m/s | January | February | March | April | May | June | July | August | September | October | Novembe | December |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2,50 | 6,52 | 7,72 | 1,57 | 3,99 | 4,93 | 8,38 | 8,89 | 9,47 | 9,94 | 5,22 | 5,44 | 6,72 |
| 2,60 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| 2,70 | 6,73 | 10,72 | 2,32 | 5,96 | 5,20 | 7,12 | 9,30 | 7,71 | 10,22 | 5,43 | 6,88 | 11,00 |
| 2,80 | 6,86 | 10,94 | 3,27 | 5,89 | 7,03 | 9,15 | 8,96 | 8,66 | 9,03 | 7,12 | 7,38 | 9,03 |
| 2,90 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| 3,00 | 8,79 | 9,15 | 3,41 | 5,33 | 8,92 | 8,59 | 9,57 | 6,97 | 8,47 | 8,21 | 9,53 | 8,83 |
| 3,10 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| 3,20 | 9,27 | 10,57 | 5,39 | 6,73 | 8,92 | 8,59 | 6,31 | 6,43 | 7,91 | 8,75 | 7,59 | 11,41 |
| 3,30 | 8,37 | 9,45 | 5,73 | 6,24 | 9,26 | 7,89 | 6,11 | 4,87 | 5,67 | 8,89 | 7,31 | 8,49 |
| 3,40 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| 3,50 | 9,13 | 10,27 | 6,34 | 7,78 | 7,97 | 9,01 | 4,48 | 4,67 | 5,25 | 8,82 | 7,09 | 7,94 |
| 3,60 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| 3,70 | 6,38 | 5,25 | 7,91 | 6,31 | 7,50 | 8,45 | 3,80 | 2,37 | 3,78 | 7,39 | 5,80 | 7,54 |
| 3,80 | 5,56 | 4,20 | 7,98 | 7,43 | 7,57 | 5,87 | 1,90 | 2,10 | 3,43 | 6,51 | 4,58 | 5,63 |
| 3,90 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| 4,00 | 4,46 | 1,87 | 9,28 | 7,50 | 5,34 | 2,79 | 1,29 | 1,76 | 1,89 | 6,11 | 5,01 | 4,68 |
| 4,10 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| 4,20 | 2,47 | 1,57 | 7,57 | 5,54 | 5,61 | 3,28 | 0,88 | 1,08 | 1,40 | 3,53 | 3,37 | 3,05 |
| 4,30 | 1,30 | 0,90 | 7,50 | 4,84 | 4,39 | 1,82 | 0,68 | 1,08 | 0,77 | 2,99 | 1,86 | 1,97 |
| 4,40 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| 4,50 | 1,99 | 0,52 | 6,41 | 4,41 | 2,70 | 1,40 | 0,61 | 1,15 | 0,28 | 2,44 | 1,29 | 1,02 |
| 4,60 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| 4,70 | 1,10 | 0,15 | 5,53 | 5,05 | 2,36 | 0,77 | 0,34 | 0,61 | 0,35 | 2,04 | 0,79 | 0,41 |
| 4,80 | 0,48 | 0,07 | 4,50 | 3,92 | 1,22 | 0,77 | 0,14 | 0,47 | 0,07 | 0,75 | 0,50 | 0,20 |
| 4,90 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| 5,00 | 0,48 | 0,22 | 4,23 | 2,87 | 0,74 | 0,49 | 0,14 | 0,20 | 0,21 | 0,75 | 0,50 | 0,14 |
| 5,10 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| 5,20 | 0,07 | 0,00 | 2,52 | 1,40 | 0,74 | 0,21 | 0,14 | 0,20 | 0,14 | 0,14 | 0,29 | 0,00 |
| 5,30 | 0,00 | 0,00 | 2,59 | 1,61 | 0,07 | 0,00 | 0,00 | 0,00 | 0,28 | 0,07 | 0,43 | 0,00 |
| 5,40 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| 5,50 | 0,00 | 0,00 | 1,77 | 0,77 | 0,27 | 0,07 | 0,00 | 0,00 | 0,14 | 0,00 | 0,29 | 0,00 |

Table E3 - Number of hours corresponding to a specific wind gradation

| Graduation m/s | January | February | March | April | May | June | July | August | September | October | Novembe | Decembe | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2,5 | 48,51 | 51,89 | 11,67 | 28,76 | 36,70 | 60,34 | 66,17 | 70,47 | 71,55 | 38,87 | 39,20 | 50,00 | 574,12 |
| 2,6 | | | | | | | | | | | | | |
| 2,7 | 50,04 | 72,04 | 17,26 | 42,89 | 38,71 | 51,28 | 69,20 | 57,39 | 73,56 | 40,38 | 49,51 | 81,82 | 644,08 |
| 2,8 | 51,06 | 73,55 | 24,36 | 42,38 | 52,28 | 65,87 | 66,67 | 64,43 | 65,00 | 53,00 | 53,12 | 67,18 | 678,90 |
| 2,9 | | | | | | | | | | | | | |
| 3 | 65,36 | 61,46 | 25,38 | 38,35 | 66,36 | 61,84 | 71,22 | 51,85 | 60,97 | 61,07 | 68,60 | 65,66 | 698,11 |
| 3,1 | | | | | | | | | | | | | |
| 3,2 | 68,94 | 71,03 | 40,09 | 48,44 | 66,36 | 61,84 | 46,97 | 47,82 | 56,93 | 65,11 | 54,67 | 84,86 | 713,06 |
| 3,3 | 62,30 | 63,47 | 42,63 | 44,91 | 68,87 | 56,82 | 45,46 | 36,24 | 40,81 | 66,12 | 52,61 | 63,14 | 643,37 |
| 3,4 | | | | | | | | | | | | | |
| 3,5 | 67,91 | 69,01 | 47,20 | 56,01 | 59,32 | 64,86 | 33,34 | 34,73 | 37,79 | 65,62 | 51,06 | 59,10 | 645,94 |
| 3,6 | | | | | | | | | | | | | |
| 3,7 | 47,49 | 35,26 | 58,87 | 45,41 | 55,80 | 60,84 | 28,29 | 17,62 | 27,21 | 55,02 | 41,78 | 56,07 | 529,64 |
| 3,8 | 41,36 | 28,21 | 59,38 | 53,48 | 56,30 | 42,23 | 14,14 | 15,60 | 24,69 | 48,46 | 33,01 | 41,92 | 458,79 |
| 3,9 | | | | | | | | | | | | | |
| 4 | 33,19 | 12,59 | 69,02 | 53,99 | 39,71 | 20,11 | 9,60 | 13,09 | 13,60 | 45,43 | 36,10 | 34,85 | 381,29 |
| 4,1 | | | | | | | | | | | | | |
| 4,2 | 18,38 | 10,58 | 56,33 | 39,86 | 41,72 | 23,63 | 6,57 | 8,05 | 10,08 | 26,25 | 24,24 | 22,73 | 288,42 |
| 4,3 | 9,70 | 6,04 | 55,83 | 34,81 | 32,68 | 13,07 | 5,05 | 8,05 | 5,54 | 22,21 | 13,41 | 14,65 | 221,05 |
| 4,4 | | | | | | | | | | | | | |
| 4,5 | 14,81 | 3,53 | 47,71 | 31,79 | 20,11 | 10,06 | 4,55 | 8,56 | 2,02 | 18,17 | 9,28 | 7,58 | 178,14 |
| 4,6 | | | | | | | | | | | | | |
| 4,7 | 8,17 | 1,01 | 41,11 | 36,33 | 17,59 | 5,53 | 2,53 | 4,53 | 2,52 | 15,14 | 5,67 | 3,03 | 143,16 |
| 4,8 | 3,57 | 0,50 | 33,50 | 28,26 | 9,05 | 5,53 | 1,01 | 3,52 | 0,50 | 5,55 | 3,61 | 1,52 | 96,12 |
| 4,9 | | | | | | | | | | | | | |
| 5 | 3,57 | 1,51 | 31,47 | 20,69 | 5,53 | 3,52 | 1,01 | 1,51 | 1,51 | 5,55 | 3,61 | 1,01 | 80,49 |
| 5,1 | | | | | | | | | | | | | |
| 5,2 | 0,51 | | 18,78 | 10,09 | 5,53 | 1,51 | 1,01 | 1,51 | 1,01 | 1,01 | 2,06 | | 43,02 |
| 5,3 | | | 19,29 | 11,60 | 0,50 | | | | 2,02 | 0,50 | 3,09 | | 37,01 |
| 5,4 | | | | | | | | | | | | | |
| 5,5 | | | 13,20 | 5,55 | 2,01 | 0,50 | | | 1,01 | 0,00 | 2,06 | 0,00 | 24,33 |
| Sum (hours) | 594,89 | 561,68 | 713,04 | 673,58 | 675,13 | 609,39 | 472,77 | 444,99 | 498,31 | 633,46 | 546,70 | 655,10 | 7079,04 |

Appendix F – Lists of equipment's

**Structure 1**

Table F1 – Configuration A, 1 wind generator

| Equipment | Amount | Lifetime | Price with VAT, RUB | Total price, RUB | Maintenance | |
|---|---|---|---|---|---|---|
| | | | | | Period | Price, Rub |
| Wind Generator SW-2,5 kW | 1 | 20 years | 278600 | 278600 | 1 (once in year) | 10000 |
| VOLTA GEL 12-200 | 28 | 10 years | 26500 | 742000 | - | - |
| Battery shelving | 6 | - | 7200 | 43200 | - | - |
| Diesel generator GENBOX KBT15M-3000 | 2 | 40000 hours | 250000 | 500000 | 1 (after each 8760 hours) | 15000 |
| Automatic Transfer Switch OptiSave L-220 | 2 | - | 15000 | 30000 | - | - |
| Charge controller Dominator MPPT 250/60 | 1 | - | 50000 | 50000 | - | - |
| Power Block Multi-Brand 5kW (48V) | 3 | - | 56000 | 168000 | | |
| Total | - | - | - | 1811800 | - | - |

Table F2 – Configuration A, 2 wind generators

| Equipment | Amount | Lifetime | Price with VAT, RUB | Total price, RUB | Maintenance | |
|---|---|---|---|---|---|---|
| | | | | | Period | Price, Rub |
| Wind Generator SW-2,5 kW | 2 | 20 years | 278600 | 557200 | 1 (once in year) | 20000 |
| VOLTA GEL 12-200 | 28 | 10 years | 26500 | 742000 | - | - |
| Battery shelving | 6 | - | 7200 | 43200 | - | - |
| Diesel generator GENBOX KBT15M-3000 | 2 | 40000 hours | 250000 | 500000 | 1 (after each 8760 hours) | 15000 |
| Automatic Transfer Switch OptiSave L- | 2 | - | 15000 | 30000 | - | - |

| | | | | | | |
|---|---|---|---|---|---|---|
| 220 | | | | | | |
| Charge controller Dominator MPPT 250/60 | 2 | - | 50000 | 100000 | - | - |
| Power Block Multi-Brand 5kW (48V) | 3 | - | 56000 | 168000 | | |
| Total | - | - | - | 2140400 | - | - |

Table F3 – Configuration A, 3 wind generators

| Equipment | Amount | Lifetime | Price with VAT, RUB | Total price, RUB | Maintenance | |
|---|---|---|---|---|---|---|
| | | | | | Period | Price, Rub |
| Wind Generator SW-2,5 kW | 3 | 20 years | 278600 | 835800 | 1 (once in year) | 30000 |
| VOLTA GEL 12-200 | 28 | 10 years | 26500 | 742000 | - | - |
| Battery shelving | 6 | - | 7200 | 43200 | - | - |
| Diesel generator GENBOX KBT15M-3000 | 2 | 40000 hours | 250000 | 500000 | 1 (after each 8760 hours) | 15000 |
| Automatic Transfer Switch OptiSave L-220 | 2 | - | 15000 | 30000 | - | - |
| Charge controller Dominator MPPT 250/60 | 3 | - | 50000 | 150000 | - | - |
| Power Block Multi-Brand 5kW (48V) | 3 | - | 56000 | 168000 | | |
| Total | - | - | - | 2469000 | - | - |

**Structure 2**

Table F4– Configuration A, 4 wind generators

| Equipment | Amount | Lifetime | Price with VAT, RUB | Total price, RUB | Maintenance | |
|---|---|---|---|---|---|---|
| | | | | | Period | Price, Rub |
| Wind Generator SW-2,5 kW | 4 | 20 years | 278600 | 1114400 | 1 (once in year) | 40000 |
| VOLTA GEL 12-200 | 28 | 10 years | 26500 | 742000 | - | - |
| Battery shelving | 6 | - | 7200 | 43200 | - | - |
| Diesel | 1 | 40000 hours | 250000 | 250000 | 1 | 15000 |

| | | | | | | |
|---|---|---|---|---|---|---|
| generator GENBOX KBT15M-3000 | | | | | (after each 8760 hours) | |
| Automatic Transfer Switch OptiSave L-220 | 1 | - | 15000 | 30000 | - | - |
| Inverter MAP SIN PRO 15 kW (48V) | 1 | - | 138800 | 138800 | - | - |
| Ballast load RBZ-028-1K4 | 1 | - | 10000 | 10000 | - | - |
| Total | - | - | - | 2328400 | - | - |

Table F5– Configuration A, 5 wind generators

| Equipment | Amount | Lifetime | Price with VAT, RUB | Total price, RUB | Maintenance | |
|---|---|---|---|---|---|---|
| | | | | | Period | Price, Rub |
| Wind Generator SW-2,5 kW | 5 | 20 years | 278600 | 1 393 000 | 1 (once in year) | 50000 |
| VOLTA GEL 12-200 | 28 | 10 years | 26500 | 742000 | - | - |
| Battery shelving | 6 | - | 7200 | 43200 | - | - |
| Diesel generator GENBOX KBT15M-3000 | 1 | 40000 hours | 250000 | 500000 | 1 (after each 8760 hours) | 15000 |
| Automatic Transfer Switch OptiSave L-220 | 1 | - | 15000 | 30000 | - | - |
| Inverter MAP SIN PRO 15 kW (48V) | 1 | - | 138800 | 138800 | - | - |
| Ballast load RBZ-019-2K2 | 1 | - | 15000 | 30000 | - | - |
| Total | - | - | - | 2627000 | - | - |

Table F6– Configuration A, 6 wind generators

| Equipment | Amount | Lifetime | Price with VAT, RUB | Total price, RUB | Maintenance | |
|---|---|---|---|---|---|---|
| | | | | | Period | Price, Rub |
| Wind Generator SW-2,5 kW | 6 | 20 years | 278600 | 1 671600 | 1 (once in year) | 60000 |
| VOLTA GEL | 28 | 10 years | 26500 | 742000 | - | - |

| | | | | | | |
|---|---|---|---|---|---|---|
| 12-200 | | | | | | |
| Battery shelving | 6 | - | 7200 | 43200 | - | - |
| Diesel generator GENBOX KBT15M-3000 | 1 | 40000 hours | 250000 | 250000 | 1 (after each 8760 hours) | 15000 |
| Automatic Transfer Switch OptiSave L-220 | 1 | - | 15000 | 30000 | - | - |
| Inverter MAP SIN PRO 15 kW (48V) | 1 | - | 138800 | 138800 | - | - |
| Ballast load RB4-056-3K2 | 1 | - | 30000 | 30000 | - | - |
| Total | - | - | - | 3 296 900 | - | - |

**Structure 3**

Table F7– Configuration B, without wind generators

| Equipment | Amount | Lifetime | Price with VAT, RUB | Total price, RUB | Maintenance | |
|---|---|---|---|---|---|---|
| | | | | | Period | Price, Rub |
| VOLTA GEL 12-200 | 28 | 20 years | 26500 | 742000 | - | - |
| Battery shelving | 6 | - | 7200 | 43200 | - | - |
| Diesel generator GENBOX KBT15M-3000 | 2 | 40000 hours | 250000 | 500000 | 1 (after each 8760 hours) | 15000 |
| Automatic Transfer Switch OptiSave L-220 | 1 | - | 15000 | 30000 | - | - |
| Inverter MAP SIN PRO 15 kW (48V) | 1 | - | 138800 | 138800 | - | - |
| Total | - | - | - | 1454000 | - | - |

## Appendix G – Financial models

### Table G1 – Calculation of configuration A (1 WG) NPV with electricity price 28 RUB/kWh with Accelerated depreciation

| Conf. A, 1WG | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Investment | 1811800 | | | | | | | | | | | | | | | | | | | | |
| Annual operation costs | | 242460 | 256959,108 | 272325,3 | 288610,3 | 305869,2 | 324160,2 | 343545 | 364089 | 385861,5 | 408936 | 433390,4 | 459307,1 | 486773,7 | 515882,7 | 546732,5 | 579427,1 | 614076,9 | 650798,7 | 689716,4 | 730961,5 |
| Investment for replacement eqipment | | | | | | | 334240,9 | | | | 1251466 | | 473590,6 | | | | | | 671037,2 | | |
| Accelerated depressiasion | | 90590 | 172121 | 163062 | 154003 | 144944 | 159759,3 | 174574,7 | 162105,1 | 149635,5 | 262312,5 | 374989,5 | 384849,6 | 418389,2 | 366090,6 | 313791,9 | 261493,3 | 209194,6 | 492414,5 | 775634,5 | 387817,2 |
| Expenses | | 242460 | 256959,108 | 272325,3 | 288610,3 | 305869,2 | 324160,2 | 343545 | 364089 | 385861,5 | 408936 | 433390,4 | 459307,1 | 486773,7 | 515882,7 | 546732,5 | 579427,1 | 614076,9 | 650798,7 | 689716,4 | 730961,5 |
| Unit Price for customer (RUB/kWh) | | 28 | 29,6744 | 31,44893 | 33,32958 | 35,32268 | 37,43498 | 39,67359 | 42,04607 | 44,56043 | 47,22514 | 50,0492 | 53,04215 | 56,21407 | 59,57567 | 63,13829 | 66,91396 | 70,91542 | 75,15616 | 79,6505 | 84,4136 |
| Revenue | | 403743,2 | 427887,0434 | 453474,7 | 480592,5 | 509331,9 | 539790 | 572069,4 | 606279,1 | 642534,6 | 680958,2 | 721679,5 | 764835,9 | 810573,1 | 859045,4 | 910416,3 | 964859,2 | 1022558 | 1083707 | 1148512 | 1217193 |
| EBT | | 70693,2 | -1193,06464 | 18087,43 | 37979,16 | 58518,69 | 55870,41 | 53949,72 | 80085,11 | 107037,7 | 9709,752 | -86700,3 | -79320,7 | -94589,8 | -22927,9 | 49891,87 | 123938,8 | 199286,3 | -59506,5 | -316838 | 98414,75 |
| TAX | | 14138,64 | -238,612928 | 3617,485 | 7595,832 | 11703,74 | 11174,08 | 10789,94 | 16017,02 | 21407,54 | 1941,95 | -17340,1 | -15864,1 | -18918 | -4585,58 | 9978,375 | 24787,76 | 39857,26 | -11901,3 | -63367,7 | 19682,95 |
| EAT | | 56554,56 | -954,451712 | 14469,94 | 30383,33 | 46814,96 | 44696,33 | 43159,78 | 64068,09 | 85630,16 | 7767,802 | -69360,3 | -63456,6 | -75671,8 | -18342,3 | 39913,5 | 99151,05 | 159429 | -47605,2 | -253471 | 78731,8 |
| Cashflow | -1811800 | 147144,6 | 171166,5483 | 177531,9 | 184386,3 | 191759 | -129785 | 217734,5 | 226173,2 | 235265,6 | -981386 | 305629,2 | -152198 | 342717,4 | 347748,2 | 353705,4 | 360644,3 | 368623,7 | -226228 | 522163,7 | 466549 |
| NPV | -520840 | | | | | | | | | | | | | | | | | | | | |
| Unit price for NPV=0 | 31,34 | rub/kWh | | | | | | | | | | | | | | | | | | | |

### Table G2 – Calculation of configuration A (2 WG) NPV with electricity price 28 RUB/kWh with Accelerated depreciation

| Conf. A, 2WG | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Investment | 2140400 | | | | | | | | | | | | | | | | | | | | |
| Annual operation costs | | 176480 | 187033,504 | 198218,1 | 210071,6 | 222633,8 | 235947,3 | 250057 | 265010,4 | 280858 | 297653,3 | 315453 | 334317,1 | 354309,2 | 375496,9 | 397951,6 | 421749,2 | 446969,8 | 473698,5 | 502025,7 | 532046,9 |
| Investment for replacement eqipment | | | | | | | | | | 397861 | 1251466 | | | | | | | | 671037,2 | | |
| Accelerated depressiasion | | 107020 | 203338 | 192636 | 181934 | 171232 | 160530 | 149828 | 139126 | 164593,2 | 315207 | 423075,4 | 380767,9 | 338460,3 | 296152,8 | 253845,2 | 211537,7 | 169230,2 | 462441,2 | 755652,2 | 377826,1 |
| Expenses | | 176480 | 187033,504 | 198218,1 | 210071,6 | 222633,8 | 235947,3 | 250057 | 265010,4 | 280858 | 297653,3 | 315453 | 334317,1 | 354309,2 | 375496,9 | 397951,6 | 421749,2 | 446969,8 | 473698,5 | 502025,7 | 532046,9 |
| Unit Price for customer (RUB/kWh) | | 28 | 29,6744 | 31,44893 | 33,32958 | 35,32268 | 37,43498 | 39,67359 | 42,04607 | 44,56043 | 47,22514 | 50,0492 | 53,04215 | 56,21407 | 59,57567 | 63,13829 | 66,91396 | 70,91542 | 75,15616 | 79,6505 | 84,4136 |
| Revenue | | 403743,2 | 427887,0434 | 453474,7 | 480592,5 | 509331,9 | 539790 | 572069,4 | 606279,1 | 642534,6 | 680958,2 | 721679,5 | 764835,9 | 810573,1 | 859045,4 | 910416,3 | 964859,2 | 1022558 | 1083707 | 1148512 | 1217193 |
| EBT | | 120243,2 | 37515,53936 | 62620,58 | 88586,92 | 115466,1 | 143312,6 | 172184,4 | 202142,8 | 197083,4 | 68097,9 | -16848,9 | 49751,01 | 117803,6 | 187395,7 | 258619,4 | 331572,4 | 406357,9 | 147567 | -109166 | 307320,5 |
| TAX | | 24048,64 | 7503,107872 | 12524,12 | 17717,38 | 23093,22 | 28662,52 | 34436,88 | 40428,55 | 39416,69 | 13619,58 | -3369,78 | 9950,202 | 23560,72 | 37479,14 | 51723,89 | 66314,47 | 81271,58 | 29513,4 | -21833,1 | 61464,1 |
| EAT | | 96194,56 | 30012,43149 | 50096,46 | 70869,54 | 92372,86 | 114650,1 | 137747,5 | 161714,2 | 157666,8 | 54478,32 | -13479,1 | 39800,81 | 94242,86 | 149916,6 | 206895,5 | 265257,9 | 325086,3 | 118053,6 | -87332,4 | 245856,4 |
| Cashflow | -2140400 | 203214,6 | 233350,4315 | 242732,5 | 252803,5 | 263604,9 | 275180,1 | 287575,5 | 300840,2 | -75601 | -881781 | 409596,3 | 420568,7 | 432703,2 | 446069,3 | 460740,8 | 476795,6 | 494316,5 | -90542,4 | 668319,8 | 623682,5 |
| NPV | 68724,53 | | | | | | | | | | | | | | | | | | | | |
| Unit price for NPV=0 | 27,559 | rub/kWh | | | | | | | | | | | | | | | | | | | |

Table G3 – Calculation of configuration A (3 WG) NPV with electricity price 28 RUB/kWh with Accelerated depreciation

| Conf. A, 3WG | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Investment | 2469000 | | | | | | | | | | | | | | | | | | | | |
| Annual operation costs | | 127530 | 135156,294 | 143238,6 | 151804,3 | 160882,2 | 170503 | 180699 | 191504,8 | 202956,8 | 215093,7 | 227956,3 | 241588 | 256035 | 271345,9 | 287572,4 | 304769,2 | 322994,4 | 342309,5 | 362779,6 | 384473,8 |
| Investment for replacement eqipment | | | | | | | | | | | 1251466 | | | | | | 597446,1 | | | | |
| Accelerated depressiasion | | 123450 | 234555 | 222210 | 209865 | 197520 | 185175 | 172830 | 160485 | 148140 | 260941,6 | 373743,2 | 336368,9 | 298994,6 | 261620,3 | 224245,9 | 336233,2 | 448220,4 | 336165,3 | 224110,2 | 112055,1 |
| Expenses | | 127530 | 135156,294 | 143238,6 | 151804,3 | 160882,2 | 170503 | 180699 | 191504,8 | 202956,8 | 215093,7 | 227956,3 | 241588 | 256035 | 271345,9 | 287572,4 | 304769,2 | 322994,4 | 342309,5 | 362779,6 | 384473,8 |
| Unit Price for customer (RUB/kWh) | | 28 | 29,6744 | 31,44893 | 33,32958 | 35,32268 | 37,43498 | 39,67359 | 42,04607 | 44,56043 | 47,22514 | 50,0492 | 53,04215 | 56,21407 | 59,57567 | 63,13829 | 66,91396 | 70,91542 | 75,15616 | 79,6505 | 84,4136 |
| Revenue | | 403743,2 | 427887,0434 | 453474,7 | 480592,5 | 509331,9 | 539790 | 572069,4 | 606279,1 | 642534,6 | 680958,2 | 721679,5 | 764835,9 | 810573,1 | 859045,4 | 910416,3 | 964859,2 | 1022558 | 1083707 | 1148512 | 1217193 |
| EBT | | 152763,2 | 58175,74936 | 88026,05 | 118923,2 | 150929,7 | 184112 | 218540,3 | 254289,3 | 291437,8 | 204922,9 | 119980 | 186879 | 255543,5 | 326079,2 | 398598 | 323856,9 | 251343 | 405232 | 561622,7 | 720664,6 |
| TAX | | 30552,64 | 11635,14987 | 17605,21 | 23784,63 | 30185,94 | 36822,4 | 43708,07 | 50857,86 | 58287,56 | 40984,59 | 23996 | 37375,8 | 51108,71 | 65215,85 | 79719,6 | 64771,37 | 50268,61 | 81046,4 | 112324,5 | 144132,9 |
| EAT | | 122210,6 | 46540,59949 | 70420,84 | 95138,53 | 120743,8 | 147289,6 | 174832,3 | 203431,4 | 233150,2 | 163938,3 | 95984 | 149503,2 | 204434,8 | 260863,4 | 318878,4 | 259085,5 | 201074,4 | 324185,6 | 449298,1 | 576531,7 |
| Cashflow | -2469000 | 245660,6 | 281095,5995 | 292630,8 | 305003,5 | 318263,8 | 332464,6 | 347662,3 | 363916,4 | 381290,2 | -826586 | 469727,3 | 485872,1 | 503429,4 | 522483,7 | 543124,3 | -2127,47 | 649294,8 | 660350,9 | 673408,3 | 688586,7 |
| NPV | 453263,8 | | | | | | | | | | | | | | | | | | | | |
| Unit price for NPV=0 | 25,19 | rub/kWh | | | | | | | | | | | | | | | | | | | |

Table G4 - Calculation of configuration A (4 WG) NPV with electricity price 28 RUB/kWh with Accelerated depreciation

| Conf. A, 4WG | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Investment | 2328400 | | | | | | | | | | | | | | | | | | | | |
| Annual operation costs | | 111160 | 117807,368 | 124852,2 | 132318,4 | 140231,1 | 148616,9 | 157504,2 | 166922,9 | 176904,9 | 187483,8 | 198695,3 | 210577,3 | 223169,8 | 236515,4 | 250659 | 265648,4 | 281534,2 | 298370 | 316212,5 | 335122 |
| Investment for replacement eqipment | | | | | | | | | | | 1251466 | | | | | | | | | | |
| Accelerated depressiasion | | 116420 | 221198 | 209556 | 197914 | 186272 | 174630 | 162988 | 151346 | 139704 | 253208,6 | 366713,2 | 330041,9 | 293370,6 | 256699,3 | 220027,9 | 183356,6 | 146685,3 | 110014 | 73342,65 | 36671,32 |
| Expenses | | 111160 | 117807,368 | 124852,2 | 132318,4 | 140231,1 | 148616,9 | 157504,2 | 166922,9 | 176904,9 | 187483,8 | 198695,3 | 210577,3 | 223169,8 | 236515,4 | 250659 | 265648,4 | 281534,2 | 298370 | 316212,5 | 335122 |
| Unit Price for customer (RUB/kWh) | | 28 | 29,6744 | 31,44893 | 33,32958 | 35,32268 | 37,43498 | 39,67359 | 42,04607 | 44,56043 | 47,22514 | 50,0492 | 53,04215 | 56,21407 | 59,57567 | 63,13829 | 66,91396 | 70,91542 | 75,15616 | 79,6505 | 84,4136 |
| Revenue | | 403743,2 | 427887,0434 | 453474,7 | 480592,5 | 509331,9 | 539790 | 572069,4 | 606279,1 | 642534,6 | 680958,2 | 721679,5 | 764835,9 | 810573,1 | 859045,4 | 910416,3 | 964859,2 | 1022558 | 1083707 | 1148512 | 1217193 |
| EBT | | 176163,2 | 88881,67536 | 119066,4 | 150360,1 | 182828,9 | 216543,1 | 251577,2 | 288010,2 | 325925,7 | 240265,8 | 156270,9 | 224216,7 | 294032,7 | 365830,7 | 439729,3 | 515854,2 | 594338,3 | 675322,8 | 758957,3 | 845400,1 |
| TAX | | 35232,64 | 17776,33507 | 23813,29 | 30072,01 | 36565,77 | 43308,62 | 50315,45 | 57602,05 | 65185,15 | 48053,15 | 31254,18 | 44843,34 | 58806,54 | 73166,14 | 87945,87 | 103170,8 | 118867,7 | 135064,6 | 151791,5 | 169080 |
| EAT | | 140930,6 | 71105,34029 | 95253,15 | 120288 | 146263,1 | 173234,5 | 201261,8 | 230408,2 | 260740,6 | 192212,6 | 125016,7 | 179373,4 | 235226,1 | 292664,6 | 351783,5 | 412683,3 | 475470,6 | 540258,3 | 607165,8 | 676320,1 |
| Cashflow | -2328400 | 257350,6 | 292303,3403 | 304809,2 | 318202 | 332535,1 | 347864,5 | 364249,8 | 381754,2 | 400444,6 | -806045 | 491730 | 509415,3 | 528596,7 | 549363,9 | 571811,4 | 596039,9 | 622155,9 | 650272,2 | 680508,5 | 712991,4 |
| NPV | 852457,9 | | | | | | | | | | | | | | | | | | | | |
| Unit price for NPV=0 | 22,33 | rub/kWh | | | | | | | | | | | | | | | | | | | |

Table G5 - Calculation of configuration A (5 WG) NPV with electricity price 28 RUB/kWh with Accelerated depreciation

| Conf. A, 5WG | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Investment | 2612000 | | | | | | | | | | | | | | | | | | | | |
| Annual operation costs | | 86840 | 92033,032 | 97536,61 | 103369,3 | 109550,8 | 116101,9 | 123044,8 | 130402,9 | 138201 | 146465,4 | 155224 | 164506,4 | 174343,9 | 184769,7 | 195818,9 | 207528,9 | 219939,1 | 233091,5 | 247030,3 | 261802,7 |
| Investment for replacement eqipment | | | | | | | | | | | 1251466 | | | | | | | | | | |
| Accelerated depressiasion | | 130600 | 248140 | 235080 | 222020 | 208960 | 195900 | 182840 | 169780 | 156720 | 268806,6 | 380893,2 | 342803,9 | 304714,6 | 266625,3 | 228535,9 | 190446,6 | 152357,3 | 114268 | 76178,65 | 38089,32 |
| Expenses | | 86840 | 92033,032 | 97536,61 | 103369,3 | 109550,8 | 116101,9 | 123044,8 | 130402,9 | 138201 | 146465,4 | 155224 | 164506,4 | 174343,9 | 184769,7 | 195818,9 | 207528,9 | 219939,1 | 233091,5 | 247030,3 | 261802,7 |
| Unit Price for customer (RUB/kWh) | | 28 | 29,6744 | 31,44893 | 33,32958 | 35,32268 | 37,43498 | 39,67359 | 42,04607 | 44,56043 | 47,22514 | 50,0492 | 53,04215 | 56,21407 | 59,57567 | 63,13829 | 66,91396 | 70,91542 | 75,15616 | 79,6505 | 84,4136 |
| Revenue | | 403743,2 | 427887,0434 | 453474,7 | 480592,5 | 509331,9 | 539790 | 572069,4 | 606279,1 | 642534,6 | 680958,2 | 721679,5 | 764835,9 | 810573,1 | 859045,4 | 910416,3 | 964859,2 | 1022558 | 1083707 | 1148512 | 1217193 |
| EBT | | 186303,2 | 87714,01136 | 120858,1 | 155203,2 | 190821,1 | 227788 | 266184,6 | 306096,3 | 347613,7 | 265686,2 | 185562,2 | 257525,6 | 331514,6 | 407650,4 | 486061,5 | 566883,7 | 650261,4 | 736347,3 | 825303,4 | 917301,4 |
| TAX | | 37260,64 | 17542,80227 | 24171,62 | 31040,64 | 38164,22 | 45557,61 | 53236,92 | 61219,25 | 69522,73 | 53137,24 | 37112,44 | 51505,12 | 66302,92 | 81530,09 | 97212,29 | 113376,7 | 130052,3 | 147269,5 | 165060,7 | 183460,3 |
| EAT | | 149042,6 | 70171,20909 | 96686,46 | 124162,5 | 152656,9 | 182230,4 | 212947,7 | 244877 | 278090,9 | 212548,9 | 148449,8 | 206020,5 | 265211,7 | 326120,4 | 388849,2 | 453507 | 520209,1 | 589077,8 | 660242,7 | 733841,1 |
| Cashflow | -2612000 | 279642,6 | 318311,2091 | 331766,5 | 346182,5 | 361616,9 | 378130,4 | 395787,7 | 414657 | 434810,9 | -770111 | 529343 | 548824,4 | 569926,3 | 592745,6 | 617385,1 | 643953,6 | 672566,4 | 703345,8 | 736421,4 | 771930,4 |
| NPV | 884061,9 | | | | | | | | | | | | | | | | | | | | |
| Unit price for NPV=0 | 22,53 | rub/kWh | | | | | | | | | | | | | | | | | | | |

Table G6 - Calculation of configuration A (6 WG) NPV with electricity price 28 RUB/kWh with Accelerated depreciation

| Conf. A, 6WG | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Investment | 2905600 | | | | | | | | | | | | | | | | | | | | |
| Annual operation costs | | 82800 | 87751,44 | 92998,98 | 98560,31 | 104454,2 | 110700,6 | 117320,5 | 124336,2 | 131771,6 | 139651,5 | 148002,6 | 156853,2 | 166233 | 176173,8 | 186709 | 197874,2 | 209707 | 222247,5 | 235537,9 | 249623,1 |
| Investment for replacement eqipment | | | | | | | | | | | 1251466 | | | | | | | | | | |
| Accelerated depressiasion | | 145280 | 276032 | 261504 | 246976 | 232448 | 217920 | 203392 | 188864 | 174336 | 284954,6 | 207853,3 | 187068 | 166282,6 | 145497,3 | 124712 | 103926,7 | 83141,32 | 62355,99 | 41570,66 | 20785,33 |
| Expenses | | 82800 | 87751,44 | 92998,98 | 98560,31 | 104454,2 | 110700,6 | 117320,5 | 124336,2 | 131771,6 | 139651,5 | 148002,6 | 156853,2 | 166233 | 176173,8 | 186709 | 197874,2 | 209707 | 222247,5 | 235537,9 | 249623,1 |
| Unit Price for customer (RUB/kWh) | | 28 | 29,6744 | 31,44893 | 33,32958 | 35,32268 | 37,43498 | 39,67359 | 42,04607 | 44,56043 | 47,22514 | 50,0492 | 53,04215 | 56,21407 | 59,57567 | 63,13829 | 66,91396 | 70,91542 | 75,15616 | 79,6505 | 84,4136 |
| Revenue | | 403743,2 | 427887,0434 | 453474,7 | 480592,5 | 509331,9 | 539790 | 572069,4 | 606279,1 | 642534,6 | 680958,2 | 721679,5 | 764835,9 | 810573,1 | 859045,4 | 910416,3 | 964859,2 | 1022558 | 1083707 | 1148512 | 1217193 |
| EBT | | 175663,2 | 64103,60336 | 98971,71 | 135056,2 | 172429,7 | 211169,4 | 251356,9 | 293078,9 | 336427,1 | 256352,1 | 365823,5 | 420914,8 | 478057,5 | 537374,3 | 598995,4 | 663058,4 | 729709,4 | 799103,3 | 871403,8 | 946785,1 |
| TAX | | 35132,64 | 12820,72067 | 19794,34 | 27011,23 | 34485,94 | 42233,87 | 50271,38 | 58615,78 | 67285,42 | 51270,42 | 73164,71 | 84182,95 | 95611,49 | 107474,9 | 119799,1 | 132611,7 | 145941,9 | 159820,7 | 174280,8 | 189357 |
| EAT | | 140530,6 | 51282,88269 | 79177,37 | 108044,9 | 137943,7 | 168935,5 | 201085,5 | 234463,1 | 269141,7 | 205081,7 | 292658,8 | 336731,8 | 382446 | 429899,5 | 479196,3 | 530446,7 | 583767,6 | 639282,6 | 697123,1 | 757428 |
| Cashflow | -2905600 | 285810,6 | 327314,8827 | 340681,4 | 355020,9 | 370391,7 | 386855,5 | 404477,5 | 423327,1 | 443477,7 | -761430 | 500512,1 | 523799,8 | 548728,6 | 575396,8 | 603908,3 | 634373,4 | 666908,9 | 701638,6 | 738693,7 | 778213,4 |
| NPV | 627580,2 | | | | | | | | | | | | | | | | | | | | |
| Unit price for NPV=0 | 23,9 | rub/kWh | | | | | | | | | | | | | | | | | | | |

Table G7 - Calculation of configuration B (0 WG) NPV with electricity price 28 RUB/kWh with Accelerated depreciation

| Conf. B, 0WG | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Investment | 1454000 | | | | | | | | | | | | | | | | | | | | |
| Annual operation costs | | 307785 | 326190,543 | 345696,7 | 366369,4 | 388278,3 | 411497,3 | 436104,9 | 462183,9 | 489822,5 | 519113,9 | 550156,9 | 583056,3 | 617923,1 | 654874,9 | 694036,4 | 735539,8 | 779525,1 | 826140,7 | 875543,9 | 927901,4 |
| Investment for replacement eqipment | | | | | | 315381,1 | | | | | 1673119 | | | | | 563734,8 | | | | | |
| Accelerated depressiasion | | 72700 | 138130 | 130860 | 123590 | 137345,4 | 151100,8 | 141027,4 | 130954 | 120880,7 | 278119,2 | 435357,7 | 391822 | 348286,2 | 304750,4 | 373961,6 | 274052,3 | 219241,9 | 164431,4 | 109620,9 | 54810,47 |
| Expenses | | 307785 | 326190,543 | 345696,7 | 366369,4 | 388278,3 | 411497,3 | 436104,9 | 462183,9 | 489822,5 | 519113,9 | 550156,9 | 583056,3 | 617923,1 | 654874,9 | 694036,4 | 735539,8 | 779525,1 | 826140,7 | 875543,9 | 927901,4 |
| Unit Price for customer (RUB/kWh) | | 28 | 29,6744 | 31,44893 | 33,32958 | 35,32268 | 37,43498 | 39,67359 | 42,04607 | 44,56043 | 47,22514 | 50,0492 | 53,04215 | 56,21407 | 59,57567 | 63,13829 | 66,91396 | 70,91542 | 75,15616 | 79,6505 | 84,4136 |
| Revenue | | 403743,2 | 427887,0434 | 453474,7 | 480592,5 | 509331,9 | 539790 | 572069,4 | 606279,1 | 642534,6 | 680958,2 | 721679,5 | 764835,9 | 810573,1 | 859045,4 | 910416,3 | 964859,2 | 1022558 | 1083707 | 1148512 | 1217193 |
| EBT | | 23258,2 | -36433,49964 | -23082 | -9366,93 | -16291,8 | -22808,2 | -5062,91 | 13141,16 | 31831,44 | -116275 | -263835 | -210042 | -155636 | -100580 | -157582 | -44732,9 | 23790,84 | 93134,66 | 163347,6 | 234481,6 |
| TAX | | 4651,64 | -7286,699928 | -4616,41 | -1873,39 | -3258,36 | -4561,64 | -1012,58 | 2628,231 | 6366,287 | -23255 | -52767 | -42008,5 | -31127,2 | -20116 | -31516,3 | -8946,59 | 4758,168 | 18626,93 | 32669,52 | 46896,31 |
| EAT | | 18606,56 | -29146,79971 | -18465,6 | -7493,54 | -13033,4 | -18246,6 | -4050,33 | 10512,93 | 25465,15 | -93019,9 | -211068 | -168034 | -124509 | -80463,9 | -126065 | -35786,3 | 19032,67 | 74507,73 | 130678,1 | 187585,3 |
| Cashflow | -1454000 | 91306,56 | 108983,2003 | 112394,4 | 116096,5 | -191069 | 132854,3 | 136977,1 | 141467 | 146345,8 | -1488020 | 224289,6 | 223788,1 | 223777,3 | 224286,5 | -315839 | 238266 | 238274,5 | 238939,1 | 240299 | 242395,7 |
| NPV | -997250 | | | | | | | | | | | | | | | | | | | | |
| Unit price for NPV=0 | 34,4 | rub/kWh | | | | | | | | | | | | | | | | | | | |